A manual of physiology : for the use of junior students of medicine / by Gerald F. Yeo.

Contributors

Yeo, Gerald F. 1845-1909.

Publication/Creation

London : J. & A. Churchill, 1893 (London : Bradbury, Agnew.)

Persistent URL

https://wellcomecollection.org/works/mjq7gz9e

License and attribution

This work has been identified as being free of known restrictions under copyright law, including all related and neighbouring rights and is being made available under the Creative Commons, Public Domain Mark.

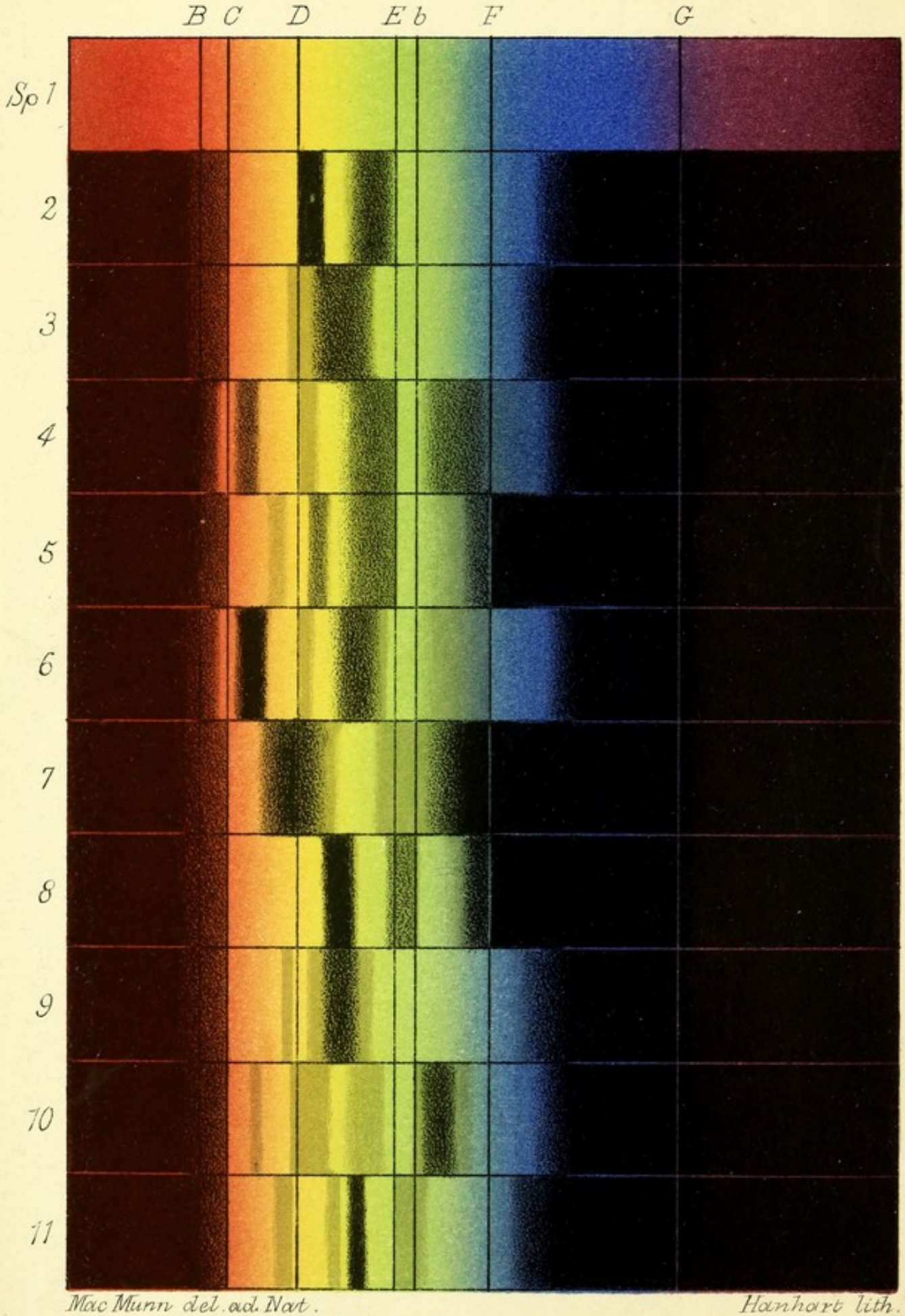
You can copy, modify, distribute and perform the work, even for commercial purposes, without asking permission.

wellcome collection

Wellcome Collection
183 Euston Road
London NW1 2BE UK
T +44 (0)20 7611 8722
E library@wellcomecollection.org
https://wellcomecollection.org

22101756088

BRITISH MEDICAL
Library
ASSOCIATION



Mac Munn del. ad. Nat. Hanhart lith.

Digitized by the Internet Archive
in 2014

https://archive.org/details/b20405455

A MANUAL

OF

PHYSIOLOGY

Library
ASSOCIATION

A MANUAL

OF

PHYSIOLOGY

FOR THE USE OF

JUNIOR STUDENTS OF MEDICINE

BY

GERALD F. YEO, M.D.Dubl., F.R.S.
EMERITUS PROFESSOR OF PHYSIOLOGY IN KING'S COLLEGE, LONDON, ETC.

THIRD EDITION

LONDON
J. & A. CHURCHILL
11, NEW BURLINGTON STREET
1893

M15351

WELLCOME INSTITUTE LIBRARY

Coll.	welMOmec
Call No.	QT 4 1893 Y46m

PREFACE

TO THE THIRD EDITION.

THE considerable advance made by Physiological Science during the last few years, has made it necessary to introduce many additions and some radical changes into the present Edition.

It has been thought advisable to re-arrange and re-write the Chapters on the Chemistry of the Tissues, on the Liver, and on the Nervous Centres.

The Chapter on Development of the Special Systems has been omitted because the limited space at my disposal was required for more purely physiological matters.

I am very much indebted to Mr. Thos. G. Brodie, M.B., Demonstrator of Physiology, King's College, London, for very valuable assistance throughout the work, more especially in the chemical part.

August, 1893.

PREFACE

TO THE SECOND EDITION.

In preparing this edition, I have done my utmost to correct inaccuracies and remove obscurities. The changes rendered necessary by recent research have also been made.

Some parts have been re-written; notably the Chapters on the Central Nervous System, to which additional illustrations have been added.

The general arrangement remains the same as that of the First Edition.

I am again deeply indebted to my friend, Mr. E. F. Herroun, for much valuable assistance.

King's College, London,
August, 1887.

PREFACE

TO THE FIRST EDITION.

THE present volume has been written at the desire on the part of the Publishers that a new elementary treatise on Physiology should be added to the series of admirable students' manuals which they had previously issued.

In carrying this desire into execution I have endeavoured to avoid theories which have not borne the test of time, and such details of methods as are unnecessary for junior students. I do not give any history of how our knowledge has grown to its present standpoint; nor do I mention the names of the authorities upon whose writings my statements depend. I have also omitted the mention of exceptional points, because I find that exceptions are more easily remembered than the main facts from which they differ; and, since we must often be content with the retention of the one or the other, I have tried to ensure that it shall be the more important.

While endeavouring to save the student from doubtful and erroneous doctrines, I have taken great care not to omit any important facts that are necessary to his acquirement of as clear an idea as possible of the principles of Physiology.

I have not hesitated to lay unwonted stress upon those points which many years' practical experience as a teacher and an examiner has shown me are difficult to grasp and

are commonly misunderstood ; and I have treated such subjects as are useful in the practice of medicine or surgery, more fully than those which are essential only to abstract physiological knowledge.

As medical students are generally obliged to commence the study of Physiology without any anatomical knowledge, I believe it to be absolutely necessary that their first physiological book should contain some account of the structure and relationships of the organs, the functions of which they are about to study. I have therefore added a short account of the construction of the various parts discussed in each chapter ; it has, however, been found necessary to curtail this anatomical portion to a mere introductory sketch. Numerous illustrations, with full descriptions attached to each, are introduced to supplement the explanation given in the text.

So far as is consistent with an accurate treatment of the subject, I have avoided technical terms and scientific modes of expression. I know that in attempting to explain physiological truths in every-day language and in a plain common-sense way, I run the risk of appearing to lack the precision that such a subject demands ; but after mature consideration, I have come to the conclusion that great scientific nicety and a scholastic style of expression have a deterrent effect upon the beginner's industry ; and I think it better that he should acquire the first principles of the science in homely language, than pick up technical odds and ends in learned terms, the meaning of which he does not comprehend.

As many words, strange to the first year's student, have to be used, and must be learned, it has been thought advisable to add a short glossary, containing an explanation of the most ordinary physiological expressions.

Great difficulty is always found in fixing upon a starting point at which to begin the study of Physiology. To begin

with the circulation of the blood, which is so essential for the life of every tissue, one should have some knowledge of nerve and muscle. To begin with nerves and muscles, the mechanisms and the uses of the blood current should be understood ; and so on, throughout the various systems, which are so inter-dependent that, for the thorough comprehension of any one, a knowledge of all is required.

I have, therefore, adopted the time-honoured plan of commencing with the vegetative systems and following the course of the aliments to their destination and final application, as I believe that this arrangement is open to as few objections as any other known to me.

I wish here to express my most cordial thanks to many friends who have aided me with kind assistance and advice. I am deeply indebted to Mr. W. Tyrrell Brooks for the great help he afforded me by compiling the chapters on Development ; and I feel I cannot sufficiently thank Mr. E. F. Herroun for his untiring and valuable assistance in the revision of the proof sheets.

To Mr. G. Hanlon I am indebted for the careful and skilful manner in which he has executed the new woodcuts, most of which he had to copy from my rough drawings.

King's College, London,
January, 1884.

CONTENTS.

CHAPTER I.

The Objects of Physiology.

PAGE

Introductory Definitions 1
Structural and Physical Properties of Organisms 4
Chemical Composition 4
Vital Phenomena 6

CHAPTER II.

General View of the Structure of Animal Organisms.

Cells 8
Protoplasm, Nucleus 10
Cell-wall 11
Cell-contents 12
Varieties of Cells 13
Modifications of Original Cell-tissues (Tissue differentiation) . . 14
I. Epithelial Tissues 18
II. Nerve Tissues 21
III. Muscle or Contractile Tissues 24
IV. Connective Tissues 27

CHAPTER III.

Chemical Basis of the Body.

Elements in the Body 35
Classification of Ingredients found in the Tissues 36
Proteids 37
Classification of Proteids 38
Albuminoids 42

PAGE
Products of Tissue Change (Metabolites) 43
Carbohydrates 56
Fats 61
Inorganic Bodies 62

CHAPTER IV.

The Vital Characters of Organisms.

Protoplasmic Movements 65
Reproduction of Cells 68
Karyokinesis 69
Life History of Cells 73
Unicellular Organisms 75
Bacteria 75
Torula 77
Amœbæ 77
Paramœcium 79
Vorticella 81

CHAPTER V.

Food.

Classification of Food-stuffs 84
Composition of Special Forms of Food 87
Milk 88
Cheese, Meat, Eggs, &c. 90
Vegetables 92
Water and Salts 93

CHAPTER VI.

Digestion.

Mechanism 95
Mastication 97
Deglutition 100
Nervous Mechanism of Deglutition 103
Vomiting 106
Movements of the Intestines 108
Defæcation 110
Nervous Mechanism of Intestinal Motion 112

CHAPTER VII.

Mouth Digestion.

PAGE
Salivary and Mucous Glands 115
Characters of Mixed Saliva 98, 118
Nervous Mechanism of Secretion of Saliva 100, 121
Changes in the Gland-cells 107, 125
Functions of Saliva 128

CHAPTER VIII.

Stomach Digestion.

Structure of the Mucous Membrane 132
Gastric Glands 133
Characters of Gastric Juice 134
Mode of Secretion of Gastric Juice 135
Action of Gastric Juice 137

CHAPTER IX.

Intestinal Digestion.

Structure of the Pancreas 144
Characters and Mode of Secretion of Pancreatic Juice . . . 145
Changes in the Gland-cells 147
Action of Pancreatic Juice on Proteids 149
Action on Fats 150
Action on Starch 150
Bile 151
Composition and Method of obtaining Bile 151
Method of Secretion of Bile 155
Functions of Bile 157

CHAPTER X.

Functions of the Intestinal Mucous Membrane.

Structure of the Small Intestine 160
Method of obtaining Intestinal Secretion 161
Characters and Functions of Intestinal Juice 162
Functions of the Large Intestine 163
Putrefactive Fermentations in the Intestine 164
Summary of Intestinal Digestion 165

CHAPTER XI.

Absorption.

PAGE
Interstitial Absorption 170
The Lymphatic System 172
Structure of Lymphatic Glands 172
Intestinal Absorption 176
Mechanism of Absorption 179
Materials Absorbed 180
Lymph and Chyle 184
Movement of the Lymph 187

CHAPTER XII.

The Constitution of the Blood.

General Characters of the Blood 189
Amount of Blood in the Body 190
Physical Construction of the Blood, Blood-plasma 192
Chemical Composition of Plasma 194
Preparation and Properties of Fibrin 196
Serum 197
Blood Corpuscles 198
Proportion of Red to White 198
The Colourless Corpuscles 199
White Blood-cells 201
Origin of the Colourless Blood-cells 201
The Red Corpuscles, Sizes and Shapes 201
Action of Reagents on Red Corpuscles 206
Method of counting Corpuscles 207
Chemistry of the Colouring Matter of Blood 208
Spectra of Hæmoglobin 210
Hæmatin, Hæmin, &c. 211
Development of the Red Discs 213
The Gases of the Blood 215

CHAPTER XIII.

Coagulation of the Blood.

Coagulation of Shed Blood 217
The Cause of Coagulation 219
Theories of Coagulation 221
Coagulation in the Vessels 223
Formation of Fibrin 225

CHAPTER XIV.

Circulation of the Blood.

PAGE
Pulmonary and Systemic Circulations 229
Method of the Circulation of the Blood 230
The Heart 232
Arrangement of Muscle Fibre 233
Minute Structure of the Heart 234
Action of the Valves 237
Cycle of the Heart-beat 238
Cardiac Movements 239
Heart's Impulse 242
Heart-sounds 244
Innervation of the Heart 246
Local Centres 248
Inhibitory Nerves 250
Accelerator Nerves 251
Afferent Cardiac Nerves 252

CHAPTER XV.

Circulation.

The Blood-vessels 252
Structure of the Vessels 253
Capillaries 255
Relative Capacity of the Vessels 257
Physical Forces of the Circulation 259
Blood-pressure 260
Measurement of Blood-pressure 263
Variations in Blood-pressure 267
Influence of Respiration on Blood-pressure 269
The Arterial Pulse 273
Methods of obtaining Pulse-tracings 275
Variations in the Pulse 276
Velocity of the Blood-current 279
Controlling Mechanisms of the Blood-vessels 281
Vaso-motor Centres 283

CHAPTER XVI.

Respiration.

Gas Interchange 289
Structure of the Lungs and Air-passages 290

PAGE
The Thorax 293
Thoracic Movements 294
Inspiratory Muscles 295
Expiration 300
Modified Respiratory Movements 301
Function of the Pleura 302
Pressure Differences in the Air 304
The Volumes of Air 305
Nervous Mechanism of Respiration 307

CHAPTER XVII.

The Chemistry of Respiration.

Composition of the Atmosphere 314
Expired Air 315
Changes the Blood undergoes in the Lungs 317
Gases in the Blood 319
Internal Respiration 320
Respiration of Poisonous Gases 321
Ventilation 322
Asphyxia 323

CHAPTER XVIII.

Blood-elaborating Glands.

Ductless Glands 326
Supra-renal Capsule and Thyroid Body 327
Thymus 329
Spleen 330
Structure of the Spleen 333

CHAPTER XIX.

The Liver.

Structure of the Liver 336
Functions of the Liver 342
Uremic Function 343
Glycogenic Function and Glycogen 347
Diabetes 349

CHAPTER XX.

Surface Glands.

PAGE
Lachrymal Glands 352
Mucous Glands 353
Sebaceous Glands 354
Mammary Glands 355
Composition of Milk 358
Sudoriferous Glands 361
Cutaneous desquamation 363

CHAPTER XXI.

Urinary Excretion.

Structure of the Kidneys 364
Blood-vessels of the Kidneys 366
Method of Secretion of the Urine 370
Urine 372
Chemical Composition of Urine 374
Urea 375
Uric Acid 376
Kreatinin, Xanthin, Hippuric Acid, Oxalic Acid, &c. 377
Colouring Matters and Inorganic Salts 378
Abnormal Constituents 379
Urinary Calculi 380
Nervous Mechanism of the Urinary Secretion 380
Outflow of Urine 382
Nervous Mechanism of Micturition 383

CHAPTER XXII.

Nutrition.

Tissue Changes during Starvation 386
Food Minimum 388
Nutritive Equilibrium 389
Excessive Consumption 392
Dietaries 393

CHAPTER XXIII.

Animal Heat.

Warm and Cold-blooded Animals 396
Variations in the Body Temperature 397

PAGE
Mode of Production of Animal Heat 399
Income and Expenditure of Heat 400
Maintenance of Uniform Temperature 402

CHAPTER XXIV.

Contractile Tissues.

Histology of Muscle 408
Properties of Muscle in the Passive State 411
Electric Phenomena of Muscle 414
Active State of Muscle 417
Muscle Stimuli 418
Changes occurring in Muscle on its entering the Active State . . 420
Muscle Contraction 423
Graphic Method of Recording Contraction 425
Tetanus, Fatigue, &c. 433
Rigor Mortis 437
Unstriated Muscle 439

CHAPTER XXV.

The Application of Skeletal Muscles.

General Arrangements 440
Joints 440
Standing 441
Walking and Running 444

CHAPTER XXVI.

Voice and Speech.

Anatomical Sketch. 446
Mechanism of Vocalisation 448
Properties of the Human Voice 451
Nervous Mechanism of Voice 453
Speech 453

CHAPTER XXVII.

General Physiology of the Nervous System.

Anatomical Sketch 455
Functional Classification 457

PAGE
Chemistry and Electric Properties of Nerves 459
Active State of Nerve-fibres 459
Nerve Stimuli 459
Velocity of Nerve-impulse 462
Electric Changes in Nerves 463
Electrotonus 465
Excitability of Nerve Fibres 466
Law of Contraction 469
Nerve Corpuscles and Terminals 471
Functions of Nerve Cells 472

CHAPTER XXVIII.

Physiology of Special Nerves.

Spinal Nerves 476
Cranial Nerves 477
Motor Occuli, Trochlear, Portio Dura, &c. 481
Trificial Nerve ; Efferent and Afferent Fibres 483
Ganglia of Trificial Nerve 485
Glosso-pharyngeal Nerve 486
Vagus Nerve 486
Spinal Accessory and Hypoglossal Nerves 489
Sympathetic System 489

CHAPTER XXIX.

Special Senses.

Skin Sensations 497
Nerve Endings 498
Sense of Locality 501
Sense of Pressure 503
Temperature Sense 504
General Sensations 506

CHAPTER XXX.

Taste and Smell.

Sense of Taste 509
Sense of Smell 511

CHAPTER XXXI.

Vision.

PAGE
Construction of the Eye-ball 515
Dioptric Media of the Eye-ball 517
Structure of the Lens 518
Dioptrics of the Eye 521
Accommodation 526
Defects of Accommodation 529
Defects of Dioptric Apparatus 530
The Iris 531
The Ophthalmoscope 534
Visual Impressions 538
The Function of the Retina 539
Colour Perceptions 546
Mental Operations in Vision 549
Movements of the Eye-balls 550
Binocular Vision 551

CHAPTER XXXII.

Hearing.

Sound 553
Conduction of Sound-vibrations through the Outer Ear . . . 557
Conduction through the Tympanum 558
Conduction through the Labyrinth 561
Stimulation of the Auditory Nerve 565

CHAPTER XXXIII.

Central Nervous Organs.

Structure of the Spinal Cord 568
White Matter of the Spinal Cord ; methods of investigation . . 569
Grey Matter of the Spinal Cord 577
Reflex Action 581
Special Reflex Centres 586
Co-ordination 587
Automatism 588

CHAPTER XXXIV.

The Bulb.

The Bulb as a Central Organ 591
The Respiratory Centre 592

PAGE
The Vaso-motor Centre 593
The Cardiac Centre 594

CHAPTER XXXV.

The Brain.

Mid and Hind Brain 597
Cerebellum 600
Crura Cerebri 603
Corpora Quadrigemina 604
Basal Ganglia 605
Cerebral Hemispheres 607
Localisation of the Cerebral Functions 609
Motor Area 611
Sensory Areas 615
Mechanism of Speech 618
Acquisition of Words 619
Memory of Words 621
Use of Words 622
Total Aphasia 624

CHAPTER XXXVI.

Reproduction.

Male and Female Generative Elements 625
Menstruation and Ovulation 628
Changes in the Ovum 631
Formation of the Membranes 636
The Placenta 642
Embryonic Circulations 647
Fœtal Circulation 650

Glossary 653

INDEX 665

COMPARISON OF THE METRICAL WITH THE COMMON MEASURES.

By Dr. Warren de la Rue.

MEASURES OF LENGTH.

	In English Inches.	In English Feet =12 Inches.	In English Yards =3 Feet.	In English Fathoms =6 Feet.	In English Miles =1,760 Yards.
Millimeter	0·03937	0·0032809	0·0010936	0·0005468	0·0000006
Centimeter	0·39371	0·0328090	0·0109363	0·0054682	0·0000062
Decimeter	3·93708	0·3280899	0·1093633	0·0546816	0·0000621
Meter	39·37079	3·2808992	1·0936331	0·5468165	0·0006214
Decameter	393·70790	32·8089920	10·9363310	5·4681655	0·0062138
Hectometer	3973·07900	328·0899200	109·3633100	54·6816550	0·0621382
Kilometer	39370·79000	3280·8992000	1093·6331000	546·8165500	0·6213824
Myriometer	393707·90000	32808·9920000	10936·3310000	5468·1655000	6·2138244

1 Inch = 2·539954 Centimeters. | 1 Foot = 3·0479449 Decimeters. | 1 Yard = 0·91438348 Meter. | 1 Mile = 1·6093149 Kilometers.

MEASURES OF CAPACITY.

	In Cubic Inches.	In Cubic Feet =1,728 Cubic Inches.	In Pints =34·65923 Cubic Inches.	In Gallons =8 Pints = 277·27384 Cubic Inches.	In Bushels =8 Gallons =2218·19075 Cubic Inches.
Milliliter or cubic centimeter	0·061027	0·0000353	0·001761	0·00022010	0·000027512
Centiliter or 10 cubic centimeters.	0·610271	0·0003532	0·017608	0·00220097	0·000275121
Deciliter or 100 cubic centimeters.	6·102705	0·0035317	0·176077	0·02200967	0·002751208
Liter or cubic decimeter	61·027052	0·0353166	1·760773	0·22009668	0·027512085
Decaliter or centistere	610·270515	0·3531658	17·607734	2·20096677	0·275120846
Hectoliter or decistere	6102·705152	3·5316581	176·077341	22·00966767	2·751208459
Kiloliter or stere, or cubic meter	61027·051519	35·3165807	1760·773414	220·09667675	27·512084594
Myrioliter or decastere	610270·515194	353·1658074	17607·734140	2200·96676750	275·120845937

1 Cubic Inch = 16·3861759 Cubic Centimeters. | 1 Cubic Foot = 28·3153119 Cubic Decimeters. | 1 Gallon = 4·543457969 Liters.

MEASURES OF WEIGHT.

		In English Grains.	In Troy Ounces = 480 Grains.	In Avoirdupois Lbs. = 7,000 Grains.	In Cwts. = 112 Lbs. = 784,000 Grains.	Tons = 20 Cwt. = 15,620,000 Grains.
Milligram	1	0·015432	0·000032	0·0000022	0·00000002	0·000000001
Centigram	10	0·154323	0·000322	0·0000220	0·00000020	0·000000010
Decigram	100	1·543235	0·003215	0·0002205	0·00000197	0·000000098
Gram	1000	15·432349	0·032151	0·0022046	0·00001968	0·000000984
Decagram	10000	154·323488	0·321507	0·0220462	0·00019684	0·000009842
Hectogram	100000	1543·234880	3·215073	2·2204621	0·00196841	0·000098421
Kilogram	1000000	15432·348800	32·150727	2·2046213	0·01968412	0·000984206
Myriogram	. . .	154323·488000	321·507267	22·0462126	0·19684118	0·009842059

CORRESPONDING DEGREES IN THE FAHRENHEIT AND CENTIGRADE SCALES.

Fahr.	Cent.	Cent.	Fahr.
500°	260°·0	100°	212°·0
450°	232°·2	98°	208°·4
400°	204°·4	96°	204°·8
350°	176°·7	94°	201°·2
300°	148°·9	92°	197°·6
212°	100°·0	90°	194°·0
210°	98°·9	88°	190°·4
205°	96°·1	86°	186°·8
200°	93°·3	84°	183°·2
195°	90°·5	82°	179°·6
190°	87°·8	80°	176°·0
185°	85°·0	78°	172°·4
180°	82°·2	76°	168°·8
175°	79°·4	74°	165°·2
170°	76°·7	72°	161°·6
165°	73°·9	70°	158°·0
160°	71°·1	68°	154°·4
155°	68°·3	66°	150°·8
150°	65°·5	64°	147°·2
145°	62°·8	62°	143°·6
140°	60°·0	60°	140°·0
135°	57°·2	58°	136°·4
130°	54°·4	56°	132°·8
125°	51°·7	54°	129°·2
120°	48°·9	52°	125°·6
115°	46°·1	50°	122°·0
110°	43°·3	48°	118°·4
105°	40°·5	46°	114°·8
100°	37°·8	44°	111°·2
95°	35°·0	42°	107°·6
90°	32°·2	40°	104°·0
85°	29°·4	38°	100°·4
80°	26°·7	36°	96°·8
75°	23°·9	34°	93°·2
70°	21°·1	32°	89°·6
65°	18°·3	30°	86°·0
60°	15°·5	28°	82°·4
55°	12°·8	26°	78°·8
50°	10°·0	24°	75°·2
45°	7°·2	22°	71°·6
40°	4°·4	20°	68°·0
35°	1°·7	18°	64°·4
32°	0°·0	16°	60°·8
30°	— 1°·1	14°	57°·2
25°	— 3°·9	12°	53°·6
20°	— 6°·7	10°	50°·0
15°	— 9°·4	8°	46°·4
10°	—12°·2	6°	42°·8
5°	– 15°·0	4°	39°·2
0°	—17°·8	2°	35°·6
— 5°	—20°·5	0°	32°·0
—10°	—23°·3	— 2°	28°·4
—15°	—26°·1	— 4°	24°·8
—20°	—28°·9	— 6°	21°·2
—25°	—31°·7	— 8°	17°·6
—30°	—34°·4	—10°	14°·0
—35°	—37°·2	—12°	10°·4
—40°	—40°·0	—14°	6°·8
—45°	—42°·8	—16°	3°·2
—50°	—45°·6	—18°	—0°·4
		—20°	—4°·0

MANUAL OF PHYSIOLOGY.

CHAPTER I.

INTRODUCTION.

BIOLOGY, the science which deals with living beings, may be divided into two branches, viz. :—

1. MORPHOLOGY, which treats of the forms and structure of living creatures ; and,

2. PHYSIOLOGY, which attempts to explain the modes of activity exhibited by them during their life-time, and may therefore be defined as the science which investigates the phenomena presented by the textures and organs of healthy living beings ; or, in short, the study of the *actions* of organisms in contradistinction to that of their structure.

The organic world appears to be naturally divided into the Animal and Vegetable kingdoms. We have, therefore, both animal and vegetable morphology and physiology. In studying the vegetable kingdom, the activity of plants together with their form and structure, constitute the science of Botany. The physiology of plants need not, therefore, be considered here, though a knowledge of it proves useful in considering many of the processes belonging to animal life. On the other hand, the morphology and physiology of animals are commonly taught separately, and in the medical curriculum are made distinct subjects.

Morphology includes the external form, the general construction or Anatomy of organisms, and the minute structure of their textures as revealed by the microscope. This latter branch of study, under the name Histology, has developed into a very extensive subject, which is inseparable from either physiology or anatomy.

In this country histology is commonly taught in the medical

schools with physiology, because the time of the teachers of morphology is occupied in expounding the nomenclature of descriptive anatomy, while the microscope is in everyday use in the physiological laboratory.

An adequate knowledge of microscopic methods, and of the various form-elements of the different textures of the body is one of the first essentials for physiological study.

As the different actions of the body are performed by different tissues, which in the higher animals are grouped together as distinct organs, anatomy and general morphology may be said to be the basis upon which physiological knowledge is built. Some knowledge of these subjects must therefore precede the study of physiology, in order that the student may be in a position to grasp even the simplest facts connected with any physiological question.

We shall soon find that the assistance of other sciences is also indispensable to physiology. Thus every action of a living texture or tissue is accompanied by some chemical change, chemical processes being an essential part of the phenomena of life. The student of physiology must, then, know something of the science of Chemistry ; indeed the mode of action of chemical elements forms quite as important a groundwork for the study of the activity of the living tissues as their general form or minute structure.

Further, the laws of Physics which govern the motions of inanimate bodies also control the actions of living tissues, for we cannot claim to be able to recognise the existence of any laws affecting living organisms other than those known to be applicable to dead matter. We must endeavour to explain all the phenomena of life by means of the laws known to chemists and physicists. By this means we may get a closer insight into the processes of life, and if there be laws belonging exclusively to living beings we may learn to know them. This method of working has already given good results, for within comparatively recent times many of the processes which were regarded as specially vital in character have been shown to be within the scope of experimental science.

It is therefore necessary for the physiologist, before he attempts to explain the activities of an organism, to be familiar not only with the structure of its body as taught by Anatomy, but also with those laws which *Chemistry* and *Physics* teach us are obeyed by inanimate matter.

Chemistry and Physics may, in fact, be regarded as the

basis of the physiology of inorganic matter, just as, when applied to the functions of living creatures, they form biological physiology. When we consider how far the chemist and the physicist still are from thoroughly grasping and interpreting all the phenomena presented by the various kinds and conditions of matter, we cannot be surprised that those who attempt to explain the actions of living beings find many processes that they are unable to comprehend, and hence term them *vital*. But when physiologists make use of the convenient term "vital phenomena," it must be remembered that they do not thereby insist upon the existence of a special living force or any kind of energy peculiar to living creatures.

The ultimate object of physiology is not yet within the reach of our modern methods of research. To explain the mode of activity of living beings, and grasp the exact relation borne by their living phenomena to the laws which govern them, is a task of enormous difficulty. Indeed the manifestations of certain energies in living organisms are so complicated that it is often, if not generally, impossible to say exactly how they are brought about, and we are therefore obliged, for the present at least, to be satisfied with their mere recognition and description.

Since the human organism is the special study of students of medicine, the contents of this volume should properly be restricted to the physiology of man. But human physiology cannot be studied alone; because in man we cannot watch sufficiently closely, or question fully by experiment, the phenomena of life. Further, no sharp line of separation can be drawn between the actions of the various organs of man and those of the lower animals. The consideration of the physiology of those animals which are akin to man must therefore go hand in hand with the study of the physiology of man himself. Much light has been thrown on the actions of the complex textures of the highest animals, by the observation of the activities of the lowest organisms, where the manifestations of life may be carefully watched with the microscope in the living animal under its normal conditions.

General Characters of Organisms.

The term organism, which is commonly used as having the same meaning as *living being*, owes its derivation to the com-

plexity of structure common among the higher forms of life, which are made up of several distinct organs. This organic construction does not hold good as a distinguishing mark between living beings and inanimate matter, because we are acquainted with a vast number of organisms, both plants and animals, which are composed of a minute piece of a soft jelly-like material, devoid of organic differentiation.

We may classify the general characters of living beings as follows :

1. Structural and physical properties.
2. Chemical composition.
3. Activities during life (vital phenomena).

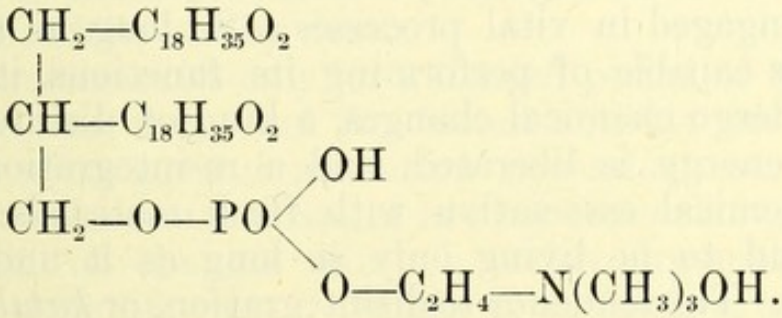
1. Structural Characters of Organisms.—The minute structure of living beings as shown by the microscope no doubt helps to distinguish the textures of organisms from inorganic structures. Although organic textures are found to differ very widely in their characters they are all related in one respect, namely, that at the earliest period of their existence they consist of a minute mass of a substance called *Protoplasm*, known as a *cell*. In plants a cellular structure remains obvious in all parts of the adult, no matter how much the texture may be modified by adaptation to the requirements of any given duty or function. If we examine with the microscope the leaves, bark, wood, or pith of a plant, in all of them a cellular structure can be recognised. In the less developed members of the animal kingdom, and during the initial stages in the existence of the highest animals, the textures are composed exclusively of aggregations of living cell-elements. We shall shortly see that in the more fully developed condition of the higher animals, the cells become variously modified in form and function, and the protoplasm manufactures various structures adapted to the performance of the diverse functions of the different parts. In all organic textures which can be said to be living, cells are dispersed in greater or less number, and regulate their nutrition and repair.

2. Chemical Composition.—There are no characters in the chemical composition of the textures of organic beings which can be said to be absolutely distinctive or to separate them from inorganic matter. No doubt their chemical construction frequently exhibits certain peculiarities, not seen in dead matter, which may be taken as characteristic, but living textures only

differ in the general plan of arrangement and composition from those most commonly met with in the construction of inorganic materials.

In the first place, the great majority of the *chemical elements* which we know of, take no share in the formation of living creatures, and are never found to enter into their composition. Practically only fifteen of some seventy *elements* known to chemists take part in making up the tissues of animals. The majority of these are only present in very small quantity and with no great constancy. On the other hand, there are four elements, namely, *carbon*, *oxygen*, *hydrogen*, and *nitrogen*, which are found with such great regularity and in so great quantity, that they may be said to make up the great bulk (97 per cent.) of the animal frame. The great constancy with which these elements occur must be regarded as a most important character of organic tissues.

Secondly, in *organic substances* the chemical elements are associated in much more complex and irregular proportions. Generally a large number of *atoms*, of each element, are grouped together to form the *molecule*, and often the compound is so complex that its chemical formula remains a matter of doubt. As an example of the complexity of bodies found in organic analysis, a remarkable substance called *lecithin*, which appears in the analysis of protoplasm and many tissues, may be mentioned. Its formula may be expressed thus :



It is peculiar in containing nitrogen and phosphorus, and in construction is like a fat.

In *inorganic substances*, on the other hand, the elements are found to be combined, as a general rule, in simple and regular proportions. The molecules are made up of but few elements arranged in a definite manner and firmly bound together, so that they are not prone to undergo decomposition. As an example, we may take water, which has the well-known formula,

$$H_2O.$$

These bodies may be taken as types of organic and inorganic substances respectively, but it must not be imagined that all organic bodies are as complex and irregular as lecithin, or that inorganic compounds, are invariably as simple as water.

It is further remarkable that *Carbon*, an element which is peculiar by the few associations it forms in the mineral world, —where it is chiefly found combined with oxygen to form CO_2—is almost invariably present in living textures, in which it is combined with hydrogen and nitrogen as well as some oxygen. Carbon exists so constantly in organic bodies that the chemistry of the carbon compounds was formerly called organic chemistry.

These complex associations of many atoms of carbon with many atoms of other elements, are readily dissociated when exposed to the air under even slightly disturbing influences. These complex bodies are stores of energy and their dissociation sets free energy in one form or another. They can burn, *i.e.*, unite rapidly with the oxygen of the air to yield heat; or they may putrify and supply energy for the development of innumerable minute organisms.

Thus *instability* is a general feature commonly met with in most substances of organic origin.

3. Vital Phenomena — Assimilation. — Chemical instability reaches the highest pitch in tissues which are actually alive and engaged in vital processes. So long as any texture lives, *i.e.*, is capable of performing its functions, it must constantly undergo chemical changes, a kind of disintegration, by which its energy is liberated, and a re-integration by means of new chemical association with fresh materials. A tissue may be said to be living only so long as it undergoes this *metabolism*. The tendency to disintegration, or *katabolic change*, is intimately connected with the functional activity of the living texture, and increases with this activity which requires the expenditure of some energy. The re-integration or constructive (*anabolic*) process requires the presence of suitable materials with which the texture may combine, in order to make up for the loss and restore the energy. Thus living tissues are ever on the point of destruction, which can only be warded off by the timely re-construction of their chemical ingredients by fresh materials. This reconstruction by means of fresh matter from without, or storing up of energy, is called

assimilation, and forms the most, if not the only, satisfactory criterion by which adequately to distinguish living beings from inorganic matter.

The object of assimilation is to renew the materials required by the various textures for the chemical processes of their functions. The steps by which this is accomplished will be found to form a great part of physiological study. The energy manifested in the living textures depends upon the various oxidising processes, and the exact laws which govern these combustions, and the results they produce in the various tissues, practically make up the second part of physiology.

The so-called vital phenomena which take place in the textures of organisms are, for the most part, performed by the agency of the living cell-elements, in which we can recognise independent manifestations of life, such as the response to stimulus, motion, nutrition, growth, &c. The living activity of organisms requires for its perfect development certain external conditions, namely, a certain degree of *warmth* and *moisture*. Without these conditions the chemical interchanges just mentioned cannot go on, and the organism either remains in a state of inactivity or is destroyed.

The nutrition of the animal body, which is accomplished by means of assimilation, enables it to undergo many changes in form and texture, and, up to a certain point, to grow. There is, however, a limit to this assimilative power : nutritive activity diminishes, growth gradually stops, and after a time decay appears and is followed by death.

Thus organisms exist only for a limited period of time, during which their size, form, and functional activity are constantly undergoing some general alteration dependent on, or concurrent with, the incessant changes in their molecular construction.

This cycle of changes through which organisms pass we speak of as their life-time. During this life-time, at the period when their functional activity is at its height, they possess the remarkable faculty of producing individuals like themselves.

This is accomplished by setting apart a cell which, under favourable circumstances, assumes special powers of growth, increases in size by the rapid formation of new cells, and developes into an independent living unit. In time it arrives at maturity, and becomes like its parent, and passes through the same cycle—by its power of assimilation it grows to maturity, reproduces its like, then decays and dies.

CHAPTER II.

GENERAL VIEW OF THE STRUCTURAL CHARACTERS OF ANIMAL ORGANISMS.

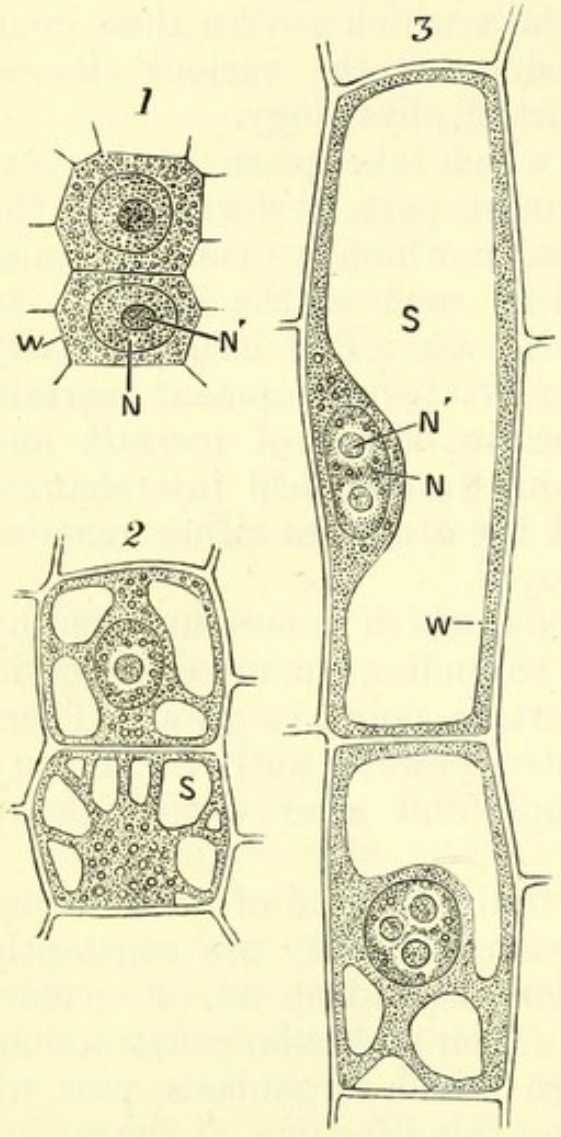


Fig. 1.—Cells from the root of a plant. (×550.)

1. Showing youngest cells with thin walls (w) filled with protoplasm and containing nucleus (n), and nucleolus (n′).

2. Older cells with thicker walls with vacuoles and cell-sap (s).

3. Shows further diminution of protoplasm and increase in cavity (s) in proportion to the growth of the cell-wall (w).

THE parts played by *Cells* in the functions of living beings are so many and so important, that it is necessary at the very outset to consider the properties of the individual elements somewhat in detail.

The demonstration of the cellular structure of plants was made in 1832 by a distinguished German botanist named Schleiden, who considered the cells to be characteristic of plant tissue. A few years later Schwann showed that the animal tissues, though not so obviously, were also made up of cells, and that they owed their beginning and development to the activity of cell elements. Thus originated the "cellular theory," which, with some modifications, is now the basis of all physiological enquiry.

The first idea which was conveyed by the term *cell* varied much from that which we now accept as a proper definition of such an organic unit.

Fully developed vegetable cells being the first discovered were taken as the type of all. The main characteristics of these may be briefly summed

up. First, a membranous sac called the *cell-wall*, generally very well defined, and secondly, within the cell-wall various *cell-contents*. Among the more conspicuous of the latter may be mentioned (1) a soft, jelly-like substance called *protoplasm* in which lies a *nucleus*, and (2) certain cavities called *vacuoles*, which are filled with a clear fluid called *cell-sap*.

Further investigation of the life history of cells, particularly in the early stages of their development, showed that the cell-wall, which played so important a part in the original conception of a cell was not always present, but was formed by the protoplasm in a later stage of growth. The cell-sap and other matters were found to occur less commonly, and appeared still

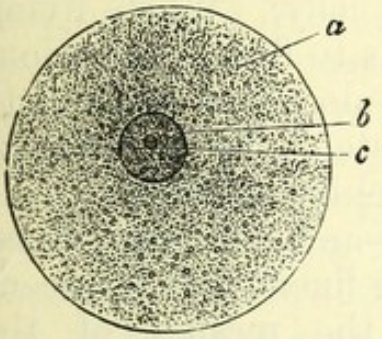


Fig. 2.—Diagram of animal cell (ovum). (Gegenbauer.)

a. Granular protoplasm.
b. Nucleus.
c. Nucleolus.

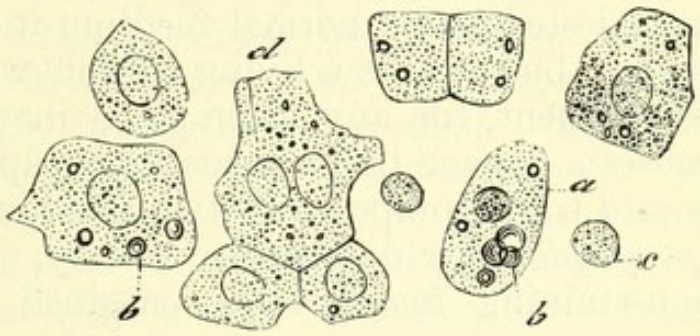


Fig. 3.—Liver cell of man, containing fat globules (*b*) and biliary matters. (Cadiat.)

later than the cell-wall in the life-time of the vegetable cell; hence it was concluded that they were the outcome of changes due to the activity of the protoplasm, and that this latter was the only essential and formative part of the cell.

Subsequently, from the facts that some vegetable cells in the youngest and most active stage of their growth have no limiting wall, and that most animal cells have none during any part of their life, it was proposed to define a cell as *a mass of protoplasm containing a nucleus*. But further research showed that the nucleus was not always present. In many cryptogamic plants no nucleus can be found, and in some animal cells, which must be regarded as independent individuals (Protamœba), there is no nucleus at any part of their life-time. This would lead us to suppose that *a mass of protoplasm capable of manifesting all the phenomena of life* would be a sufficient definition. Though this is probably correct in a few cases, the vast majority of cells do contain nuclei. As it is difficult to divest

our minds of the connexion between the two, it has been proposed to give the name *cytod* to the non-nucleated forms, which certainly are very exceptional, reserving the term *cell* for the common nucleated unit. Each part of the cell may now be considered in the order of its importance, viz., protoplasm, nucleus, cell-wall, and cell-contents.

I. Protoplasm is usually seen to be a colourless, pale, milky, semi-translucent substance, more or less altered in appearance by various foreign matters lying in it. It has a granular appearance, but when fully matured, or fixed, it exhibits a linear marking or fine network. During life its consistence is nearly fluid, varying with the circumstances in which it is placed, from that of a gum solution to a soft jelly. When living unmolested in its normal medium it seems to flow into various shapes, but this is a living action which does not prove it to be diffluent, for any attempt to investigate it by experiment causes a change in its consistence approaching to rigidity. It is said to be composed of two substances—an elastic reticulum, *spongioplasm*, which stains readily, and a fluent homogeneous non-staining *hyaloplasm* contained in the meshes of the former.

The comprehension of the functions of this substance is essential, as it lies at the root of the greater part of Physiology. A more detailed account of its properties is given in Chapter IV. on Vital Phenomena (p. 65), when it will be discussed at greater length.

II. The Nucleus.—The majority of independent masses of protoplasm, and all highly organized cells, contain one or more nuclei in their substance. The nucleus is able to resist the action of dilute acids better than the remainder of the cell, so that it stands out clearly, when the surrounding protoplasm is made transparent by the addition of weak acetic acid. Its presence can generally be made much more conspicuous by treating the cell with certain chemical re-agents, and various dyes, viz., dilute acetic acid or logwood, which colours the nucleus more quickly and deeply than the protoplasm. Although it is accredited with special independent movements that occur under certain circumstances, compared with the protoplasm it is not obviously contractile. It appears to be intimately associated with the vital phenomena of the cell, and may be said to control or initiate its most important activity, namely, its division.

If a nucleus be carefully examined, it is found to consist of the following parts :—

(1) The nuclear membrane.
(2) The nuclear network.
(3) The nuclear matrix, or liquid material in the meshes of the network.
(4) Nucleoli.

The nuclear membrane is a fine structure formed by the cell protoplasm and surrounds the other three components of the nucleus. It is achromatic, *i.e.* does not stain with the staining re-agents usually employed.

The nuclear network consists of a number of fibres, of varying sizes, arranged irregularly. A recent description of them divides them into two kinds, one termed primary, and the other secondary. The primary fibres are the larger, and each forms a loop at one part of the nucleus, called the polar field. The two limbs radiating away from this region end abruptly at the opposite side of the nucleus or antipolar field. The secondary fibres are smaller, and start from the sides of the primary fibres, and by forming connections with similar secondary fibres from adjacent primary, they complete the nuclear network. These fibres are all called chromatic elements, because they stain deeply with the ordinary nuclear stains, logwood, carmine, safranin, &c.

The nuclear matrix is the fluid surrounding the fibres and is structureless. It does not stain (*achromatin*). It is rich in proteids.

The nucleoli are one, or more, small spherical masses lying in the nuclear matrix, distinct from the network, and behave differently to staining re-agents. (Fig. 38.)

Remarkable changes in the arrangement of the network are seen to precede the division of the protoplasm by the method called *karyokinesis*. (See p. 69.)

III. The Cell-Wall.—It has already been stated that the most active cells, such as are found in the earliest stages in the life of an organism (embryonic cells), have no enclosing membrane or cell-wall. But in the more advanced stages of cell life we find this second form of protoplasmic differentiation to be common enough. In animal cells the limiting membrane has never the same importance as the cell-wall in vegetable tissues, where some of the principal textures may be traced to a direct modification of the cell-wall, still recognizable as such. Whenever such a limiting membrane exists, it is formed by the outer layers of protoplasm undergoing changes so as to become

of greater consistence. In the animal tissues the cells form various structures, which are not limiting membranes or cell-walls, but rather give the idea of lying between the cells. Hence, in one large group of tissues, they have been called *intercellular substance*, while in others they appear as materials specially modified for the furtherance of the functions of the special tissues.

IV. Cell-Contents.—Regarding protoplasm as the essential living part of the cell, under this heading will come only those extraneous matters which are the outcome of protoplasmic activity.

The cell-contents which are present with such constancy and in such variety in vegetable cells, form in them an all-important part; but in most animal cells the contents do not occupy such a striking position.

No doubt animal protoplasm, as well as that of vegetables, is capable of making out of its own substance, when adequate nutriment is supplied to it, a great variety of materials, but these are seldom stored in such large quantities in the cells of animals as in those of plants.

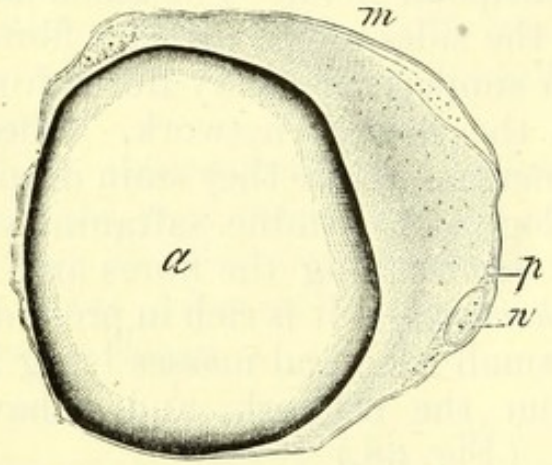


Fig. 4.—Cell from connective tissue containing large fat globule (*a*), showing an early stage in the formation of oil vesicle, (*p*) protoplasm, (*n*) nucleus, (*m*) membrane. (Ranvier.)

In the cells of some kinds of animal textures, particularly that called *Connective Tissue*, we commonly find large quantities of fat formed, and accumulated to such a degree in the cell that the protoplasm can be no longer recognised as such (see fig. 4). Its remnant, in which the nucleus persists, is devoted to forming a limiting membrane for the fatty contents, so that the cell is converted into an oil vesicle, and here what may be termed the contents become the most important part of the cell. In various glandular cells as will be seen hereafter, different substances are made and stored up temporarily in the protoplasm. These may be seen as bright refracting granules, which are subsequently discharged in the secretion of the gland.

In other cells, notably those of the liver, nutrient material

allied to starch (Glycogen) may be deposited in considerable quantity, just as starch is stored in certain cells of plants. Owing to the greater and more constant activity of most animals, the amount laid by never attains that found in the store-textures of vegetables, where the result of an entire summer's active work is put by as a provision for the next winter and the fresh burst of energy which follows it in the spring. In some hybernating animals an analogous process occurs.

But while the above are all more or less temporary contents of cells, we have an example of a permanent deposit in them, viz., pigment which is formed from the colouring matter of the blood by the protoplasm, and has a special physiological use. Thus in the tissue behind the retina—or nerve layer of the eye-ball—the cells are filled with granules of a pigmented substance, which absorb the light falling upon them, and thus prevent reflection which would interfere with the clearness of sight.

It also occurs in the skin of the negro and other races, and in that of the frog and other animals, but in these its function is not fully known.

VARIETIES OF CELLS.—Great varieties of cells are found in the various mature tissues of the higher animals, all of which have passed through the stage of being a simple nucleated mass of protoplasm in the earlier periods of their development. All cells may then be divided into two chief types, the undifferentiated and the differentiated.

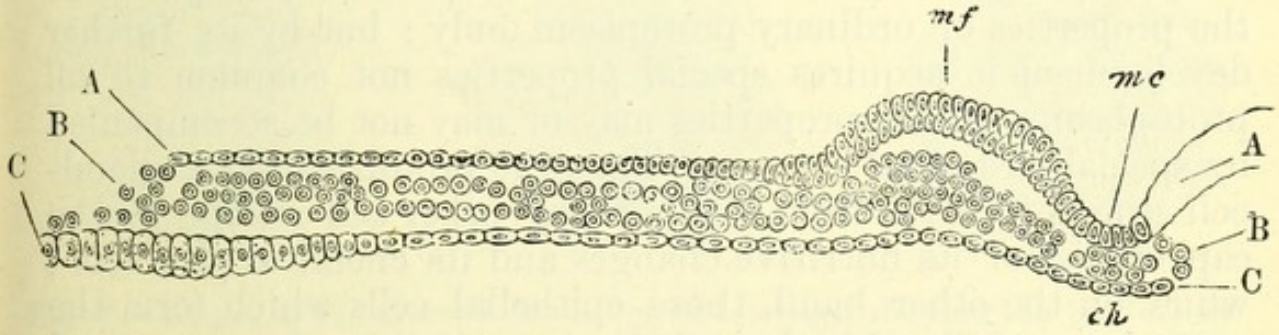


Fig. 5.—Transverse section of Blastoderm, showing the undifferentiated elements in the earlier stage of the development. A, epiblast; B, mesoblast; C, hypoblast.

Under the category of *undifferentiated cells* may be placed all such as retain the characters of the first embryonic cells, and have not acquired any special structure or property by which they can be distinguished from the simplest form. Such cells are the only ones in the early stages of the embryo (fig. 5). In

the adult tissues they also occur, having various duties to perform. They are found in the blood and lymph, and scattered throughout the tissues. They are without a cell-wall, and have no special contents to mark their function.

Among the *differentiated cells* we find many special characters, adapting them to certain special duties, for all these cells are modified from the original type and applied to the performance of some special function.

Space prevents even a short enumeration of the varieties of cells met with in the tissues of plants, where they not only carry on the active functions of the organism, but also form the supporting structures.

The differentiation of a cell is accomplished by its protoplasm, which forms new structural parts, and sometimes seems itself to diminish in quantity until an element is produced in which there may be no protoplasm recognizable.

We find then matured and differentiated cells which vary—

1. In shape, being spherical, flattened, fusiform, stellate, &c.
2. In size.
3. In their mode of connection.

Cells may also be classified according to their function, *e.g.*, Glandular, Nervous, &c., and the greater portion of the following pages will be devoted to the functions of these various forms of cells.

So long as the cell remains in its indifferent stage it possesses the properties of ordinary protoplasm only ; but by its further development it acquires special properties not common to all protoplasm. These properties may or may not be accompanied by special structural change. Thus the protoplasm of a gland-cell differs in little from that of any other cell except in the capabilities of its nutritive changes and its chemical products ; while on the other hand, those epithelial cells which form the outer layer of the skin lose their protoplasmic characters and are completely modified in structure.

Tissue Differentiation.

The first stage in the existence of any organism, from the simplest form of plant to man, consists of a single cell (in animals called the ovum or egg,) which differs in no essential points of structure from an ordinary cell.

There is moreover a class of organisms in which the individuals never go beyond this stage, but pass their entire lifetime in the state of a simple unicellular organism. The individuals composing this group (*Protista*), though insignificant in point of size, may vie with the higher plants and animals in number, species, and variety of form, so that they might well be placed in a kingdom by themselves (as has been proposed) apart from the vegetable and animal kingdoms.

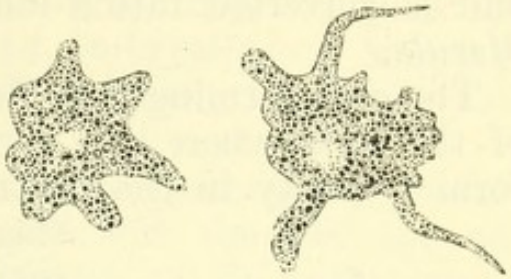


Fig. 6.—Unicellular organism. Small amœba changing its shape. (Cadiat.)

The group of these organisms which most resembles animals, is called *Protozoa*, and is divided from other animal forms by

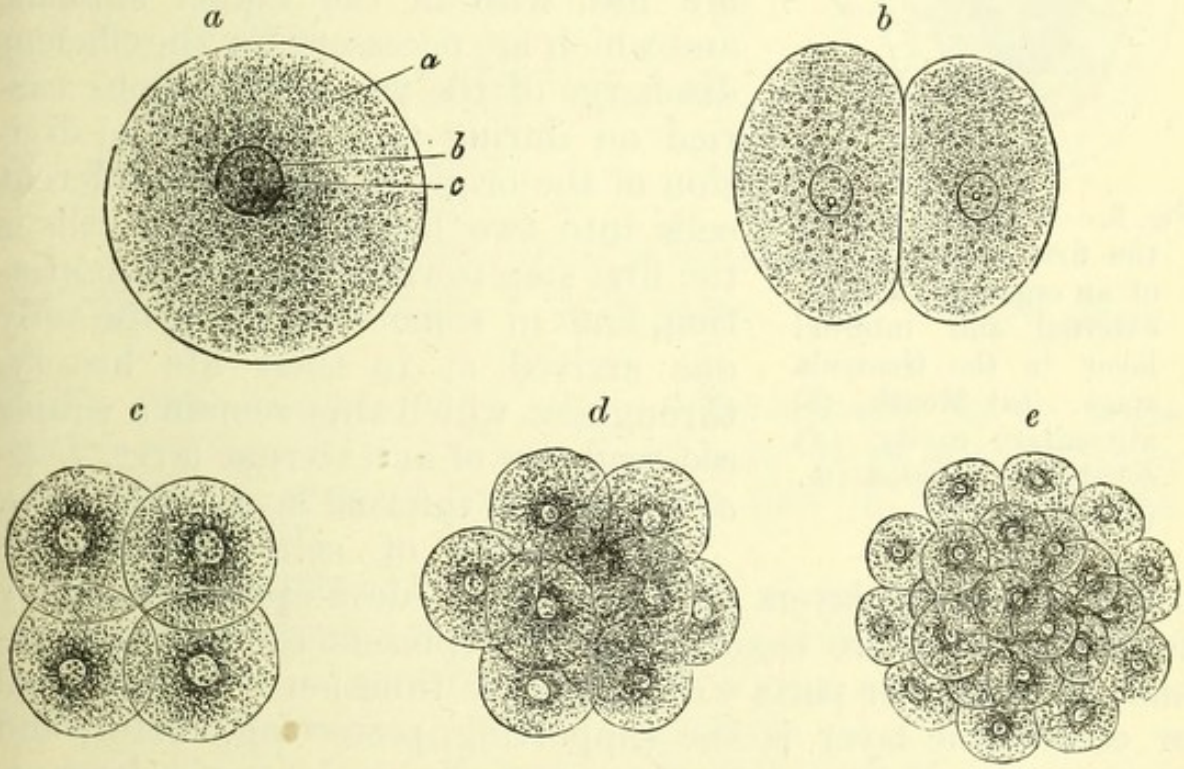


Fig. 7.—Stages in the division of the egg cell (ovum), showing the production of a multiple mass by division. (Gegenbauer.)

a, undivided ovum ; *b*, stage of primary division ; *c* and *d*, secondary stages of division ; *e* morula or mulberry stage.

the manner of development of the ovum of the latter, which divides into cells that subsequently become differentiated into tissues. This group is called the *Metazoa*.

In the Protozoa the ovum never divides, the animal always remaining a single cell. On the contrary, the ovum of the

Metazoa changes its characters during its development. At first possessing a stage common to both divisions, viz., a single cell, it soon passes through rapid stages of cell proliferation, and is converted into a multiple mass, the mulberry stage or *Morula*.

The cells forming this Morula stage approach the periphery of the mass, where they arrange themselves in two layers, and form a cavity in the centre. This is known as the *Gastrula* stage. Following this cell multiplication we find a qualitative differentiation of the cells, by which certain groups of cells assume special peculiarities, fitting them for some special duty.

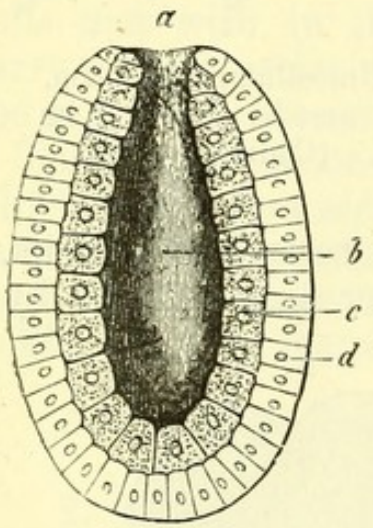


Fig. 8.—Diagram showing the first differentiation of an organism into an external and internal layer in the Gastrula stage. (*a*) Mouth, (*b*) alimentary cavity, (*d*) ectoderm, (*c*) endoderm. (Gegenbauer.)

Thus we arrive at the production of special textures and organs such as are met with in the higher animals, and which are necessary for the efficient discharge of the various functions carried on during their lives. The division of the original mass of indifferent cells into two layers of special cells is the first step towards tissue differentiation, and in some animals is the only one arrived at in their life history, throughout which they remain a simple sac made up of an external layer, *Ectoderm*, and an internal layer, *Endoderm*.

The groups of cells forming the outer and inner layers of this stage of development, not only form the primitive tissues, but also represent the first appearance of organs or parts with a specific function. The external or ectodermic layer is the supporting, protecting, motor, and respiratory organ, while the inner or endodermic layer is devoted to a primitive form of digestion, preparing the food for assimilation, and generally presiding over the nutrition of the body.

Although this sac-like (Gastrula) stage is supposed to have formed a step in the life history of nearly all animals, yet it forms a less striking part in the development of the individuals as we ascend the animal scale, and in the higher animals such a stage is hardly recognised. In the Vertebrates, the germ-cells derived from the ovum are from an early period divided

into three distinct layers, as those which correspond to the Ectoderm and Endoderm of the lower organisms, form between them a third layer or *Mesoblast*.

From these germinal layers all the organs and tissues of the body are subsequently evolved. In embryological language the three primitive layers are called *Epiblast*, *Mesoblast*, and *Hypoblast*.

Thus it can be seen that, as we can compare the primitive unicellular state of the lowest animals with the first egg-cell stage of existence of the highest animals, so we can compare

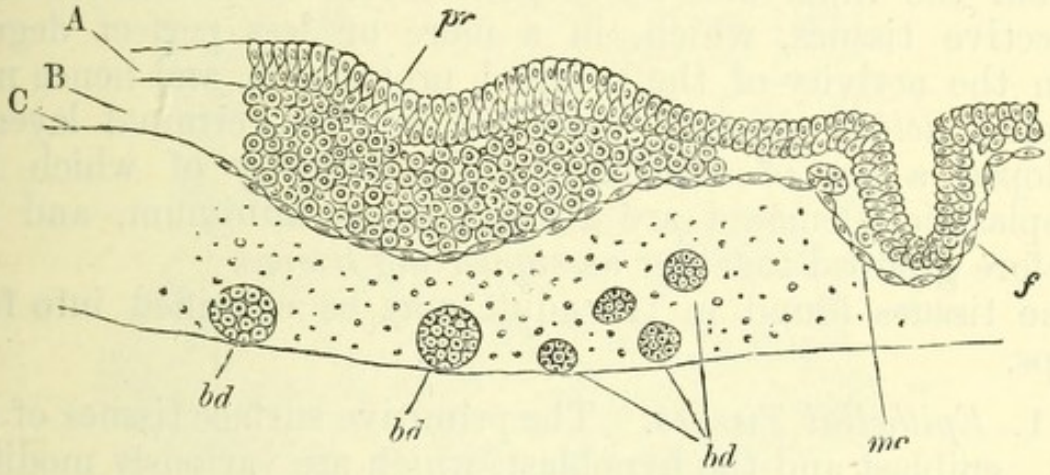


Fig. 9.—Transverse section of blastoderm of chick.

A. Epiblast. B. Mesoblast. C. Hypoblast. *pr*. Primitive groove.

all the steps of tissue and organ differentiation as we trace them in the embryo of a mammal, with the steps of elaboration in organic and textural parts that we find in ascending the scale of animal life.

The history then of the development of any mammal from a single cell or egg to the complex adult individual, is analogous with the more protracted history of the evolution of the animal kingdom from the Protista upwards.

It is impossible to separate the differentiation of tissues and organs, or to say which is of older date in the history of animal evolution. Even in unicellular animals, where we have no trace of tissue difference (Paramæcium, Vorticella), there being only one cell, we have a distinct foreshadowing of organic and functional differentiation (vide Chapter III.). And in creatures made of many parts, the same cells have several duties to perform. But when an aggregation of specialised cell-units exists, it may be said to be a tissue. If these cells have no very special characteristic then the tissue may be called

primitive or embryonic. But, as has just been stated, the aggregation of embryonic cells—in the higher forms of life—have special characters from the very first, which mark them off from one another as destined for different functions.

The middle germ-layer (mesoblast) is derived from the upper (epiblast) and lower (hypoblast), the relative amount contributed by each being doubtful. From the earliest period the middle layer has distinctive characteristics, and ultimately gives rise to a set of tissues which can always be distinguished from those which originate from the upper and lower layers.

From the inner and outer germ-layers are formed several connective tissues, which, in a more or less perfect degree, retain the activity of the original protoplasm, and hence may be called *active tissues*. From the middle germinal layer is developed a set of textures, in the majority of which the protoplasmic elements are reduced to a minimum, and are therefore grouped together as *supporting tissues*.

The tissues found in the adult may be classified into four groups.

1. *Epithelial Tissues*. The primitive surface tissues of the epiblast and the hypoblast, which are variously modified for several distinct functions.
2. *Nerve Tissues*. Springing from the former, are modified for receiving, conducting, controlling, and distributing impressions.
3. *Muscle, or Contractile Tissues*. In close relation to both the previous and the next groups.
4. *Connective Tissues* formed only from the middle germ-layer. They are much modified in different parts, so as to give shape to the body, and to support and hold the various organs and parts firmly together. They are, in fact, the materials used in the general body architecture.

1. Epithelial Tissue, although the oldest tissue, both in the animal series and in developmental history, retains the embryonic character of being entirely composed of cells placed in close relationship on the internal and external surfaces of the body. The individual cells retain the embryonic character in form and function, being soft rounded masses of protoplasm, only altered in shape by the pressure of their neighbours. The cells which lie next the nutrient vessels of the mesoblast, are endowed with energetic powers of growth and reproduction.

As the young cells are produced they take the place of the parent cell, whose future life-history determines the special characters of the different kinds of tissues.

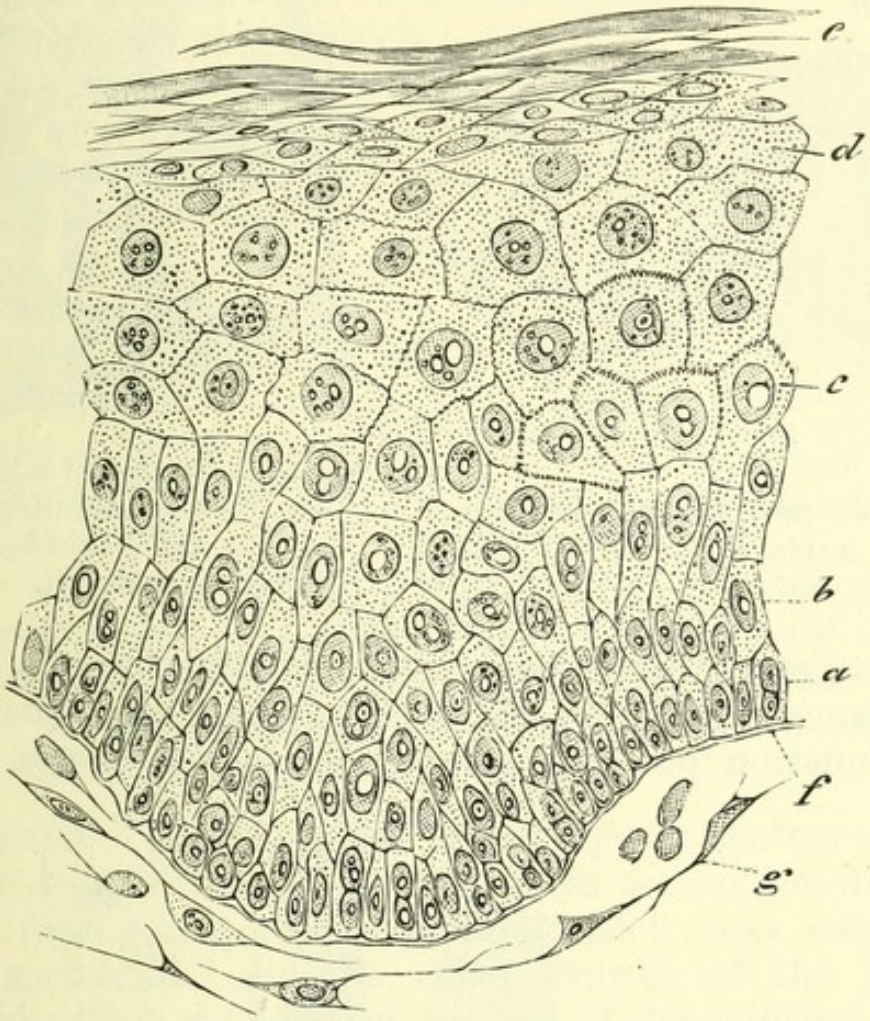


Fig. 10.—Section of the epiderm of the prepuce, showing the super-imposed layers of cells of a stratified epithelium. (Cadiat.)

a. Young proliferating cells. *b*—*d*. Cells advancing towards surface. *e*. Flattened cell of horny layer. *f*. Basement membrane. *g*. Connective tissue.

Sometimes the cells are retained, as in the skin, and are arranged in several layers, one over the other. As the cells are conveyed from the deeper layer, where they take their origin, towards the surface, the efforts of the waning nutritive power of the protoplasm are devoted to the manufacture of a tough insoluble substance. The cells thus gradually lose their vital activities, and are converted into horny scales, which form the external protecting skin, and its many modifications giving rise to the different dermal appendages, such as hair, feathers, &c. Instead of a horny substance, the protoplasm may manufacture fat in the bodies of the cells, as seen in the

mammary gland, and sebaceous glands of the skin. In other cases the reproductive activity of the cell is in abeyance, and

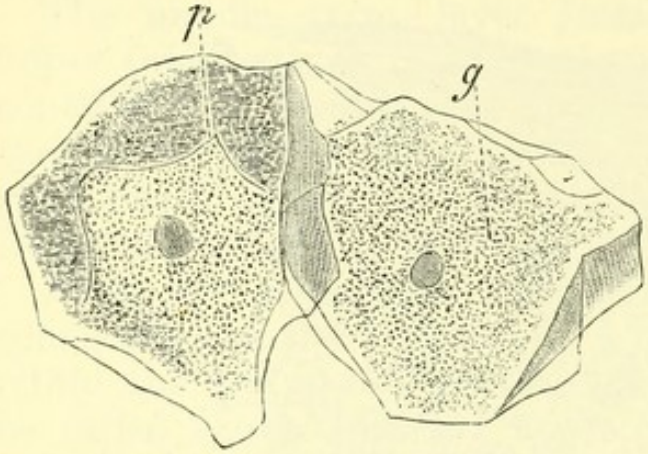


Fig. 11.—Two cells of scaly epithelium from the inside of the cheek. (Ranvier.)

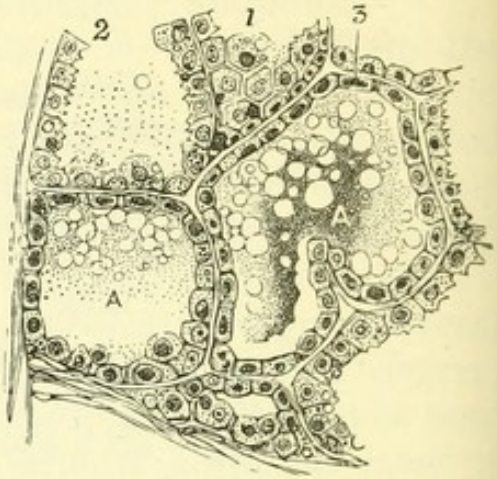


Fig. 12.—Section of milk-gland of cat, showing secreting cells containing fat globules, and some secretion in alveoli.

its nutritive energy is devoted to the manufacture of a material which is poured out of the cell at certain periods. Thus we have another function performed by the epithelial tissues, namely,

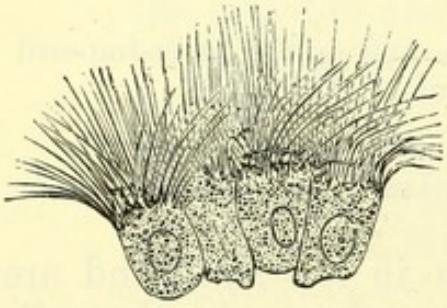


Fig. 13.—Ciliated epithelial cells from the gills of mussel. (Cadiat.)

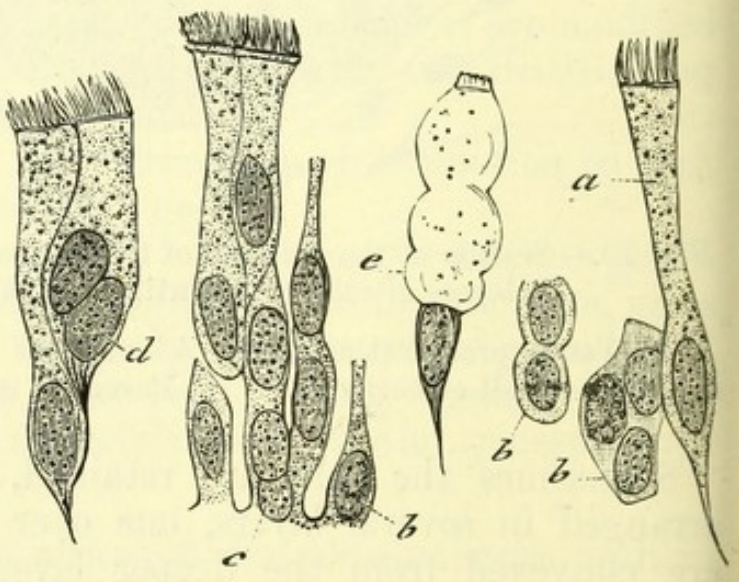


Fig. 14.—Stratified ciliated epithelial cells from the trachea of man. (Cadiat.)

a. Large surface cells, with cilia on surface.
b. Lower cells in earlier stage of development.
e. Cell charged with mucus.

that of manufacturing certain materials which, being collected by suitable channels, appear as secretions.

The active elements of glandular tissue are epithelial cells

whose nutrition leads to the formation of specific chemical products within their protoplasm. These products pass out commonly as fluids, and form various substances of great importance in the economy. A gland is simply a special arrangement of epithelial cells lining the sacs or tubes into which the secretion is poured.

Some tracts are covered with fine moving hair-like processes, called cilia, which give rise to a slight motion of the fluids in contact with them (fig. 13).

The epithelium in various places is thus seen to be modified in different ways, so as to make it suitable for the special function of the part in which it is placed.

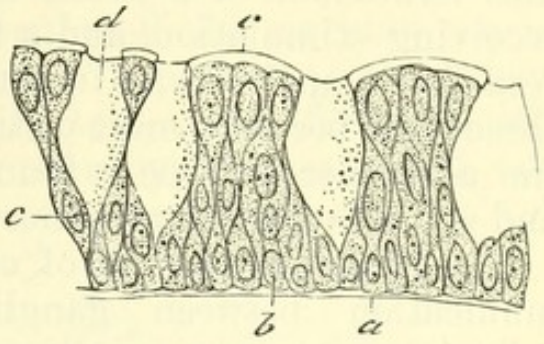


Fig. 15.—Epithelial cells, some of which are filled with mucus (*d*), forming goblet-like cells. (Cadiat.)

Other differences will be given in detail with the description of the uses of the many mucous surfaces. The most interesting modifications are those in the special sense organs, where the cells are in immediate connection with nerves, and aid in forming the special nerve terminals.*

2. Nerve Tissues.—The great nervous centres are formed from the cells of the epiblast, which, in the earliest days of the embryo, form a longitudinal furrow, which sinks into the cells of the mesoblast. By the rapid growth of the latter the depressed part is cut off from the rest of the epiblast, and forms the rudiment of the spinal cord and brain. In looking for special conducting tissue in animals possessing the most simple structure, we find cells which would seem to possess certainly a two-fold, and possibly a three-fold function,—one of which is conduction. In the so-called "neuro-muscular" cells of the hydra, processes are described as passing off from them, and uniting beneath the ectoderm with other fibre-like processes, which are evidently contractile. Here we

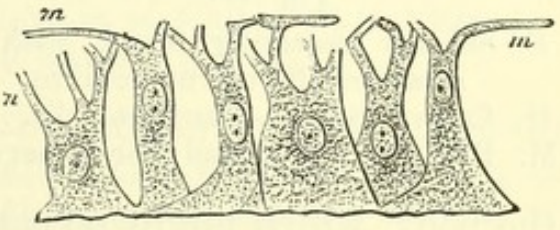


Fig. 16.—Neuro-muscular cells of hydra. *m*. Contractile fibres. (Kleinenberg.)

* A further account of the Histology of these tissues will be found in the chapters specially devoted to these subjects.

mention for the first time a portion of protoplasm specially devoted to acting as a conductor of impulses, and attached by the one end to a contractile fibre, and by the other to a surface (sensory) cell. The intimate relation between the development of nerve and muscle fibres is thus established, and we have the first indication of a nerve mechanism, viz., a cell capable of receiving stimulation, and a fibre capable of transmitting the resulting impulse. As further differentiation proceeds, each of these parts becomes more distinct from the other, and ultimately the adult nerve tissue is found to be made up of nerve fibres, and special cells, forming nerve endings.

The fibres act as lines of communication between ganglion-cells: they connect together the numerous cells in the various parts of the brain and spinal cord, or pass between those of the central nervous organs and ganglia distributed throughout

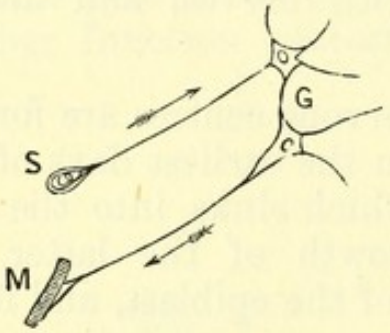


Fig. 17.

S. Sensory receiving organ with attached afferent nerve-fibre.
G. Central organs—ganglion cells.
M. Peripheral organ and efferent nerve.

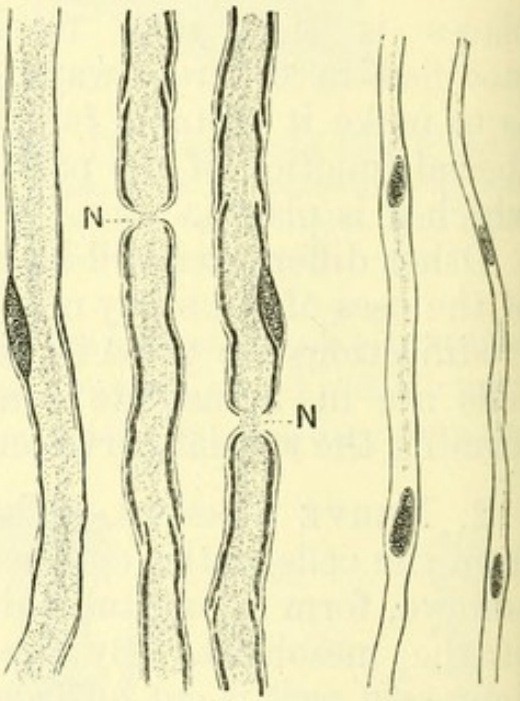


Fig. 18.—Three medullated nerve-fibres, the medullary sheath of which is stained dark with osmic acid. N, Nodes of Ranvier.
Two non-medullated nerve-fibres, with nuclei in the primitive sheath.

the body, which might be called the peripheral nerve-organs.

The simplest idea then of a special nerve apparatus is a fibre connecting two cells. The peripheral cell may be a receiving organ (fig. 17, s), from which, when stimulated, impulses are transmitted along the fibre to the central nerve cell, where they give rise to certain impressions, and so we have a sensory nerve apparatus. Or the central nerve cell may be the receiving agent, getting stimuli from its central neighbours, and transmitting impulses to a peripheral nerve terminal, by which they are handed over to a muscle (M) or gland, and thus we have a

simple motor or secretory apparatus. Where the effect of a stimulus can be definitely traced from one nerve cell to another, and from thence by a second fibre to a third cell, the impulse is said to be reflected by the second cell to the third. And there we have what is called a *reflex act.*

The essential part of a nerve fibre is a kind of protoplasmic band, in which the finest fibrillar or thread-like marking can be made out with the aid of re-agents and a powerful microscope. This is called the *axis-cylinder*. In some nerve fibres (mostly in the brain and spinal cord) the axis-cylinder is naked, and even a single fibril may so pass from one cell to another in the

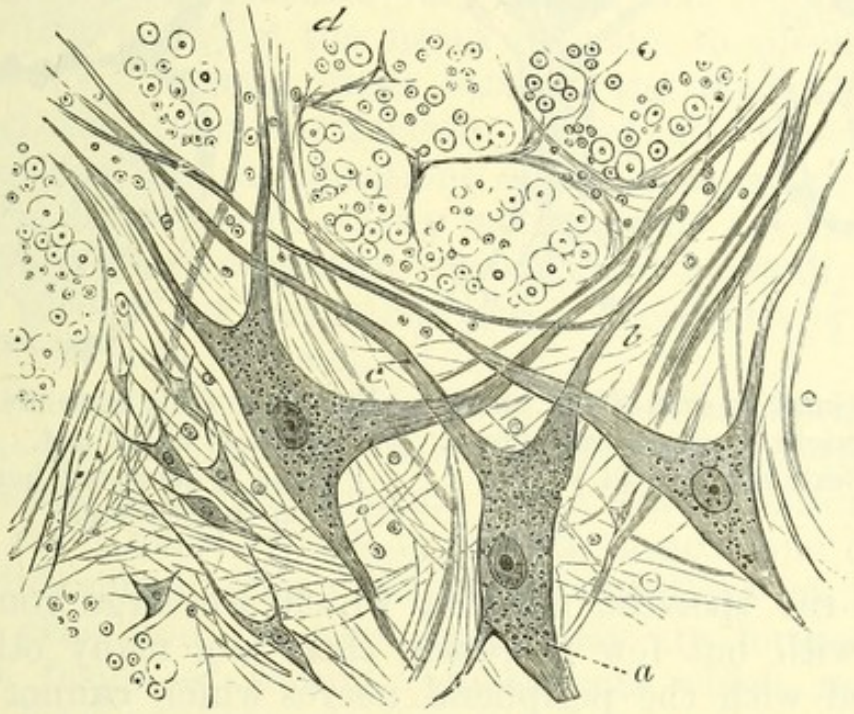


Fig. 19.—Multipolar cells from the anterior grey column of the spinal cord of the dog-fish (*a*) lying in a texture of fibrils ; (*b*) prolongation from cells ; (*c*) nerve-fibres cut across. (Cadiat.)

brain matter. In other parts the axis-cylinder is generally covered by a thin membrane, called the *primitive sheath*, or with a soft oil-like substance, called the *medullary sheath*, or, as is commonly the case in most peripheral nerves, by both. The primitive sheath encloses the medullary sheath, which surrounds the axis-cylinder.

These fibres are made of peculiarly modified cells, which are, however, so elongated as not to be very easily recognised as such in adult tissue.

The nerve or ganglion cells vary extremely in general form and size. The commonest in the nerve centres are large bodies with a clear, well-defined, vesicular, single nucleus,

and distinct nucleolus; they have two or more processes, which are connected by nerve fibres to other cells, and to the axis-cylinder of nerves.

The peripheral nerve cells are generally much modified, and often small compared with those in the centres. Besides the

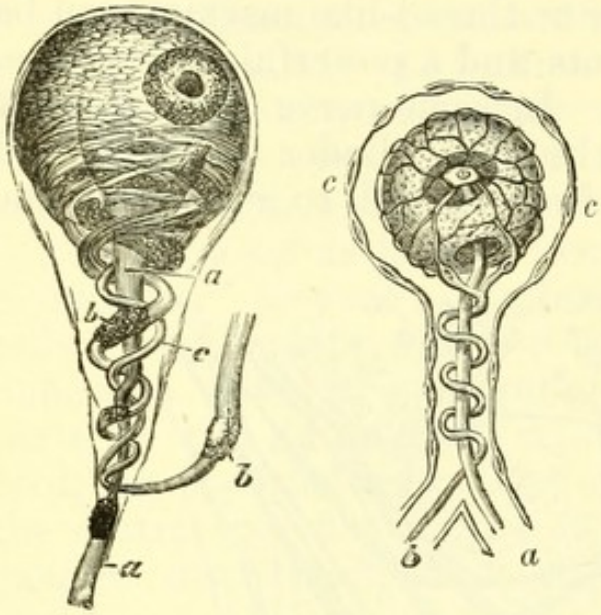


Fig. 20.—Ganglion cells of frog, showing straight and spiral fibres. (After Beale and Arnold.)

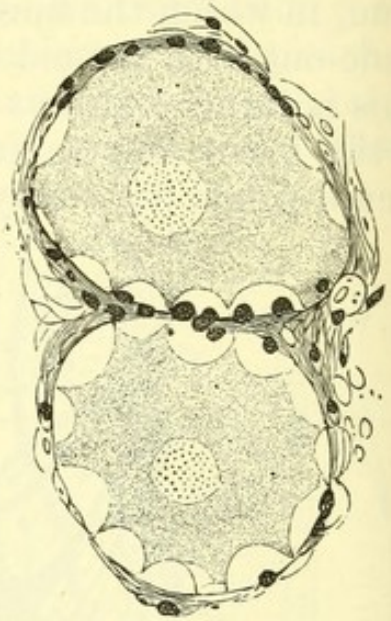


Fig. 21.—Cells from the sympathetic ganglion of a cat. The protoplasm is retracted here and there from the cell-wall.

cells in the sporadic ganglia, which are large rounded corpuscles with but few processes, there are many other bodies connected with the peripheral nerves which cannot be called ganglion corpuscles. They are nevertheless nerve cells.

3. Muscles or Contractile Tissues.—When changes take place in protoplasm adapting it specially for contraction, it is termed muscle tissue. The large masses of this tissue attached to the skeleton so as to move its various parts, form the flesh of the higher animals. Muscle tissue is, almost invariably, connected with nerve tissue, and acts in response to stimuli communicated from the nerves. In some of the lower animals the two tissues are so intimately related that it is not easy to distinguish them, and the development of both progresses equally as we ascend the scale of animal life. They are nearly related in their origin, or even spring from the same primitive tissue. In fact, as has already been mentioned (*vide* p. 21), they form but one structure in some of the more simple and less differentiated animals. The neuro-muscular

tissue, which is formed from the outer layer of the embryo, is the forerunner of the muscles as well as of the nerves of the embryo of the higher animals.

In the higher animals and man, muscle tissue consists of three kinds, known as—

a. Smooth, or non-striated muscle.
b. Striated muscle.
c. Heart muscle.

In the smooth muscle the individual elements present the characters of elongated and flattened cells, and contain single long nuclei. They contract very slowly, and require a comparatively long time for the nerve influence to affect them, so that an obvious interval exists between the moment of their stimulation and their contraction. They are found in the internal organs and in situations where gradual and lasting contractions are required. They receive their nervous supply generally from the sympathetic system, and generally perform their duty without our being conscious of their activity or being able to control it by our will.

Striated muscle tissue is made up of cylindrical fibres of such length that both extremities cannot be brought into the field of the microscope at the same time. Their exact relation to cells is not so easily made out as in smooth muscle, and doubtless varies in different muscles. Sometimes the fibres are made up of single cells, and in other cases they are formed by the permanent fusion of several cell-elements which never differentiate into separate elements, owing to the imperfect division of the cells, but make up one mass, the multiple nuclei of which alone make its mode of origin apparent. The contractile substance is made up of two kinds of material, one of which looks light and the other dark by transmitted light. These are ranged alternately across the fibre, making the transverse markings or striæ from which it gets its name. This striated material is quite soft and is encased in a thin homogeneous elastic sheath called *sarcolemma*, which fits closely around the soft contractile substance.

This form of muscle is the widest departure from the primitive protoplasmic type, being specially modified so as to perform strong and quick contractions. It moves with wonderful rapidity, contracting almost the instant its nerve is stimulated. It forms the great mass of the quick-acting skeletal muscles, being attached to the bones by bands com-

posed of a form of fibrous tissue, which form the tendons and fasciæ. Muscles made of striated tissue are frequently under

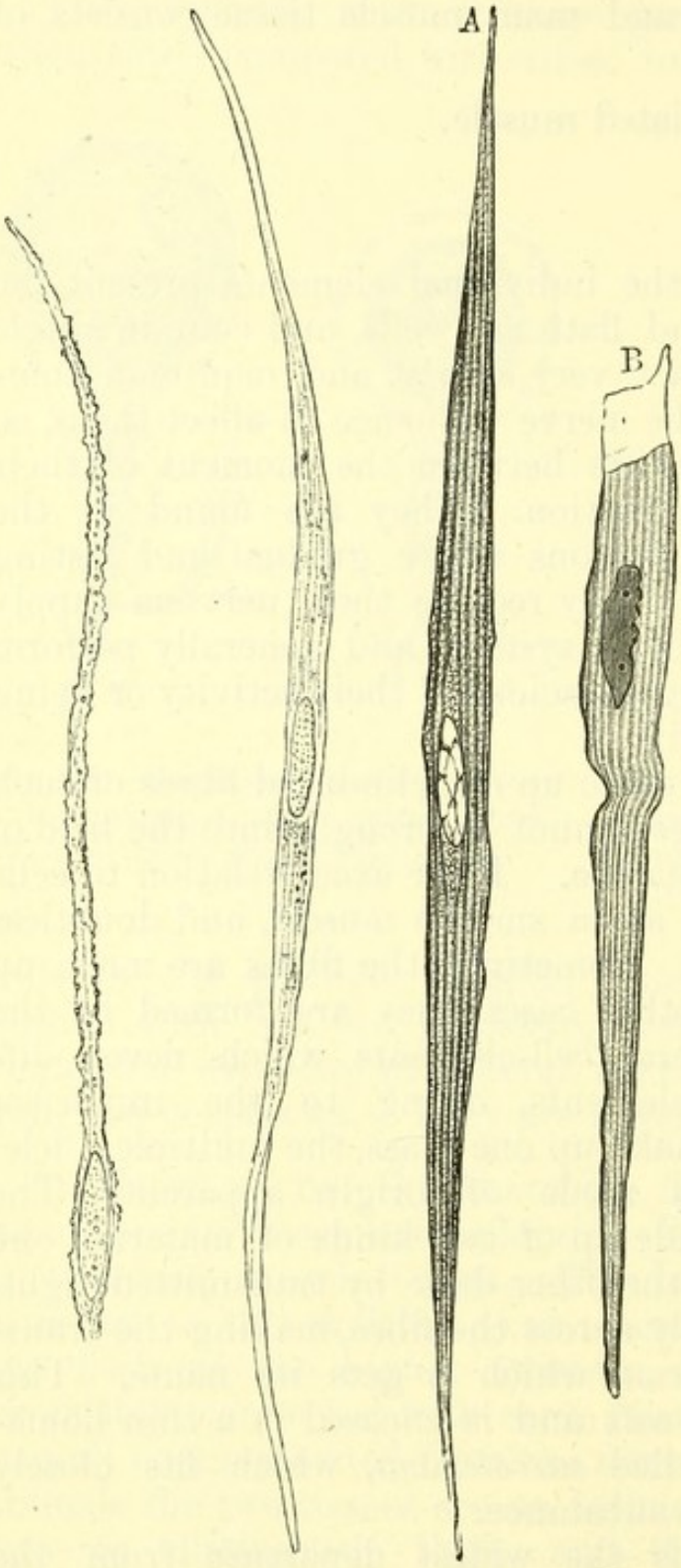


Fig. 22.—Cells of smooth muscle-tissue from the intestinal tract of rabbit. (Ranvier.)

A. and B.—Muscle-cells in which differentiation of the protoplasm can be well seen. (Schäfer.)

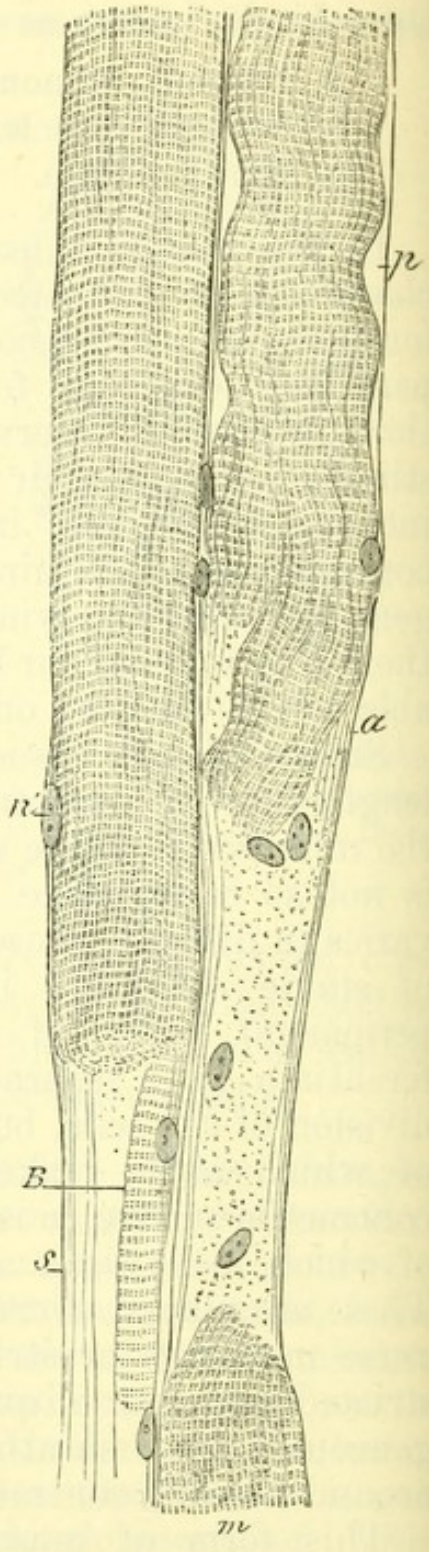


Fig. 23.—Two fibres of striated muscle, in which the contractile substance (*m*) has been ruptured and separated from the sarcolemma (*a*) and (*s*); (*p*) space under sarcolemma. (Ranvier.)

the control of the will, and hence are commonly spoken of as voluntary muscles, but this term is misleading, for the action of many striated muscles is habitually unconscious and cannot be governed by voluntary control.

4. The Connective Tissue group, coming exclusively from the mesoblast, exhibits very great varieties of form. Its cells differ much from the epithelial cells both in their character and their relations, and particularly in the adult tissues.

Under the heading Connective Tissues are generally classed all those which support the frame and hold together the various other tissues and organs. They are—

a. Mucous tissue.
b. Retiform connective tissues.
c. White fibrous tissue.
d. Yellow elastic tissue.
e. Cartilage.
f. Bone.
g. Endothelium.

The cells of all these tissues have the property of manufacturing some material which does not generally enclose them as a cell-wall, but remains between the cells and forms the intercellular substance. The younger the tissue the greater is the proportion of its cellular constituents, and the older the tissue the greater will be found the preponderance of the intercellular substance.

(*a*). Mucous Tissue.—In certain parts of the embryo and in some of the lower animals a kind of connective tissue is found in which there is but little intercellular substance, the mass of the tissue being thus made up of cells. The cellular connective tissue never forms an important texture in the adult, but is interesting as the probable material from which the connective tissues are formed in the embryo, and as occurring in abnormal growths or tumours.

The first step in its differentiation is the secretion of a large quantity of soft homogeneous, semi-gelatinous or fluid material like the mucus secreted by epithelium. In this the cells lie, either free or united by long protoplasmic processes. The processes uniting the cells may not be present, and the cells may be reduced to a minimum, as occurs in the vitreous humour of the eye.

(*b*). Retiform Tissue.—More commonly the soft gelatinous substance is reduced in amount, and the processes connecting

the cells are converted into a dense network of delicate threads to form the retiform tissue of lymphoid structures.

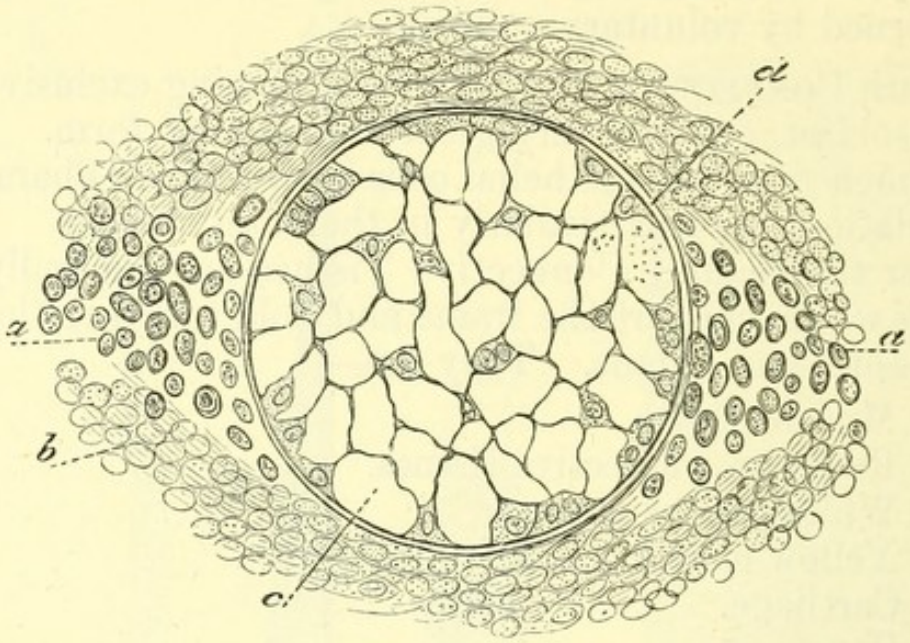


Fig. 24.—Transverse section of the chorda dorsalis and neighbouring substance. *a*, cartilage cells ; *b*, cell of the middle layer of embryo ; *c*, mucous tissue ; *d*, boundary of chorda. (Cadiat.)

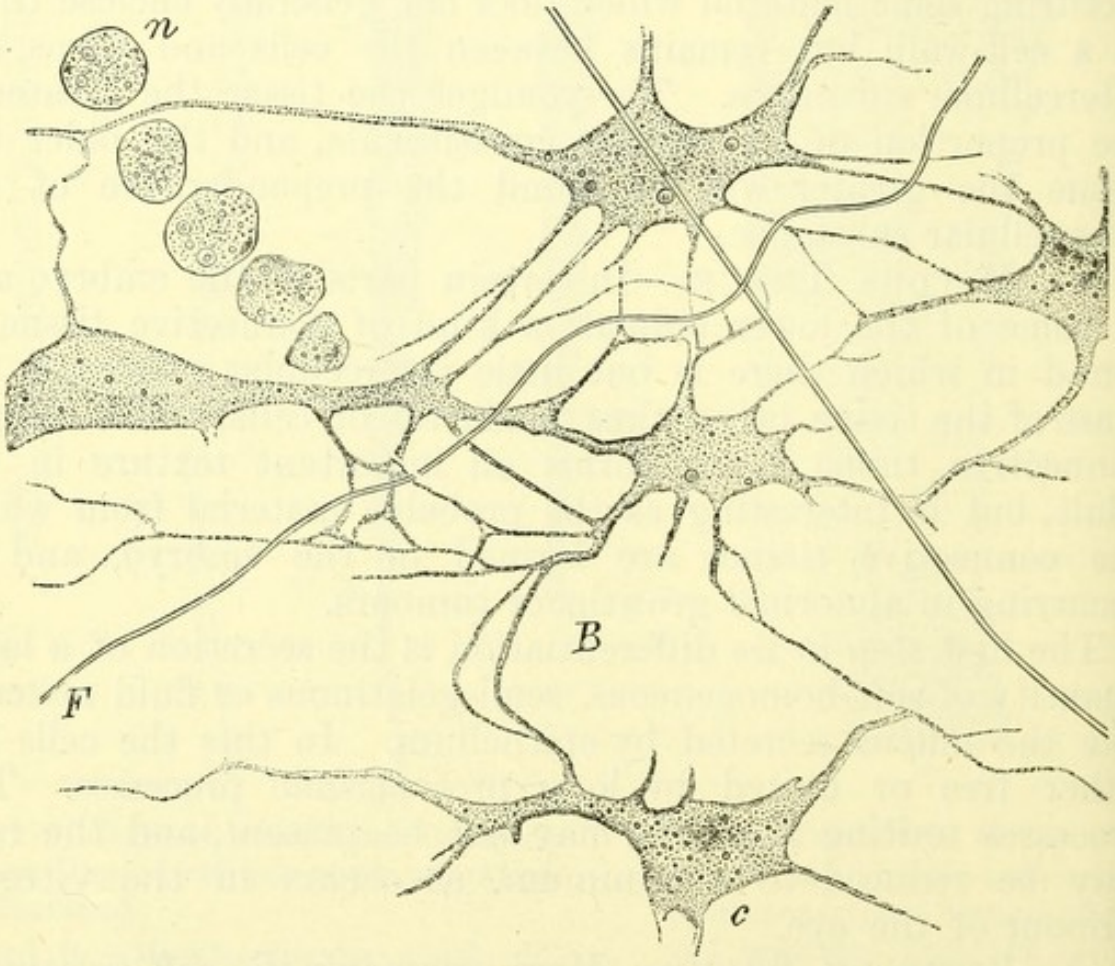


Fig. 25.—Cells of mucous tissue with branching processes (B), and a couple of elastic fibres (F). (Ranvier.)

(*c*). WHITE FIBROUS TISSUE. — The cells of the last described variety may become differentiated by a process of fibrillation. The growth of the cells leads to the formation of a fibrillated substance which ultimately forms the great bulk of the tissue, while the cells become gradually and proportionately fewer in number. In this case, only sufficient of the mucous substance generally remains to cement the fibrils together into bundles. A few of the cells, however, remain between the

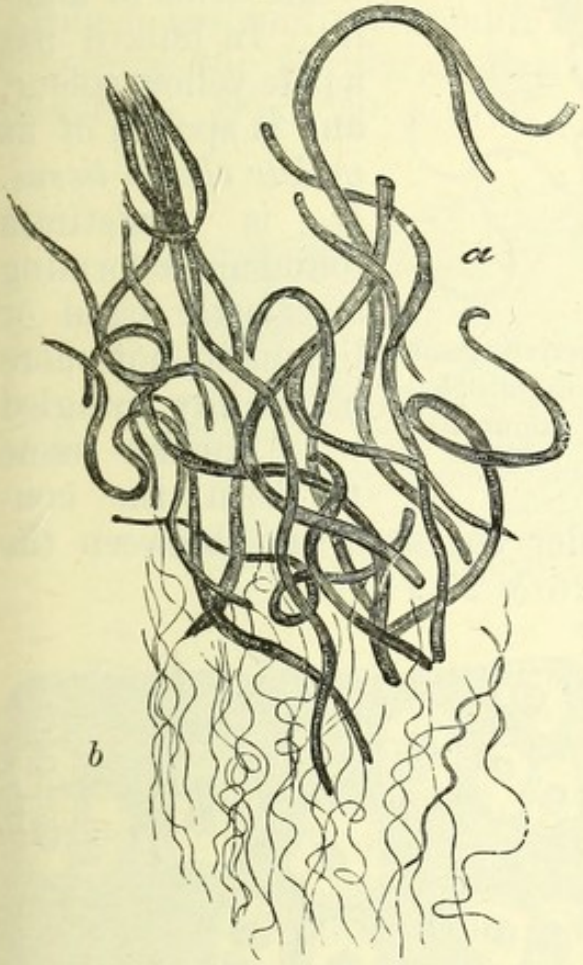


Fig. 26.—Coarse (*a*) and fine (*b*) yellow elastic fibres after treatment with strong acetic acid. (Cadiat.)

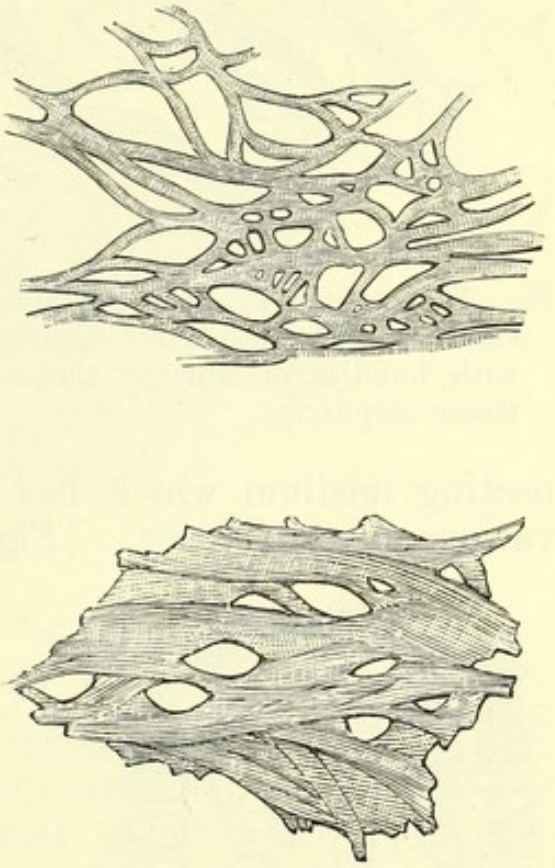


Fig. 27.—Elastic membrane from inner-coat of aorta, and, below, mesh-work of elastic fibres from a yellow ligament. (Cadiat.)

bundles of fibrils to preside over the nutrition of the tissue. Thus is formed the non-elastic or white fibrous tissue of tendon. (Fig. 28.)

These fibrils of white fibrous tissue are easily affected by chemical re-agents. Weak acids cause them to swell up and become indistinct. Baryta water affects the cement and renders them easily separable. They swell and dissolve in boiling water, yielding gelatine, which forms a jelly on cooling.

(*d*). YELLOW ELASTIC TISSUE.—In some parts of the body a kind of intercellular substance is formed, which differs in many respects from the foregoing. It is highly elastic, does not give gelatine on boiling, and is not affected by weak acids or alkalis. In bulk it has a pale yellow colour, and is spoken of as *yellow elastic tissue*. It is sometimes found alone forming an elastic band or ligament, but more commonly mingled with fibrillar tissue to form the connecting medium which lies under the skin and between the various other textures. (Figs. 26 & 27.)

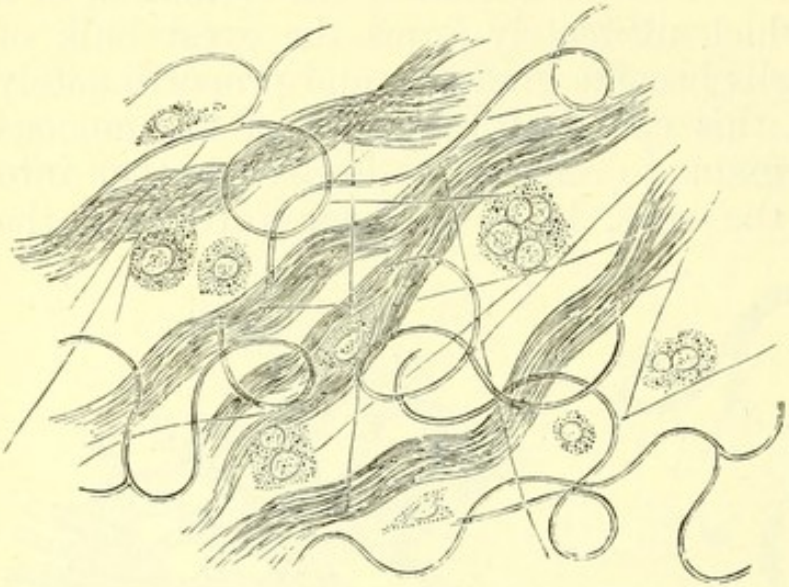


Fig. 28.—A teazed preparation of connective tissue showing fine and coarse elastic fibres mingled with bundles of fibrillar tissue and connective tissue corpuscles.

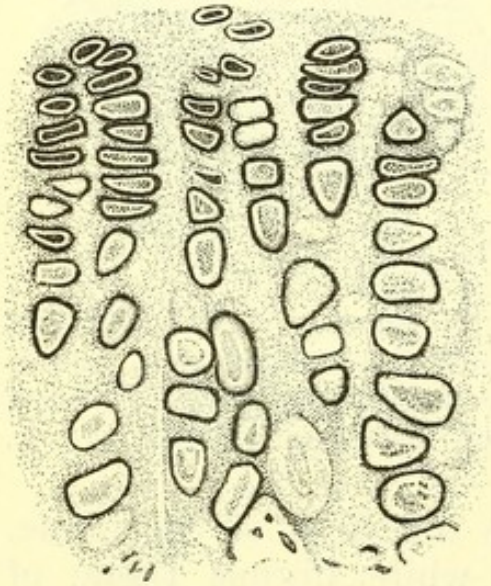


Fig. 29.—Section of hyaline cartilage, from the end of a growing bone, showing a decrease in the intercellular substance compared with the number of cell-elements, which are arranged in rows.

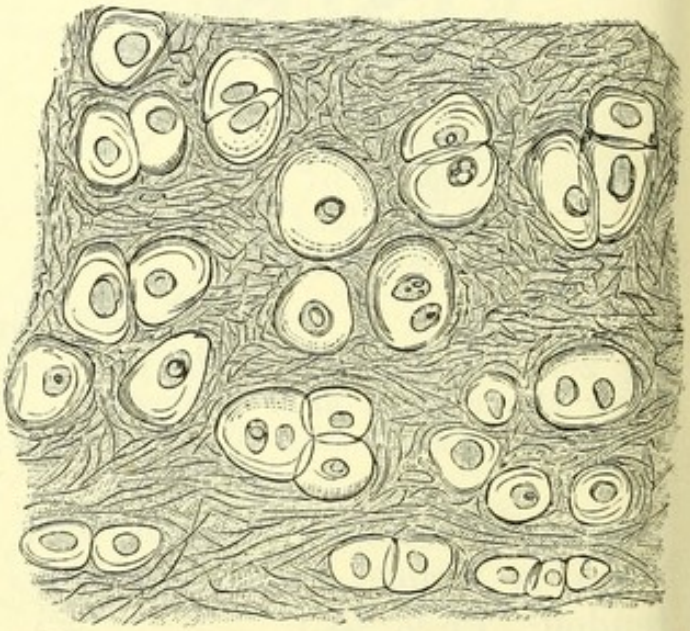


Fig. 30.—Elastic fibro-cartilage, showing cells in capsules and elastic fibres in matrix. (Cadiat.)

(*e*). CARTILAGE.—In this tissue the intercellular substance secreted by the cells is hard, and forms in the earlier stages of

its development cases or cell-walls for the cells. These cases subsequently increase in thickness, and become fused together into a homogeneous intercellular substance, where ultimately the areas belonging to the different cells can no longer be distinguished from one another, so that in the adult tissue there is a tough matrix of intercellular substance, in which the cells are scattered, apparently occupying small cavities. These cells preside over the nutrition of the tissue. The intercellular substance, which is quite homogeneous in common hyaline cartilage, is sometimes modified so as to resemble fibrous tissue, sometimes the fibrillar, and sometimes the elastic form being produced. (Figs. 30 & 31.)

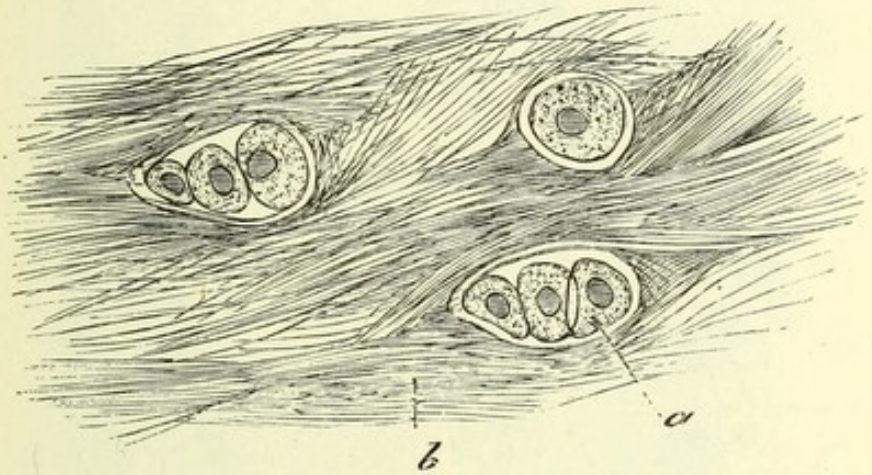


Fig. 31.—White fibro-cartilage, showing cells (*a*) in capsules and fibrillar matrix (*b*). (Cadiat.)

(*f*). Bone.—This is the most marked differentiation of the connective tissue group. The intercellular substance is characterised by containing a great quantity of inorganic matter (65% of total solids), which gives the bone its enormous strength. The cells of the tissue are enclosed in little cavities called *lacunæ*, which are related by minute canaliculi to each other. The intercellular substance is everywhere traversed by the processes of the cells lying in the little canals which connect the lacunæ, and thus the adequate nutrition of the tissue is secured. Chemically, bone tissue consists of about :—

Calcium phosphate	53
Calcium carbonate	11
Magnesium phosphate, calcium fluoride and soda salts	1
Gelatine yielding animal matter	33

In the formation of bone from fibrous or cartilaginous tissue the original intercellular substance disappears, and a set

of cells with new formative powers come upon the field (Fig. 33). These new cells (osteoblasts) cover the growing surface of the bone and secrete and lay down in layers a new kind of intercellular substance, which is the bone matrix. Here and there, at wonderfully regular intervals, an osteoblast ceases to secrete the calcareous intercellular substance, while its neighbours continue formative activity. Consequently, this osteoblast, or as it may now be called young bone cell, becomes surrounded

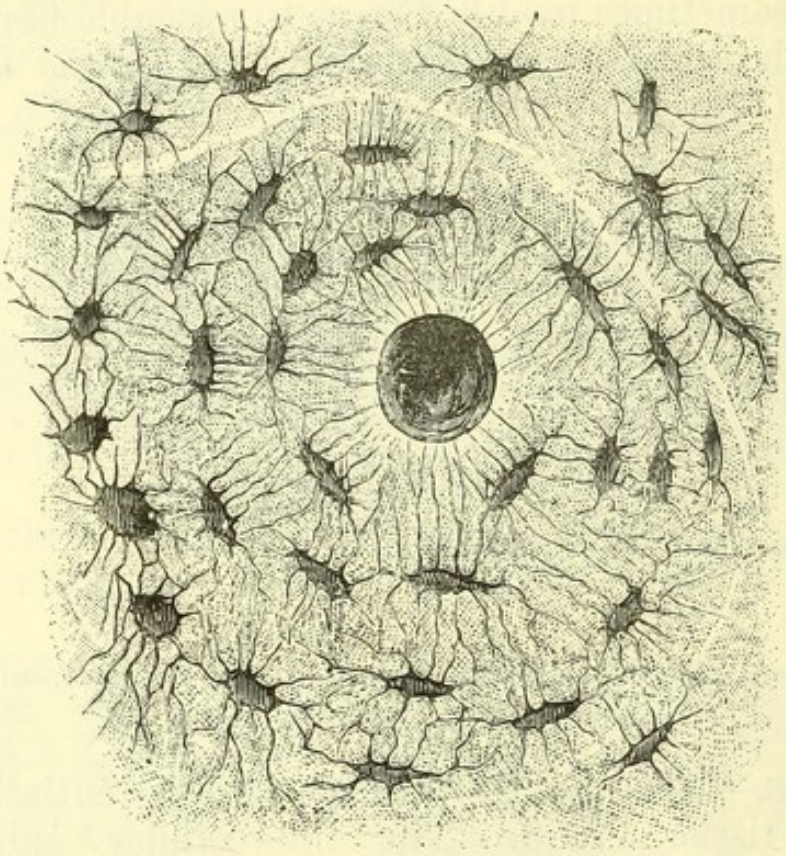


Fig. 32.—Transverse section of bone showing a system of Havers, with Haversian canal in centre, and bone-cells arranged around it in *lacunæ*, which are connected by the delicate *canaliculi*. (Cadiat.)

by calcareous intercellular substance, and is permanently lodged in the bone tissue.

(*g*). Endothelium.—Wherever a surface occurs in the connective tissues it is generally covered by a single layer of thin cells with a characteristic outline, which can only be made visible by staining the intervening cement substance with silver nitrate. This tissue, which forms the immediate lining of all vessels and spaces developed in the tissues arising from the mesoblast, is called *endothelium*, in contradistinction to the *epithelium* developed from the epi- and hypo-blast.

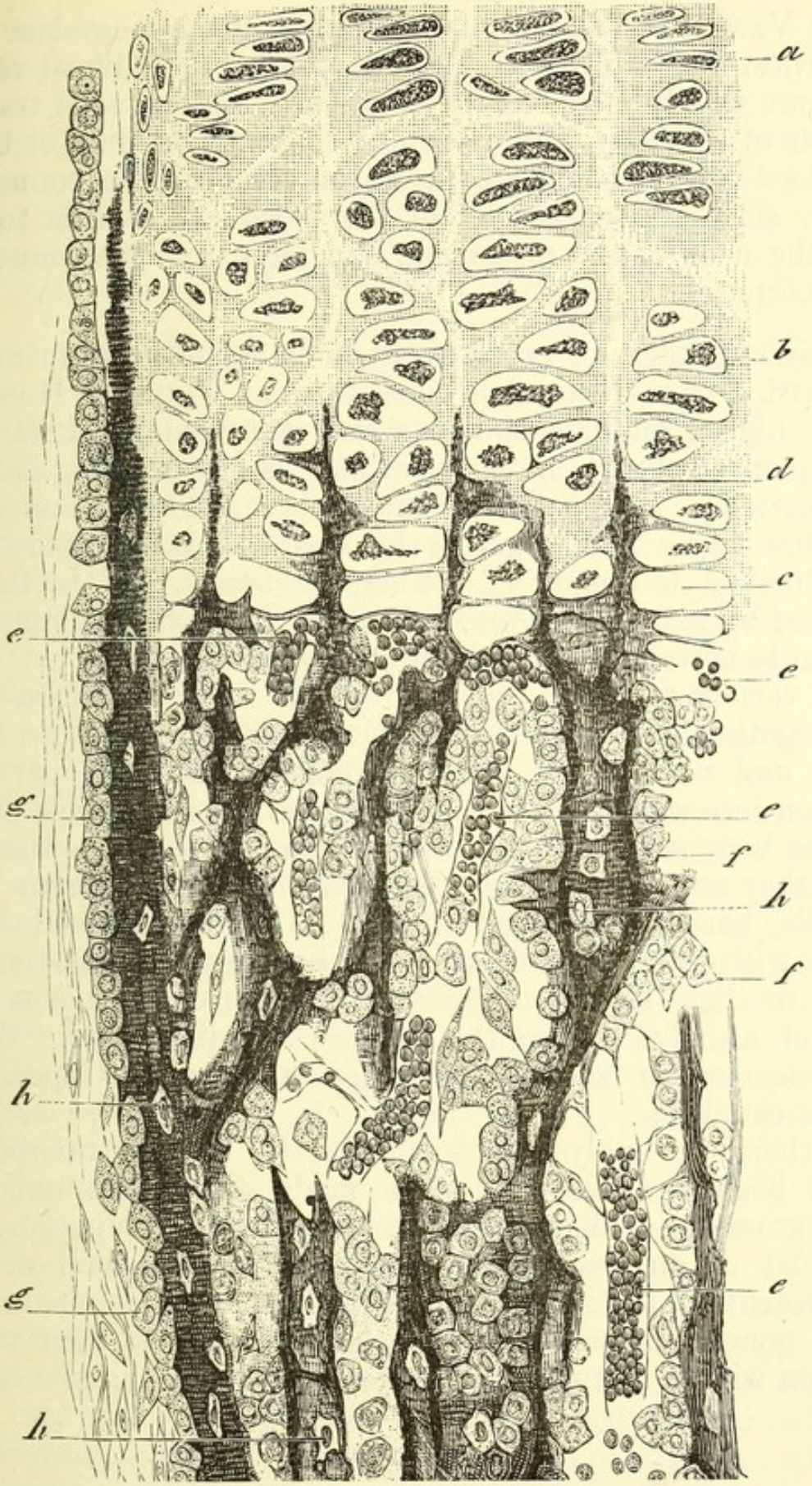


Fig. 33.—Section through ossifying cartilage and young bone. (Cadiat.)

a. Cartilage cells.
b. Degenerating cartilage cells.
c. Cell space, empty.
d. Spiculæ of calcareous deposit.
e. Blood corpuscles.
f. Osteoblasts.
g. Ditto of periosteum.
h. Bone cells.

The VASCULAR SYSTEM is developed in the mesoblast with the earliest stages of the connective tissue. The blood vessels, which are chiefly made up of connective tissues, soon traverse all parts of the body, and distribute the nutrient fluid or blood. The blood may be considered as an outcome of the connective tissues, since the corpuscles of the blood are at first formed from the cells of the mesoblast, and later from the connective tissue corpuscles.

An arrangement of special cells, such as epithelial or muscle cells, with a special function, constitutes an ORGAN. However, in the higher animals and man an organ is almost invariably a complex structure, having various tissues entering into its construction. Thus a skeletal muscle is made up of a quantity of muscle fibres held together by sheets of connective tissue, and attached to bones by connecting bands. It is further traversed by many blood vessels, and the fibres are in immediate relation to certain nerves which terminate in them.

The various secreting organs are made up of epithelial cells, held together by connective tissue in close relation to blood vessels and nerves, and are so arranged that they pour their secretion into a duct. The bones, which are the organs which give the body support, contain in addition to the bone tissue of which they are composed, a great quantity of indifferent cells, fat cells, nerves and blood vessels. They are covered on the outside with a tough vascular coat, which gives them strength, assists in their nutrition, growth, and repair, and acts as a point of attachment for the muscles and ligaments. Where the bones are in contact at the joints, they are tipped with hyaline cartilage.

If, then, we analyse anatomically the architecture of the human body, we find that it is made up of a number of complex parts, each adapted to some special function, and composed of an association of simple tissues such as the requirements of the special part demand.

The general arrangements of these organs and their modes of action will be discussed in future chapters.

CHAPTER III.

CHEMICAL BASIS OF THE BODY.

It seems natural to commence the description of the molecular changes that take place in the various tissues and organs of the body, with a brief account of the chemical composition of the most characteristic substances found in animal textures, because none of the processes of cell life, or tissue activity, can be satisfactorily studied without familiarity with the more common terms occurring in physiological chemistry.

The chapter on this subject here introduced, is intended rather to give the medical student a general view of the chemical composition and characters of the substances most frequently met with in the chemical changes specially connected with animal life, than to supply a complete or systematic account of the relationships of the chemical bases of the body, for which reference must be made to more advanced text-books, or treatises on the special subject of physiological chemistry. This review must, for the sake of brevity, be inadequate in the case of many substances, but these will be again referred to when speaking of the function with which they are associated.

It has already been stated that of the seventy elements known to chemists, a comparatively small number form the great bulk of the animal body, although traces of many are constantly present. Thus, we see that four elements, namely, (1) oxygen, (2) carbon, (3) hydrogen, (4) nitrogen, are present in large proportions in every tissue, and together make up about 97 per cent. of the body; and sulphur, phosphorus, chlorine, fluorine, silicon, potassium, sodium, magnesium, calcium, iron, and in certain animals copper, are indispensable to the economy, and are widely distributed, but are found in comparatively minute quantities. Occasionally traces of zinc, lead, lithium, and other minerals may be

detected, but these must be regarded rather as accidental than indispensable ingredients.

The attempt to investigate the composition of a living tissue by chemical analysis, must cause its death, and thus alter the arrangements of its constituents, so that its true molecular constitution during life cannot be determined.

We know that the composition of all living textures is extremely complicated, having a great number of components, most of which contain many chemical elements associated together in very complex proportions.

But as has already been pointed out, the complexity of their chemical constitution is not so wonderful as the fact, which indeed sounds paradoxical, that in order to preserve their elaborate composition, they must constantly undergo change or renewal, which is necessary for, and forms the one essential characteristic of, their life. In other words, their complexity and instability is such, that they require constant reconstruction to make up for the changes inseparable from their functional activity.

Their chemical constituents are easily permanently dissociated, and the various components are themselves readily decomposed, generally uniting with oxygen to form more stable compounds.

The investigation of the chemical changes, known as assimilation, forms a great part of physiological study, and therefore will occupy many chapters of this book. Here we can only call attention to the chief characteristic substances to be found in the animal body, as the result of the primary dissociation or death of the textures, and briefly enumerate the products of their further decomposition as obtained by the analysis of the different substances.

The tissues of the higher animals present a great variety of substances, materially differing in chemical composition ; they have all been made from protoplasm, and contain a proportion of some substance forming a leading chemical constituent of protoplasm. Every living tissue contains either protoplasm or a derivative of it, and the special characters of each tissue depend upon the greater development of some one of these substances.

It is of little use to classify the numerous chemical constituents found in the animal body in such a systematic manner as to satisfy the rules of modern chemistry, because their classification, from a strictly chemical point of view, does not set forth their physiological importance or express

adequately the relation they bear to the vital phenomena of organisms.

The following enumeration of the chief chemical ingredients found in the tissues has regard to their physiological dignity as well as to their chemical construction, and will thus, it is hoped, assist the student to distinguish the different groups, and give him a better idea of their vital relationships, than a more strictly systematic classification.

I. *Proteids:* Highly complex bodies made by plan assimilation, and required for animal metabolism, *e.g.*, albumin, globulin, &c.
II. *Albuminoids:* Bodies which are the outcome of protoplasmic specialisation, *e.g.*, mucin, gelatine, &c.
III. *Nitrogenous products of metabolism, e.g.*, leucine, urea, &c.
IV. *Carbohydrates*, in which hydrogen and oxygen are in the same proportion as in water, *e.g.*, starches and sugars.
V. *Fats*, which contain oxygen in smaller proportion than the last.
VI. *Salts.*
VII. *Water.*

Group I. Proteids.

It is difficult to say how far these bodies exist *as such* in the living organism, but they can be obtained from nearly all the fluids and solids of the body.

They do not occur normally in any secretion except those connected with the offspring, viz., the ovum, semen, and milk. They have a highly complex molecule, containing carbon, oxygen, nitrogen, hydrogen and sulphur. No satisfactory formula has been suggested to express their chemical composition, but the average per-centage of the elements they contain is remarkably alike in all members of the group. This may be said to be in round numbers as follows :—

Carbon	53 per cent.
Oxygen	22 ,,
Nitrogen	16 ,,
Hydrogen	7 ,,
Sulphur	1 ,,

With one exception (oxyhæmoglobin) they are amorphous,

i.e. do not crystallise, and with the exception of peptones belong to the class *colloids*, *i.e.* they will not diffuse through animal membranes.

So far as we know at present, albumins cannot be constructed *de novo* in the animal body, but must be supplied in one form or another as part of the food. Albumins are therefore always the outcome of the activity of vegetable life.

They all rotate the plane of a beam of polarised light to the left, i.e. they are *lævo-rotatory*.

They are insoluble in alcohol or ether, and are of variable solubility in water.

Many coagulate on boiling as in the familiar instance of the white of eggs.

They all respond, as do also many of the next group, to the *Xanthoproteic test*, *i.e.*, the addition of strong nitric acid and gentle heat, which gives a pale yellow colour turning to deep orange on the addition of ammonia.

An acid solution of proto-nitrate of mercury (*Millon's reagent*) gives a white precipitate which soon turns yellow, and changes to rosy-red on warming or on standing for some days.

Classification of Proteids.

The classification of proteids depends on their solubilities in

1. Distilled water.
2. Weak solutions of neutral salts, such as, sodium chloride, magnesium sulphate, etc.
3. Concentrated solutions of neutral salts. (Sodium chloride, magnesium sulphate, etc.)

Class 1.—*Albumins.*

These have the following properties :—

They are soluble in distilled water and in weak solutions of neutral salts.

They are not precipitated by saturating their solutions with magnesium sulphate or sodium chloride.

They are precipitated by saturation with sodio-magnesic sulphate, or with ammonium sulphate.

Their solutions in water or in weak salt solutions are coagulated by heat. The temperature of coagulation lies usually between 70° C. and 80° C.

The chief members of this class are :—

1. Serum-albumin (not precipitated from its solution by shaking with ether).
2. Egg-albumin (precipitated by ether).
3. Muscle-albumin.
4. Lact-albumin.

Class 2.—*Globulins.*

These are insoluble in distilled water, but are soluble in weak solutions of neutral salts.

They are precipitated by saturation with magnesium sulphate, sodium chloride, or half saturation with ammonium sulphate.

Their solutions are coagulated by heat, and their temperatures of coagulation vary considerably.

The important globulins are :—

1. Fibrinogen. } From blood.
2. Paraglobulin. }
3. Myo-globulin. } From muscle.
4. Myosinogen. }
5. Globin. From hæmoglobin.
6. Crystallin. From the crystalline lens.

Class 3.—*Albuminates or Derived Albumins.*

These are formed by the action of either weak acids or alkalies on albumins and globulins. They have the following properties :—

They are insoluble in distilled water, but are dissolved by weak acids or alkalies, or in weak solutions of neutral salts.

They are precipitated by saturation of their solutions with magnesium sulphate or sodium chloride.

They are not coagulated by heat.

(*a.*) Acid-albumin or syntonin. This is precipitated from its solution by neutralising the acid with dilute alkali. The precipitate is readily soluble in excess of alkali.

(*b.*) Alkali albumin. Precipitated by neutralising with dilute acid—the precipitate readily dissolves in excess of acid.

Class 4.—*Proteoses.*

These are bodies formed as intermediate products in the conversion of proteids into peptones and probably represent an

intermediate stage of hydration. They are formed during gastric and pancreatic digestion and also by treating proteids with superheated steam. They are termed albumoses, globulinoses, myosinoses, caseoses, etc., according as they have been formed from albumin, globulin, myosin, casein, etc.

We will take albumoses as a type, the others showing strictly analogous properties.

The distinctive characters of the albumoses are :—

1. Their solutions are not coagulated by heat.
2. If a slight trace of copper sulphate be added to a solution of an albumose, and then a solution of caustic potash, a rose-red colour is produced. (When this rose-red colour is formed this reaction is called the Biuret reaction.)
3. A solution is precipitated by adding a drop of nitric acid. This precipitate dissolves on warming and reappears on cooling the solution. This is the characteristic test for an albumose.

The albumoses are of two kinds, termed hemi-albumose and anti-albumose,—the distinction being that the former on being subjected to pancreatic digestion is first converted into hemi-peptone, and this can be split up still further into simpler bodies, the most important being leucine and tyrosine, whereas the latter (anti-albumose) under similar conditions is only converted into anti-peptone.

In the conversion of an albumin into a peptone we can distinguish two stages in the hydration. The results are called primary albumose, and secondary or deutero-albumose.

Primary albumoses are two ; proto-albumose and hetero-albumose. These have the following properties :—

(*a*) *Proto-albumose* is soluble in cold or hot water, and in weak salt solutions, but is precipitated by saturation with sodium chloride, magnesium sulphate, etc.

(*b*) *Hetero-albumose* is insoluble in water but soluble in neutral salt solution. It is precipitated from this solution by heating, but is not coagulated, as the precipitate is readily soluble in weak acids or alkalies. It is precipitated by saturation with sodium chloride, magnesium sulphate, etc. Thus these two albumoses have much in common with the globulins.

Deutero-albumose. This is soluble in water hot or cold, and is not precipitated by saturation with sodium chloride or mag-

nesium sulphate, but is precipitated by saturation with ammonium sulphate.

Class 5.—*Peptones.*

These are the last products of the hydration of the proteids. They are of two kinds, hemi-peptone and anti-peptone formed respectively from hemi-albumose and anti-albumose. They have the following properties :—

They are soluble in hot and cold water. They are not precipitated by saturation with sodium chloride, magnesium sulphate, nor ammonium sulphate. They are not coagulated by heat. They give the biuret reaction.

Class 6.—*Coagulated Proteids.*

These are insoluble bodies produced by heating a solution of an albumin or globulin, or by heating the neutralisation precipitate of an albuminate.

They are insoluble in solutions of neutral salts of any strength and only with difficulty in strong acids or alkalies.

Class 7.

This contains three bodies which are formed by the action of ferments upon other proteids. They are :—

Fibrin.
Casein.
Myosin.

Class 8.—*Hæmoglobin.*

The properties of these two classes are described when treating of blood, milk, and muscle respectively.

Solubility of Proteids.

The solubilities of the more important proteids may be contrasted as in the following table :—

	Distilled Water.	Weak Solutions of Neutral Salts	Saturated Solution of Magnesium Sulphate, or of Sodium Chloride.	Saturated solution of Ammonium Sulphate.
Albumins . . .	Soluble.	Soluble.	Soluble.	Insoluble.
Globulins . . .	Insoluble.	Soluble.	Insoluble.	Insoluble.
Albuminates . .	Insoluble.	Soluble.	Insoluble.	Insoluble.
Proto-Albumoses .	Soluble.	Soluble.	Insoluble.	Insoluble.
Hetero-Albumoses .	Insoluble.	Soluble.	Insoluble.	Insoluble.
Deutero-Albumoses	Soluble.	Soluble.	Soluble.	Insoluble.
Peptones . . .	Soluble.	Soluble.	Soluble.	Soluble.

Group II.—Albuminoids.

These may be said to be the outcome of protoplasmic activity each being specially adapted to meet the requirements of certain tissues.

They are allied to each other and to the last group by—(*a*) their percentage composition being very similar—(*b*) being colloids—(*c*) containing N in considerable proportion.

1. *Mucin* is the characteristic ingredient of the secretions manufactured by many epithelial cells, and is the chief constituent of the ground substance of connective tissue. There are probably several mucins varying in composition according to their several sources. They are all soluble in dilute alkalies *e.g.*, lime water. They give a peculiar thick ropy consistence to fluids containing them. They are all precipitated by acetic acid and are insoluble in excess of this reagent.

On boiling them with sulphuric acid they are split up into a proteid (probably belonging to the globulins) and animal gum, this latter yielding a reducing sugar on further treatment with sulphuric acid. Leucine and tyrosine are also produced by this treatment.

2. *Gelatine* is produced from the white fibres of connective tissue (tendons, ligaments, areolar tissue, &c.) by boiling with water. Pure gelatine is a colourless brittle body which swells up but does not dissolve in cold water. On heating, it dissolves, and on cooling, the solution sets to a jelly. This property of gelatinising is destroyed by boiling the solution for some hours.

Gelatine is not precipitated by acetic acid, and is thus distinguished from mucin.

It gives only a faint xanthoproteic reaction, and is further distinguished from proteids by yielding no precipitate with acetic acid and ferrocyanide of potassium, nor with lead acetate and most other salts of the heavy metals. It is however precipitated by mercuric chloride and tannic acid, the last reaction being the one that is taken advantage of in the manufacture of leather from skins. On boiling with sulphuric acid it yields glycine and leucine but no tyrosine.

3. *Chondrine* is the name of the substance formed from cartilage by boiling it with water. It has been shewn to be a mixture of mucin and gelatine and gives the reactions of such a mixture.

4. *Elastine*, is the substance of which yellow elastic tissue is composed.

It is a very insoluble material, being unaffected by hot or cold water, acetic acid, dilute alkalies, dilute mineral acids, alcohol or ether.

It is dissolved slowly by both pepsin and trypsin, forming bodies of the albumose class (elastoses).

It is dissolved, but at the same time decomposed by cold concentrated sulphuric acid, or by hot potash. The solution in sulphuric acid yields leucine but no tyrosine.

5. *Keratine*, is an exceedingly insoluble substance found in the cuticle, hairs, hoofs, nails, &c. all of which are epiblastic in origin. A substance of similar properties, *neurokeratine*, is found in nervous structures, which are also epiblastic in origin.

It is insoluble in water, weak acids, or dilute alkalies. It is dissolved by heating with mineral acids, and yields with sulphuric acid both leucine and tyrosine. It contains a considerable amount of sulphur.

6. *Nuclein.* This substance has been described as occurring in yolk of egg, spermatozoa, milk, pus, &c., in fact, wherever nuclei are present. It is a sticky substance which shews most of the physical properties of mucin. It is soluble in weak alkalies and precipitated by weak acids. It is unaffected by gastric digestion. It is found to contain a large percentage of phosphorus. Probably there are many different varieties according to the tissue they are prepared from.

7. *Nucleo-albumins.* These are substances allied to nucleins but less readily soluble in weak alkalies. They are described as occurring in the cells of many organs, viz., thymus, kidney, testes, brain, lymphatic glands, liver, &c. They have physical properties much like those of mucin. They are probably compounds of nuclein with proteids—chiefly globulins—and contain phosphorus. The viscid, ropy substance in bile formerly described as mucin is a nucleo-albumin.

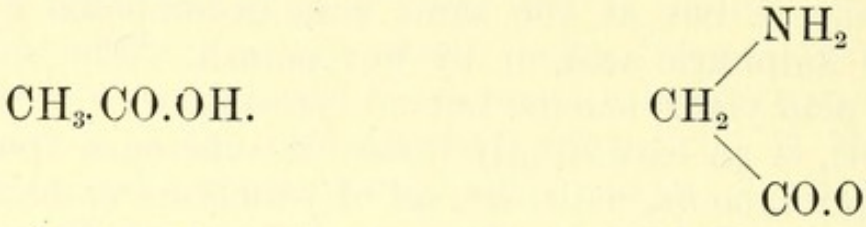
They are soluble in weak alkalies and precipitated by weak acids. They are partially dissolved by gastric digestion, leaving a residue of nuclein.

Group III.—Products of Tissue Change.

In this group are placed many bodies of very varying chemical structure and which on the whole are not very similar in their reactions. They are formed as the outcome of the complex chemical changes occurring within the cells of the different tissues. Only small amounts of them can be found in the tissues in which they are formed, for they are carried away

by the blood or lymph, and are eliminated as excreta or undergo further change in other organs.

Glycine, glycocine or amido-acetic acid. $C_2H_5NO_2$. This is acetic acid in which one of the hydrogen atoms in the CH_3 radicle is replaced by NH_2.



Acetic acid. Amido-acetic acid.

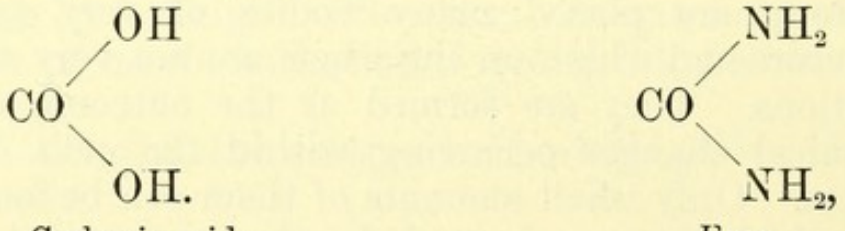
It is soluble in water, but not in ether or alcohol. The solution in water is acid. It crystallises in rhombohedral prisms. In chemical combination with cholalic acid it forms one of the bile acids (glycocholic). United with benzoic acid it forms hippuric acid. It is produced as a product of the decomposition of proteids and albuminoids. It occurs free in the intestine, due to the decomposition of glycocholic acid. It is converted by the liver into, urea, uric acid, or glycocholic acid. If benzoic acid be present with it, it can be converted by the kidney into hippuric acid.

Sarcosine or methyl-glycocine. $C_3H_7NO_2$. This is glycocine in which one of the hydrogen atoms of the amidogen radicle is replaced by methyl.

Glycocine. Sarcosine.

It is not found free in the body. United with cyanamide ($CN.NH_2$) it forms kreatinine. It is soluble in water, the solution being neutral.

Urea, or carbamide. $CO(NH_2)_2$. This may be regarded as carbonic acid in which the two hydroxyl radicles are each replaced by amidogen radicles.



Carbonic acid. Urea.

It is readily soluble in water and in alcohol but not in ether. Its solution is neutral to litmus. It crystallises in fine white needles or in long four-sided prisms with oblique ends. Traces of it are found in every tissue and fluid within the body. It is eliminated by the kidney, an average of about 35 grms. (500 grains) being excreted per diem. It is most important as being the substance by means of which the waste nitrogen of the body is eliminated.

It was the first of the so-called organic compounds to be made artificially, being obtained by Wohler in 1828, by mixing watery solutions of potassium cyanate and ammonium sulphate, evaporating to dryness and extracting with alcohol, or in short by heating ammonium cyanate, with which urea is isomeric.

$$\underset{\text{Ammonium cyanate.}}{NH_4.CNO} = \underset{\text{Urea.}}{CO.(NH_2)_2}$$

It can also be prepared from carbonyl chloride by treatment with ammonia.

$$\underset{\text{Carbonyl chloride.}}{CO\begin{matrix}Cl\\Cl\end{matrix}} + 4NH_3 = \underset{\text{Urea.}}{CO\begin{matrix}NH_2\\NH_2\end{matrix}} + 2NH_4.Cl.$$

There are two methods by which it is generally obtained from urine.

1. The urine is evaporated to $\frac{1}{6}$ of its bulk and a large volume of strong nitric acid is added. The urea is precipitated as urea nitrate. This is separated and mixed with barium carbonate, warmed and then extracted with alcohol. The urea goes into solution and may be crystallised out.
2. To the urine, after evaporation, a quantity of oxalic acid is added, when insoluble crystals of urea oxalate appear. These are filtered off, mixed with calcium carbonate and extracted with water. The urea is thus obtained in a watery solution.

When nitrous acid is added to a solution of urea, brisk effervescence occurs, the urea being decomposed into CO_2, N, and H_2O.

$$CO(NH_2)_2 + 2HNO_2 = CO_2 + 2N_2 + 3H_2O.$$

This is used as a test for urea.

Sodium hypobromite causes a somewhat similar change.

$$CO(NH_2)_2 + 3NaBrO. = CO_2 + N_2 + 2H_2O + 3NaBr.$$

The sodium hypobromite, however, always contains a large excess of caustic soda, and this absorbs the acid gas CO_2, so that the effervescence in this case is less than in the former. The gas collected in this reaction consisting of pure N, which may be collected, and the urea estimated from its volume. In the other reaction the gas is a mixture of N and CO_2.

On standing urine becomes ammoniacal in odour. This is due to the decomposition of the urea in solution, which is brought about by the growth of an organised ferment called the micrococcus ureæ. The change is one of hydrolysis ammonium carbonate being formed. The following formula represents the reaction :—

$$CO\begin{matrix}NH_2\\NH_2\end{matrix} + 2H_2O = CO\begin{matrix}O.NH_4\\O.NH_4.\end{matrix}$$

When acid mercuric nitrate is added to a solution of urea, a dense white precipitate is formed, having the formula $CO(NH_2)_2,Hg(NO_3)_2, 3HgO$. This reaction is important as Liebig based a method for the determination of the quantity of urea present in a solution, upon it :—and this method is one of those commonly in use.

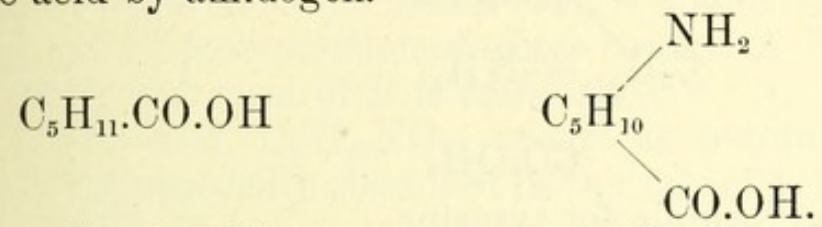
When heated to just below 170° C. urea is decomposed, forming biuret, ammonia being given off. Thus :—

$$2\,CO\begin{matrix}NH_2\\NH_2\end{matrix} + \text{heat} = \begin{matrix}CO\\NH\\CO\end{matrix}\begin{matrix}NH_2\\\\NH_2\end{matrix} + NH_3$$

Biuret.

When a drop of a weak solution of sulphate of copper is added to this and then KOH, a rose-red colour appears (Biuret reaction).

Leucine, or amido-caproic acid. $C_6H_{13}NO_2$. This is an amido-acid, being formed by replacing one of the H atoms of caproic acid by amidogen.



Caproic acid. Leucine.

It is soluble in water, slightly soluble in alcohol, but insoluble in ether. It forms needle-shaped crystals which arrange themselves in masses to form little spheres. It is neutral in reaction.

It is one of the chief bodies found when proteids are decomposed with acids, alkalies, &c., and during putrefaction. It is also found as a result of the action of the pancreatic digestion of proteids. It is present in freshly collected pancreatic juice, independent of the digestion of proteids. It is found in small quantities in many tissues of the body. In disease it is sometimes found in the urine, viz., in cases of acute yellow atrophy of the liver, or in phosphorus poisoning. It is always associated with tyrosine. Pure leucine does not give either the xantho-proteic or Millon's reaction.

Tyrosine, $C_9H_{11}NO_3$. We can best understand the chemical structure of tyrosine by gradually building it up from its simpler elements.

We may start with the monatomic radicle phenyl, the formula for which is,

$$C_6H_5-$$

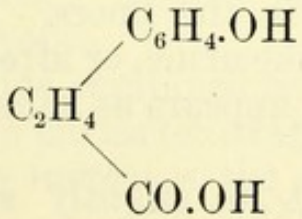
replacing one of the H atoms by hydroxyl (OH) we get oxy-phenyl.

$$C_6H_4O.H.$$

The composition of propionic acid is,

$$C_2H_5.CO.OH$$

Replacing one of the H atoms of the C_2H_5 by oxy-phenyl, oxy-phenyl-propionic acid is formed.



and replacing another H by amidogen ($-NH_2$) we get amido-oxy-phenyl-propionic acid, which may be thus expressed,

$$\begin{array}{l} \quad\quad C_6H_4.OH \\ \quad\quad / \\ C_2H_3 \;\; - NH_2 \\ \quad\quad \backslash \\ \quad\quad CO.OH. \end{array}$$

This is also the formula for tyrosine.

Tyrosine is slightly soluble in water, but insoluble in alcohol and ether. It crystallises in long needles which often arrange themselves so as to form little sheaf-like masses.

It is one of the chief decomposition products of proteids, being associated with leucine. Wherever the one is found in the body, the other is likewise to be detected.

Unlike leucine it gives the Xantho-proteic and Millon reactions.

Taurine, $C_2H_7NSO_3$, or amido-isethionic acid.

Starting with ethylic alcohol, represented as :

$$\begin{array}{l} CH_2.OH \\ | \\ CH_3 \end{array}$$

if we replace one of the H atoms of the CH_3 group by the monatomic radicle $-SO_2.OH$, isethionic acid is formed thus :

$$\begin{array}{l} CH_2.OH \\ | \\ CH_2.SO_2.OH \end{array}$$

and replacing the hydroxyl by amidogen, we get, amido-isethionic acid or taurine, which may be written thus :

$$\begin{array}{l} CH_2.NH_2. \\ | \\ CH_2.SO.OH. \end{array}$$

Taurine is soluble in water but insoluble in alcohol or ether. It crystallises from its watery solutions in six-sided prisms having no colour.

It occurs in the body in combination with cholalic acid, forming one of the bile acids (taurocholic), and is found free in the intestines after the decomposition of that acid. A small amount leaves the body in the fæces. The rest is absorbed and eliminated, either in the urine, or after re-combination with cholalic acid, in the liver, appears as taurocholate again in the bile.

Cholalic acid, $C_{24}H_{40}O_5$, is slightly soluble in water and

readily soluble in alcohol and ether. It crystallises in large prisms. It exists in the bile in combination with taurine or glycine to form the bile acids. It is found free in the intestines, after decomposition of these acids. A little is passed in the fæces, but most of it is reabsorbed.

Glycocholic acid, $C_{26}H_{43}NO_6$, occurs as sodium glycocholate in bile, being especially abundant in the bile of herbivora. This acid is soluble in hot water, in alcohol, and, slightly, in ether. Its solution tastes first sweet and then bitter. It crystallises in slender needles. The sodium salt also crystallises in needles which are soluble in alcohol and water but not in ether, and have a similar taste.

By the action of hydrolytic agents—warm dilute alkalies or acids,—the acid or its salt is split up into glycine and cholalic acid. The following equation shews the change :—

$$C_{26}H_{43}NO_6 + H_2O = C_{24}H_{40}O_5 + CH_2\begin{matrix}NH_2\\ \\ CO.OH.\end{matrix}$$

Glycocholic acid. Cholalic acid. Glycine.

This decomposition also occurs in the intestines.

It precipitates many albumins and proteoses from their solutions.

Taurocholic acid, $C_{26}H_{45}NO_7S$. is soluble in water and alcohol, but not in ether, and forms needle-shaped crystals. Its solution is intensely bitter. The same facts are true of its sodium salt.

It is found as a salt of sodium in bile, especially of carnivorous animals. The sulphur it contains shews that it is derived from proteid.

On hydration, which normally occurs in the intestine it is split up into taurine and cholalic acid.

$$C_{26}H_{45}NO_7S + H_2O = C_{24}H_{40}O_5 + C_2H_7NO_3S.$$

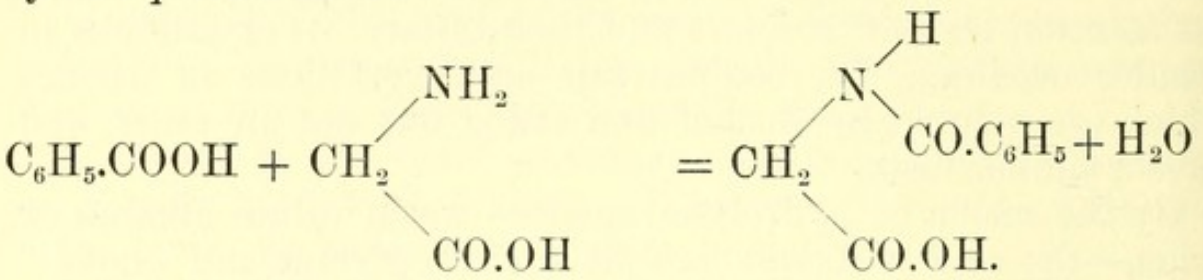
Tauro-cholic acid. Cholalic acid. Taurine.

Like glycocholic acid, it precipitates some albumins and proteoses.

Hippuric acid, $C_9H_9NO_3$. It may be said to be benzoic acid in combination with glycine.

It is found in the urine combined with alkalies, the quantity present varying with the character of the food. Thus ingestion of benzoic acid directly increases the amount of hippuric acid

found. Other aromatic substances related to benzoic acid ; or vegetables containing such substances likewise increase the amount. Consequently it is found in greater quantity in the urine of herbivora, where it replaces uric acid. In all cases benzoic acid, or substances related to it, have been united to glycine to form hippuric acid. It has been shewn that this synthesis is effected by the kidney cells. We may represent it by an equation thus :—



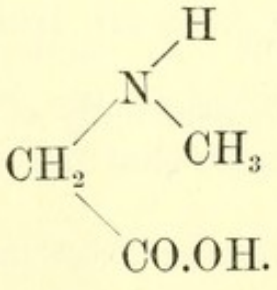
Benzoic acid. Glycine. Hippuric acid.

It is found in the alimentary canal, probably as the result of fermentative action. From 5 to 50 grains are eliminated in human urine daily, the amount of course depending on the diet.

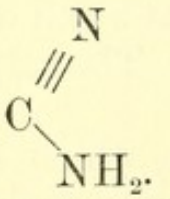
It is only slightly soluble in water (1 in 600), but very readily soluble in hot alcohol. It crystallises in colourless four-sided prisms. Its taste is bitter. It is a monobasic acid.

It reduces Fehling's solution.

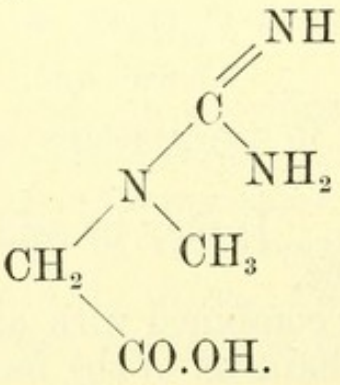
Kreatine, $C_4H_9N_3O_2$. This is formed artificially by heating cyanamide with sarcosine.



Sarcosine.



Cyanamide.

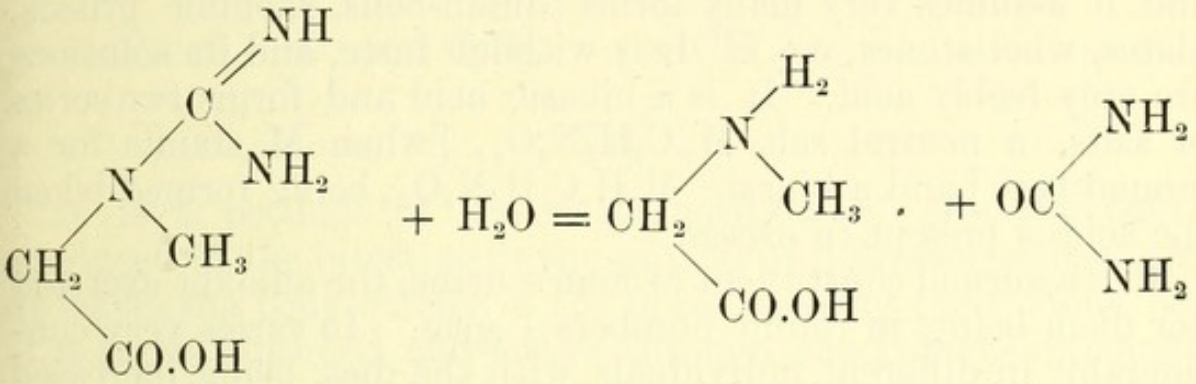


Kreatine.

Kreatine is soluble in water and almost insoluble in alcohol or ether. It crystallises in colourless rhombohedral crystals. Its solution is neutral. It acts as a base forming salts with acids.

It is found chiefly in muscle, but also in blood, liquor amnii and in the testes.

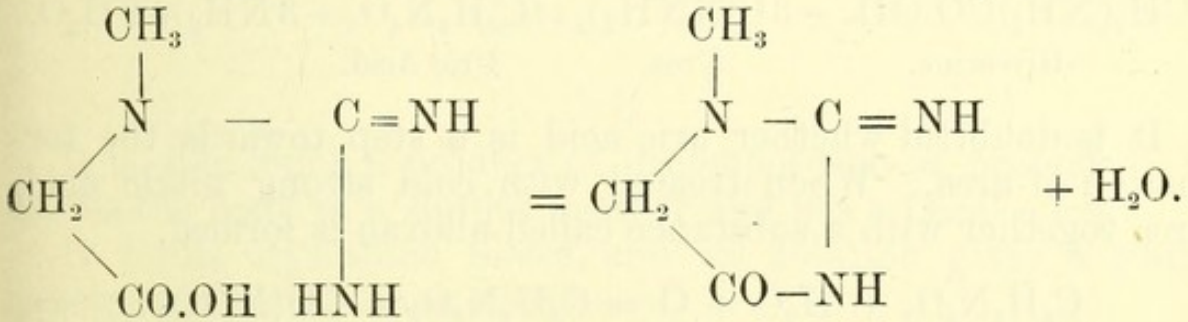
On being boiled with baryta water kreatine is split up into sarcosine and urea.



Kreatine. Sarcosine. Urea.

Although probable, it is not yet proved that kreatine is an intermediate product in the formation of urea. Some of it leaves the body in the urine in the form of kreatinine.

Kreatinine, $C_4H_7N_3O$, is kreatine minus one molecule of water. If we write the graphic formula for kreatine as in the following equation, we can easily understand their relationship to one another.



Kreatine. Kreatinine. Water.

Kreatinine is soluble in water and in alcohol, but not in ether. It is feebly alkaline to litmus and acts as a base. It crystallises in large colourless prisms.

Kreatinine is found chiefly in the urine, but has also been stated to occur in muscle.

Kreatine can be converted into kreatinine by heating its solution with HCl.

When zinc chloride is added to a solution of kreatinine fine

crystalline needles gradually form, and all the kreatinine becomes precipitated as kreatinine-zinc-chloride. ($C_4H_7N_3O.ZnCl_2$.) This is used both as a test and to determine the amount of kreatinine present in a solution.

Uric acid, $C_5H_4N_4O_3$, is only very sparingly soluble in cold water, but more so in hot, being insoluble in alcohol or ether. When pure it crystallises in colourless rhombic plates, but as obtained from urine the crystals are tinged yellow with pigment, and it assumes very many forms (dumb-bells, rhombic prisms, plates, whet-stones, &c.). It is without taste, and its solutions are only feebly acid. It is a bibasic acid and forms two series of salts, a neutral salt $M_2.C_5H_2N_4O_3$, [when M stands for a monad base] and a biurate $M.H.C_5H_2N_4O_3$, being formed when the acid is present in excess.

It is a normal constituent of man's urine, the amount excreted per diem being in round numbers 1 grm. It varies very considerably in different individuals, with the diet, being increased by animal food and by a want of healthy exercise. The free acid never occurs in normal urine, but it is present as a urate. The solid urine of birds and reptiles consists of almost pure urate of sodium. Urate of sodium is found in the blood, especially of those suffering from gout, and has also been separated from the kidneys, muscle, brain, lungs, spleen, liver, &c. Uric acid has been prepared synthetically by heating urea with glycocine :—

$$\underset{\text{Glycocine.}}{CH_2(NH_2)CO.OH.} + 3\,\underset{\text{Urea.}}{CO(NH_2)_2} = \underset{\text{Uric Acid.}}{C_5H_4N_4O_3} + 3NH_3 + 2H_2O.$$

It is doubtful whether uric acid is a step towards the formation of urea. When treated with cold strong nitric acid, urea together with a substance called alloxan is formed.

$$\underset{\text{Uric acid.}}{C_5H_4N_4O_3} + H_2O + O = \underset{\text{Alloxan.}}{C_4H_2N_2O_4} + \underset{\text{Urea.}}{CO(NH_2)_2}.$$

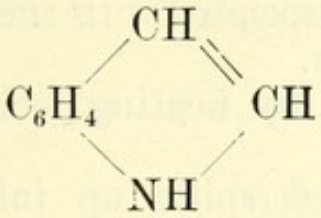
and alloxan when boiled with a strong alkali yields mes-oxalic acid and urea.

$$\underset{\text{Alloxan.}}{C_4H_2N_2O_4} + 2\,H_2O = \underset{\text{Mes-oxalic acid.}}{C_3H_2O_5} + \underset{\text{Urea.}}{CO(NH_2)}\ .$$

The murexide test, usually employed for detecting uric acid, consists in carefully evaporating a strong solution of the acid with a drop of strong HNO_3, taking care not to heat the

capsule so much as to cause charring. The residue obtained is yellow and becomes purple on adding ammonia, or bluish-violet with KOH.

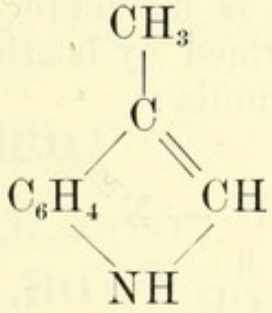
Indol, C_8H_7N, is an oily fluid easily soluble in alcohol and ether. When mixed with water it crystallises. It has a fæcal odour. It belongs to the benzene series of carbon compounds, its formula being represented as follows.



It is a product of the decomposition of proteids, being produced in the intestine by the growth of putrefactive bacteria. It leaves the body chiefly in the fæces, causing their odour, but it is partly absorbed and leaves through the kidneys in combination with alkaline sulphates, forming the substance indican, or indoxyl-sulphate of potassium.

With fuming nitric acid it gives a red precipitate which is soluble in alcohol.

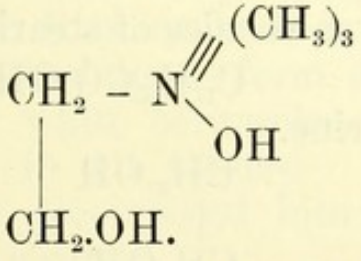
Skatol, C_9H_9N, is methyl-indol and may be represented thus,



It is, like indol, a product of decomposition of proteids. It leaves the body in a similar manner and has a fæcal odour.

It forms crystalline plates, and its solution gives a white precipitate with fuming nitric acid.

Choline, $C_5H_{15}NO_2$, is an ammonia base or alkaloid and has the graphic formula :—



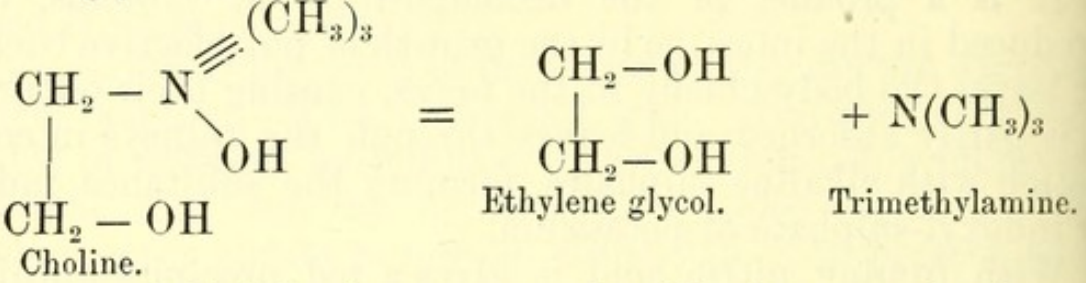
It is a syrupy liquid soluble in alcohol and ether, not in water, its solutions being strongly alkaline. It unites with HCl, and

H_2SO_4, the chloride is precipitated by $PtCl_4$ to form a definite crystalline compound $2(C_5H_{15}NO_2.HCl).PtCl_4$ which is used to determine the quantity of choline present in a solution. Choline is produced during the decomposition of proteids, either as a result of katabolic processes, or after death by putrefactive agencies. It occurs in combination with distearyl-glycero-phosphoric acid as lecithin.

It is nearly always associated with the allied alkaloid neurine, both are very poisonous.

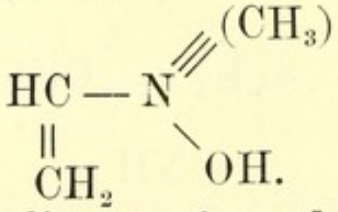
It may be obtained by heating lecithin or protagon with baryta water.

Choline when heated splits up into trimethylamine and ethylene glycol.



Choline. Ethylene glycol. Trimethylamine.

Neurine, $C_5H_{13}NO$, is a syrupy liquid of strong basic properties which occurs in association with choline in the putrefaction of proteids. It is far more poisonous than choline, from which it may be formed by heating it with HI. It has the following graphic formula :



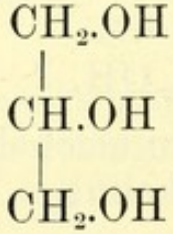
Both neurine and choline are formed in the intestine from lecithin, but are probably decomposed by the action of bacteria into harmless CO_2, CH_4 and NH_3.

Lecithin, $C_{44}H_{90}NPO_9$, is a complex nitrogenous fat whose composition can be best understood by a consideration of the following formulæ :

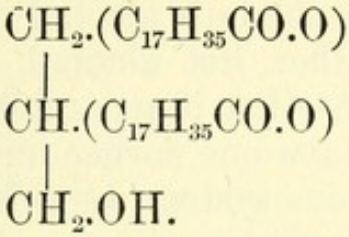
Combining two molecules of stearic acid :—

$$C_{17}H_{35}CO.OH.$$

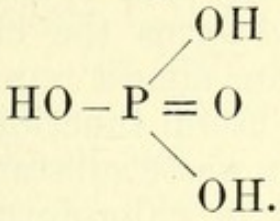
with one of glycerine.



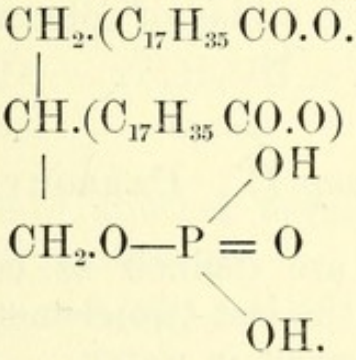
distearine is produced.



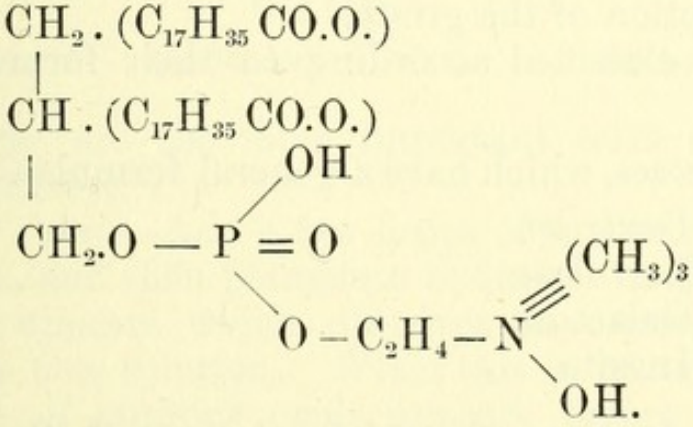
If now we combine this with phosphoric acid,



we obtain distearyl-glycero-phosphoric acid,



If choline be united to this, lecithin is formed, and may be represented as follows :—



It forms a yellowish-white, waxy solid, soluble in ether, chloroform, or hot alcohol. It is insoluble in water, but it can be fairly easily rubbed up with water to form an emulsion. It is found in yolk of egg, in white corpuscles, brain, milk, semen, and to a slight extent in all tissues. When heated with baryta water it is easily decomposed into glycero-phosphoric acid, choline and barium stearate.

Cholesterine, $C_{26}H_{43}.OH$. Though it does not contain N,

cholesterine may be conveniently mentioned here. It is a monatomic alcohol. It is the only alcohol occurring free in the body. It is soluble in ether, hot alcohol, chloroform, or solutions of bile salts. From ether it separates out as flat rhombic plates which frequently have one corner unformed.

It is found in the nervous system, especially in myelin drops, in blood corpuscles, yolk of egg, semen, milk, bile, fæces, and the spleen. Pathologically it is found in tubercular deposits, atheromatous cysts, and forms the chief constituent of gall-stones, many of which are almost pure cholesterine. It is not known whether it has a useful function to perform in the body, or whether, it is simply a waste substance.

If some be dissolved in chloroform and strong H_2SO_4 be added the solution turns a purple red colour. If iodine be first added and then the acid, a play of colours, blue, red, then green takes place.

Group IV. Carbohydrates.

The carbohydrates are defined as compounds of carbon, hydrogen and oxygen, the last two elements being in the proportion in which they occur in water.

A few only occur in animal tissues, most of them being formed by plants. The chief of these will be included in the short description of the group.

They are classified according to their formulæ into three groups :

I. Glucoses, which have a general formula $C_6H_{12}O_6$ include,

Dextrose,
Lævulose,
Galactose,
Inosite.

II. Saccharoses, whose formula is $C_{12}H_{22}O_{11}$, of which,

Cane sugar or sucrose,
Malt sugar or maltose,
Milk sugar or lactose,

are the more important.

III. Amyloses or starches $(C_6H_{10}O_5)_n$, where "n" varies in the different cases, and in some represents probably a very large number.

The chief of these are :—

Starch,
Dextrine,
Glycogen,
Cellulose.

Glucoses.

(*a*) *Dextrose or Grape-sugar*, $C_6H_{12}O_6$, exists in small quantities in the blood and tissues of the body, and in the urine in cases of the disease called diabetes. It also exists in fruits and in honey. It is soluble in water and in alcohol. Its solution is sweet and rotates the plane of polarisation to the right.

Under the influence of yeast, dextrose is converted into alcohol and CO_2.

$$\underset{\text{Dextrose.}}{C_6H_{12}O_6} = \underset{\text{Alcohol.}}{2C_2H_5OH} + 2CO_2$$

Under the influence of another organism lactic acid is produced, this occurs in the intestines,

$$C_6H_{12}O_6 = 2C_2H_4\begin{matrix}OH\\ \diagdown\\ \diagup\\ CO.OH\end{matrix} \qquad \text{or, } = 2C_3H_6O_3.$$

Dextrose. Lactic acid. Lactic acid.

The following are the more important tests used for the detection of dextrose.

1. *Trommer's test.*—Add a few drops of a dilute solution of cupric sulphate, and then potassium hydrate. A precipitate of cupric hydrate appears which dissolves in excess of potash, forming a deep blue solution. When this is heated an orange red precipitate of cuprous oxide appears before the boiling point is reached.

2. *Fehling's test.*—Fehling's solution consists of cupric sulphate, sodio-potassic tartrate and potassium hydrate, which forms a clear deep blue solution. This when added to a solution of dextrose, gives on heating the same red precipitate of cuprous oxide as in the former test.

3. *Moore's test* consists in adding potassium hydrate and boiling, when the solution turns yellowish brown.

4. *Johnson's test.*—To the solution add a solution of picric

acid, and then caustic potash, on boiling a deep red colour is produced which deepens, becoming almost black, if much dextrose be present.

(*b*) *Lævulose*, $C_6H_{12}O_6$, has been found in blood, and urine. It is very soluble in water and alcohol and does not crystallise. It gives the same tests as dextrose, the difference being that it rotates the plane of polarisation to the left.

(*c*) *Galactose*, $C_6H_{12}O_6$, is formed by the hydration of lactose. It is dextro-rotatory, ferments with yeast and reduces Fehling's solution.

(*d*) *Inosite*, $C_6H_{12}O_6$, is found in muscle, urine, kidney, lungs, spleen, liver and brain, as well as in several vegetables, peas, lentils, potatoes, &c. It is soluble in water, but not in alcohol nor ether. It has a sweet taste and crystallises in monoclinic prisms. Its solutions have no action on polarised light. It does not undergo the alcoholic fermentation with yeast, but is converted into lactic acid by fermentation. It does not reduce Fehling's solution and gives no colour on boiling with KOH.

It is precipitated by basic acetate of lead and ammonia.

Saccharoses.

(*a*) *Sucrose or Cane-sugar*, $C_{12}H_{22}O_{11}$, is found in abundance in many plants, sugar-cane, beetroot, &c. It is very soluble in water, its solution being sweet, and dextro-rotatory. On boiling with dilute mineral acids, sulphuric being preferable, it is inverted, *i.e.* the solution becomes lævo-rotatory. The change is one of hydration, one molecule of sucrose, forming with water, a molecule of dextrose, and another of lævulose.

$$\underset{\text{Sucrose.}}{C_{12}H_{22}O_{11}} + H_2O = \underset{\text{Dextrose.}}{C_6H_{12}O_6} + \underset{\text{Lævulose.}}{C_6H_{12}O_6}$$

As a molecule of lævulose has more effect on the beam of polarised light than one of dextrose, the mixture of equal quantities of the two sugars produces a solution which rotates the plane of polarisation to the left.

With yeast, cane-sugar is first inverted, as above, and then alcoholic fermentation of the glucoses occurs with the production of ethylic alcohol and CO_2.

On adding $CuSO_4$ and KOH to a solution of cane-sugar a deep blue solution is formed if excess of KOH be present, but this does not reduce, *i.e.* there is no red precipitate of cuprous

oxide produced on heating. Thus it is distinguished from glucose, &c.

On boiling with KOH no brown colour appears. In this again, it differs from glucose.

(*b*) *Maltose*, $C_{12}H_{22}O_{11}$. This is the sugar produced from starch during salivary or pancreatic digestion. It is soluble in water producing a strongly dextro-rotatory solution—from which needle-shaped crystals can be obtained.

By boiling with dilute sulphuric acid, it is hydrated, two molecules of dextrose being produced :

$$\underset{\text{Maltose.}}{C_{12}H_{22}O_{11}} + H_2O = \underset{\text{Dextrose.}}{C_6H_{12}O_6} + \underset{\text{Dextrose.}}{C_6H_{12}O_6}.$$

It reduces Fehling's solution, though not so powerfully as dextrose, and undergoes alcoholic fermentation with yeast.

(*c*) *Lactose, or Milk-sugar*, $C_{12}H_{22}O_{11}$, occurs in milk. It is soluble in water but much less so than cane-sugar or dextrose, and its solution has only a faintly sweet taste. Its solution is dextro-rotatory, and yields rhombic prisms on evaporation.

On hydration galactose is produced.

$$\underset{\text{Lactose.}}{C_{12}H_{22}O_{11}} + H_2O = \underset{\text{Galactose.}}{C_6H_{12}O_6} + \underset{\text{Galactose.}}{C_6H_{12}O_6}.$$

It reduces Fehling's solution, but to a much less extent than dextrose. Yeast first converts it into galactose, and then alcohol and CO_2 are slowly produced.

Lactic fermentation, by means of a special organism occurs rapidly, lactic acid being formed from the galactose.

$$\underset{\text{Galactose.}}{C_6H_{12}O_6} = \underset{\text{Lactic acid.}}{2C_3H_6O_3}.$$

A further change is at times produced, when lactic acid follows putrefactive fermentation, butyric acid being formed,

$$\underset{\text{Lactic acid.}}{2C_3H_6O_3} = \underset{\text{Butyric acid.}}{C_3H_7.COOH} + 2CO_2 + 2H_2.$$

These two changes frequently occur in the alimentary canal, especially the former.

Amyloses.

(*a*) *Starch* $(C_6H_{10}O_5)_n$, is very widely found in plants, in which it occurs in granules having a characteristic structure. It is almost insoluble in cold water, but when boiled with water the granules burst and an imperfect solution is formed, which sets to a jelly on cooling if the solution be strong. It is also insoluble in alcohol and ether. It is dextro-rotatory.

On boiling with dilute mineral acids it is rapidly hydrated, dextrose, erythro-dextrin, and achroo-dextrin being produced. By the action of diastase, saliva, or pancreatic juice, the same effect is produced, with the exception that it is maltose and not dextrose, which is formed; in the former case, the maltose is hydrated by the acid into dextrose as soon as it is formed. The following series of equations have been suggested as indicating the successive steps of the hydration :—

$$\underset{\text{Starch.}}{(C_6H_{10}O_5)_n} + H_2O = \underset{\text{Dextrine.}}{(C_6H_{10}O_5)_{n-2}} + \underset{\text{Maltose.}}{C_{12}H_{22}O_{11}}$$

$$(C_6H_{10}O_5)_{n-2} + H_2O = \underset{\text{Dextrine.}}{(C_6H_{10}O_5)_{n-4}} + \underset{\text{Maltose.}}{C_{12}H_{22}O_{11}}$$

$$(C_6H_{10}O_5)_{n-4} + H_2O = \underset{\text{Dextrine.}}{(C_6H_{10}O_5)_{n-6}} + \underset{\text{Maltose.}}{C_{12}H_{22}O_{11}}$$

&c. &c. &c. &c.

$$(C_6H_{10}O_5)_4 + H_2O = \underset{\text{Dextrine.}}{(C_6H_{10}O_5)_2} + \underset{\text{Maltose.}}{C_{12}H_{22}O_{11}}$$

$$(C_6H_{10}O_5)_2 + H_2O = \underset{\text{Maltose.}}{C_{12}H_{22}O_{11}}$$

The series of bodies occurring first on the right hand side of these equations are all dextrines, but they are all different. The first few of them give a red colour with iodine and are consequently called erythro-dextrines, the latter give no colour and are termed achroo-dextrines. The hydration of the achroo-dextrines into maltose, &c., is only effected slowly and with difficulty.

The tests for starch are :—

1. A solution of iodine when added to starch gives a deep blue colour, which disappears on heating, but reappears on cooling if the solution has not been boiled so long as to drive off all the iodine.

2. Microscopic examination may shew the characteristic granules, if they have not been burst by boiling, or broken mechanically by grinding, &c.

(*b*) *Dextrines* $(C_6H_{10}O_5)_n$, where "$_n$" is less than in the case of starch. They are amorphous. They do not reduce Fehling's solution, nor ferment with yeast; they are strongly dextro-rotatory. There are many of these bodies, which are all soluble in water, giving clear solutions, but are insoluble in alcohol or ether.

The dextrines are divided into two classes depending on their giving a colour with iodine or not. The former are erythro-dextrines, the latter achroo-dextrines. The red colour produced by the former disappears on warming, and if the solution be cooled it reappears.

Dextrine is not precipitated by basic acetate of lead, but is precipitable by this reagent on addition of ammonia.

(*c*) *Glycogen, or animal starch* $(C_6H_{10}O_5)_n$, was first discovered in the liver and has since been found in muscle, especially during embryonic life, or in most actively growing tissues. It is a white tasteless amorphous powder, readily soluble in water forming a markedly opalescent solution. It is insoluble in alcohol and ether. It is dextro-rotatory.

On hydrolysis by dilute acids, &c. it is converted into dextrose. Saliva, pancreatic juice and extracts of most tissues convert it into maltose, bodies analogous to dextrines being produced as intermediate products.

With iodine it gives a red colour, identical in appearance with that given by dextrine, it also disappears on heating and reappears on cooling. Glycogen is, however, precipitated by basic acetate of lead. It does not reduce Fehling's solution.

(*d*) *Cellulose* $(C_6H_{10}O_5)_n$ is the material which forms the cell-wall and woody-fibre of plants. It is insoluble in water, alcohol and ether. By boiling with dilute H_2SO_4 dextrose is produced. The digestive ferments have no action on cellulose. In the large intestine, micro-organisms are said to convert it into marsh gas, acetic and butyric acids, CO_2, and H_2, &c.

Group V. FATS.

These bodies have the same three elements in their composition as the last group, but the hydrogen and oxygen have variable proportions—not that of water. Fats are found in large masses in some tissues, and also as fine particles, suspended

in many of the fluids. The fat of adipose tissue in man is a mixture of oleine, palmitine, and stearine, which are spoken of as the neutral fats.

The first is liquid and the last two solid at ordinary temperatures, and the varying consistence of the fat of different animals depends upon the relative proportions of the solid or liquid fats.

Fats are soluble in ether and chloroform, but quite insoluble in water. When agitated in water containing an albuminous body, and an alkaline carbonate in solution, fluid fat is broken up into small particles, which remain suspended in the liquid, forming an opaque milky emulsion.

Chemically, they are regarded as ethers derived from the triatomic alcohol glycerine, $C_3H_5(OH)_3$, by replacing the OH group with the radicals of the fatty acids : thus—

$$\underset{\text{Glycerine}}{C_3H_5(OH)_3} + 3\,\underset{\text{Palmitic Acid}}{(C_{16}H_{32}O_2)} = \underset{\text{Tripalmitine}}{C_3H_5(C_{16}H_{31}O_2)_3} + \underset{\text{Water.}}{3H_2O}.$$

Under the influence of certain ferments they are saponified to form glycerine and the fatty acid, uniting with the necessary elements of water.

When the neutral fats are boiled with alkaline solutions they are similarly decomposed, and uniting with the elements of water, form glycerine and fatty acids. The glycerine is thus set free, but the fatty acid combines with the alkaline metal to form a soluble *soap*. An insoluble soap may be obtained by substituting lead or lime, &c., for the alkali.

This splitting up of the neutral fats, stearine, palmitine, and oleine into sodium stearate, palmitate, or oleate goes on during digestion, and is said to be useful in aiding the absorption of fatty matters.

Group VI. Inorganic Bodies.

Water (H_2O) is present in nearly all tissues in larger proportion than any other compound, making up about 70 per cent. of the entire body-weight. The amount in each texture varies, the different tissues having widely different consistence.

Water is introduced into the body not only as drink, but a large quantity is also taken with our solid food. It is highly probable, that in the chemical changes which take place in the tissues, some water is formed by the oxidation of the hydrogen of the more complex substances.

In the economy it acts as the universal solvent in the fluids of the body, and as the agent by means of which the chemical changes of the various tissues can be accomplished.

Water leaves the body by the lungs as vapour, and by the skin, kidney, and many other glands, as the fluid in which the solids of their secretions are dissolved.

Acids: Inorganic acids occur in the body, either combined, forming salts, in which condition we find several (sulphuric, phosphoric, silicic), or uncombined. In the latter state we have only two, viz:—

Hydrochloric Acid, HCl, which is formed in the stomach, where it occurs in the free state and plays an important part in gastric digestion.

Carbonic Acid Gas, CO_2, exists in most of the fluids of the body, having been absorbed by them from the tissues. The venous blood contains a considerable quantity, some of which is got rid of during the passage of the blood through the lungs. It is a waste product, which must be constantly eliminated from the body (see Respiration).

Salts. A large number of salts occur, generally in small quantity, in solution in the tissues. In the teeth and in bone-tissue salts exist in the solid form, and in much greater proportion than in any of the soft parts. Most of the salts are introduced into the economy with the food, but some, doubtless, are formed in the body itself. Our knowledge of the exact position occupied by the salts in the textures is very incomplete, as their amount is usually estimated from the ash of the tissue which remains after ignition, by which process some become altered, so that it is impossible to say what are the exact salts that are present in the body. They form chemical combinations with the complex organic compounds, which we do not understand, and probably have important functions to perform, such as rendering certain materials (globulins) soluble, or otherwise facilitating tissue change. The salts pass out of the body in many secretions, largely in the urine, where they influence the elimination of urea, and therefore form an important constituent of that secretion.

Common Salt (*Sodium Chloride*), NaCl, is the most widely distributed, and is present in greater quantity than any other salt in all animal fluids and most tissues, except bones, teeth, red blood corpuscles, and red muscle.

Potassium Chloride and *Phosphate* accompany sodium chloride in small quantity. In the red blood corpuscles and in muscle

they occur in greater amount than the sodium salt, while in the blood plasma but little is found in comparison with the sodium salts, and any excess seems to act as a poison to the heart.

Carbonates and phosphates of calcium, sodium, and magnesium occur in small quantities in most tissues. The earthy part of bone is chiefly composed of calcium and magnesium phosphate and calcium carbonate, together with some calcium fluoride.

Sulphates of sodium and potassium, probably formed in the body from the oxidation of the sulphur in the complex proteid materials, occur in most tissues, and are removed from the body by the kidneys.

Two of the elements can be obtained in the free state from the textures. Of these *Oxygen* plays by far the most important part. It is widely distributed among the fluids of the body, from which it can be removed by reducing the pressure of oxygen of the atmosphere by means of an air-pump. Oxygen is introduced into the body by the lungs, where the blood takes it from the air. In the blood only a small quantity of that which can be removed by the air-pump is really free; the remainder is chemically combined with the colouring matter of the blood. It is absolutely necessary for life, as it alone can enable the chemical changes of the tissues, which are mostly oxidations, to go on. It is, in fact, the element necessary for the slow combustion, which takes place in the nutrient material after its assimilation.

Nitrogen also occurs in the blood, but in insignificant quantity. It is absorbed from the atmosphere as the blood passes through the lungs. So far as we know, it has no physiological importance in the body.

CHAPTER IV.

THE VITAL CHARACTERS OF ORGANISMS.

THE manifestation of so-called *vital phenomena* in man, forms the subject-matter of the following chapters, and some explanatory definition of the vital characters of the simpler organisms will be useful in preparing the beginner's mind for the more intricate questions in human physiology. This, with the foregoing short account of the chemical and structural peculiarities of animals, will complete a rough outline of the general character of organisms.

Protoplasm has already been referred to, as the material capable of showing vital phenomena, the most obvious and striking of which are its movements.

Besides the common molecular or Brownian movement of the granules in protoplasm—which may be seen in most cases where fine granules are suspended in a less dense medium—protoplasm can perform motions of different kinds which must be regarded as distinctly vital in character. This movement may be said to be of three different kinds, according to the results produced, viz. :—(1.) The production of internal currents. (2.) Changes in form. (3.) Locomotion. In reality the two latter are dependent on the first.

The existence of *currents* moving from one part of the protoplasm to another can be well seen in vegetable cells, when the cell-wall restricts the more obvious change in form, or place. Thus in the cells forming the hairs on the stamens of *Tradescantia virginica* the various currents can be seen in the layer of protoplasm which lines the cell-wall.

The granular particles course along in varying but definite directions, passing one another like foot-passengers in a crowded street. The first and most obvious result of this is, that the different parts of the substance are frequently brought into contact with one another, and thus the products of any chemical changes taking place at a given part of the cell-body are rapidly distributed over the entire mass of the protoplasm.

The *change in form* occurs if there be no definite cell-wall—as in naked vegetable spores and amœboid forms of animal life—to restrict or direct the current of protoplasm; it flows out in various directions in bud-like processes, which appear at various parts of the protoplasmic mass, so as to cause a constant change in the form of the cell. These outstretched processes sometimes flow together and become fused, often enclosing some of the medium in which the creature is suspended, or catching some foreign particle floating near them.

The flowing out of these *pseudopodia* usually takes place for some time persistently from one side of the cell; and the body of the cell has to follow, as it were, the protrusion of the processes in such a manner that in a short time definite change in position or movement in a certain direction occurs: thus the protoplasmic unit may be said to perform definite progression or *locomotion*. All these movements may be seen in the white blood corpuscle of a cold-blooded animal, such as a frog, and still more easily in the uni-cellular amœba.

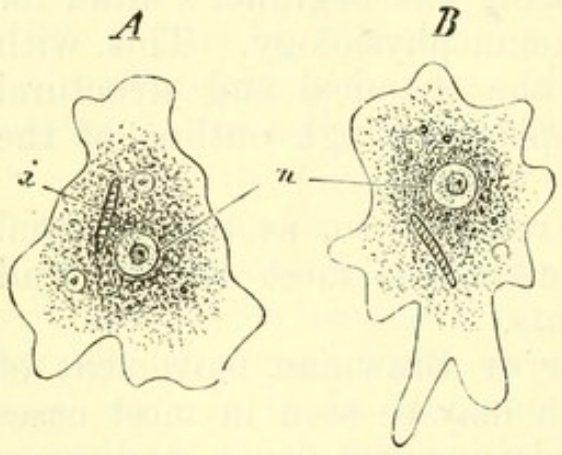


Fig. 34.—An amœba figured at two different moments during movement, showing a clear outer layer and a more granular central portion. (*n*) Nucleus; (*i*) Ingested food. (Gegenbauer.)

Various influences may be seen to affect the rate of movements and probably influence at the same time the other activities of the protoplasm. Foremost among these must be named:—(1.) *Temperature.* If a protoplasmic unit, which is observed to be motile, be gently warmed, the movements become more and more active as the temperature is raised, up to a certain point, about 35°—42° C., when a spasm occurs, resulting in the withdrawal of the pseudopodia; soon after this the cell assumes a spherical shape. If the heat be carefully abstracted before it has attained too great a height, the protoplasm may recover and again commence its movements. If, on the other hand, cold be applied to moving protoplasm, the motions become less and less active, and commonly cease at a temperature about or a little above 0° C. (2.) *Mechanical irritation* also produces a marked effect

on the movements of protoplasm. This may be well seen in the behaviour of a living white cell of frog's blood under the microscope. It is spherical when first mounted, owing to the rough treatment it goes through while being placed on the glass slide and covered ; shortly its movements become obvious by its change in form, which may again be checked by a sudden motion of the cover-glass. (3.) *Electric shocks* given by means of a rapidly-broken induced current cause spasm of the protoplasm, the cell becoming spherical. (4.) *Chemical stimuli* also have a marked effect ; carbonic acid causing the movements to cease, and a supply of oxygen making it active. The movements and other activities of protoplasm are, during life, frequently modified and controlled by nerve influence, as will appear in the following pages. This may readily be seen in the stellate pigment cells of the frog's skin, which can be made to contract into spheres by the stimulation of the nerves leading to the part.

The motions of protoplasm are thus seen to be affected by external influences, but the most careful observer cannot find physical explanations of the various movements which have been described. It is necessary, therefore, to ascribe this power of motion to some property inherent in the protoplasm, and hence the movements are called *automatic*. We are unable to follow the chemical processes upon which the activities of the protoplasm depend, and we therefore call them *vital actions ;* but we must assume that these so-called vital properties depend on certain decompositions in the chemical constitution of the protoplasm. We know that some chemical changes take place, as we can find and estimate products which indicate a kind of combustion ; but we know little or nothing of the details of the chemical process.

From the foregoing description of the manner in which protoplasm responds to external stimuli, it may be gathered that it is capable of appreciating impressions from without ; indeed it can be said *to feel.* We can only judge of the sensitiveness of any creature by the manner in which it responds to stimuli, and we may therefore conclude that the smallest particle of living protoplasm is endowed with definite sensitiveness : this must be noted as one of the most striking properties of protoplasm.

Every particle of living protoplasm has the power of *assimilation.* Taking into its structure any nutrient matters it meets with, by flowing around them in the way mentioned, it brings

them into direct contact with different parts of its protoplasmic substance. This nutrition of the cells gives rise to their growth, and finally leads to their reproduction. These facts will be more closely examined when speaking of their relation to cell life (p. 79).

When a certain size has been attained, the cell does not further increase, but prepares to bring forth a cell unit similar to itself. This is spoken of as the *reproduction* of cells.

Reproduction.

Different kinds of cell-reproduction have been observed, which are all, however, modifications of the same general plan.

Fig. 35.—Cells of the yeast-plant in process of budding. Between yeast cells are some bacteria.

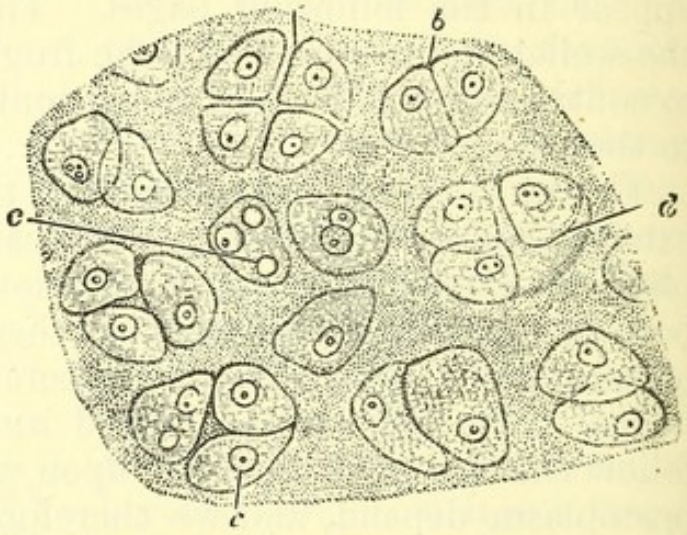


Fig. 36.—Cartilage from young animal showing the division of the cells (*b*), preceded by division of the nuclei.

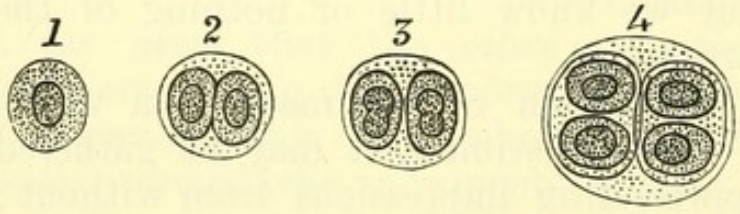


Fig. 37.—Cells of a fungus (*Glœocapsa*) showing different stages (1—4) of endogenous division. (After Sachs.)

The first is that by the formation of a *bud* from the side of the parent cell ; this bud increases in size, and finally detaches itself from the parent and becomes a separate individual (Fig. 35). This process, which is called *gemmation*, can readily be seen in all its stages in growing yeast, where the torula cells have various-sized buds growing from them. If the newly-formed portion be large, nearly equal in size to the cell itself, the process receives the name of *fission*, or division.

The division of the cell is always preceded by the division of the nucleus, and of this two modes of division are described. The first, called the direct division of the nucleus, is the one described by older observers, and in it the nucleus becomes first constricted and then divided into two equal parts (Fig. 37).

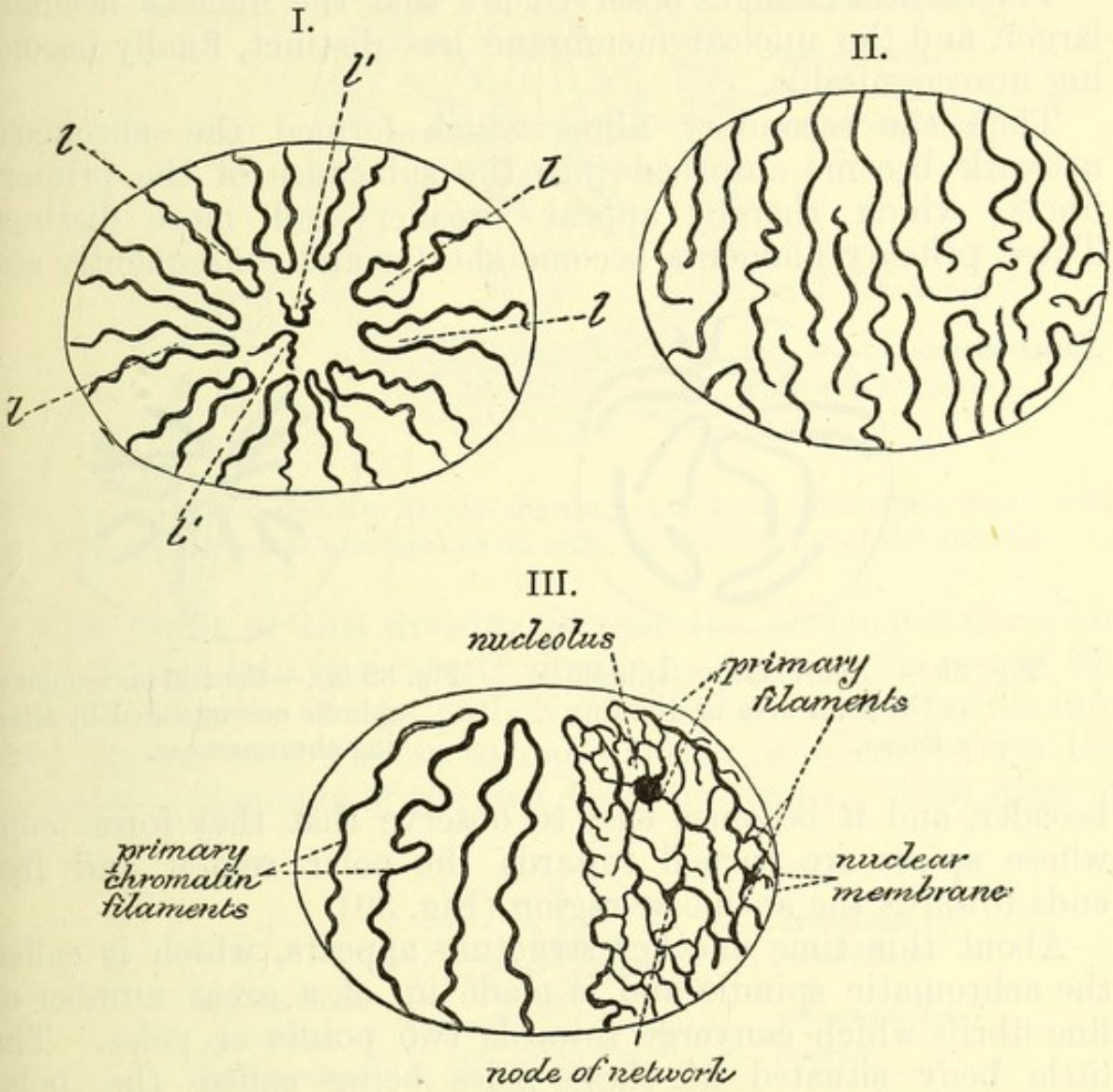


Fig. 38.—Diagram of the chromatic filaments in a nucleus—

I. Viewed from the pole. II. Viewed from the anti-polar end.
III. Viewed from the side, the pole being above. The left side shows the earlier stage.

This is followed by an equal division of the protoplasm, each half going to one of the nuclei and in this way two daughter-cells are formed.

The second method is called the indirect division of the nucleus, and is preceded by a series of changes in the chromatic filaments and in the protoplasm of the cell, which result ultimately in the foundation of two daughter-cells. To the changes which the nucleus undergoes the name *karyokinesis* is

given, the process also being called *mitotic*, in contradistinction to the direct method which is termed *amitotic*.

The following is a very brief account of the chief changes noted in a typical instance of indirect division as described by a recent observer (Rabl).

The earliest changes observed are that the nucleus becomes larger, and the nuclear membrane less distinct, finally becoming unrecognisable.

Then the secondary fibres which formed the chromatic network become absorbed into the substance of the primary fibres, which thereby appear broader and more distinct. These primary filaments become shorter and consequently still

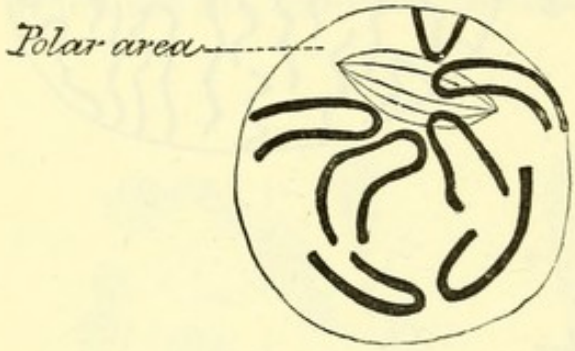


Fig. 39. — Achromatic spindle in the polar area of dividing nucleus.

Fig. 39 (a).—Central movement of spindle accompanied by altering chromosomes.

broader, and it becomes easy to observe that they form loops whose apices are turned towards the polar region and free ends towards the antipolar region (Fig. 39).

About this time another structure appears, which is called the achromatic spindle and is made up of a great number of fine fibrils which converge towards two points or poles. The little body situated at these poles being called the pole-corpuscle. This arrangement of fibrils, as its name implies, does not stain with nuclear re-agents. The spindle first appears in the polar region, but gradually moves so as to lie straight across the nucleus, and as it moves the chromatic fibres or *chromosomes* also move, so that ultimately they are arranged in a radiating manner around the equator of the spindle (Fig. 40).

If the nucleus be viewed at this stage along the axis of the spindle, the appearance produced by the arrangement of the chromosomes is that of a star, and the stage is consequently termed the Monaster. By this time it is found that another change has gradually been effected, and this is the longitudina

splitting of the chromosomes, into two exactly similar portions which remain at this stage parallel to one another (Figs. 40, 41).

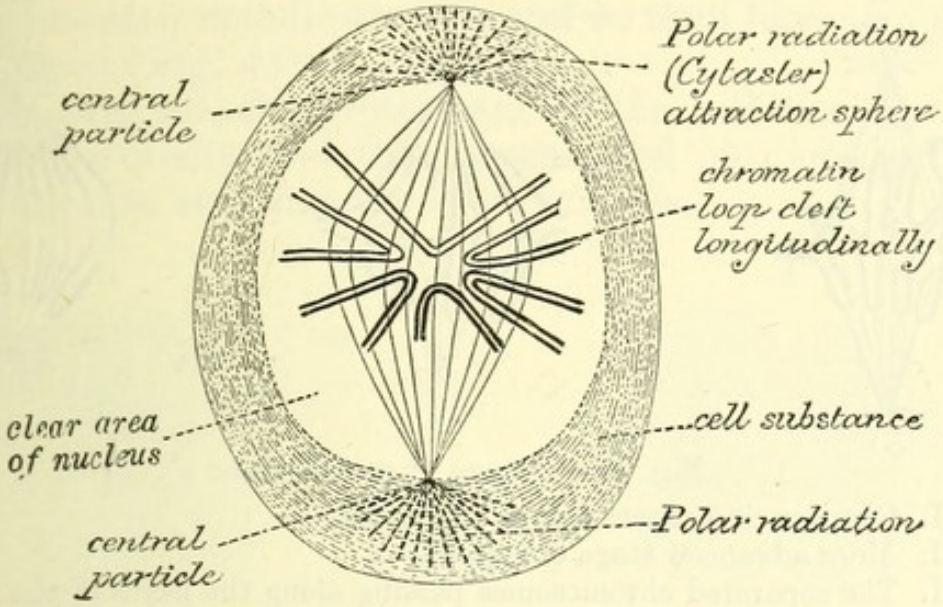


Fig. 40.—Nucleus about to divide showing spindle of achromatic fibres, with the chromosomes arranged as an aster at the equator of the spindle.

The result of this division is that the chromatic fibres are now divided into two exactly similar halves, and the rest of the process consists in the gathering together of the halves into two groups, each similar to one another, which will form the chromatic filaments of the two daughter-nuclei. This stage of

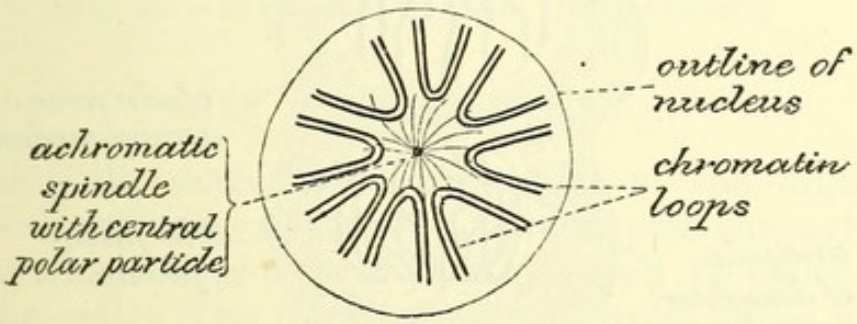


Fig. 41.—The aster stage of dividing nucleus seen from the pole. The spindle is foreshortened.

the process is termed *metakinesis* (Fig. 42). The separation of the chromosomes starts at the apices of the loops and takes place along the lines of the achromatic spindle, so that the apices of the daughter-chromosomes move in either direction towards the two poles of the spindle. The apices thus converge to one another, and as they approach the pole the appearance they present when viewed along the axis of the spindle is that of a

star, but as there are two sets of filaments, there are two stars and the stage is hence called the *dyaster*.

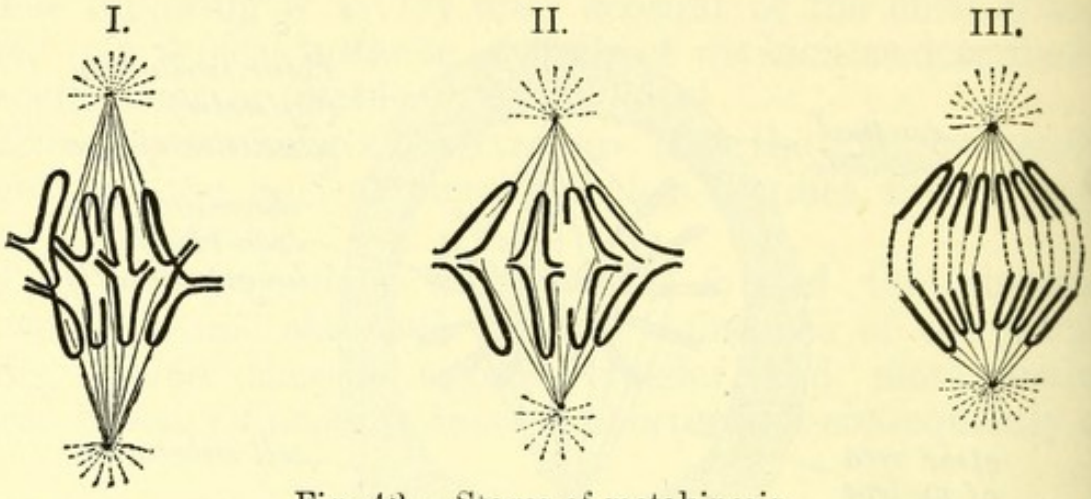


Fig. 42.—Stages of metakinesis.

I. Commencing separation of chromosomes.
II. More advanced stage of separation.
III. The separated chromosomes passing along the fibres of the spindle.

As the daughter-chromosomes separate, the space between them is seen to be free from the fibrils of the nuclear spindle, and when they have completely separated there are two

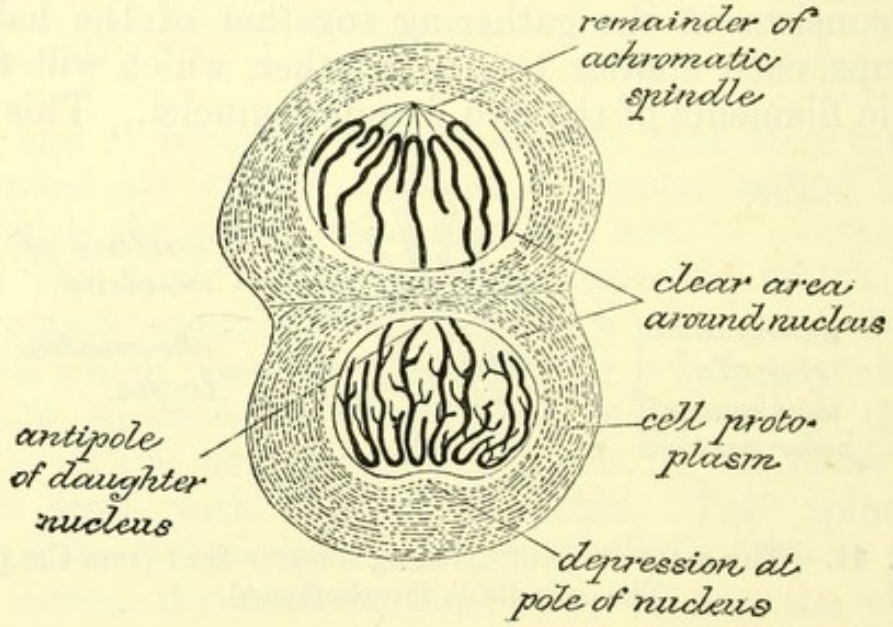


Fig. 43.—Formation of chromatic network in daughter nuclei. The upper nucleus shows the early and the lower the later stage and the beginning of the network.

nuclei having an equal number of chromosomes, arranged in loops radiating away from the two poles of the spindle, which become the poles of the two daughter-nuclei. The remaining changes each undergoes are, that the chromosomes lengthen,

give out little fibrils, (secondary fibrils) and become much thinner ; the secondary fibrils unite with one another to form the nuclear network, the nuclear membrane appears, all traces of the achromatic spindle are lost, and we then have two perfect resting nuclei (Fig. 43).

By this time too, the protoplasm of the cell has been constricted equatorially, and then is separated into two parts, one to each nucleus, and thus we have two cells.

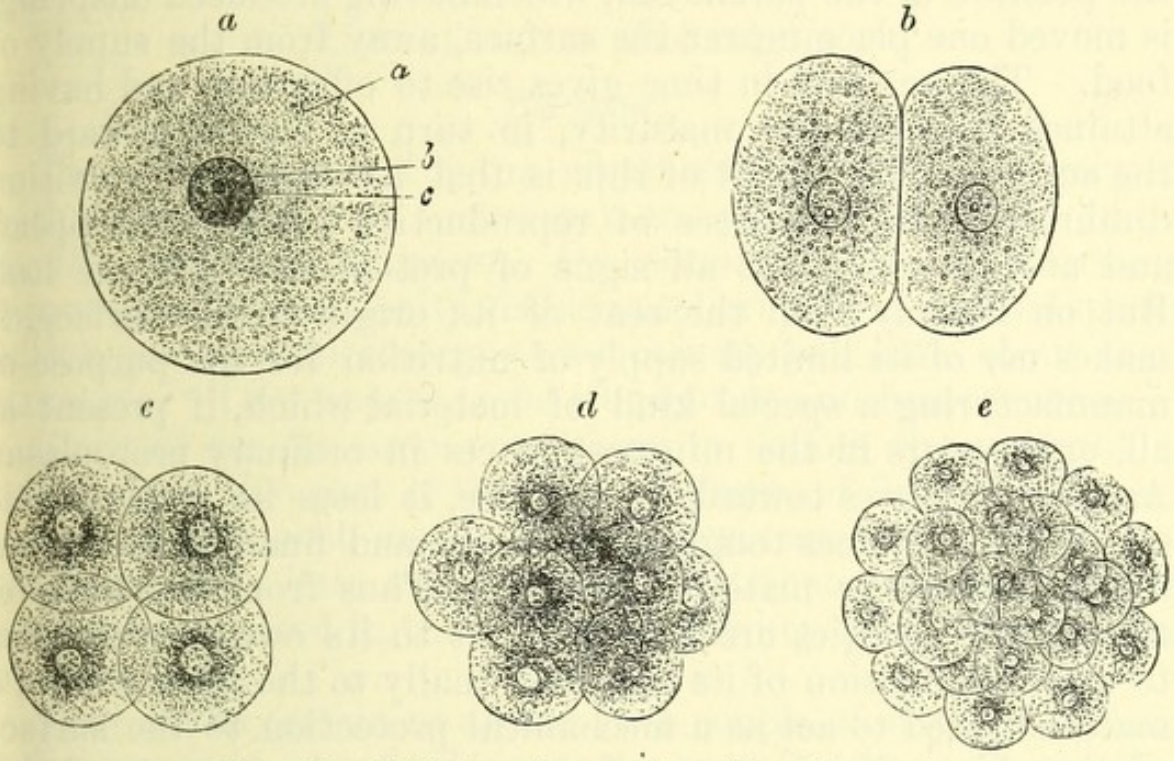


Fig. 44.— Division of egg-cell. (Gegenbauer.)

Life History of Cells.

In tracing the stages of development of the highly differentiated cells of some tissues, we have to pass through a series of changes which form a cycle that may well be called the life-time of the cell. The duration of this cycle varies greatly in different individual cells. Some cells are very short-lived, being destroyed by their act of secretion ; others possibly endure for the life-time of the animal. The life-history of all cells begins with the stage when they are composed entirely of undifferentiated protoplasm, in which various modifications are subsequently produced.

Let us take as an example a cell of the outer skin or *cuticle*, and examine its life-history. The cuticle is made up of numerous layers of epithelial cells laid one on the other, and the surface cells are constantly being rubbed or worn off.

These cells have their origin from the cells of the deepest layer, which is next to the supply of nutriment. This layer is made of soft protoplasmic units, which have, no doubt, certain specific inherited characteristics, but apparently the same as the motile, sentient, growing protoplasm of an indifferent cell. By a process of fission or budding, constantly going on in this deepest layer of cells, new protoplasmic units are produced. These become distinct individuals, and occupy the position of the parent cell, which having produced offspring, is moved one place nearer the surface, away from the supply of food. The new cell in time gives rise to offspring, and having attained reproductive maturity, in turn is moved onward to the surface. The result of this is that its supply of nutrition diminishes, the evidences of reproductive activity disappear, and at a certain point all signs of protoplasmic life are lost. But on its way from the seat of its origin to the surface, it makes use of its limited supply of nutrition for the purpose of manufacturing a special kind of material which, if present at all, only occurs in the minutest traces in ordinary protoplasm. As the cell moves towards the surface, it loses its protoplasmic characters, becomes tougher and drier, and finally nothing but the special horny material remains. Thus from the birth of the cell, its energies are devoted, first to its own growth, then to the reproduction of its like, and finally to the formation of a material fitted to act as a mechanical protection to the surface of the skin. Having manufactured a certain amount of this material, the protoplasm dwindles, and finally disappears, so that the cell may be said to die. Its horny, insoluble and impermeable skeleton has, however, yet to do service in the outer layer of the skin while it is passing towards the surface, to be in its turn rubbed off.

It has already been stated that the material, protoplasm, which forms all active cells, is capable of carrying on the many functions required for the independent existence of simple creatures. It will be found in the subsequent pages that, not only can protoplasm perform all the activities necessary for the life-history of unicellular organisms, but that it can also work out all the functions of the most complex animals. Indeed, the cells which accomplish the most elaborate functions in man, are but protoplasm more or less modified for the special purpose to be attained.

The different living operations of many independent unicellular organisms can be more completely watched than the changes

which take place in the cells of the higher animals, both on account of their greater size, their freedom, and the more obvious character of the changes taking place in them. The student is therefore advised to spend some time in contemplating the operations which go on in those simple organisms, whose life is not complicated by structural, or functional elaboration, before attempting to solve the difficult question of the mechanism of the human body.

Unicellular Organisms.

Bacteria.

The lowest forms of living creatures that we are acquainted with (*micrococcus* and *bacterium*), are placed among the fungi in the vegetable kingdom. On account of their extremely minute size—being hardly visible as spherical or elongated specks with a powerful microscope— we can say but little about their structure. They appear to be translucent and homogeneous.

Since we use the term protoplasm to denote the material of which the active part of the simplest forms of living beings are composed, we must assume that bacteria are small particles of that material, but the characters attributed to protoplasm cannot be detected in the minute glistening mass which makes up their body.

They are so certain to appear in a couple of days in organic infusions, or in any fluid prone to putrefaction, and multiply with such astounding rapidity, that they had been supposed by some to develop spontaneously. But this is now known not to be a fact. Bacteria can no more than any other form of living thing appear without progenitors. They float inanimate and dry, in multitudes, through our atmosphere, and adhere to all substances to which the air has free access. The moment they light upon a suitable habitat, they burst into prodigious activity, at first forming masses or colonies, which may be seen as a jelly-like scum on the fluid. Such a habitat is supplied by any organic substance capable of ready decomposition, for which process, as is well known, the great requirements for life, moisture and warmth, are to a certain degree necessary. Many varieties of these organisms are now known. They differ in shape, method of growth, in habitat, and in their properties. Some are obviously composed of two distinct layers, some are provided with a fine hair-like process, by the lash-like motions of which they move rapidly in a definite direction.

They are known to be inseparable from putrefactive changes in organic materials, without them no putrefaction can go on, since this process is but the product of their living activity. Great heat kills them, too great cold or dryness checks their activity and stops putrefaction. When an organic substance is absolutely protected from their presence by exclusion of the air, &c., no putrefaction occurs, even though the substance be prone to decomposition, and be placed under favourable circumstances as to warmth and moisture.

Bacteria would not deserve so much notice here were it not for the pathogenic influence some of them have on the higher forms of life. We do not know that they are necessary for any of the more important processes that normally go on in the human body, though they are constantly present in the intestinal tract, and are inseparable from at least one change taking place there that may be regarded as physiological. It is their relation to the diseased state that makes a knowledge of these organisms imperative to medical men.

So long as the tissue of a higher animal is healthy and well nourished, the commoner forms of pathogenic bacteria cannot thrive in immediate contact with it. They can only exist in the intestine, &c., because there they find accumulations of lifeless fluids, which offer them a suitable nidus. Active living tissues may be said to have antiseptic power, *i.e.* are able to destroy septic bacteria, and it is only owing to this bactericide power of our textures, that we can with immunity breathe into our lungs the atmospheric air often crowded with these organisms, and swallow multitudes of them with our food. But for it every wound would become putrid, every breath might admit deadly germs to our blood.

When the vitality of the body generally is lowered, the vital activity of the tissue may fall below that necessary to insure the death of the bacteria, whose victory is signalled by unwonted and often fatal changes. Morbid fluids allowed to accumulate in the textures facilitate the growth of bacteria, and give rise to various grades of "wound-infection." But if all fluid accumulations be avoided, the bacteria being in close relation with the living tissue can only irritate and cause local suffering to the patient. They cannot propagate in living tissue as they do in lifeless fluids. As a rule, the injurious effect of bacteria is in inverse proportion to the vital power of the textures which they invade. This is seen in many cases familiar to the physician and the surgeon.

There are, however, many forms of *pathogenic* bacteria which, if introduced into the system by inoculation, are able to overcome the vital activity of the tissues of certain animals even in the most robust health.

Torula.

We next come to forms of fungus, which set up a process very like putrefaction, such as the yeast-plant, *Torula cerevisia*, which causes alcoholic fermentation in sugar solutions. In the torula an external case containing protoplasm may readily be seen, and multiplication of the cells goes on rapidly by a process of budding. Torulæ, however, like bacteria, though called vegetables, have not the power of assimilation as ordinary green plants, but require nutriment to be supplied to them which already contains organic or complex compounds. Structurally but little different from torula is a one-celled plant, the green protococcus, which, like a higher plant, can build up its texture from the simplest food-stuffs, and carry on its functions. It consists of a case made of cellulose, within which lies a mass of protoplasm with a nucleus. This protoplasm is coloured green by a peculiar substance called chlorophyll. We shall see presently that it is to protoplasm containing chlorophyll, that plants owe all their most characteristic and wonderful properties; viz., the property of assimilating simple inorganic materials and constructing complex carbon compounds.

Amœbæ.

The smallest and simplest organisms classed as animals are generally larger than the vegetable cells just alluded to. They consist of protoplasm without any nucleus, and only sometimes with a structural difference between any part of their substance. As an example we may take *Protamœba*. This is a small mass of protoplasm without any nucleus, but its outer layer is clearer and less granular than the central part. It can move by sending out protoplasmic processes, in which currents can be observed resembling those in the vegetable cells. Excepting as regards the nucleus, it is much the same as the *Amœba*, which can be readily found and watched, and will be more accurately described.

The amœba is a single cell or mass of uncovered protoplasm,

containing a well-defined nucleus, within which is a nucleolus. There is also generally a vacuole. The central part of the protoplasm is densely packed with coarse granules, but the outer more active part is structureless, and translucent-looking, somewhat like a fine border of muffed glass, encasing the coarsely granular middle portion. Such an animal has no parts differentiated for special purposes, the requirements

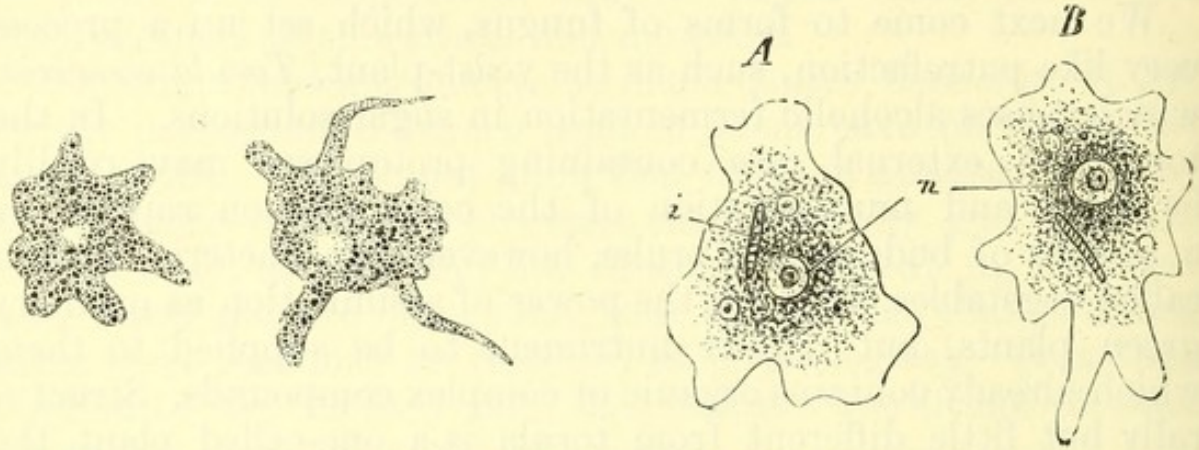


Fig. 45.—Two different forms of Amœbæ in different phases of movement. Those on the left after Cadiat. A and B show an outer clear zone. (Gegenbauer.)

of its functions being so limited that the protoplasm can fully accomplish them.

Thus the processes of protoplasm, which flow out with considerable rapidity from the body, frequently encircle particles of nutrient material, and then closing in around them, press them into the midst of the granular central mass. Here they sojourn some time, and during this period no doubt any nutritive properties they possess are extracted from them, and they are then ejected from the plastic substance. This form of assimilation demands no previous preparation of the food such as we shall see takes place in the alimentary tract of man, and in the special organs of the higher animals ; yet it is a form of digestion adequate at least to the requirements of this simple organism. The repeated alteration of relationship between the different parts of the protoplasm, and the surrounding medium during the flowing, hither and thither, of the currents, produces not only a change in the shape and position of the animal, but also, acts as a means of distributing the nutriment to the different parts of the body, and of collecting and carrying to the surface, the various products of tissue-decomposition ; thus the streaming protoplasm does the work of a circulating fluid such as we see in the more elaborate

organisms, for the distribution of nutriment and elimination of waste materials. The surface of the amœba is sufficient to allow of the gas-interchange necessary for life, and by means of the ever-changing material exposed, sufficient oxygen is taken for its tissue combustions, and so a function of respiration is established. The growth that results from the perfect performance of these vegetative functions proceeds until the maximum size is attained, and further nutritive activity is then devoted to reproduction. When growth ceases, commonly the cell divides and forms two distinct individuals. The movements which form the most striking operations of the amœba are the same as those which take place in protoplasm except that they are more rapid and obvious. The clear outer layer first flows out as a bud-like process, and, as it is gradually enlarging, some of the central granular part of the cell suddenly tumbles into its midst, where it remains, while other pseudopodia are being thrown out in the neighbourhood, and the same changes repeated in them. It is difficult to watch the motions of an amœba without being impressed with the idea that it is not only endowed with sensibility but that it can also discriminate between different objects, for we see it greedily flowing around some food-material, whilst it carefully avoids other substances with which it comes in contact.

If a glass vessel, containing several amœbæ, be placed in a window, they will be found to cluster on the side of the glass most exposed to the light. From this it would appear that, in some obscure way, protoplasm can appreciate light, and respond to its influence by moving towards it.

This single-celled animal, or nucleated mass of protoplasm, can perform all the functions of a higher animal. It can move from place to place and assimilate nutriment, apparently discriminating between different materials. It distributes nutrient stuffs and oxygen throughout its body by a kind of tissue circulation, and it can appreciate and respond to the most delicate form of stimulus, namely light, which subtle motion has no effect on the sensory nerve-fibres of the higher animals.

Paramœcium.

In some unicellular animals certain parts of the cell are specially modified for the performance of special functions, a division of labour thus taking place which insures the more

perfect accomplishment of the different kinds of activity. In one of the commonest of the Infusoria (*Paramœcia bursaria*), which swarm in dirty water, this is well exemplified. The outer layer of the flattened body is denser, and forms a kind of fibrillated corticular case (ectosarc), which is covered over with hair-like processes (vibratile cilia), constantly moving in a certain direction, so as to propel the creature rapidly through the water. The internal part of the cell is very soft, almost fluid, and coarsely granular in appearance, containing many bodies which have obviously been introduced from without. This soft internal protoplasm (endosarc) moves slowly round in a definite direction, completing its circuit in one or two minutes, and thus carries on a circulation which mixes the various matters contained in it. At one point of the ectosarc, or cortical layer, an orifice or mouth leading to an œsophageal depression is found. This orifice is lined by moving cilia, which by their vibrations drive the food into the œsophagus, whence it is periodically jerked into the soft internal protoplasm or endosarc, together with some water, and thus forms a food vacuole, which is carried round in the circulation of the ectosarc. Besides a well-marked nucleus and nucleolus in the central part of the cell, these paramœcia have one or more clear spaces placed near the surface at the extremities of the animal. These vacuoles suddenly contract, and disappear every now and then. When this contraction occurs, fine canals radiating from the contractile vacuole are distended with a clear fluid which has probably entered the vacuole from without. Thus a permanent set of water-vessels carry fluid from the contractile vacuole throughout the endosarc.

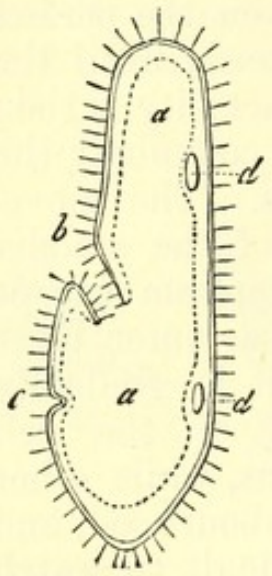


Fig. 46.—Diagram of Paramœcium showing digestive cavity. (*aa*) Body-space filled with soft protoplasm, into which food is taken. (*b*) Mouth. (*c*) Anus. (*d*) Contractile vesicle. (After Lachmann.)

In such an animal, compared with the amœba, there is a distinct advance of function: a more elaborate and specialised method of feeding: a more systematic and regular circulation of nutrient matters: a respiratory distribution of water by the contractile vesicle and its water-canals; more rapid motion; and more obvious sensation.

Vorticella.

In the bell animalcule, or *Vorticella*, the same kind of division of labour exists, but in one of its commonest conditions it is attached, by a thin stalk, to the branch of some weed or other object. Besides the ciliary movement we here find that the general mass of the protoplasm can suddenly and forcibly contract, so as to completely alter its shape, and change the bell into a rounded mass. This spasm of the body is commonly associated with a wonderfully rapid contraction of the stalk. This stalk consists of a delicate transparent sheath, in the centre of which is a thin thread of pale protoplasm. The rapid contraction of the protoplasm of the stalk and the spasm of the bell occur on the application of the least mechanical excitation, such as a touch to the cover-glass. Here in a single cell we have certain portions set apart for special purposes, most of which are the same as in paramœcia. But the animal being attached requires a special way of escaping from its enemies, and hence we find it endowed with three special forms of motion. Besides the ciliary and streaming protoplasmic motion, its body can spasmodically change its shape, and the stalk contracts with a velocity comparable with that of the most specially modified contractile tissue (muscle) of the higher animals, by means of which their rapid and varied movements are carried out.

CHAPTER V.

FOOD.

THE continuation of life depends on certain chemical changes which are accompanied by a loss of substance on the part of the active tissues. This loss must be made good by the *assimilation* of material from without, and the manner in which assimilation takes place constitutes an important difference between Plants and Animals. In the majority of the former (certain fungi form the main exceptions) the cells in those portions of the plant which are exposed to the light and air, contain a peculiar green substance called chlorophyll, and through the agency of this substance they are able to use all the oxidized food they obtain from the inorganic kingdom. Water, with such salts as may happen to be in solution, is taken up by the roots, and carried through the stem to the leaves; here the active chlorophyll-bearing cells, by the aid of the energy borne by the sun's rays, can cause its elements to unite with the carbon of the carbonic anhydride present in the air, and thus form organic substances, of which we may take starch or cellulose as examples. The reaction may be represented chemically, thus :—

$$6CO_2 + 5H_2O = C_6H_{10}O_5 + O_{12}.$$

Starch or cellulose.

A large proportion of oxygen is thus set free and discharged into the atmosphere.

The most striking property of plant protoplasm is the power of using the energy of the sun's rays to separate the elements of the very stable compounds, carbon dioxide and water, and from the elements thus obtained, to make a series of more complex and unstable compounds, which readily unite with more oxygen, and again form carbonic anhydride and water.

The carbon compounds made by the protoplasm of the green plants are some of the so-called "organic compounds," which

enter into the composition of both plants and animals, and form an essential part of the food of the latter. They may be divided into three groups—

i. *Carbohydrates*—bodies containing carbon, hydrogen and oxygen in which the hydrogen and oxygen are in proportion to form water, *e.g.* :—
   a. Glucoses, $C_6H_{12}O_6$, of which the most important is grape-sugar or dextrose.
   b. Saccharoses, $C_{12}H_{22}O_{11}$, of which sucrose or cane-sugar, lactose and maltose are examples.
   c. Amyloses $(C_6H_{10}O_5)_n$, when "$_n$" varies in the different substances, in some being as high as 10 or even higher. Examples are :—Starch, dextrin, glycogen.

ii. *Fats*—compounds of carbon and hydrogen with a less proportion of oxygen than carbohydrates, *e.g.* :
   Oleine (principal constituent of olive oil), $C_{57}H_{104}O_6$.

iii. *Albuminous bodies* which contain nitrogen in addition to carbon, hydrogen, and oxygen. These are of complex composition, and, as a rule, cannot be represented by chemical formulæ.

Animals cannot thrive on the simple forms of food obtainable from the inorganic kingdom, which suffice for the nutrition of plants. They require for assimilation materials nearly allied in chemical composition to their own tissues ; substances to be used as fuel in producing the activities of their bodies. In short, they require as food the very organic substances which plants make during their assimilation : viz., starches, fats, and albuminous bodies. These complex substances, the result of the work done in vegetable life, must be supplied ready made, to animals, either directly as vegetable food or indirectly as animal food.

The chief acts of animal protoplasm are oxidations, a slow burning away of its substance, which results in the production of inorganic materials like those used by plants as food.

Plants use simple food stuffs, and from them they manufacture complex combustible materials, and thus store up the energy of the sun's rays in their textures.

Animals, on the other hand, use complex food-stuffs to renew their tissues, which are constantly being oxidised, and by this means the energy for the performance of their active functions is set free.

Although the various kinds of food-stuffs used by animals are highly organised and like the animal tissues in composition, yet they cannot be admitted at once into the economy without having undergone a special preparation, which takes place in the digestive tract, where the various food-stuffs are so changed as to allow them to pass into the fluids of the body.

We shall first consider the food-stuffs, next their preparation for absorption (digestion), then their absorption and finally the means by which they are distributed to the tissues (circulation). The final steps in tracing the assimilation of the food follow the intimate processes which go on between the blood, which carries the nutriment, and the different tissues which receive it.

Classification of Food-stuffs.

There are two portals, namely, the lungs and the alimentary canal, by which new materials normally enter the animal body.

Within the lungs the blood comes into close relation with the air, and takes from it oxygen. The oxygen is then carried to the various tissues, where it aids in the combustion accompanying the life and functions of these tissues. Oxygen is the most abundant element in the body, taking part in almost every chemical change, and a continuous supply of this element is more immediately necessary for life than that of any other substance, yet it is not counted as food, because tissue oxidation is distinguished from tissue nutrition.

The details of the union of oxygen with the blood will be found in the Chapter on Respiration.

It is then only to the liquid and solid portions of the material income of an animal—that, in short, which it must busy itself to obtain—that the term "food" is usually applied. These are introduced into the alimentary canal, where the nutrient materials are separated and prepared for absorption, while the portions which are not useful for nutrition are carried away as excrement. We are, therefore, quite prepared to hear that the really nutritious food-stuffs are composed of materials which are chemically like the tissues, although, as we shall see, we have no grounds for believing that the different chemical groups of nutritive stuffs are exclusively destined to replace corresponding substances in the body. On the contrary, we have good reason to think that within the body the conversion of one group into another is common.

In Chapter III. the tissues of the animal body were shown

to consist of chemical compounds, which have been classified into certain groups. It has also been stated that the tissues are constantly undergoing chemical changes inseparable from their life, and that for these changes a supply of nutritive material is necessary.

The nutriment required for an animal is made up of substances which may be divided into the same chemical groups as the tissues of the body: viz, proteids, fats, carbohydrates, salts, and water. So that each of the various substances which we make use of as food, contains in varying proportions several of the different kinds of nutrient material, either naturally or artificially mixed so as to form a complex mass, the important item water being the only one which is commonly used by itself. These substances may be considered to be the chemical bases of the food, as they are also the chemical bases of the animal body.

The following classification shows the relationships between the chief constituents of food, from a chemical point of view, and their distribution in the various substances we eat.

I. Organic.

1. Nitrogenous—

A. Albuminous—abundant in eggs, milk, meat, peas, wheaten flour, &c.

B. Albuminoid—in soups, jellies, &c.

2. Non-Nitrogenous—

A. Carbohydrates (sugar, starch)—abundant in all kinds of vegetable food, and in milk, and present in small quantity in meat, fish, &c.

B. Fats—in milk, butter, cheese, fat tissues of meat, some vegetables, oils, &c.

II. Inorganic.

1. Salts—mixed with all kinds of food.
2. Water—mixed with the foregoing or alone.

The *nutritive value* of any kind of food depends upon a variety of circumstances, which may be thus summed up :—

I. *Chemical composition*, of which the main points are—

(1.) The proportion of soluble and digestible matters (true food-stuffs) to those which are insoluble and indigestible, such as cellulose, keratin, elastic tissue, &c.

(2.) The number of different kinds of nutrient stuffs present in it.

(3.) The relative proportion of each of these chemical groups.

II. *Mechanical Construction.*—The degree of subdivision in which the substance is introduced into the stomach, materially influences its nutritive value, since the smaller the particles the greater the amount of surface exposed to the action of the digestive juices.

The relation of the nutrient to the non-nutrient parts is also of importance, as is seen where the nutritious starch of various vegetables is enclosed in insoluble cases of cellulose, which, if not burst by boiling, prevent saliva from reaching the starch.

III. *Digestibility.*—This depends partly upon how the substances affect the motions of the intestines, and partly upon their construction. Thus, some substances, such as cheese, though chemically showing evidence of great nutritive properties, by their impermeability resist the digestive juices, and are not very valuable as food.

IV. *Idiosyncrasy.*—In different animals and in different individuals, and even in the same individuals under different circumstances, food may have a different nutritive value.

Food Requirements.

Chemically foods are composed of a limited number of elements similar to those found in the animal tissues, viz., carbon, oxygen, nitrogen, and hydrogen, together with some salts. If nothing more were needed by the economy than a supply of these elements and salts in a proportion like that in which they exist in the tissues, such could be easily obtained from inorganic sources ; but, as has already been stated, it is necessary that an animal obtain these elements associated in the form of organic materials of complex construction (namely, proteids, &c.). Allowing the necessity of organic food, it might be supposed that, since the necessary elements exist in proper proportion in the proteids, an abundant supply of proteids would suffice for all nutritive purposes, and alone form an adequate diet. Theoretically, proteid alone might appear to be sufficient for nutrition. It, however, has been frequently tested by experiment, and practically decided, that animals will not thrive upon a free supply of pure proteid food alone ; and in the human subject such exclusive diet would induce dangerous abnormal conditions in a short time. Since nitrogen is an

important element in nearly all parts of the body, we could hardly expect that a diet composed of non-nitrogenous food-stuffs alone could support the animal economy. In short, the results of numerous experiments show that no one group of the food-stuffs enumerated can alone sustain the body, but rather prove that a certain proportion of each is absolutely necessary for life.

Special Forms of Food.

The articles of diet we make use of are *animal* or *vegetable*, according to the source from which they are derived. It will be seen that a varying quantity of all chemical classes of food-stuffs is present in most kinds of food, whether animal or vegetable. The following diagram shows roughly the proportion of the more important food-stuffs in some examples of the materials commonly used as food :—

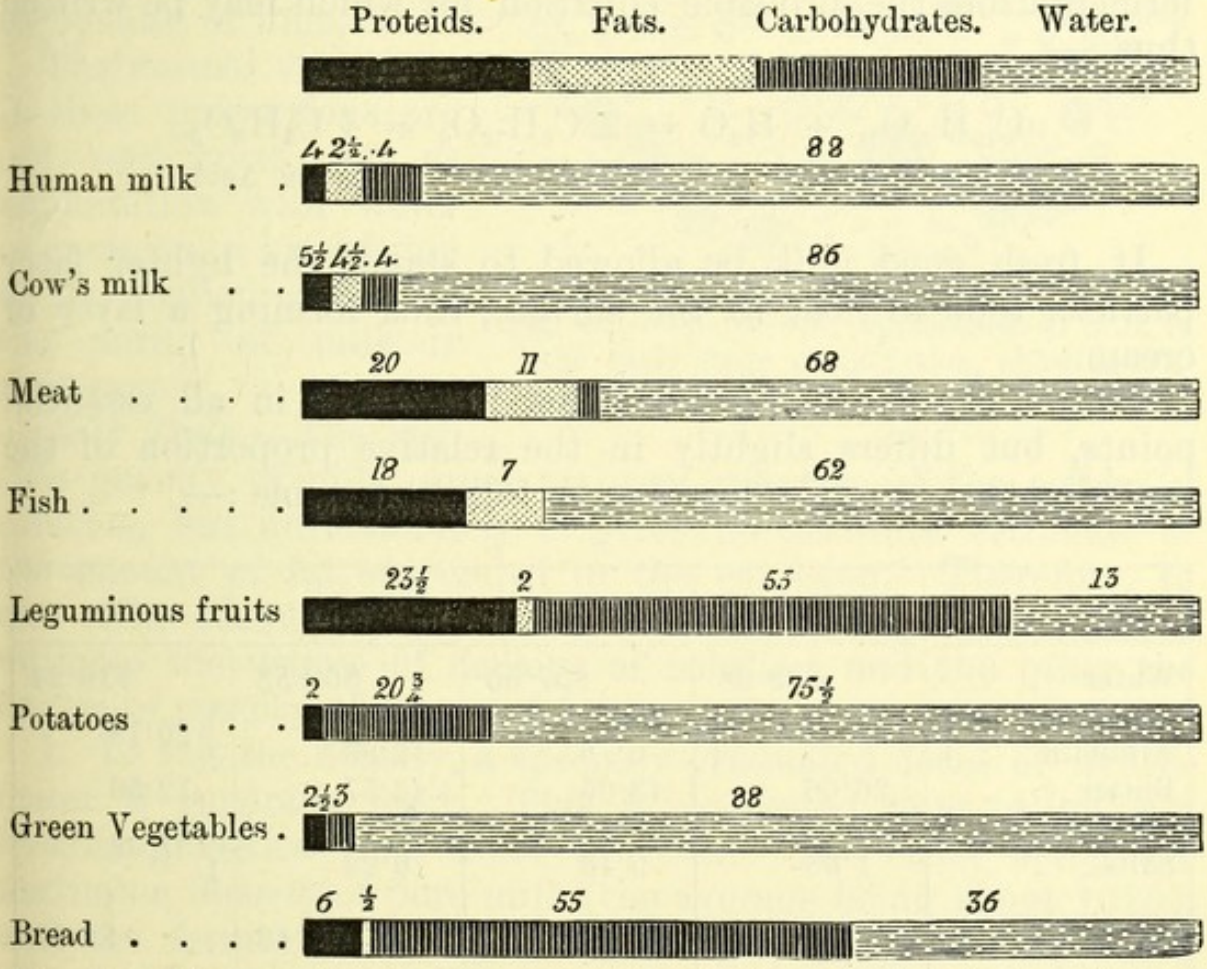


Fig. 47.—Diagram showing the proportion of the principal food-stuffs in a few typical comestibles. The numbers indicate per-centages. Salts and indigestible materials omitted.

Among animal foods are included milk, the flesh of various animals, and eggs. These may be more fully described as typical examples.

Milk.—For a certain period of their life-time the secretion of the mammary gland forms the only food of all mammals, and it is the one natural product which when taken alone affords adequate nutriment.

It consists of a slightly alkaline watery fluid, containing :—

1. Proteids, caseinogen and albumin in solution.
2. Fats, finely divided to form a perfect emulsion.
3. Carbohydrate, sugar in solution.
4. Salts, in solution.
5. Water.

Owing to the action of certain organisms which readily propagate in milk, if exposed to the air at a warm temperature for some time, it loses its alkaline reaction, and becomes sour from the formation of lactic acid from the milk-sugar, by a kind of fermentation, the probable equation for which may be written thus :—

$$\underset{\text{Milk-Sugar.}}{C_{12}H_{22}O_{11}} + H_2O = \underset{\text{Galactose.}}{2\ C_6H_{12}O_6} = \underset{\text{Lactic Acid.}}{4\ C_3H_6O_3}.$$

If fresh good milk be allowed to stand, the lighter fatty particles tend to float to the surface, thus forming a layer of cream.

The milk of different animals is similar in all essential points, but differs slightly in the relative proportion of the ingredients, as may be seen in the following table :—

	Human.	Cow.	Goat.	Ass.
Water . . .	889·08	857·05	863·58	910·24
Casein . . }	39·24	48·28	33·60	20·18
Albumin . }		5·76	12·99	
Butter . . .	26·66	43·05	43·57	12·56
Milk Sugar . .	43·64	40·37	40·04	57·02
Salts	1·38	5·48	6·22	
Solids . . .	110·92	142·95	136·42	89·76
	1000.	1000.	1000.	1000.

Milk varies both in the amount of solids in solution, and fat, according to the age and general condition of the animal, period of lactation, time of day, &c.

Since human milk is much poorer in proteid, fat, and salts (see Table), and richer in sugar, than that of the cow and other domestic animals, it is necessary to dilute the latter with water, and add sugar, when it is substituted for human milk in feeding infants.

The great value of milk as nutriment depends upon the fact that it contains every class of food-stuff, viz., proteids, fat, carbohydrates, salts, and water, in the proportion demanded by the economy; the salts in milk being those required for building up the bones of the infant, viz., phosphates and carbonates of lime, &c.

The normal variations in these proportions are not very great, but as adulteration with water is common, a knowledge of the method of testing the purity of milk is necessary.

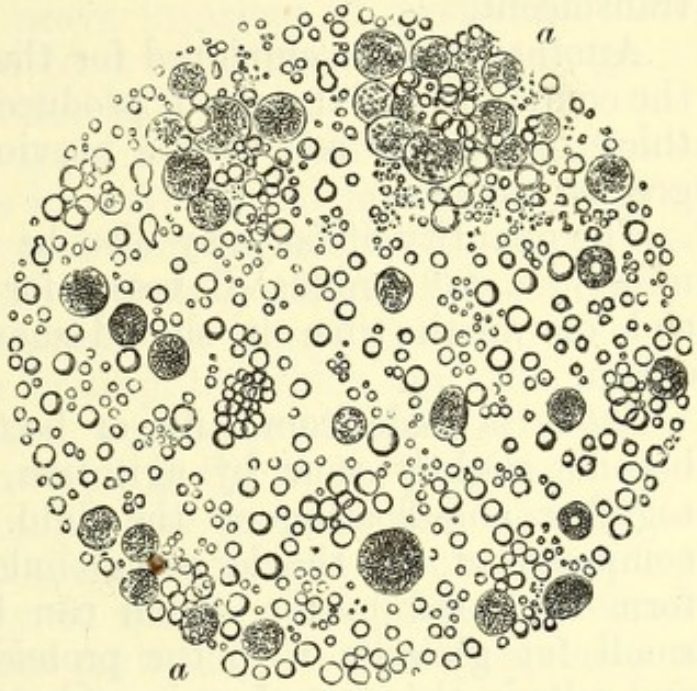


Fig. 48.—Microscopic appearance of milk in the early stage of lactation, showing colostrum cells (*a*).

Milk Tests.—The specific gravity of milk gives an easy measure of the solids in solution, but unfortunately it gives no accurate estimate of the amount of fat suspended in the emulsion. Therefore, to test milk adequately two methods must be employed: one to estimate the degree of density of solution, and the other the degree of opacity of the emulsion.

I. To test the density, a specially graduated form of hydrometer is generally used. This is graduated so as to indicate specific gravities from 1014 to 1042. The latter being the maximum density of pure milk (the average being about 1030), and the former being about the density of pure milk when mixed with an equal bulk of water. Every reduction of 3 in the specific gravity may be said to correspond to about 10 per cent. of water.

II. The degree of opacity is estimated by the amount of water required to render a small quantity of milk sufficiently translucent to allow a candle-flame to be seen through a layer

of the mixture one centimetre thick. One cubic centimetre of the milk (which has been shown by the microscope and the iodine test not to contain chalk or starch) is placed in a test-glass with flat parallel sides, just one centimetre apart, and water is cautiously added from a graduated pipette. The more water required the richer the milk is in fat; good fresh milk requires about 70 times its bulk of water to become translucent.

Another method employed for the same purpose consists in the comparison of the colour produced by a layer of milk 1 mm. thick in a black cell with a previously prepared standard of greyish colours.

The quantity of fat may also be estimated by placing the milk in a tall graduated vessel for twenty-four hours, at the end of which time it should show at least 10 per cent. of cream.

Butter is made from milk, or better from cream, which has become slightly sour by agitation, the oil globules running together and floating on the fluid. It is almost completely composed of fat, the larger globules having run together to form the solid butter, which can be removed, leaving some small fat globules with the proteids, milk-sugar, lactic acid, and salts in the water forming "butter-milk."

Cheese is another form of food made from milk by precipitating the proteid either by lactic fermentation, or the addition of rennet—an extract of calves' stomach which, without the presence of any acid, curdles milk—and draining off the solution of milk-sugar and salts (whey). It contains most of the proteid, and a great deal of the fat of the milk. During the ripening of the cheese more fat is formed, apparently from the proteid, while leucine and tyrosine also appear.*

Meat.—We use the flesh of the vegetable-feeding mammals and birds that are most easily obtainable, and many kinds of fish. The invertebrate animals, mostly shell-fish, need hardly be mentioned in a physiological dietary, and are not spoken of as meat.

As it comes from the butcher, meat consists of many of the animal tissues, the chief ones being flesh (muscle tissue), fat, and some sinews (fibrous tissue). The fleshy or lean part of meat is chiefly made up of nitrogenous materials, and contains: (1) Several proteids, chiefly a globulin, *myosin* 20%; (2) gelatine-

* For the details of secretion of milk, &c., see Mammary Gland.

yielding substances 2% ; (3) carbohydrates, as inosite and grape-sugar ; (4) small quantities of fat ; (5) extractives ; (6) several inorganic salts 3·2%.

Many animals thrive on raw meat, but as it is impossible to impart to it the various flavours which our artificial tastes demand without some special preparation, it is generally cooked before use. Moreover, the not infrequent occurrence in muscle of parasites which would prove injurious if swallowed alive, makes the exposure of meat to a temperature high enough to ensure their destruction advisable.

Apart from pleasing the taste, it is of great importance so to prepare meat as to preserve in it all the nutrient parts, many of which are soluble in water, and therefore are apt to be removed if that solvent be injudiciously used. Thus, the process of roasting, in which all its nutrient parts are retained, ought to be more satisfactory than boiling, by which the salts, extractives, carbohydrates, gelatin, and some albumin may be dissolved by the water. However, if the meat be plunged into water which is already boiling, the proteids near the surface are rapidly coagulated, and the water cannot reach the central parts in sufficient quantity to remove the soluble ingredients. The whole of the albuminous parts may be thus coagulated as the temperature of the inner parts rises to boiling point. In treating meat to obtain "stock" (bouillon) for the foundation of soups, the opposite procedure is adopted. The meat should be subdivided. Cold water is used, and the temperature slowly and gradually raised, but not quite to boiling point, in order that as much as possible of the soluble materials may be extracted, and a tasteless friable muscle tissue remains ("bouilli"). As the fluid is generally allowed to boil in order to clear it, much of the proteid material which was dissolved in the earlier stage is coagulated and removed with the scum. Although "stock" cannot contain any great proportion of the most important constituents of meat, it is of much value as a nutriment in medical practice, possibly on account of some stimulating action of its ingredients upon the motions of the intestines and heart. A strongly albuminous extract of meat, "beef-tea," may be made by digesting flesh in a small quantity of water, keeping the temperature below that at which albumin coagulates, and adding vinegar and salt to facilitate the formation of syntonin and the solution of myosin. The salt can be then removed by dialysis.

Eggs.—Eggs consist of two edible parts, one, the white

composed of albumin, and the other, the yolk, chiefly made up of fat.

The white is concentrated watery solution of albumin, held together by delicate membranous meshworks. Besides the albumin it contains traces of fat, sugar, extractives, and salts.

The yellow fat emulsion of the yolk contains a peculiar proteid, vitellin, some grape-sugar, and some inorganic salts, in which combinations of phosphoric acid and potassium are conspicuous. Raw eggs are easy of digestion, as is all albumin in solution. Hard boiled eggs, if not finely divided by mastication, are very difficult to digest, for the gastric juice cannot penetrate the hard masses of coagulated albumin which are so easily and commonly swallowed. Eggs, when lightly cooked, are more easily digested, as the albumin is only partially coagulated, and cannot be introduced in large solid masses into the stomach. Eggs are of very great nutritive value, as they contain so large a per-centage of proteid, fat, and salts.

Vegetable Food.—Vegetables differ from animal food :—

(1.) In containing a much greater proportion of material which for man is indigestible (cellulose), and a less proportion of nutritive material.

(2.) The per-centage of proteid is below that of animal food, and the proportion of carbohydrates is generally much greater, while the amount of fat is small, but varies considerably. In order, therefore, to get the required amount of nutritive material from a purely vegetable diet, it is necessary to consume a much greater quantity, and the amount of excrement indicating the indigestible matters is proportionately increased.

Cereals.—The most valuable forms of vegetable foods are those obtained from the seeds of certain kindred plants (*Graminaceæ*)—wheat, rye, maize, oats, rice, &c. ; which when ground are used either as "whole meal," or, the integument "bran" being removed, as "flour." They contain different kinds of proteid. (1.) A native albumin soluble in water and coagulable by heat, and in many respects like animal albumin ; but as it cannot be obtained pure it is imperfectly known. (2.) Vegetable fibrin, an elastic body, which coagulates spontaneously and is difficult to separate. (3.) Vegetable glue or gliadin, which gives the peculiar adhesiveness to the *gluten*, as the proteid mixture obtainable from corn is commonly called. Cereals also contain traces of fat, and a very large proportion of starch and some salts.

The following table gives the per-centages of the chief different nutritive stuffs in some common cereals :—

	Wheat.	Barley.	Oats.	Maize.	Rice.
Water	13	14·48	10·88	12	9·20
Proteid	13·53	12·26	9·04	7·91	5·06
Fats	1·58	2·63	4·	4·83	·75
Carbohydrates . .	69·61	67·96	73·49	73·19	84·47
Salts	2·	2·65	2·59	1·28	·5

Green Vegetables. — These contain some starch, sugar, dextrine, salts, and minute quantities of proteid, and are of small nutritive value.

Potatoes contain very little proteid, but a considerable quantity of starch, upon which their nutritive value almost entirely depends.

The following table gives the relative proportions of the various *nutritive materials* contained in some of the common vegetable foods :—

	Peas.	Beans.	Potatoes.	Cauliflower.
Water	14·50	12·85	72·74	79·18
Proteid	22·35	22·	1·32	·50
Carbohydrates . .	56·61	56·65	23·77	18·
Extractive . . .	1·18	3·32	·97	
Fats	1·96	1·59	·15	
Salts	2·37	2·53	1·05	·7

The most striking points are the very large proportion of proteid in the leguminous fruits, and the comparative richness of all vegetables in starchy food-stuffs.

Water is the great medium by which the food is dissolved, and made capable of ingestion. Spring-water always has a certain quantity of lime and other salts in solution, and in proportion to the amount of salts is said to be "soft" or "hard." Water is tasteless, inodorous, and colourless when pure. Soft water, such as rain-water, is pure, but not so agreeable to taste as spring-water, and is very liable to contamination in passing through gutters, &c., previous to collection. Standing water should be avoided for drinking, owing to the probability of its containing organic matter.

Since water is known to be a common means of communicat-

ing disease, care must be taken as to the source of drinking water, and we should be able to form an opinion as to impurity when its source is not known. It is, perhaps, impossible to detect in it the specific impurity which causes any disease, but there are some characters supposed to be commonly associated with its pathogenic properties which can be easily recognised, and should be familiar to a student of Physiology. The want of brilliant limpidity must be regarded with suspicion. Any kind of smell, disagreeable or not, indicates impurity. The reduction (loss of colour) of permanganate of potash, when added in small quantity to acidified water, indicates the probable presence of organic matter. A high percentage of chlorides is often associated with sewage contamination.

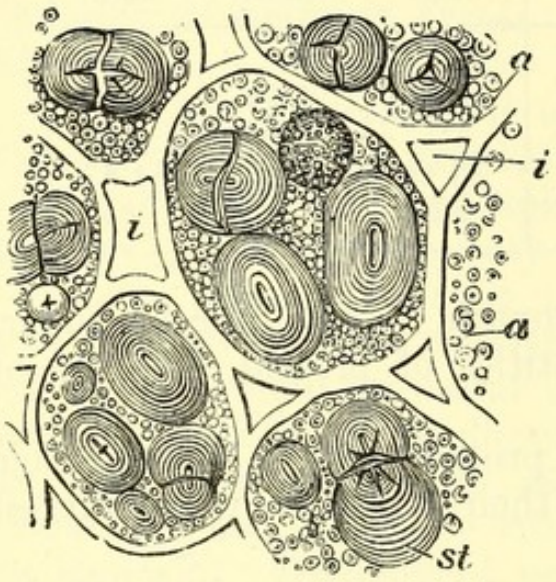


Fig. 49.—Section of Pea, showing starch and aleurone granules imbedded in the protoplasm of the cells. (After Sachs.)

a.—Aleurone granules.
st.—Starch granules.
i.—Intercellular spaces.

Salts.—Great varieties of salts are taken into the system, of which chloride of sodium forms the largest proportion. These have no doubt very important functions to perform, in entering into combination with the various tissues, and also probably in aiding the chemical changes of parts of which they do not form a normal constituent. They help to render certain substances soluble, and stimulate the cells of certain glands to more active secretion, *e.g.*, the kidney excretes more urea when there is an abundant supply of common salt in the food.

The selection of adequate dietaries will be discussed in the Chapter on Nutrition.

CHAPTER VI.

DIGESTION.

THE acts of digestion may be divided into *mechanical* and *chemical* processes. Under the *mechanical* processes come the arrangements for the subdivision, onward movement, and general mixture of the food. The chief objects of the *chemical* changes may be said to be the change from the insoluble to the soluble form of certain kinds of food-stuffs (starch and proteids) and the finer subdivision of others, such as fats, which do not dissolve in the intestinal secretions or in the juices of the body.

MECHANISM.

For further details concerning the muscle tissue the student must turn to the Chapter (p. 408) on that subject. Here, however, it may not be out of place to describe briefly the special character of the muscles found in the wall of the digestive tube and their general arrangement.

Attention has already been called to the fact that there are different kinds of contracting textures, and that they are capable of different kinds of motion, some slow and steady, some rhythmical, some sharp, short and sudden. It must also be remembered that the more energetic and sudden the motions are, the more marked becomes the differentiation of the tissue. Thus the active, quick-contracting skeletal muscles and the rhythmically acting heart, are made up of tissue which is very distinct in structure and in mode of action from that of the contracting cells composed of ordinary protoplasm, while in the slowly moving internal organs we meet tissue elements which in different animals show many stages of gradation between simple, indifferentiated protoplasm and the special striated muscle tissue.

It is necessary that in the first stages of alimentation the motions should be quick and energetic ; so the mouth, pharynx, and upper part of the œsophagus are supplied with

striated muscle tissue, which differs in function and structure from that of the rest of the alimentary canal. In the stomach and intestines slower and more gradual kinds of motion are

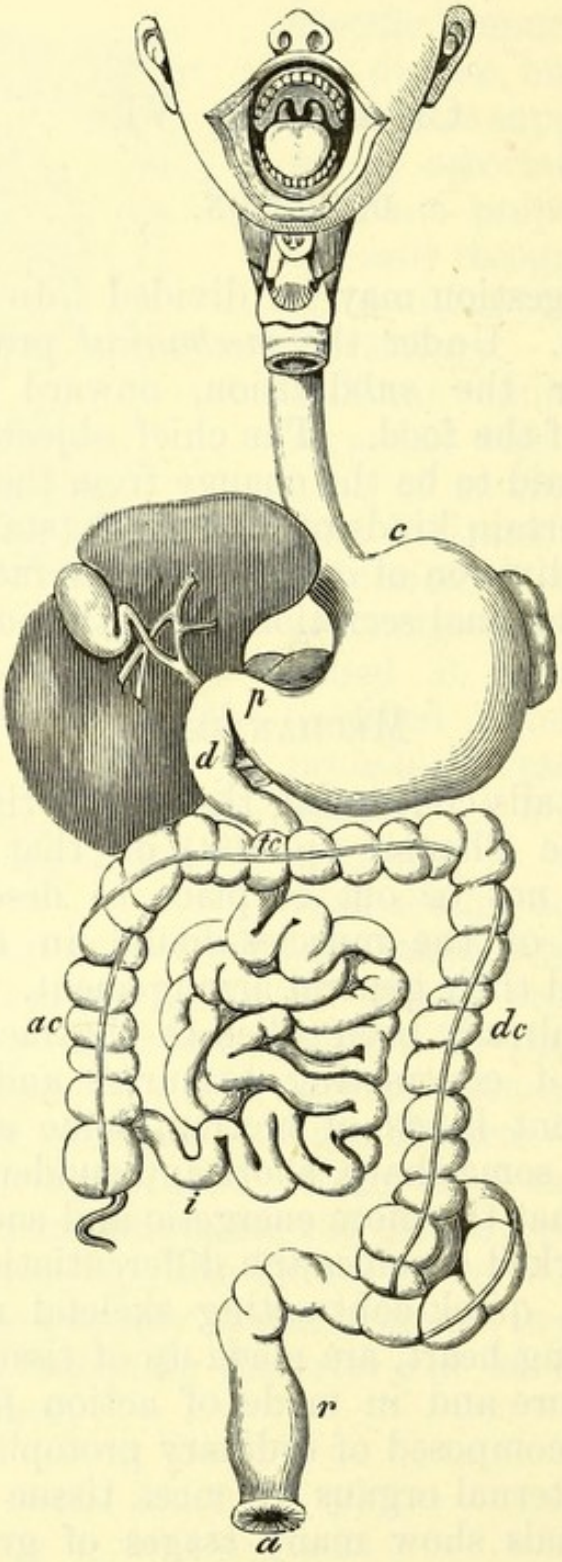


Fig. 50.—Diagram of Alimentary Tract, &c. Angles of mouth slit to show the back of the buccal cavity and the top of the pharynx. (*c*) Cardiac; (*p*) Pyloric parts of stomach; (*d*) Duodenum; (*i*) Jejunum and Ileum; (*ac*) Ascending, (*tc*) transverse, and (*dc*) descending colon; (*r*) Rectum; (*a*) Anus.

required, and here we find a good example of non-striated muscle tissue.

Around the extremity of the rectum is a band of smooth muscle, which remains in a condition of continuous or *tonic* contraction.

MASTICATION.—In man, the introduction of food into the mouth is generally accomplished by artificial means, so that the biting teeth (incisors) and the tearing teeth (canines) are comparatively little used for obtaining a suitable morsel of

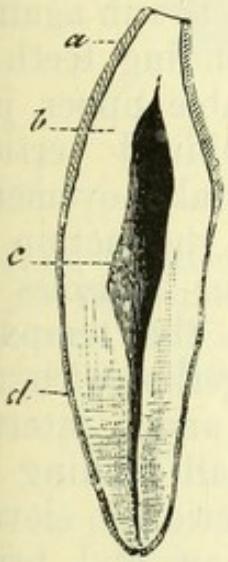


Fig. 51.—Vertical section of the Canine Tooth of a man. (*a*) Enamel; (*b*) Dentine; (*c*) Pulp cavity; (*d*) Crusta petrosa. (Cadiat.)

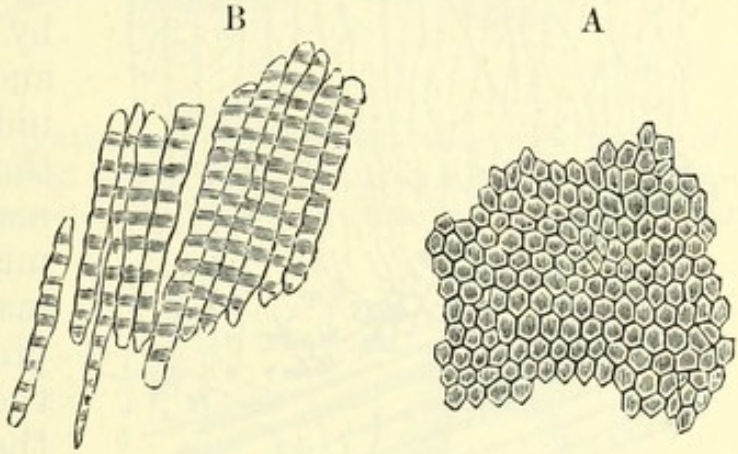


Fig. 52.—Structural elements of the Enamel of Tooth.
A. Prisms cut across showing the hexagonal section.
B. Isolated prisms. (Kölliker.)

food. In the mouth the essential act of chewing or mastication is accomplished by means of the motions of the lower jaw, the tongue, and the cheeks. This process of breaking up the solid parts of the food ought to be continued until all hard substances are ground into a soft pulp.

Structure of the Teeth.—The exposed part of the teeth is covered by a dense substance of flinty hardness called *enamel*, which is developed from the epithelium, and consists of hexagonal prisms set on end, which are really modified epithelial cells only containing about 2 per cent. of animal matter (Fig. 52). The bulk of the tooth is made up of *dentine*, a substance like bone in composition, pierced by numerous fine canals, *dentine tubules*, which radiate towards the surface, from the

pulp cavity, in the centre of the tooth. Filaments of protoplasm run in the dentine tubules from the tooth cells, which line the pulp cavity and provide for the nutrition of the tooth (Figs. 53, 54). The pulp cavity contains vessels, nerves, &c. which enter at the root of the tooth which is enclosed in a kind of modified bone tissue called *crusta petrosa*.

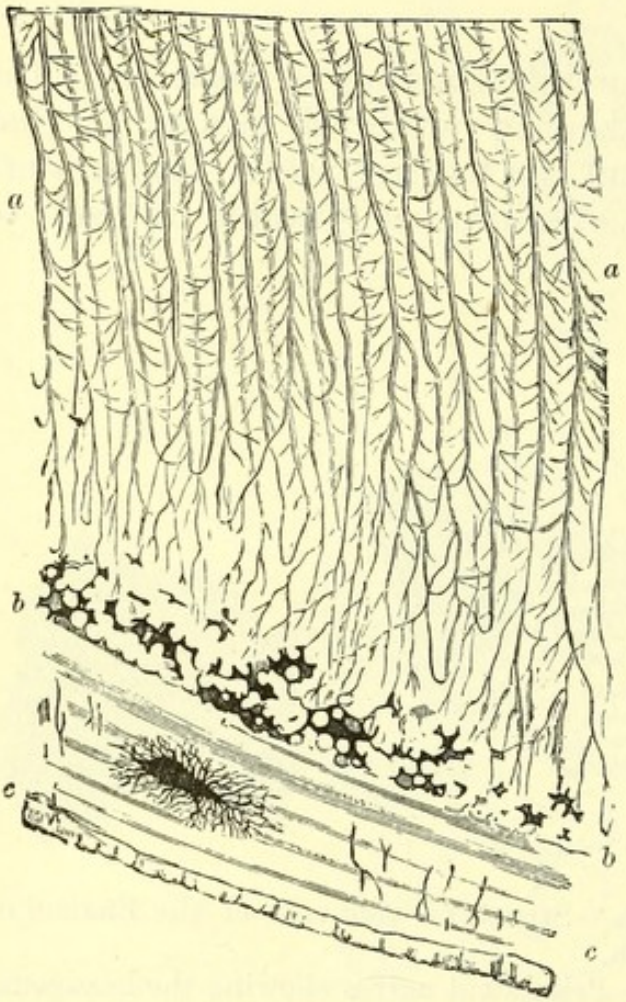


Fig. 53.—Section through a portion of the fang of a tooth. (*a*) Dentine tubules near the surface of the fang; (*b*) Granular layer; (*c*) Crusta petrosa.

The two rows of grinding teeth, composed of molars and premolars, of the lower jaw are made to rub against the corresponding teeth in the immoveable upper jaw by the combined vertical and horizontal movements induced by the action of the powerful muscles of mastication, the temporal muscles, together with the masseters and internal pterygoids, all tending by their contraction to elevate the lower jaw and bring the teeth forcibly together. This action is opposed by the digastric, the genio- and mylo-hyoid muscles, which by their combined force depress the jaw and separate the teeth. The horizontal movements are in the main accomplished by the external pterygoid muscles, which, acting together, pull the lower jaw forward so as to make the lower teeth protrude beyond the upper. In this action they are opposed by the digastric and hyoid muscles. One external pterygoid on either side acting alone, advances that side of the lower jaw only, and thereby causes the lower teeth to incline towards the opposite side in a lateral direction. The two muscles acting alternately cause a horizontal motion from side to side. Thus, while the lower teeth are pressed firmly against the upper ones they are at the same time made to glide over them, either from side to side or backwards and forwards. By these movements the bruised

food is soon pushed from between the teeth, and passes towards either the tongue or cheek. The morsel is soon replaced

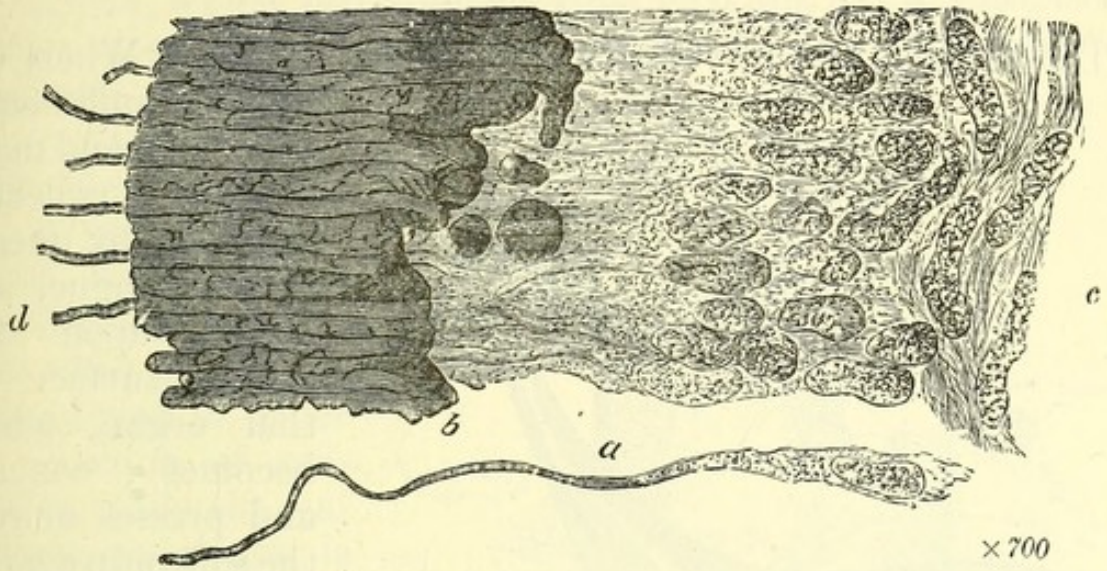


Fig. 54.—Section through a portion of dentine next the pulp cavity of a growing tooth. (*a*) An isolated odontoblast; (*b*) Growing part; (*c*) Odontoblasts; (*d*) Filaments of protoplasm projecting from the tubules of hard dentine. (Beale.)

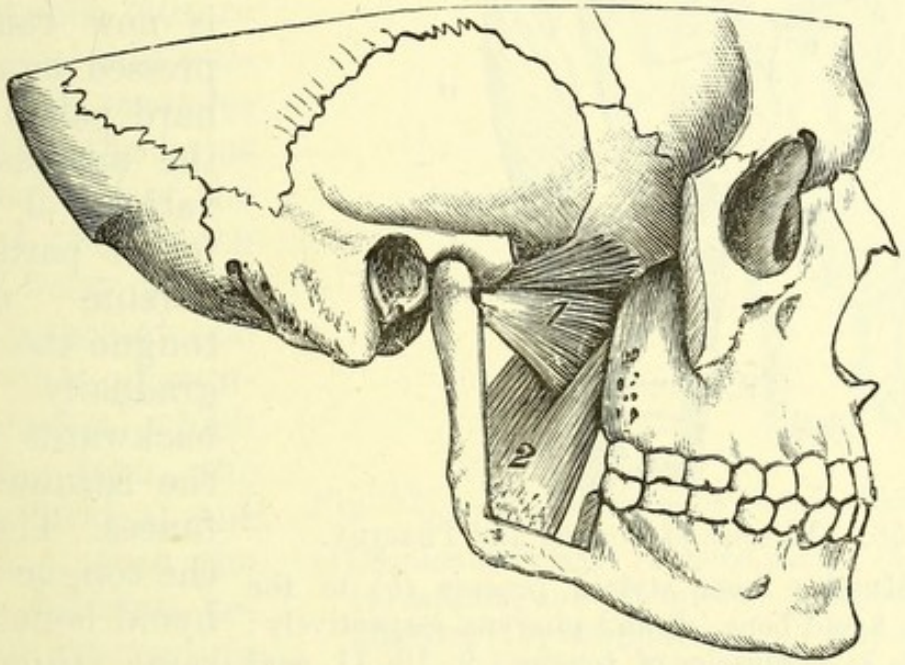


Fig. 55.—The Pterygoid Muscles seen from without after removal of the superficial parts, the temporal muscle, the zygomatic arch, and a portion of the lower jaw and masseter. (1) External, (2) Internal pterygoid muscle.

between the teeth by the action of the tongue on the one hand and the buccinator muscle in the cheek on the other, which act as the feeders of the mill.

While the process of mastication is going on, the food becomes thoroughly moistened with the fluid secreted within the mouth.

DEGLUTITION.—The next step is swallowing. When the food is sufficiently triturated and moistened it is collected together by means of the tongue, and placed upon the upper surface of that organ, which becomes concave and presses or rolls the soft pulp against the hard palate so as to shape it into an oblong mass or bolus. The apex of the tongue (Fig. 56) is now raised and pressed against the hard palate, and by the successive elevations of the different parts of the dorsum of the tongue the bolus is gradually pushed backwards towards the isthmus of the fauces. The root of the tongue with the hyoid bone is at the same time drawn upwards and forwards, so that the bolus easily slips down along the retreating slope leading from the mouth cavity, and gets within the reach of the constrictors of the fauces. Immediately before the morsel of food is grasped by the muscles of the fauces the levator palati draws the soft palate upwards and backwards to completely close the

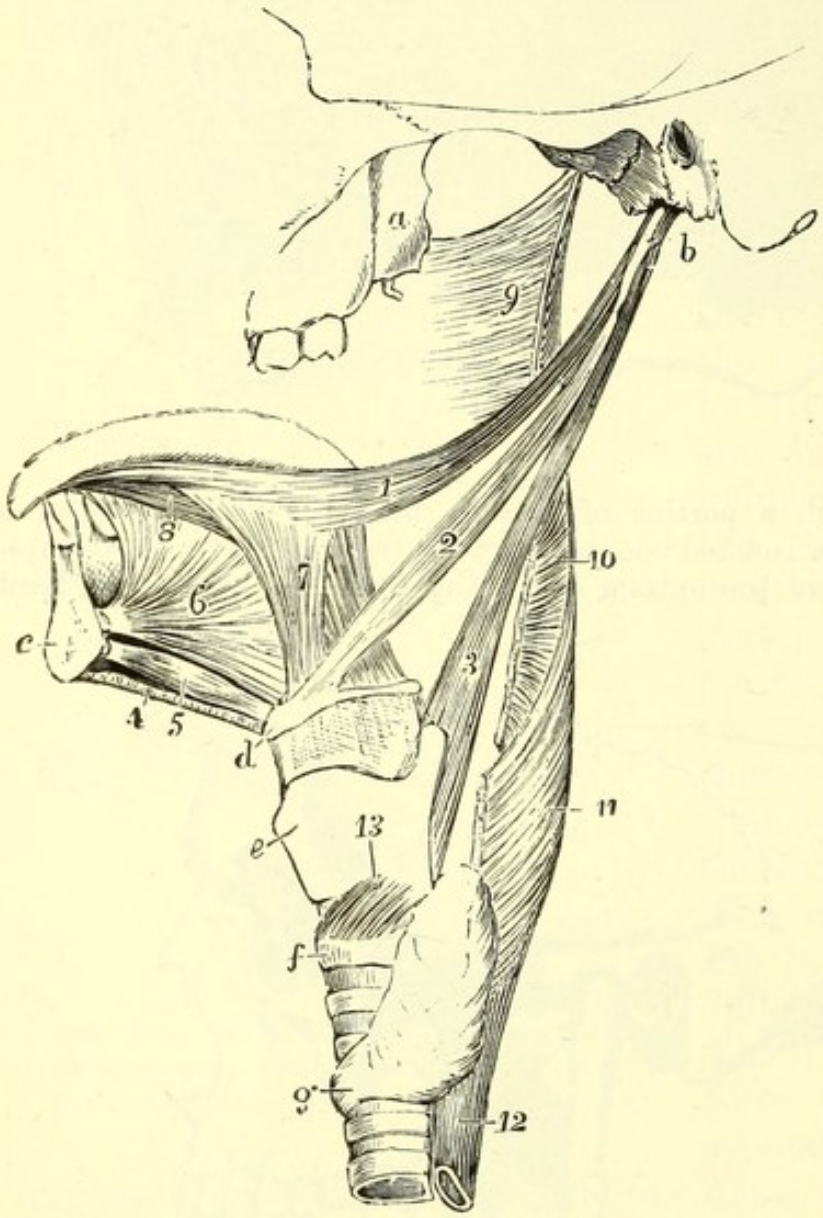


Fig. 56.—Muscles of Tongue and Pharynx.

1, 2, 3, Muscles from styloid process (*b*) to the tongue, hyoid bone (*d*) and pharynx respectively; 4, 5, 6, 7, 8, muscles of tongue; 9, 10, 11, constrictors of pharynx; 12, œsophagus; 13, is placed on larynx (*e*). (Allen Thomson.)

posterior openings of the nasal cavity, as is shown by the fact that during the act of swallowing the pressure in the nasal cavity is raised. At the same moment the intrinsic muscles of the larynx, which surround the rima glottidis like a constrictor, firmly close that opening by approximating the cords and arytenoid cartilages. The entire larynx is at the same time drawn up behind the hyoid bone by the thyro-hyoid muscle. The rima glottidis is thus tucked in under the cushion of epiglottis, while the leaf of the epiglottis is pulled down over the larynx by the oblique aryteno-epiglottidean and thyro-epiglottidean muscles.

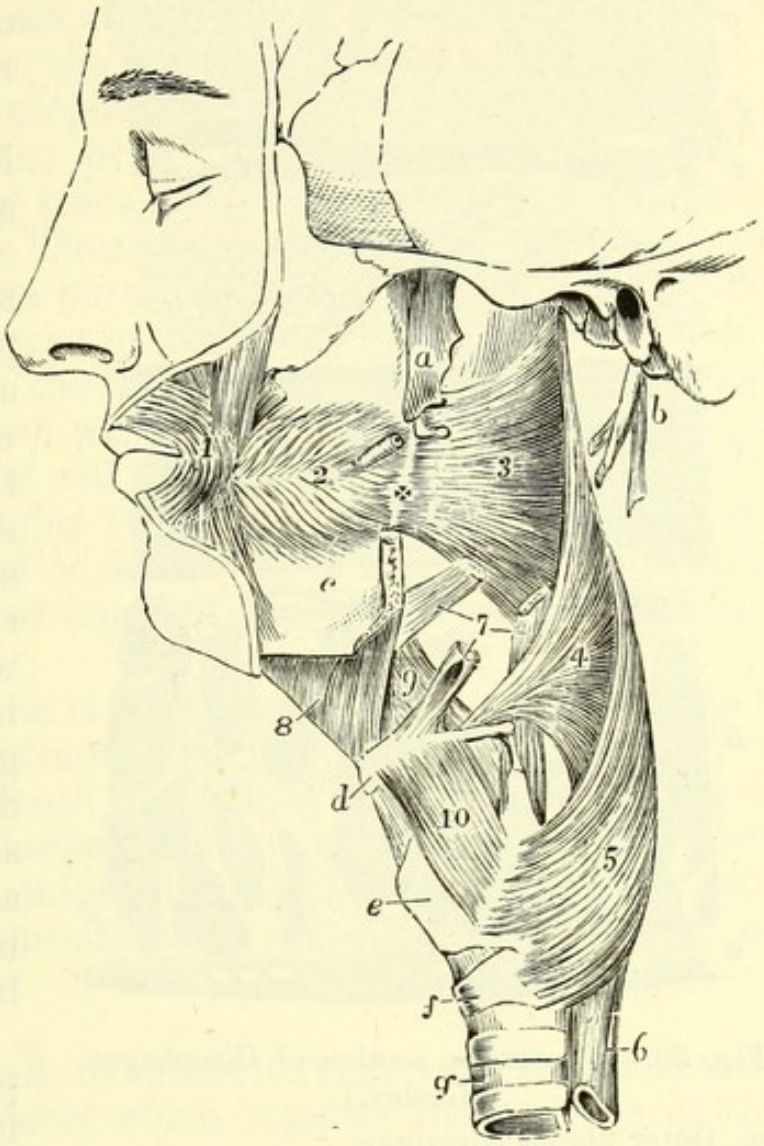


Fig. 57.—Deep Muscles of Cheek, Pharynx, &c.

(1) Orbicularis oris ; (2) buccinator ; (3) superior, (4) middle, and (5) inferior constrictors of the pharynx ; 6, œsophagus ; (7) styloid muscles cut across ; (8, 9, 10) muscles attached to the hyoid bone (*d*) and thyroid cartilage (*e*). (Allen Thomson.)

While the closure of the nasal and pulmonary air passages is going on, the bolus has passed out of the cavity of the mouth and has been caught by the palato-glossal and palato-pharyngeal muscles which force it into the pharynx, and at the same time close the isthmus faucium behind the descending morsel. The stylo-pharyngeus and the pharyngeal constrictors now grasp the bolus spasmodically, and the latter contract in rapid succession, moving the bolus onwards, and drawing themselves over it, pass it on to the œsophagus, where, by a progressing ring-like contraction of the circular muscles

and a simultaneous shortening of the longitudinal layer of fibres the mass is slowly squeezed down to the cardiac orifice of the stomach. The movements of the œsophagus are essentially peristaltic in character, the peculiarities of which form of motion will be discussed when speaking of the intestinal movements.

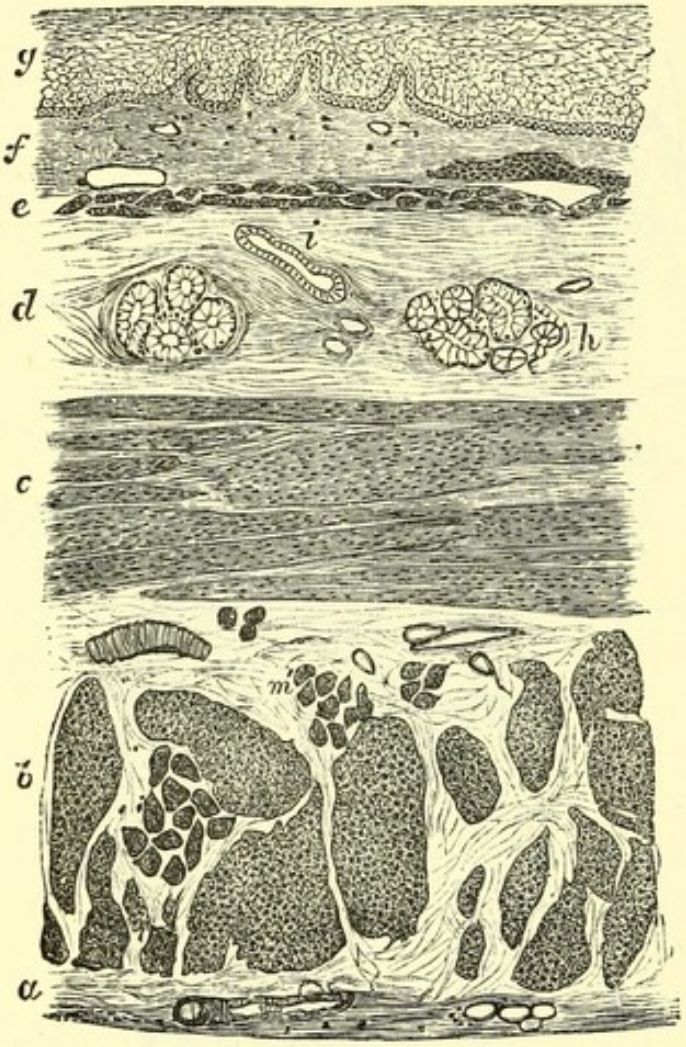


Fig. 58.—Transverse section of Œsophagus. (Horsley.)

a. Outer fibrous covering.
b. Bundles of longitudinal muscle cut across.
c. Transverse muscular coat cut obliquely.
d. Sub-mucous coat with glands in section.
e. Muscular layer of the mucous membrane.
f. Mucous membrane with cut vessels.
g. Stratified epithelium.

The process of swallowing is performed by a continuous series of co-ordinated muscular movements, quite independent of gravitation, as may be seen in animals which drink with their heads downwards. Although these complex sets of movements follow each other regularly and without any check or interval, the act of deglutition is commonly divided into three stages, between which, as there is no pause, it is not easy to draw a hard and fast line.

The *first stage* is simply the initiatory step of placing the morsel of food, or some liquid in such a position as to excite the second or spasmodic act of deglutition. This first step is a voluntary act, and it is the only part of the movements of swallowing over which we can exert complete control. The progress of the morsel between the tongue and palate towards the fauces may be as slow and gradual as we wish, but the moment a certain point is reached volition is at an end, and we are unable to check the completion of the act.

By the *second stage* is meant the period occupied by the passage of the food bolus through the pharynx and past the top of the larynx. Although we are not able to influence it in any way by our will, we are conscious of the food passing in this region. It is a rapid involuntary spasm in which a great number of striated muscles take part.

The *third stage* includes all the rest of the time during which the bolus is passing from the grasp of the lower pharyngeal constrictor and along the œsophagus. Not only has our will no influence over this stage of deglutition, but we are hardly conscious of its taking place, since no sensations accompany the greater part of it. Thus the more essential movements of the act of swallowing are purely reflex and involuntary, though we can call forth this series of reflexions by voluntary stimulation of a certain part of the fauces by means of a morsel of food or a drop of liquid. And without such a stimulus as food or liquid we cannot by our will excite swallowing. We think we can perform the muscular movements of swallowing when we please, without any food or fluid, but in this we are mistaken, as careful observation of our own performance of the act will show.

The pharyngeal spasm is always preceded by the deposition in the region of the isthmus faucium of some drop of saliva collected from the mouth or fauces themselves. In fact, without a slight preliminary movement of the posterior part of the tongue—which might be called the last act of mastication—the more essential stages of deglutition cannot be excited.

Nervous Mechanism of Mastication and Deglutition. —The voluntary influences which regulate the motions of the muscles of mastication pass along the efferent branches of the fifth nerves (trigemini) which accompany its inferior division. The muscles which depress the jaw to open the teeth and the intrinsic muscles of the tongue are supplied by the ninth pair of nerves (except the posterior belly of the digastric, which has a branch from the facial, and the mylohyoid and anterior belly of the digastric, which are supplied from the third division of the fifth). The co-ordination of the movements of mastication and suction seem to reside in the medulla oblongata, but are obviously under the control of the will.

The afferent impulses which excite the nerve centres in the medulla, and give rise to reflex acts which cause the swallowing

movements, pass from the mucous membrane of the fauces along (1) the descending palatine branches of the spheno-palatine ganglion and the second division of the trigeminus, also along (2) the pharyngeal branches of the superior laryngeal branch of the vagus to the medulla, where the co-ordination of pharyngeal spasm and œsophageal peristalsis is accomplished. Thence the efferent impulses pass by (1) the hypoglossal to the hyoid and glossal muscles, (2) the glosso-pharyngeal and vagus to the pharyngeal plexus to supply the constrictors, and (3) the facial and fifth to supply the fauces and palate, as indicated by their anatomical distribution.

The act of deglutition can be readily excited in an animal which is deprived of all the nerve centres down to the medulla oblongata, and may also be seen in those human monstrosities (an-encephalous fœtus) born without the upper part of the brain being developed, but which can notwithstanding both suck and swallow.

The movements of the œsophagus are reflections from the central nervous system (medulla), both sets of impulses (possibly the afferent and certainly the efferent) passing along the branches of the vagus.

It would appear that the normal peristaltic movements of the œsophagus are always initiated by a pharyngeal spasm, and that they form an inseparable sequel to it. Thus the wave of contraction passes along the entire length of the œsophagus, even when the bolus is stopped mechanically, and on the other hand a body introduced into the œsophagus without passing through the pharynx excites no peristaltic wave and remains motionless.

But it has been observed, in apparent contradiction to the foregoing statement, that the œsophagus when removed from the body, and therefore quite independent of the pharynx and its nervous connections, can be excited to move peristaltically. In this case the medulla or vagus can have no part in bringing about this wave of movement. To explain this discrepancy it may be urged that the local nerve and muscle mechanism in the tissues of the œsophagus are capable by themselves of carrying out peristaltic contraction independently of the central nerve organs, but that this power is, under ordinary circumstances, held in check by the vagus. The inhibition is temporarily suspended as a sequence of pharyngeal spasm, and consequently a wave of peristaltic contraction is excited in the œsophageal muscles, either in response to the direct stimulus of a passing

bolus, or as a result of impulses reflected along the vagus channels from the medulla.

MOVEMENTS OF THE STOMACH.—The stomach and greater part of the intestinal tract move freely within the abdomen, being covered by the smooth serous lining of that cavity, which also keeps in position, so as to restrict their movements, those parts, such as the duodenum, into which the ducts of large glands open. When the stomach is empty it hangs with the great curvature downwards, and the muscular coats are quiescent. On being filled it is passively rotated on its long axis, so that the greater curvature is turned forwards, here meeting with less resistance, and the lesser curvature is turned backwards to its line of attachment. In the main, the motions of the stomach are peristaltic. They become very active about fifteen minutes after the introduction of food, and gradually become more and more energetic until the end of stomach digestion, which lasts about five hours.

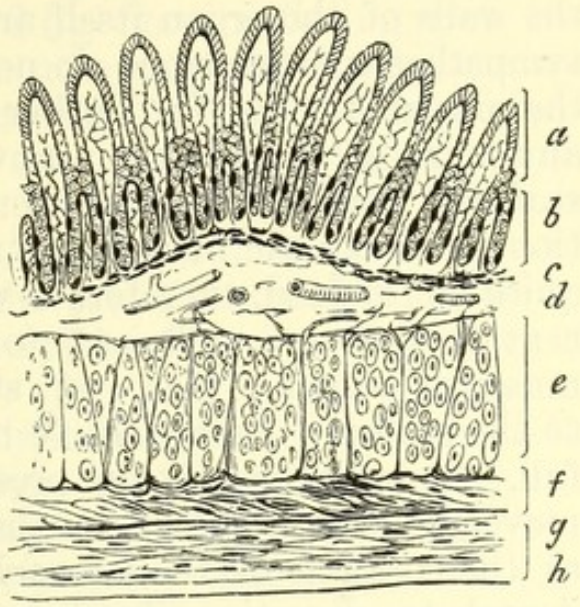


Fig. 59.—Diagram of Wall of the Stomach showing the relative thickness of the mucous membrane (*a*, *b*, *c*), and the transverse (*e*), oblique (*f*), and longitudinal muscle fibres.

The result of the peristaltic motion is to move the food, particularly the part next the gastric wall, along the great curvature towards the pylorus. A back current towards the cardiac extremity has been noticed running along the lesser curvature, and the median axis of the food mass. At the same time a peculiar rotatory motion of the gastric wall takes place, similar to that of rolling a ball between the palms of the hands, so that the food is twisted in a given direction, and the deeper lying portion is brought into contact with the mucous membrane.

While the fundus keeps up considerable pressure on the contents of the stomach, the indistinct peristaltic action of the central parts is intensified on nearing the pylorus into a strong circular contraction, which proceeds as a definite wave towards the pyloric valve, through which it gradually forces the more or

less digested food. At first only the fluid parts are allowed to pass, but towards the later stages of digestion the fatigued pyloric muscle admits solid masses into the duodenum.

NERVE INFLUENCE ON STOMACH MOVEMENTS.—The stomach has nerve connections with the cerebro-spinal axis through the vagi, and the splanchnic branches of the sympathetic, and in the walls of the organ itself are numerous ganglion cells. The sympathetic connections do not seem to have any influence on the muscular coats, for neither their stimulation nor section has any marked effect on their movements. If the vagi be severed, stomach contractions still occur, but no form of local stimulation produces the normal gastric motions, even if the organ be quite full of food, therefore it would appear that the local nerve centres are not sufficient to excite the normal rhythmical muscular action. Moreover, stimulation of the cut vagi leading to the stomach causes active movements when the stomach is full. It is not merely the presence of food that produces the movements, as is shown by the fact that the motions increase as the contents of the stomach diminish, but conditions incidental to digestion (hyperæmia, &c.) probably also act as a stimulus.

VOMITING is the ejection of the contents of the stomach by means of a convulsive action of the respiratory and abdominal muscles associated with an abnormal contraction of the stomach wall, which aids in opening the cardiac orifice while it keeps the pylorus firmly closed.

The act of vomiting is commonly preceded by (1) a feeling of sickness or nausea, (2) a great secretion of saliva, (3) retching. The latter consists in a violent inspiratory effort in the midst of which the root of the tongue and the larynx are raised and the rima glottidis suddenly closed so as to prevent air entering the wind-pipe. The inspiratory muscles still acting, and the pharynx and upper part of the œsophagus being held open, air is drawn into the gullet and dilates this tube nearly as far as the opening into the stomach. A contraction of the muscle fibres radiating from the œsophagus over the stomach, then opens the cardiac orifice and allows some gas to escape. Now the act of vomiting is completed if at this moment—the mouth and pharynx being open, the larynx closed, the œsophagus on the stretch, the cardiac orifice relaxed, and the pylorus firmly closed—the expiratory muscles forcibly contract, and, pressing

upon the abdominal cavity, give a sudden stroke to its contents so as to empty the stomach. The wall of the stomach also contracts evenly throughout, but not with any forcible anti-peristaltic action such as would greatly aid in the operation of rapidly ejecting the vomit. The chief object attained in the adult by the action of the muscular coat of the stomach seems to be the relaxation of the cardiac orifice. In children, when the fundus is little developed, and the fibres radiating over the stomach from the œsophagus are numerous and strong, the act of vomiting requires less effort on the part of the respiratory muscles, the frequent puking of suckling infants being accomplished by the gastric muscle alone. When the vomit is emitted, the hyoidean, laryngeal, and neck muscles relax, and the air is forcibly driven out of the partially distended lungs so as to clear away any remaining particles from the upper part of the air passages.

Vomiting is usually caused by irritation of the stomach itself, and may be induced by either mechanical, electrical, or chemical stimulation of the mucous membrane. In this way some emetics, such as mustard, sulphate of copper, &c., act. It may also be caused by intestinal irritation, as when a hernia is strangulated, or the mucous membrane irritated by intestinal worms.

Gentle stimulation of the fauces and neighbourhood of the root of the tongue commonly induces vomiting. In the early stages of pregnancy the unusual condition of the uterus causes frequent vomiting, which is known as "morning sickness." The irritation of a calculus passing through the ureter, or a gall-stone impacted in the bile duct, usually excite vomiting. Injuries of the brain, and physical impressions, particularly those excited by the sense of smell or unusual disturbance of equilibrium, may give rise to vomiting. Moreover, a number of medicaments, as apomorphine, emetine, &c., if introduced into the blood, act on the centre and cause vomiting.

From the foregoing facts it appears that vomiting is a complex and irregular muscular act, which may be induced by the stimulation of various parts of the internal surfaces of the body, particularly those which receive branches from the vagus nerve.

One would therefore be inclined to suppose that some afferent nerve channels exist in the vagus which bear impulses to a vomiting nerve centre and excite it, so as to cause it to send forth peculiar and irregular impulses to the respiratory,

gastric, and other muscles, and give rise to their characteristic spasm.

In short, it would seem to be a reflex act, the afferent impulses of which pass to the medulla oblongata by the vagus, and the efferent impulses are conveyed by the ordinary spinal nerves to the respiratory muscles, by the vagus to the pharyngeal, laryngeal and gastric muscles, and by the fifth, seventh, and ninth nerves to the palatine, facial, and hyoidean muscles. This vomiting nerve centre must lie in the medulla, in very close relationship to the respiratory centre, with which it is associated. This centre may bring about the whole sequence of events known as vomiting when stimulated either directly by poisons, contained in the blood, indirectly through the vagus, or even from the higher centres by emotions or ideas. Section of the vagi renders vomiting impossible, as it cuts off both the commonest source of stimulus going to the centre, and also the important efferent impulses which cause the muscle coat of the stomach to contract and to open the cardiac orifice.

In some animals vomiting is not possible, while with others this act may be considered under voluntary control, like chewing the cud in ruminants.

Movements of the Intestines.—The muscular coats are somewhat differently arranged in the small and the large intestines, but have the same general relation to each other, viz., a thin longitudinal layer lying externally, next the serous membrane, and a layer of circular fibres considerably thicker lying internally under the mucous membrane. In the large intestine the external longitudinal fibres are collected into three bands placed at equal distances one from another, which, being rather shorter than the remainder of the intestine, throw the intermediate part into a series of pouches.

It is in the small intestine that peristaltic motion of the most typical kind occurs. A wave of contraction passes from the pylorus along the circular fibres, so as to look like a broad ring of constriction progressing slowly downwards.

The longitudinal fibres at the same time contract so as to shorten the piece of intestine immediately below the ring of constriction, and also cause a certain amount of rolling movement of those loops of intestine which are free enough to move.

This motion takes place periodically in proportion to the amount and character of the contents of the intestine, the

food passing over the mucous membrane being to all appearance the stimulus which normally calls forth and intensifies the action.

The activity of the peristaltic movements varies with many circumstances besides the contents of the intestines. Of these the most noticeable is the amount and character of the blood flowing through the vessels of the intestinal wall. Thus stoppage of the blood current by tying the arteries, or deficiency of oxygen and excess of carbonic acid, causes inordinate activity of the peristaltic action. Direct irritation of the serous surface of the intestine, with mechanical, chemical, or electrical stimuli also causes an increase in the movements of the intestine.

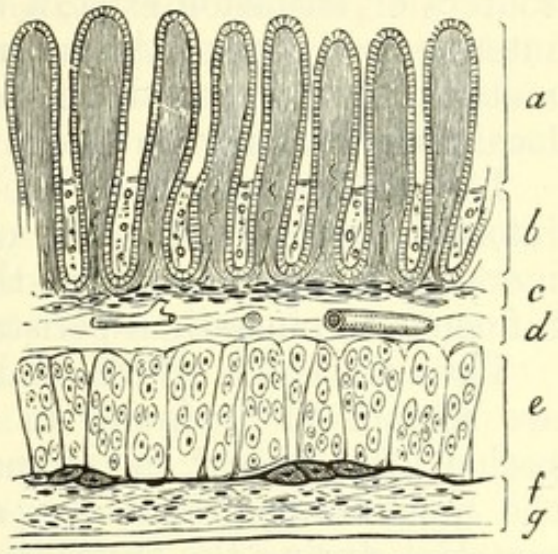


Fig. 60.—Diagram of a longitudinal section of the wall of the small intestine.

a. Villi.
b. Lieberkühn's Glands.
c. Tunica muscularis mucosæ, below which lies Meissner's nerve plexus.
d. Connective tissue in which many blood and lymph-vessels lie.
e. Circular muscle fibres cut across with Auerbach's nerve plexus below it.
f. Longitudinal muscle fibres.
g. Serous coat.

The great activity of the motion observed when the abdominal cavity of a recently killed animal is opened depends partly on the exposure to cool air, and partly on the venous character of the blood in the vessels no longer oxidised by respiration.

The irregular and impetuous action of the intestine which follows the constriction or strangulation of a hernial protrusion, probably depends chiefly on the mechanical stimulation, but also is intimately related to interference with the blood supply consequent on the pressure exerted by the constricting band. Prolonged over-work often induces immobility of the intestinal wall, and hence we find the purging and vomiting, which accompany a temporary hernial constriction, followed by inability of the intestine to propel its contents. These points have also been proved by results of experiments on the lower animals.

The movement of the large intestines is the same in char-

acter as that of the small, but not so obvious, owing to the modified sacculated shape of this part of the alimentary canal. The contractions of the colon begin at the ileo-cæcal valve where the peristaltic wave of the ileum ceases. The normal intestinal motions thus pass in an almost uninterrupted wave from the pylorus to the end of the gut, but when special sources of irritation exist, a wave may originate in almost any intermediate part of the intestine. A reversed "anti-peristaltic motion," as it is called, only occurs as a result of some intense local stimulation, such as the strangulation of a hernia, &c.

The motion produced by the substances contained in the intestine depends on their character. The solid parts excite more rapid movements, and the more fluid portions but slightly influence the intestinal peristalsis.

Thus the solids which make their way through the pylorus are seldom to be found in the jejunum, no matter at what period after a meal the animal be killed, whereas the folds of the mucous membrane are always bathed in a fluid creamy material during the entire period of digestion, aud even for a considerable time after all the food has left the stomach.

Mechanism of Defæcation.—This is a point of much importance, for the evacuation of the lower bowel is intimately connected with feelings of comfort and health, and, in illness, the insuring of its accomplishment forms an essential part of the physician's duty.

The movements of the intestine cause the various excretions and indigestible parts of the food to pass towards the sigmoid flexure of the colon, where their onward motion is checked for a time by the strong circular muscle of the rectum (called the superior, or *tertius sphincter* by Hyrtl), which does not carry on the peristaltic wave. The materials here get packed into a more or less solid mass, which is gradually augmented.

The lower outlet of the alimentary canal is closed by two distinct sphincter muscles. One thin external superficial muscle, made up of striated fibres, belongs to the perineal group, and has little influence on the closure of the anus. The deep or internal sphincter, which is much stronger, surrounds the gut for rather more than an inch (3 centimetres, Henle) in height, and is one quarter inch thick. It is made of smooth muscle, and therefore capable of prolonged (tonic) contraction. It would appear, however, that this strong sphincter is merely a supernumerary guard to the anal outlet, but rarely called into

active contraction, for during the interval of rest between the acts of defæcation, the fæces do not come in contact with the portion of intestine surrounded by this muscle. The rectum for quite one inch above the sphincter is perfectly empty, being kept free from fæculent particles partly by a fold of the intestinal wall, and partly by the repeated action of the voluntary muscles in the neighbourhood, which by intensifying the angle that exists at this point, and flattening this inch of rectum, can squeeze back the approaching matters. Anyone familiar with the digital examination of the unevacuated rectum, knows that no fæces are met with for about two inches.

Considerable accumulation may take place in the sigmoid flexure without much discomfort ensuing, but when the rectum is distended, an urgent sensation of wanting to empty it is experienced, and the voluntary movements mentioned above, are performed by the levator ani and the neighbouring perineal muscles, with the object of preventing any substance reaching the part of the rectum immediately above the sphincter.

If the rectum be distended with fluid, the occasional anal elevation does not suffice to keep it back, and a continuous and combined action of the sphincters and levator ani, &c. is necessary to ward off the expulsion of the contents.

When the lower bowel is habitually emptied at the same hour daily—a habit which should be carefully exercised—the sensations of requirement to go to stool occur with great punctuality, or can be readily induced by the will, so that normal defæcation, in the adult, is reputed to be, and practically is, a voluntary act. But not completely so, for, somewhat like swallowing, the later stages of defæcation consist essentially of a series of involuntary reflex events which we can initiate by the will, but when once started, are powerless to modify until the reflex sequence is completed.

Under ordinary circumstances, the evacuation of the fæces is commenced by the voluntary pressure exercised on the abdominal contents by the respiratory muscles. The diaphragm is depressed, the outlet of the air passages firmly closed, and the expiratory muscles thrown into action, while at the same moment the muscles which close the pelvic outlet relax, and allow the anus to descend, so that the inferior angle of the rectum is straightened, and a voluntary inhibition of the sphincter is brought about. This voluntary expiratory effort seldom requires to be continued for more than three or four seconds before some fæcal matter reaches the part of the rectum

just above the sphincter. When this has occurred, no further abdominal pressure is necessary (except when the masses of fæces are large and hard), for the local stimulus starts a series of reflex acts which carry on the operation. These consist of an increased peristaltic contraction of the colon and sigmoid flexure, the waves of which pass along the rectum. These waves are accompanied by synchronous rhythmical relaxation of the sphincter, which replaces its normal condition of tonic contraction.

The effect of the voluntary effort, and the amount of the

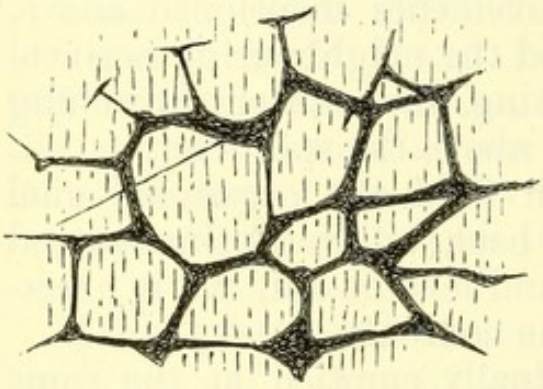


Fig. 61.—Auerbach's plexus from between the muscle coats of the intestine with low power.

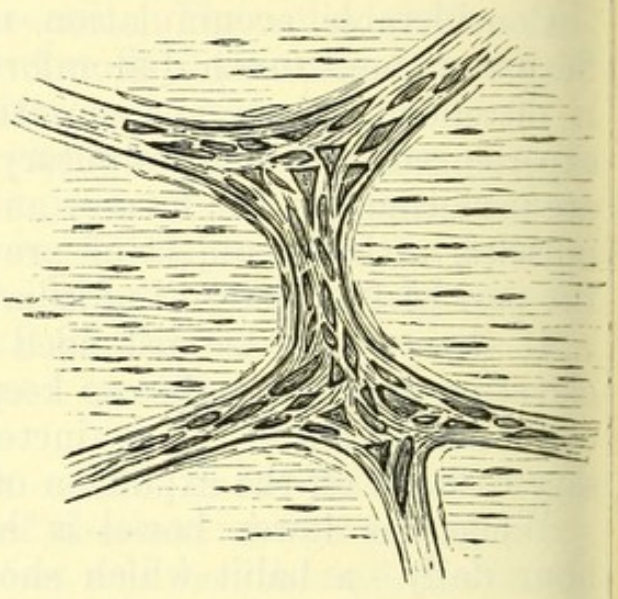


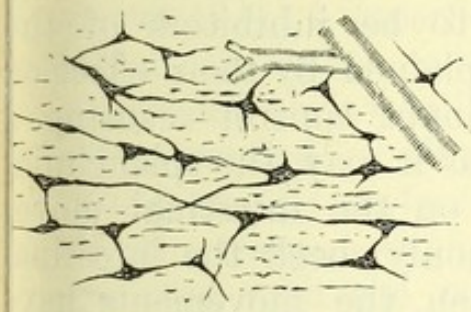
Fig. 62.—A nodal point of Auerbach's plexus under high power, showing the nerve cells.

abdominal pressure required, depend upon the consistence of the fæces. When quite fluid, they constantly tend to come in contact with the sensitive point of the rectum, and a voluntary effort is required to prevent the reflex series of events from taking place, a momentary relaxation of the sphincter with voluntary abdominal pressure is sufficient to eject the contents of the bowel. On the other hand, when the fæces are firm, time is required in order that the slowly-acting smooth muscle may pass the mass onward. In common constipation, the difficulty is to get the solid mass down to the sensitive exciting point, in which case a few drachms of warm fluid, used as an enema, may awaken the necessary reflex movements.

Nervous Mechanism of the Intestinal Motion.—Many points in the nervous control exerted over the intestinal

nuscles are obscure. We know that intestinal movements vhich are peristaltic in their nature occur in a portion of ntestine removed from the body, and thus separated from all :entral nervous control. We know also that there are abundant ierve elements in the walls of the intestines which have all the haracters of ganglion cells, and therefore probably are controlling agents.

With regard to these local nervous agencies, anatomists have nade out two distinct sets, both of which have the form of a ietwork of nerve fibrils studded with cell elements at their iodal points. One of these, a closely meshed plexus with



ig. 63.—Meissner's plexus, low power.

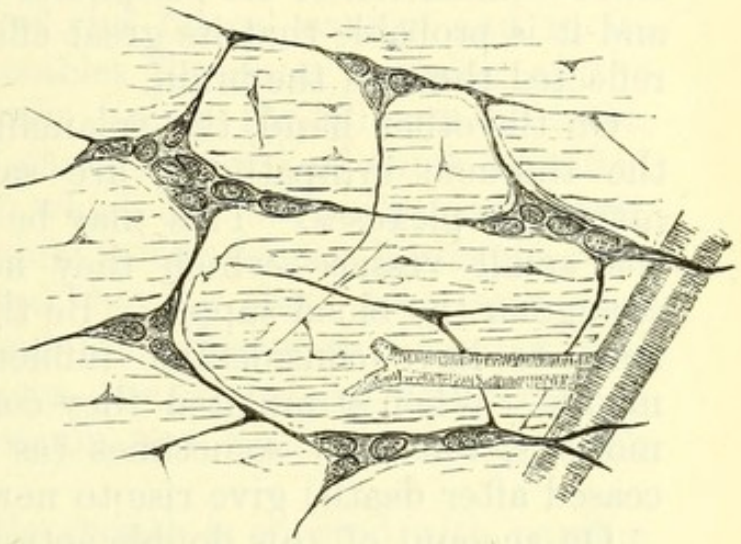


Fig. 64.—Meissner's plexus (high power), showing cells grouped at nodal points.

attened cords and ganglionic masses at their points of union, es between the longitudinal and circular layer of muscles Figs. 61, 62) forming the *plexus myentericus exterior* of uerbach, and most probably controls the movements of these ayers of muscle. The other lies internal to the circular uscle, in close relation to the muscularis mucosæ, and is alled the *plexus myentericus interior* of Meissner ; the meshes f which are looser and more irregular, and the cords and anglia more rounded and finer than those of Auerbach's lexus. (Figs. 63, 64.)

The blood flowing through these nerve centres in all probaility acts as a sufficient stimulus under ordinary circumstances, o produce some peristaltic motions, and hence we may say hat they are automatic. When food comes into the intestine t increases the flow of blood, as well as mechanically irritating he intestinal wall. The intestinal vessels remain engorged so

long as the process of digestion goes on. Food seems to act more effectually than insoluble mechanical stimuli, for when insoluble substances are placed in the gut, they at first call forth active movements; but these do not last long, for the stimulus is not of itself adequate to excite prolonged action, except it be associated with continuing congestion dependent upon other causes, such as the vaso-motor changes accompanying the general digestive process, and the absorption of the prepared food-stuffs.

With regard to the influence of other nerves, it seems to be admitted on all sides that the vagus acts as an exciting nerve since stimulation of its peripheral part causes increased action and it is probable that its great efferent channel for impulses is reflected through the brain.

On the other hand, the splanchnic nerves, which come from the thoracic sympathetic, are said to be inhibitors of the myenteric plexuses. This may be explained by their effect on the small vessels—which they no doubt control—causing a change in the blood supply. Be this as it may, the splanchnics seem to have considerable influence on the intestinal movements. When stimulated they commonly check the intestinal motions, but may sometimes (as when the movements have ceased after death) give rise to new movements.

On account of this double action, it has been said that there are two kinds of fibres, (1) inhibiting, which are easily excited and during life have greater influence, and (2), exciting, which though less excitable, retain their irritability longer.

However, most of these effects may be explained by referring them to vaso-motor changes.

With regard to defæcation, we know that a nerve centre exists in the lumbar portion of the spinal cord, which governs the sphincter, and seems to keep up its tonic contraction. The centre may be either excited to increased action or inhibited by peripheral stimuli or by central influences from the brain.

Thus the local application of warmth causes inhibition of the centre, and thereby relaxation of the sphincter, while cold gives rise to increased central action, causing contraction of the sphincter muscle (a point to be remembered when examining parts operating within its grasp). Besides the voluntary variations which we can bring about in the activity of this lumbar centre, many other central influences, such as emotions, may operate upon it. Thus terror inhibits the centre, and loosens the sphincter independently of our will.

CHAPTER VII.

MOUTH DIGESTION.

Structure of the Mucous Membrane.

The cavity of the mouth is lined by a bright red membrane, hich is continuous with the skin at the lips. It varies in ructure in different parts of the buccal cavity, and in its eneral construction more resembles the outer covering of the ody than the mucous membrane lining the alimentary tract. consists of (1) a superficial part composed of thick stratified ithelium, the upper cells of which are flat, scaly, and tough, id are placed horizontally, while in the deeper layers the cells e soft, rounded or elongated, having their long axis per-endicular to the surface; and (2) a deeper part composed of ro-elastic tissue, which, over the alveoli of the teeth, is nalgamated with the periosteum and forms the dense tough ms.

The mucous membrane of the mouth is covered with papillæ hich on the dorsum of the tongue attain great magnitude id variety of shape and ithelial covering. In man, ree kinds are described:— .) Narrow and pointed, *filiform*. (2.) Blunt and clubbed the summit, *fungi-form*. (3.) road complex papillæ, surunded by a fossa, *circumllate*, of which there are but limited number (about a zen).

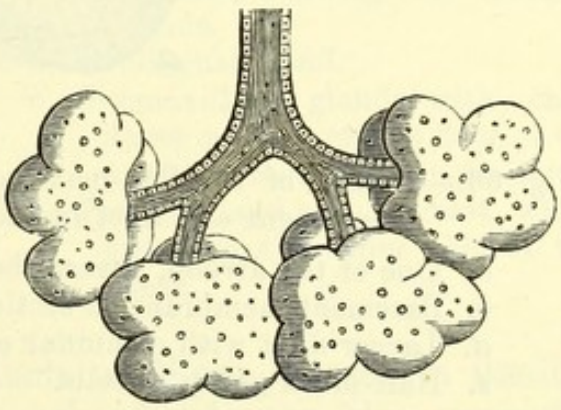


Fig. 65.—Diagram taken from a small portion of sacculated gland from Cockroach, showing branching duct and saccules.

Glands.

The special secreting organs glands, which pour their juices into the mouth, all have the me general type of structure, though they vary much in tail as to the variety and character of their cells. They are

known as the *acinous* or *sacculated* glands, from their being made up of numerous *acini*, or minute elongated sacs or tubules, arranged at the end of a repeatedly branching duct like grapes on the terminals of the successive little branches growing from the central stalk to form a bunch. In the glands the saccules are packed together closely around the ducts, and by mutual pressure are made to assume various shapes. The wall of the saccule is formed of a very delicate clear transparent membrane, on the outside of which are

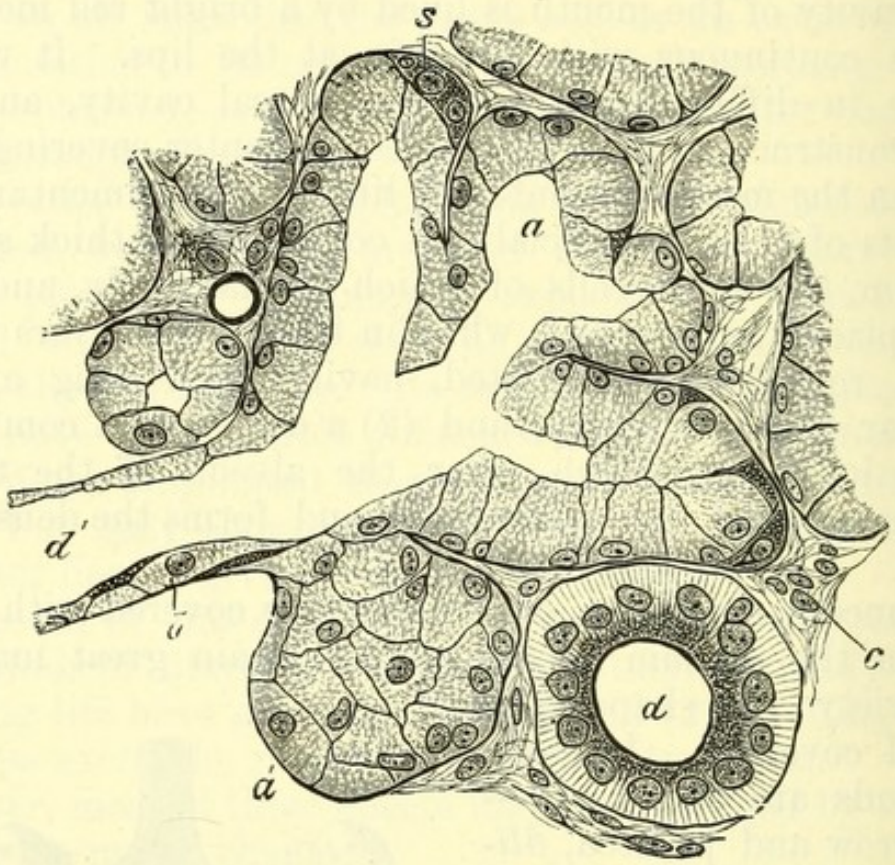


Fig. 66.—Section of the Sub-maxillary Gland of the Dog, showing the commencement of a duct in the alveoli. × 425. (Schäfer.)

a. One of the alveoli, several being grouped round the ductlet (*d'*).
b. Basement membrane in section.
d. Larger duct with columnar epithelium.
s. Half-moon group of cells.

numerous flattened branching stellate cells, the branches which anastomose one with another, and appear to penetrate the membrane in order to reach the inside of the acini.

The cavity of the little sacs is almost completely filled with large polygonal *gland-cells*, so that only a very narrow space exists in the centre. (Fig. 66.) From this space there is free communication to the main duct of the gland by means of the proper ductlet of each saccule. In the saccules of a fe

glands, *e.g.*, some of the so-called mucous salivary glands, another kind of cell element is seen between the gland cells just described and the wall of the sac, their outer side following accurately the concave boundary of the saccule, their inner side impinging upon the gland cells. They thus acquire a more or less half-moon shape. These demilune cells will be again referred to (page 125).

Between the saccules are numerous blood vessels which branch and form a network of capillaries on the outside of each little sac. Numerous nerves are also found, which, according to some observers, have ganglionic cell-connections in the gland substance, and send terminals into the gland-cells direct.

Although this account of the nerve terminations in the secreting cells of other glands has met with doubt, it is certain that in the lower animals nerve terminals have been traced into gland-cells, and upon physiological grounds, as will presently appear, we are forced to believe that a similar connection must exist in mammalia.

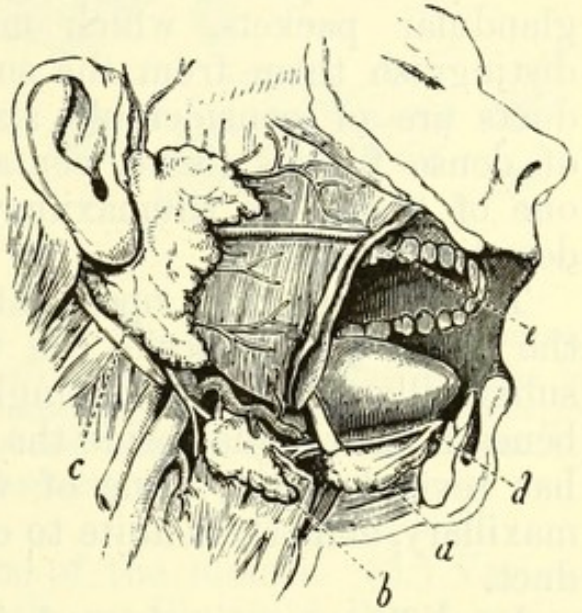


Fig. 67.—A Dissection of the side of the face, showing the Salivary Glands.

a. Sublingual gland.

b. Submaxillary glands with their ducts opening on the floor of the mouth beneath the tongue at (*d*).

c. Parotid gland and its duct, which opens on the inner side of the cheek.

The ducts are lined with short cylindrical epithelium which does not appear to have any secreting function. All the glands are made up of numerous packets of lobules bound together in one mass and united by their ducts. Each of these lobules is itself a perfect gland. The smaller mouth glands are also separable into lobules, and hence are called compound acinous glands.

The mouth glands are divided into two sets, which produce different kinds of secretion :—(1.) *Mucous glands*, which secrete *mucus*, and (2.) *Salivary glands*, which produce watery *saliva*. The functional distinction is seldom absolute, for most salivary glands have a mixed secretion, and various

gradations of transition from purely salivary to purely mucous glands are met with.

The proper *mucous glands* are small, varying in size from a pin's head to a pea. They are found in groups under the mucous membrane in various parts of the mouth, and from their positions are called labial, buccal, &c. Their cells contain a clear substance, called mucinogen.

The great *Salivary glands* are the three large glands on each side, which are known as the parotid, submaxillary and sublingual. On account of their great size they form striking anatomical objects, being large masses of irregularly arranged glandular packets, which might be spoken of as lobes to distinguish them from the smaller packets or lobules. Their ducts are of considerable size, and have strong walls made of dense fibrous tissue, containing many elastic fibres, and in one of them, the submaxillary, smooth muscle tissue has been demonstrated.

The parotid duct opens into the mouth about the middle of the cheek just opposite the upper second molar tooth. The submaxillary has also a single duct (Wharton's), which opens beneath the tongue beside the frænum. The sublingual gland has several ducts, some of which open into that of the submaxillary, and others unite to enter the mouth beside Wharton's duct.

In different animals and in different glands of the same animal a variable amount of mucus is secreted by these glands which are all called salivary, though the parotid alone deserves the name, in the strictest sense of the term, owing to the freedom of its secretion from mucus.

The Characters of Mixed Saliva.

The liquid in the mouth is a mixture of the secretion of the salivary glands with that of the small purely mucous glands.

It is a slightly turbid tasteless fluid of a distinctly alkaline reaction, of 1004—1008 specific gravity, and so tenacious that it can be drawn into threads. The amount secreted by an adult human being during 24 hours varies greatly according to circumstances, and has been variously estimated by different authors, by whom the wide limits of 200—2000 grms. (7–70 oz.) have been assigned as the daily amount.

Saliva contains about ·5 per cent. of solids. Of these the greater part are organic ; namely, (1.) *Mucin*, from the sub

naxillary, sublingual, and small mucous glands, which can be recipitated by acetic acid. To this substance the viscidity f the saliva is due. (2.) Traces of *albumin* precipitable by oncentrated nitric acid and boiling. (3.) Traces of *globulin*, precipitated by carbonic acid. (4.) *Ptyalin*, a peculiar ferment.

The inorganic constituents are salts, among which an inonstant amount of *potassium sulpho-cyanate* is ound, a substance which loes not exist in the blood.

There are also many norphological elements, of hese the majority are accilental, being the remains of food, &c.; others are nore or less characteristic; namely, (1.) *Salivary corpuscles*, which are rounded protoplasmic masses conaining nuclei and coarse granules which show Brownian movements. (2.) *Epithelial scales*, from the surface of the mucous membrane of the mouth. (3.) Various forms of *bacteria*, which propagate readily amid the decaying particles of food in the mouth. No bacteria or other fungi exist in the ducts of the glands or saliva taken from them with the necessary aseptic precautions. (Fig. 68.)

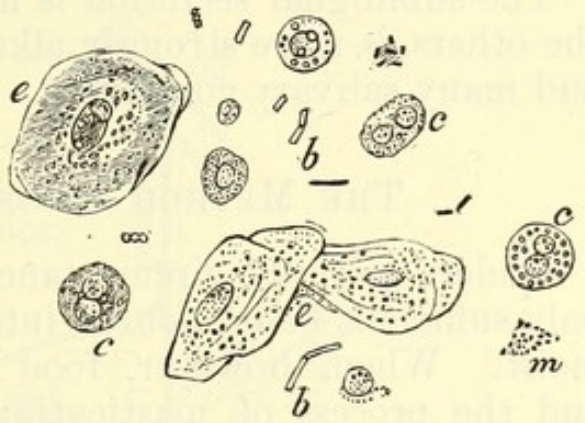


Fig. 68.—The form elements from mixed saliva from tip of tongue, showing (*e*) large irregular scaly epithelial cells, (*c*) round salivary corpuscles, several (*b*) bacteria, and (*m*) micrococci.

Collection of the Secretion.

Ordinary mixed saliva may be easily collected by chewing some insoluble material, such as a bit of rubber tubing, and collecting the fluid which this action causes to be poured into the mouth.

The collection of the secretion of the different glands requires more delicate methods. It may be collected separately by placing a canula in the duct of each gland.

Parotid saliva obtained in this way is found to have no structural elements nor mucus, and is a thin fluid, dropping easily, and not capable of being drawn into threads. It contains some serum albumin, globulin, potassium sulpho-cyanate, and ptyalin. The portion first collected is slightly acid, from

decomposition of the fluid while stagnant. It never is strongly alkaline. Its specific gravity is 1003—1004. On standing it becomes turbid from the precipitation of carbonate of lime, which existed as bicarbonate.

The submaxillary secretion is more strongly alkaline than that of the parotid ; it contains structural elements and mucin, but is not so viscid as the general mouth-fluid.

The sublingual secretion is much more viscid than either of the others, is more strongly alkaline, and contains much mucus and many salivary corpuscles.

The Method of Secretion of Saliva.

Under ordinary circumstances very little saliva is secreted, only sufficient being poured into the mouth to keep the surface moist. When, however, food is introduced into the mouth, and the process of mastication commences, the secretion goes on more or less rapidly according to the stimulating or non-stimulating character of the food.

The activity of a salivary gland is at once brought about by means of special nervous agencies when a stimulus is applied to the mouth. We know that the nervous mechanism which regulates this secretion is called a reflex act. The stimulus travelling from the surface of the mouth to the nerve centres is reflected thence to the glands. We speak, then, of *afferent nerves*, which carry the impulses to the *nerve-centre*, and *efferent nerves*, which carry them from the centre.

If we review the ordinary circumstances giving rise to a flow of saliva, there will be no difficulty in determining the nerves which act as the *afferent channels* in the simple reflex act.

Stimulation of the mucous membrane of the tongue and mouth, whether chemically, as with irritating condiments, or mechanically, as by the motions of mastication, is generally transmitted to the centre by the sensory branches of the fifth cranial nerve, which supply the mouth, and by the branches of the glosso-pharyngeal.

The stimulus of the sense of taste is sent by the nerves of that sense, mainly the glosso-pharyngeal, to the taste centre in the cortex cerebri, and from thence to the secreting centre by means of inter-central fibres.

The stimulation of the olfactory region with certain odours induces salivation through a channel of a similar kind passing along the olfactory nerve to the brain, and thence to the special

salivary centre. Even in the absence of taste or smell, mental emotion may be excited by seeing or thinking of food, and may cause activity of the salivary glands, here the inter-central channel is the only one occupied in bearing the impulse to the special secreting centre.

Irritation of the gastric mucous membrane stimulates the

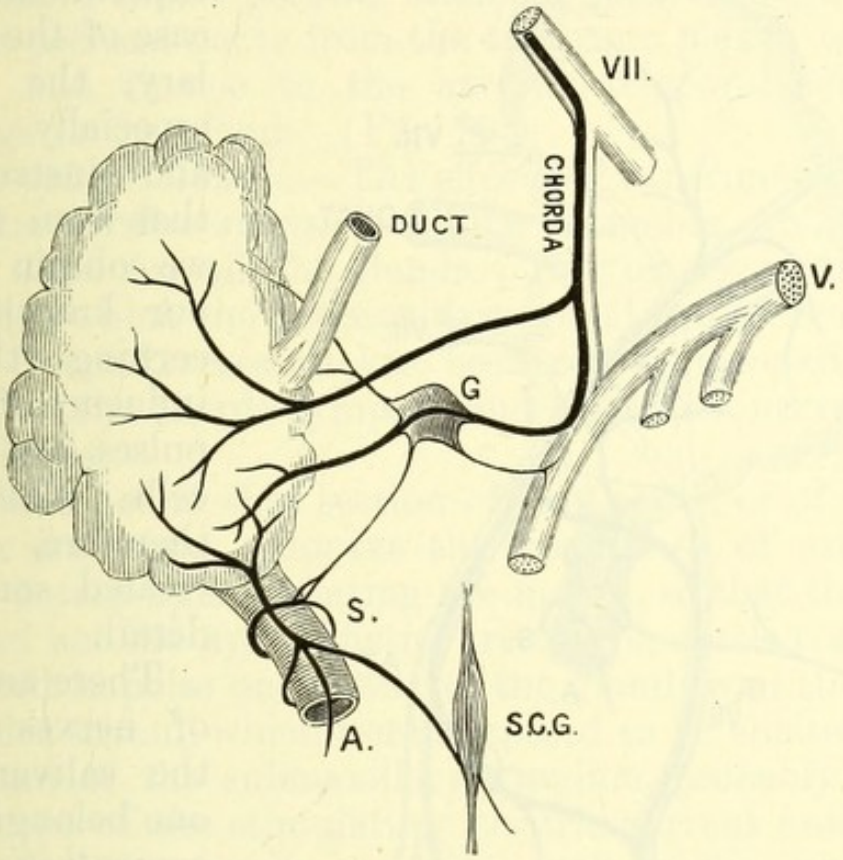


Fig. 69.—Diagram of Nerves of the Submaxillary Gland. The dark lines show the course of the nerves going to the gland.

(VII.) Portio dura ; (V.) Inferior maxillary division of the fifth cranial nerve ; (G) Submaxillary ganglion ; (S) Sympathetic round facial artery (A) ; (S. C. G.) Superior cervical ganglion.

salivary glands, as may be seen with a gastric fistula, or by the sudden flow of saliva which commonly precedes vomiting. In this case the impulses are carried by the gastric branches of the vagus.

The stimulation of the central end of the cut sciatic is said to cause an increase in the flow of saliva, so that it would appear that even an ordinary sensory nerve can excite the centre to action. Lastly, many drugs, when introduced into the blood, cause a flow of saliva, among these are pilocarpine, physostigmine, and digitaline, while atropine and daturine, on the other hand, check the action of the glands.

From this we learn that the *nerve-centre*, controlling the activity of the salivary glands, receives impulses from many distant and diverse sources, or may be influenced directly by the quality of the blood flowing through the nerve-centre itself.

The channels traversed by the *efferent impulses* going to the salivary glands have been demonstrated by experiment. In the case of the submaxillary, the route is especially distinct and instructive, so that from this gland we obtain most of our knowledge concerning the direct influence of nerve impulses on the gland cells. This question, therefore, will be treated somewhat in detail.

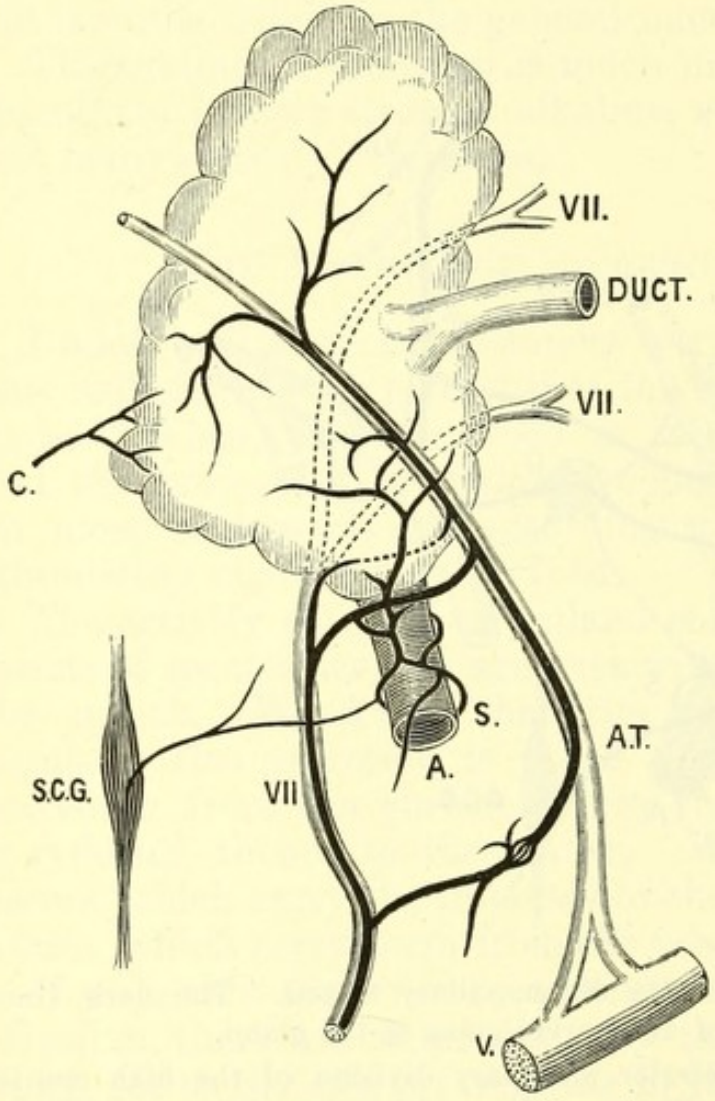


Fig. 70.—Diagram of Nerves supplying the Parotid Gland. The dark lines indicate the course of the nerves of the gland.

(V.) Inferior division of fifth nerve and its (A T) auriculo-temporal branch.

VII.) Portio dura.

S. C. G.) Superior cervical ganglion sending a branch to the carotid plexus around the artery.

There are two sets of nerves going to the salivary glands, one belonging to the *sympathetic* and the other to the *cerebro-spinal* systems, both of which have been proved to exert a certain amount of influence on the action of the glands, the share taken by each apparently differing in different animals.

The sympathetic branches for the submaxillary and sublingual gland come from the plexus which embraces the facial artery, those for the parotid come from the plexus surrounding the internal maxillary as that artery traverses the gland. Both of these

nervous plexuses are derived from the superior cervical part of the sympathetic chain.

The cerebro-spinal fibres for the submaxillary and sublingual glands lie in the complex nerve known as the chorda-tympani, which comes from the portio dura of the seventh, and joins the lingual branch of the fifth. They pass thence through the submaxillary ganglion to the glands. (Fig. 69.)

The cerebro-spinal parotid branches pass through the lesser superficial petrosal nerve from the tympanic plexus to the otic ganglion, and thence to the auriculo-temporal nerve which sends twigs to the gland. (Fig. 70.)

Cerebro-spinal Stimuli.—The effects of experimental stimulation of the *cerebro-spinal* glandular branches are, so far as we know, alike for all the glands. But owing to the greater facility with which the submaxillary gland can be reached, and its nerve isolated, research has been chiefly devoted to it, by operating on the chorda tympani and the other nerves supplying the glands.

It has been found that section of this nerve, or of the portio dura near its origin, removes the possibility of exciting the glands to action by stimulating the mouth, so that the cerebro-spinal, and not the sympathetic, are the channels traversed by the reflected impulse on its way to the gland from the centre.

The reflex stimuli which were supposed to be elicited through the medium of the submaxillary ganglion, probably depended on the escape of the stimulating electric current used, and the reflection from a sporadic ganglion, such as the submaxillary, has never been satisfactorily demonstrated.

It has further been shown that direct stimulation of the chorda tympani nerve, although it be cut off from its central connections, causes a copious secretion of thin watery saliva, and this increased secretion is accompanied by a great dilatation of the small arteries going to the gland, so that a pulsation may be seen in the small veins, and the blood retains its bright arterial colour when leaving the organ.

These two chief results of stimulation, *activity of the secreting cells* and *vascular dilatation*, are distributed by different nervous agencies, as appears from the action of atropine, which stops the secretion of saliva, but does not prevent the dilatation of the vessels on stimulation of the chorda tympani ; from which we conclude that its effect is restricted to a mechanism engaged exclusively in controlling the activity of the gland cells.

Stimulation of the chorda tympani causes the secretion to be

carried on with great energy. The fluid was found to enter the duct with a pressure equal to 200 m.m. (about 8 inches) of mercury, while the blood pressure in the carotid artery of the animal was only 112 m.m. (about $4\frac{1}{2}$ inches) mercury; that is to say, the force by means of which secretion is driven outwards, is nearly twice as great as the pressure in the blood vessels in the gland. The secretion of saliva cannot then be a question of mere filtration, for if the physical agency—pressure—alone were acting, the saliva, if produced, would be forced into the lymph or blood vessels when the pressure in the duct exceeded that in the vessels.

The force and rate with which the secretion is produced vary with the strength of the stimulation. The flow of saliva steadily increases within certain limits as the stimulus gets stronger. It is not only the quantity of the secretion that depends on the amount of nerve impulse, but also its quality; that is to say, with a fresh gland, not wearied by previous experiment, the amount of solids in the saliva increases as the stimulus is increased, so that not only is the activity of the gland cells under the control of nerve influence, but the kind of work they perform is also regulated by the intensity of nerve impulse they receive.

It has been found that the increase in the blood flow is only associated with the secretion called forth by stimulation of the chorda tympani. This is shown by the fact that even when the blood supply is cut off by any means (strong sympathetic stimulation, ligature of the vessels, or even decapitation) an amount of saliva can be made to flow from the gland which could only have been stored up in its cells prior to the stimulation of this nerve.

Sympathetic Stimuli.—With regard to the influence exerted by the *sympathetic branches*, the most obvious result of stimulation of these is a contraction in the arterioles, and a consequent diminution of the amount of blood flowing through the gland. The glands look pale, and the blood leaving them is intensely venous in character; the exact opposite, in fact, to the result obtained by stimulation of the cerebro-spinal nerves. But the sympathetic has also an effect on the gland cells, as it produces an increased flow of saliva. In the dog the secretion of "sympathetic saliva" is only temporary and scanty, having high specific gravity, and being overloaded with the solids. In the cat and rabbit "sympathetic saliva" is scanty, and not thicker than the "chorda saliva" of the same animal. So far

as regards the blood-vessels, the chorda is directly opposed to the sympathetic. To explain this antagonism, we may either assume the existence of local nerve centres governing the muscular coats of the arterioles, and suppose that the sympathetic stimulates and the chorda inhibits the activity of these centres, or, what seems more simple, in the absence of anatomical evidence that such a centre exists, we may attribute to the arterial muscle cells themselves an automatic tonic power of contraction which can be increased by the sympathetic and diminished by the chorda tympani. It is singular that if all the secretory nerves leading to the gland be cut, a copious secretion of watery saliva begins after some hours, and lasts for some weeks, after which the cells undergo atrophic changes, and the gland becomes reduced in size. The explanation of the appearance of this so-called "paralytic saliva" is not clearly made out. Possibly the removal of some trophic nerve-influences induces abnormal nutritive changes which cause stimulation of the cells, and ultimately lead to their degeneration.

Histological Changes.—The histological investigation of the elements of these glands in the various stages of secretion throws considerable light on the behaviour of the cells during their periods of activity and rest.

It is now certain that the different stages are accompanied by constant structural changes in the cells, which doubtless are intimately connected with secretory activity. During the period of rest, that is, the time when the gland is not discharging its secretion, the cells slowly undergo a change in their appearance, which is the more obvious in proportion to the ease with which the material they secrete is recognised in the protoplasm. Thus, in mucous glands, or in mucus-yielding salivary glands, the changes are conspicuous; whilst in those which give a watery secretion they are less easily seen.

As an example we may take a mucous gland, such as the orbital gland of the dog, and follow the changes which occur in one of its cells, during the period which may be called its cycle of activity. (Fig. 71.)

Immediately after the prolonged and active discharge of the secretion of the gland, the cells have all the characters of ordinary protoplasmic units, and the distinction between the polygonal cells and those next the wall of the acinus (demi-lune cells) is made out with great difficulty, because all the cells

stain evenly with carmine, and have no special characters except those belonging to active protoplasm.

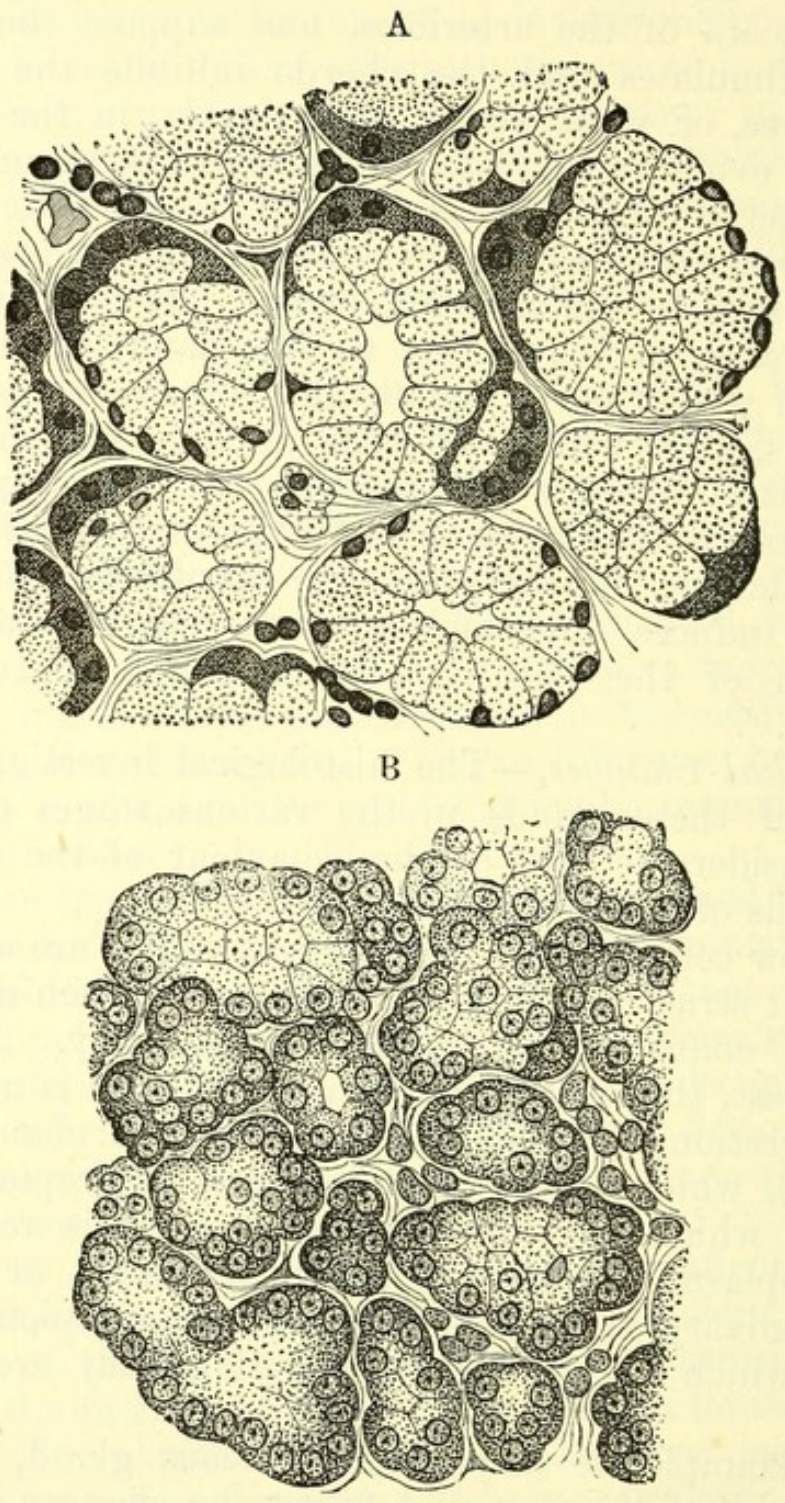


Fig. 71.—Sections of Orbital Gland of the Dog. (Heidenhain.)
(A) After prolonged period of rest. (B) After a period of activity.
In (A) the secreting cells are clear, being swollen up with mucigen, and the half-moon cells are very distinct and darkly stained.
In (B) the accumulated material has been discharged from the cells, and the alveoli are shrunken.

During rest certain changes gradually appear in those gland-cells which are next the lumen of the saccule. They appear to

well towards the lumen, and at the same time become clear nd resist staining with carmine, their protoplasm becoming mpregnated with mucus-like material (mucinogen), while the emi-lune cells remain protoplasmic and stain easily, and are hereby readily distinguished from the cell in the cavity of he saccule.

If the discharge of secretion be induced either by normal eflex excitation, or by direct stimulus of the chorda tympani erve, the cells discharge the contained specific material, some f them probably being destroyed by the act. If the active ecretion be continued for some time, the cells return to their ormer protoplasmic state, and those which have been worn out re replaced by others from the demi-lune or marginal cells.

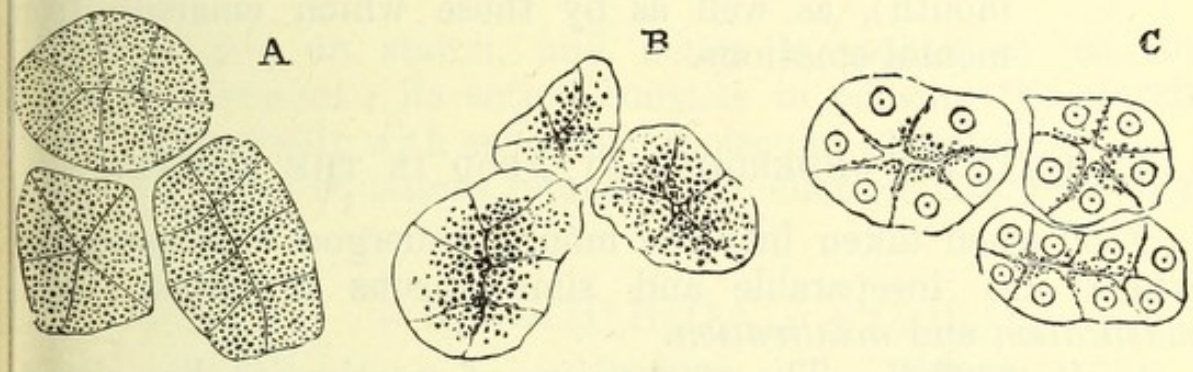


Fig. 72.—Cells of the Alveoli of a Serous or Watery Salivary Gland. (Langley.)

(A) After rest. (B) After a short period of activity. (C) After a prolonged period of activity.

In the glands which do not produce any mucus the brilliant ook of the cells after rest is wanting, but a corresponding hange occurs. The secreting protoplasm becomes extremely granular during the resting period, and again clear after the lischarge of the secretion. (Fig. 72.)

Thus it would appear that during the so-called period of est, when little or no fluid is poured into the duct, the gland-ells are busy at their manufacturing process, diligently adding o their stock in hand, in order to be ready for a sudden lemand which they could not meet by merely concurrent work.

To sum up, then, we may conclude :—

I. That the manufacture of the specific materials of the secretion is accomplished as the result of the intrinsic power of the protoplasm of the gland cells.

II. That a vital process is called forth in the gland cells

by the action of nerve impulses, because—(1.) The force with which the secretion is expelled cannot be accounted for by the blood pressure. (2.) The quantity and quality of the secretion is modified by the intensity of the nerve stimulation. (3.) The temperature of the blood is raised. (4.) Structural changes in the cells can be observed.

III. The normal stimulus to secretion passes from the centre in the medulla oblongata to the salivary glands along cerebro-spinal nerves.

IV. This centre for salivary secretion, which at ordinary times is moderately active, may be excited to energetic action by impulses coming from taste, smell, and ordinary sensory nerve terminals (particularly in the mouth), as well as by those which emanate from mental emotions.

Changes undergone by Food in the Mouth.

Food when taken into the mouth undergoes two processes which are inseparable and simultaneous in action; viz. *mastication* and *insalivation*.

1. *Mechanical.*—The mechanism of mastication has already been discussed, so far as its triturating power is concerned. In its final object of forming the subdivided food into a bolus which can be easily swallowed, it is much aided by *insalivation* particularly in chewing dry food; and in this latter, the moistening of the particles, so as to make them adhere together, is the most necessary act of mouth digestion, and is next in importance to the subdivision accomplished by the teeth. The saliva, also, covers the bolus with a coating of viscid fluid, so that it can be more easily propelled down the œsophagus. Deglutition of solids is difficult without an adequate supply of saliva.

While in the mouth the saliva dissolves a great quantity of the more readily soluble materials, such as sugar and salt which may be either mingled with the insoluble substances and swallowed together with the bolus, or separately in a fluid form. Solution, then, is an important item in mouth digestion.

2. *Chemical.*—In many carnivorous animals the use of the mouth-fluid is chiefly mechanical, dissolving some insignificant part of the food, and aiding mastication and deglutition. In

nan, however, and other animals that make use of much 'egetable food, it has a chemical function, and acts on the nsoluble starch, converting it into soluble sugar.

The active principle which brings about this change is *Ptyalin*. This is one of a series of *ferments* to which most of he chemical changes in digestion are due.

As a group they are remarkable for the following characters n which they differ from most chemical agents :—(1.) They ffect alterations in the substances on which they act, while hey themselves do not undergo any preceptible change or iminution. (2.) They exist in such small quantities that as rule their presence can only be shown by the effects they roduce. (3.) They are most active at the body-tempera- ure, but are "killed" by about that at which albumen oagulates.

Ptyalin acts on starch, and hence is spoken of as an mylolytic ferment ; its action consists in causing the starch o unite chemically with successive molecules of water.

The following equations represent the changes that probably ccur :—

$$(C_6H_{10}O_5)_n + H_2O = (C_6H_{10}O_5)_{n-2} + C_{12}H_{22}O_{11}$$
Starch. Dextrine. Maltose.

$$(C_6H_{10}O_5)_{n-2} + H_2O = (C_6H_{10}O_5)_{n-4} + C_{12}H_{22}O_{11}$$
Dextrine. Maltose.

$$(C_6H_{10}O_5)_{n-4} + H_2O = (C_6H_{10}O_5)_{n-6} + C_{12}H_{22}O_{11}$$
Dextrine. Maltose.

* * * * *

$$(C_6H_{10}O_5)_2 + H_2O = C_{12}H_{22}O_{11}$$
Maltose.

During this process, which is termed hydrolysis, and takes t the least a few minutes to complete, various stages can thus e detected : first, substances are formed which together are ommonly spoken of as dextrins ; those with the higher olecular formulæ are called erythro-dextrins, because they ive a red colour with iodine, and the others with the lower olecular formulæ are called achröo-dextrins, because they ive no colour with iodine.

The sugar thus formed is maltose, and belongs to the

group of saccharoses. It is a reducing sugar, giving the re actions described page 57. Experiments may be carried ou with saliva obtained directly from any of the glands, but th mixture of the secretions of all is found to be more efficaciou than that of any single one. The ordinary mouth-fluid filtere serves well for ordinary experiments.

An effective glycerine solution of ptyalin may be obtained b steeping chopped salivary glands in alcohol, and then extract ing for some days with glycerine and water.

The following facts must be borne in mind concerning th amylolytic action of ptyalin :—

*1. The extremely small amount of the ferment required t make the fluid effective.

*2. There is no appreciable diminution in the amount o ferment, so that it cannot be said to be used up in th process.

3. The action takes place most readily in alkaline solu tions, such as the saliva, slowly in neutral solutio and not at all in acids of the strength of ·2 per cen of hydrochloric acid.

*4. Temperature has a marked effect on the process. Col (0° C.) quite checks the action ; heat (75° C destroys the power of the ferment, which is mo active at the body temperature (35°—40° C.).

*5. Strong acids or alkalies destroy the hydrolytic power o the ferment.

6. The ferment has no effect on raw starch, its ce lulose coating protecting it ; but it acts rapid on well-boiled starch, in which this coating burst.

7. Ptyalin is more active in weak starch solutions, and much impeded in its action by an accumulation o sugar.

To recapitulate, we find that the following changes tak place in the mouth :—

(1) Solid food is, or should be, finely subdivided ; (2) d food is moistened, (3) rolled into a bolus, (4) a lubricated ; (5) the soluble part is dissolved, a

* The paragraphs marked thus are applicable to all digestive ferments.

rendered capable of being tasted ; (6) and part of the indiffusible starch is converted into soluble diffusible sugar by the action of a ferment called *ptyalin*.

In the short time occupied by the passage of food through he œsophagus no special change takes place in it, so we may ass at once to the gastric digestion, which will occupy the ext chapter.

CHAPTER VIII.

STOMACH DIGESTION.

Structure of the Mucous Membrane.

The surface of the stomach is covered by a single layer o cylindrical epithelial cells, which also line the orifices of th numerous glands with which the mucous membrane is thickl studded. This single layer of cylindrical cells commence abruptly at the cardiac orifice of the stomach, and is marke off from the stratified squamous cells lining the œsophagus b a sharp line of demarcation.

The glands of the stomach are tubes which often divide int two or three branches. The conical orifice is covered with th cylindrical epithelium common to the surface of the stomacl and the fundus is filled with specific glandular cells. Th glands dip down to the delicate submucous tissue, the branch ing tubes lying parallel and close to each other. A dens net-work of capillary blood-vessels may be demonstrated b injection, to surround the tubes, and closely invest the thi basement membrane which forms the boundary of the glanc and the basis of attachment of the glandular cells. A clos meshed net-work of absorbent vessels also surrounds th tubules of the glands, and leads to the larger vessels in th submucous tissue.

In the cardiac end of the stomach of most animals, glanc are found (*cardiac glands*) with two distinct kinds of cells i the deeper part of the gland tubes. Much the more numero are small pale spherical cells, which occupy the lumen of th gland and form the regular cell-lining of its cavity. The cells have been called the "chief cells" (Hauptzellen "central" or *spherical cells*.

The cells of the other form are comparatively few, beir altogether wanting in some of the glands. They are larg and more striking than the central or spherical cells, betwe which and the basement membrane, they lie scattered here a

here over the fundus of the gland, making the delicate membrane bulge. They stain more easily, and have darker granules than the central cells. On account of their position they have been called "parietal," "marginal or border cells" (Belegzellen), from their producing acid they have been named "*oxyntic*," and from their oval shape *ovoid cells*. (See fig. 73.)

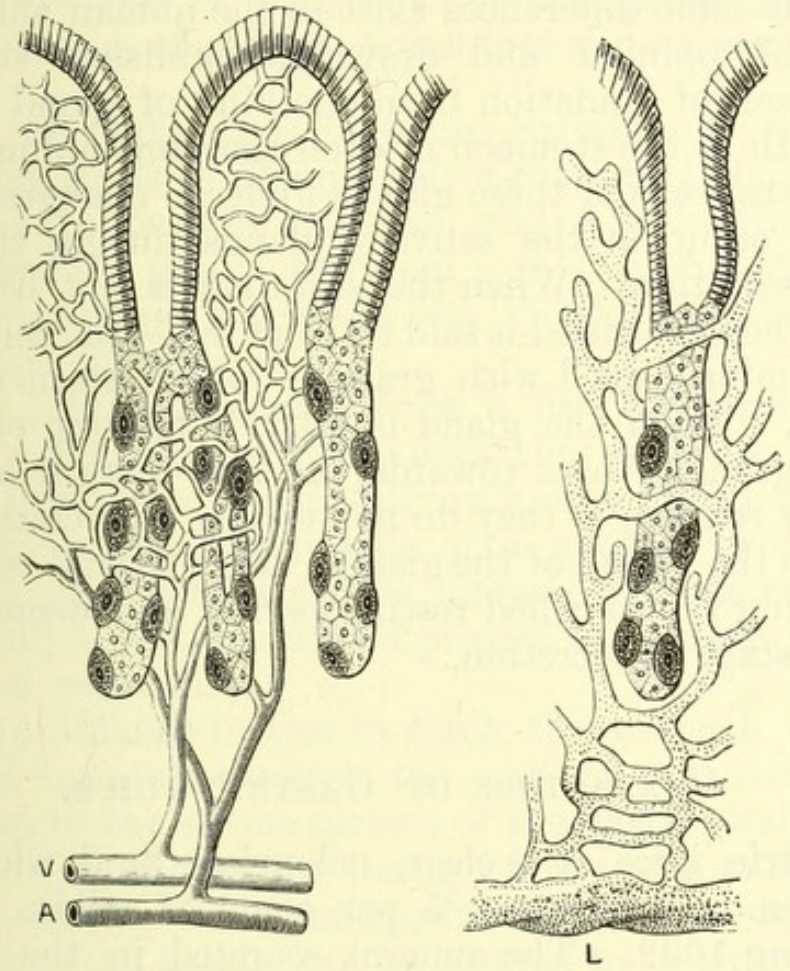


Fig. 73.—Diagram showing the relation of the ultimate twigs of the blood-vessels (V and A), and of the absorbent radicals (L) to the glands of the stomach, and the different kinds of epithelium, viz., above cylindrical cells; small pale cells in the lumen, outside which are the dark ovoid cells.

There is a different class of gastric glands, called *pyloric*, because they are found chiefly near the pyloric end of the stomach, in which—in addition to the cylindrical epithelium covering the surface of the stomach, and dipping into the conical orifices which lead to the glands—there is but one kind of cells in the fundus. These are spherical like the central cells of the other glands.

Experimental research shows decisively that the anatomical differences denote differences of function as regards the production of acid, which is only produced at the cardiac end of

the stomach. The pepsin is produced in the pyloric as well as in the cardiac part.

The difference between the two kinds of glands found in the stomach, both as regards their distribution and way of branching, and the cells which line the deeper parts of the tubes, is found to vary in different animals. The difficulty of obtaining fresh specimens of the human stomach makes it still uncertain whether the same differences exist in the human subject. The varieties of opinion and drawings published suggest that various stages of gradation from one kind of gland to another are met with in the stomach of even the same animal.

The central cells of these glands undergo changes similar to those that occur in the salivary glands during the different phases of secretion. When the secretion is not being poured out—*i.e.* when the gland is said to be at rest—the cells gradually swell, becoming loaded with granules which stain darkly with osmic acid. When the gland is actively pouring out its secretion these granules pass towards the free margin of the cells, where they remain, if they do not escape as secretion and disappear into the lumen of the gland. The parietal cells increase in size during the so-called resting period and decrease during the active stage of secretion.

Characters of Gastric Juice.

The gastric juice is a clear, colourless fluid with strongly acid reaction. It contains ·5 per cent. of solids, its specific gravity being 1002. The amount secreted in the day is extremely variable, and depends upon the quantity and character of the food ; in well-fed dogs it has been estimated to be one-tenth of the body weight.

It contains :—

1. About ·2 per cent. of free hydrochloric acid in man, but in the dog considerably more. The lactic, formic, butyric, and other acids which have been found in the gastric juice probably depend on the fermentation of some of the ingesta. The HCl is sometimes deficient, its absence causing one form of dyspepsia.
2. Pepsin, the specific substance which gives the gastric juice its digestive qualities, is a nitrogenous ferment which, with the foregoing acid, acts on proteids. About ·3 per cent. is present in the secretion of the

human stomach. Its presence is constant even in disease.

3. Associated with the pepsin are other less-known ferments, one of which, rennin, curdles milk in the presence or absence of any free acid.
4. A variable quantity of mucus, probably abnormal, may be found in the secretion of the stomach.
5. It contains ·2 per cent. of inorganic salts, chiefly chlorides of sodium, potassium and calcium.

METHOD OF OBTAINING GASTRIC SECRETION. — Formerly ttempts were made to obtain gastric juice by inducing a dog, vhile fasting, to swallow a sponge, and withdrawing it when aturated with the gastric secretion ; or a fasting dog, allowed o swallow insoluble materials, was killed, and the secretion collected from the stomach.

It is best obtained directly from a fistulous opening in the bdominal wall communicating with the stomach. A gastric istula was first made accidentally in a man by injury. A case n which the surgical treatment of a gunshot wound of the tomach left a permanent fistula, allowed the gastric secretion o be carefully investigated, and proved a valuable subject for experimental research.

It is not a difficult matter to reach the stomach by making n artificial opening through the wall of the abdomen, and having brought the serous surface of the gastric wall into firm connection with the serous lining of the abdominal wall, to pen the stomach. The juxtaposition of the parts, as well as he patency of the fistula, can be secured by a suitable flanged annula closed with a well-fitting cork. By removing the cork he gastric juice may be obtained in small quantities, and various kinds of food may be introduced through the cannula, nd the changes occurring in them studied.

For experimental purposes an artificial gastric juice may be sed. This can be made from the gastric mucous membrane f an animal (pig) by extracting the pepsin from the finely divided glandular membrane, with a weak acid (less than ·2 per cent.) or better with a large quantity of glycerine, and subsequently adding HCl to the extent of ·2 per cent. The effects f such a fluid cannot be distinguished from those of natural gastric juice.

Mode of Secretion.

The gastric juice is not secreted in large quantity when the stomach is empty, but only when the mucous membrane is irritated with some chemical or mechanical stimulus. The swallowing of alkaline saliva acts as a gentle stimulus and causes secretion, so that the surface of the stomach becomes acid. When the lining membrane of the stomach is mechanically stimulated through a fistula it becomes red, and drops of secretion appear at the point of stimulation, but the amount of secretion thus produced is very scanty when compared with that called forth by chemical irritants.

Thus ether, alcohol, and pungent condiments produce copious secretion. Weak alkaline solutions also cause secretion, but the most perfect form of stimulant seems to be a mass of food saturated with the alkaline saliva.

It appears probable that the chief secretory activity resides in the small central cells, and not in the large ovoid border-cells, since less distinct changes can be seen in the latter, and the smaller gland-cells seem to contain the pepsinogen, for if the mucous membrane be treated with weak hydrochloric acid, these central gland-cells are rapidly dissolved by a process of digestion, while the border-cells simply swell up and become more transparent.

The granules above referred to as being passed out from the cells when the gland is *secreting*, are supposed to be the material that gives rise to the pepsinogen, or mother ferment, of *pepsin*.

The acid is found only on the surface of the stomach in the mouths of the glands. The mode of its production seems distinct from that of pepsin, but is not well understood. It is thought probable that the HCl is the outcome of "mass-influence" of weak acids upon salt. The CO_2 and lactic acid, being present in such large quantities, are able to rob the NaCl of some of its base, and make some free HCl appear. It was thought possible that the surface epithelial cells store up in their protoplasm and render inert the small quantities of HCl which are constantly being set free from the NaCl. The amount of HCl thus slowly accumulated in time becomes considerable and is discharged by the cells at appropriate periods.

Although the fact that the deeper part of the glands do not

give an acid reaction, while the neck and orifices of the gland are distinctly acid, would support the former view, there is some reason for believing that the manufacture of acid from the alkaline blood is really an active process carried out by some of the glandular cells.

It has been suggested that the cell elements which produce the acid are the ovoid border-cells, from whence it rapidly passes to the orifice of the glands. This view is supported by the alkalinity of the pyloric end of the stomach where the border-cells are not found. In some animals the distinct distribution of the different cell elements and the accompanying reaction of the secretion are well marked.

In all probability the secretion of the gastric juice is under the control of a special nerve mechanism, and the way in which the state of activity follows stimulation of the part seems to point to its being a simple reflex act. However, the nervous connections (vagi and splanchnics) between the stomach and central nervous system may all be severed without any marked effect on the secretion, other than that which would naturally follow the changes in the amount of blood supply, which of course is greatly altered by cutting the vaso-motor nerves—the splanchnics. Whether this be so or not, there must be some connection with the nerve-centres, for sudden emotions check the secretions, and the sensations caused by the sight or smell of food give rise to gastric secretion.

It has been suggested that Meissner's sub-mucous ganglionic net-work may act as a reflex centre and regulate the secretion. But as the reflection from local ganglionic centres has not yet been definitely demonstrated, we are hardly entitled to assume that it occurs here, and since the stimulus comes into close contiguity with the secreting cells, it seems quite as probable that these elements are excited to activity by direct stimulation of their protoplasm.

Action of the Gastric Juice.

The gastric juice has in the absence of mucus no effect on the carbohydrates, and probably the amylolytic fermentation set up by the saliva is impeded, if not completely checked, by the free acid in the stomach as soon as the bolus is completely moistened by the gastric fluid.

On *Fats*.—Fats are not affected by the gastric juice but are simply melted by the warmth of the stomach.

On *Proteids.*—Upon the *albuminous bodies* gastric digestion produces a marked effect. The proteids being colloid bodies, cannot readily pass through an animal membrane by the process called dialysis ; it has therefore been assumed that they cannot be absorbed through the lining membrane of the stomach. They are often eaten in an insoluble form. To convert the insoluble and indiffusible albumins into a soluble and diffusible substance would obviously be a great step towards their absorption. This power is possessed by the gastric juice. The steps of the process may be accurately followed in a suitable glass vessel, irrespective of the stomach, by using artificial gastric juice, and attending to the various conditions necessary for its action. The power of artificial gastric juice carefully prepared from the mucous membrane of an animal's stomach differs in no essential respect from that of the natural secretion in the stomach, if all the circumstances which aid the action of the gastric ferments be applied in the experiment. This action consists in a conversion of proteids into the peculiar, soluble and more diffusible forms known as *proteoses* and *peptones.*

The term proteose is now used to comprise the class of substances derived from the various proteids in the earlier stages of their hydrolysis, and thus includes *albumoses*, *caseoses*, *myosinoses*, &c. (see p. 39).

Shortly after the introduction of a proteid, such as fibrin, into gastric fluid at the temperature of the body, the masses of fibrin swell up, become transparent, and eventually are easily shaken to pieces and dissolved.

The pepsin by itself cannot convert proteid into albumose or peptone, as may be seen in the want of efficacy of a neutral solution of pepsin, in which no albumose is formed. In other words, pepsin solution can only change proteids into albumose by the aid of the acid. It would appear probable, however, that it possesses this property to an unlimited extent, since it undergoes no change itself, and with fresh supplies of acid a very minute quantity of pepsin can convert an indefinite amount of proteid into albumose.

The change brought about in proteids by the gastric juice is now known to be very complex, consisting of a series of stages of hydration. The ultimate step in this process, viz., the formation of peptone is not essential or even general in the stomach digestion. The bulk of the proteid only reaches the albumose stage, and is probably absorbed as such

The albumin passes through stages in which can be recognised ome acid albumin and the following substances :—

I. *Primary Albumoses* are not coagulated by boiling, but are precipitated by the addition of $MgSO_4$ to saturation. They iffer from acid albumin by (*a*) being soluble in neutral solutions ; (*b*) by giving the biuret reaction—a rose colour after ddition of a *trace* of $CuSO_4$, and KOH to excess ;—and (*c*) iving on the addition of a drop of strong HNO_3 a precipitate hich dissolves on heating and reappears on cooling.

II. *Secondary Albumoses*, which are also not coagulated by oiling, further agree with the *primary* in showing their last hree characteristics, but differ from them in not being precipitated by saturation with $MgSO_4$. On the other hand, they are recipitated by saturation with $(NH_4)_2SO_4$.

III. *Peptones*, which are very soluble in hot and cold water, nd give the biuret reaction, but do not give the HNO_3 test, or are they precipitated either by $MgSO_4$ or $(NH_4)_2SO_4$ to aturation.

The following table shows the general plan of the changes ccurring in gastric digestion in proteid, albumin being taken as he type. Globulin, casein, myosin, &c., pass through similar tages, the steps being globuloses, caseoses, myosinoses, &c.

(The acid albumin is omitted for brevity.)

ppt$^{d.}$ at about 75° C.		Albumins	
Sol. in hot and cold water, and give the biuret reaction.	Give HNO_3 reaction.	Primary Albumoses	— ppt$^{d.}$ by $MgSO_4$.
		Secondary Albumoses	not ppt$^{d.}$ by $MgSO_4$ but by $(NH_4)_2SO_4$.
	Give no HNO_3 reaction.	Peptone . . .	no ppt$^{t.}$ with either $MgSO_4$ or $(NH_4)_2SO_4$.

The rapidity with which proteid is converted varies according o the circumstances under which it is placed as well as he kind of proteid used. If the same proteid be used the following circumstances will be found to influence the rapidity of he process :—

1. The temperature. As already stated, the *optimum* degree of heat for the change is somewhat above that of the body, 40°—50° C.

The activity of the gastric juice diminishes when the temperature rises above or falls below this standard. The *minimum* at which it is capable of producing any effect is about 1° C. and the *maximum* is below 70° C. Boiling permanently destroys the function of pepsin.

2. The percentage of acid, as well as the kind of acid has a marked effect. Though the action will go on with other acids, hydrochloric, ·2 per cent., is the most effective. Hence digestion is impeded by voluminous food, or copious drinks during meals. The acidity tasted by dyspeptics is due to the acid of fermentation.
3. A condensed solution of albumoses, peptones, or large quantities of salts in solution impede the action, a certain degree of dilution being necessary for the process. In strong solutions of proteid, the peptones must be removed by dialysis in order to allow of the continuance of the action. This occurs in the stomach by means of the blood and absorbent vessels.
4. The degree of subdivison to which the proteid has been subjected materially influences the rapidity of its conversion into peptone. The more finely subdivided the substance the greater will be the relative extent of surface exposed to the action of the digestive fluids. When large masses of coagulated albumen, such as boiled white of egg, are introduced into the stomach, the gastric fluid cannot reach the central portions, and their digestion must await the completion of that of the exterior part.
5. Motion aids the action of the foregoing factors.

All these requisites are present during normal digestion. The temperature of the stomach is 38° C. (100° F.). Hydrochloric acid is present in the proportion of about ·2 per cent. As the albumoses are formed they are removed by absorption from the stomach, and thus the needful dilution is sustained. Finally, if the mouth has done its duty, the pieces of proteid have been reduced to a pulp, composed of minute particles. These are kept in constant motion by the gastric walls, and thus are repeatedly brought in contact with fresh supplies of the digestive fluid.

There can be little doubt that the conversion of proteid is normally brought about by the pepsin, which acts as a ferment in some way or other facilitating a process which without it is

extremely difficult to accomplish. Proteids may, however, give rise to albumose, &c., without the presence of any pepsin, if they be treated with strong acids, alkalies, boiling under high pressure, putrefactive and other fermentative actions. This, together with the analogy suggested by the chemical details of the amylolytic action of saliva, which one may say depends on a molecule of water being taken up, suggests that the change of proteid into peptone is also hydrolytic, the peptones being simply an extremely hydrated form of proteid.*

So far we have found that the action of the gastric juice affects proteids alone. Its action on other constituents of food varies. *Gelatinous material* is dissolved by the gastric digestion and rendered incapable of forming a jelly ; its conversion into a form of albumose has been established. The connective tissue of meat and adipose tissue is therefore soon removed, and the muscle-fibres fall asunder, the sarcolemma is dissolved, and the muscle-substance converted into true peptone. The delicate sheets of elastic tissue, such as basement membranes and those of small vessels, are dissolved, but larger masses of yellow elastic tissue are not easily affected by the gastric digestion. The horny part of the epidermis, hairs, &c., and nuclein, are quite unaltered, and most of the mucus passes along the alimentary tract without change. Bone dissolves slowly, the animal part being attacked at the surface by the gastric juice and the acid slowly removing the salts.

On *Milk*, the action of the gastric juice is somewhat peculiar. On reaching the stomach, milk is curdled by a special ferment, *rennin*, formed in the gastric mucous membrane. A fluid known as "Rennet" containing this ferment, is made from the stomach of the calf, and used in the manufacture of cheese. The change of caseinogen to casein, *i.e.*, the true curdling of milk, is not brought about by the hydrochloric acid (although the acid can precipitate the caseinogen), because neutralised gastric juice has the same effect. It appears that this special ferment alters the caseinogen to casein, which clots in the presence of lime salts, and causes the coagulation. It is

* Though proteids will not diffuse through a dead animal-membrane, they may be passed through the wall of the stomach by the living cells. It must be remembered that the gastric mucous membrane is a living active structure. The fact that albumoses cannot be found, in any quantity in chyle or portal blood, tends to prove that they do not pass through the stomach wall by a simple physical process of diffusion.

not due to common lactic ferment, for, though lactic acid is produced, it is formed too slowly to account for the very rapid coagulation of milk which occurs in the stomach.

On *Starch.*—The gastric juice has little effect on *vegetable food* in general, though well-masticated bread may be very materially altered, owing to the action of the saliva on the starch continuing until the mass is broken up, and the gastric juice then dissolving the proteids (gluten). The greater part of the substance of bread, however, leaves the stomach in an imperfectly digested state.

In short, the amount of change which any given form of food will undergo in the stomach, will depend on the amount and exposed condition of the proteid it contains.

In recapitulating the chief events of gastric digestion, it must be remembered that while the food is yet in the mouth, the secretion of the gastric juice commences, and is greatly increased by the arrival of a bolus of food and a quantity of frothy alkaline saliva. As the stomach is filled, more and more secretion is produced, and as some food is absorbed an additional stimulus is supplied. Being kept in motion in a large quantity of liquid, which dissolves the cases in which the food particles are contained, the bolus of food soon falls asunder and each of its ingredients is fully exposed to the action of the gastric juice. The acid reaction of the gastric fluid neutralizes the alkalinity of the saliva, so that the action of the ptyalin is hindered, and the starch granules float about quite unaffected by the pepsin or hydrochloric acid. The heat of the stomach melts the fats, and the motion breaks up the oily fluid into smaller masses. They are then mingled with the general liquid, which becomes more and more turbid owing to the admixture of starch granules, fat globules, dissolved proteoses, and minute particles of partially digested proteids. This dull-grey, turbid fluid is called *chyme*. The proteids (the only food-stuffs affected by the gastric digestion) are changed more or less rapidly according as their particles are small and uncovered, or large and massed together, so that they can be more or less readily reached by the gastric juice. It may be stated as a rule that the more easily soluble the proteids are when used as food, the more readily are they digested. Thus, raw white of egg disappears much more rapidly from the stomach than when firmly coagulated by boiling. The chyme contains but little proteoses, so we may conclude that, when formed, they

:e rapidly absorbed, as are also the soluble sugar and ordinary uids taken with the food. The chyme begins to leave the ylorus soon after gastric digestion has begun, some passing ıto the duodenum in about half an hour. The materials hich resist the gastric secretion, or are affected very slowly by , are retained many hours in the stomach, and the pylorus ıay refuse exit to such materials for an indefinite time, so that fter causing much uneasiness they are finally removed by omiting. However, many solid masses, unchewed vegetables, c., escape through the pylorus when it opens to let out the ıyme.

CHAPTER IX.

INTESTINAL DIGESTION.

THE copious secretions of two of the largest glands of the body—the pancreas and the liver—are poured into the duodenum. This is the widest part of the small intestine, and the extent of the surface of its lining membrane is increased by crescentic, shelf-like projections, called *valvulæ conniventes*. The pancreas being the more important for digestion may be considered first.

PANCREAS.

Structure.—The pancreas is a large compound sacculated or acinous gland, composed of numerous irregular packets of gland-tissue attached by its lateral branchlets to the main central duct. The saccules are elongated, and have the same general construction as those of the serous salivary glands already described, but they are less loosely held together by the intervening connective tissue, and thus the pancreatic tissue does not show such a regular and compact arrangement on section as the salivary glands. The single layer of irregular or slightly conical secreting cells lining the saccule, shows a difference of structure in its central or peripheral sides, so that an external homogeneous zone, and an internal granular zone may be distinguished. Each zone corresponds to one half of the cells, the clear half being next the boundary, and the granular half next the lumen of the saccule. The relative width of these zones varies with the digestive process, so that the nuclei which are situated between them sometimes appear to be in the outer clear zone, and sometimes in the inner granular zone. The outer zone colours readily with carmine whilst the inner zone remains unstained.

The large duct which passes down the axis of the gland receiving tributaries on all sides, is surrounded with a layer of loose connective tissue which forms its outer coat. The proper coat of the duct is composed of elastic tissue, lined by a single layer of cylindrical epithelium.

Pancreatic Juice.

From a temporary fistula the secretion of the pancreas can e obtained in sufficient quantity to determine its character and roperties. It is difficult to establish a satisfactory permanent stula : the secretion soon alters its characters, becoming thin, id losing its efficacy, probably owing to an altered or abnormal ate of the gland.

An artificial pancreatic juice may be extracted by water om the finely minced gland, taken twenty-four hours after eath, (to allow trypsinogen to be converted into trypsin,) om an animal killed during active digestion (a couple of hours ter eating). This extract, used with proper precautions, is und to have the same effect as the secretion itself.

A glycerine solution containing the active principles of the ncreatic secretion may be made from the pancreas by treating e minced gland twenty-four hours after death with absolute cohol for a couple of days, removing the alcohol, and allowing e gland to soak for a week in sufficient glycerine to cover This glycerine extract, filtered, contains but little else than ncreatic ferments.

Characters of the Secretion.—The pancreatic juice of dog is a very thick, transparent, colourless, strongly alkaline id, which turns to a jelly if cooled to 0° C. It often contains out ten per cent. of solids when obtained from a temporary tula, but it may have as little as two per cent.

Of these a considerable proportion are organic, namely :—

I. Ferments. These constitute the largest part of the ganic matter. They are four in number, viz. :—

a. Trypsin.
b. Amylopsin.
c. Steapsin.
d. A milk curdling ferment.

II. A small amount of proteid which is coagulated by heat.
III. Small quantities of leucine and tyrosine.

The inorganic substances are :—

I. Water.
II. Salts.

The chief of these are sodium carbonate and alkaline phosates. To these the juice owes its alkaline reaction.

Mode of Secretion.

The pancreas does not continue in a state of activity during the interval between the periods of active digestion. When the gland is at rest it is of a pale yellow colour, and is flaccid but during active digestion it becomes more turgid, and assumes a pinkish colour from the increased flow of blood. The secretion commences immediately after taking food, and rises rapidly for a couple of hours, then falls and rises again in the later hours of digestion, five to seven hours after a meal: then it gradually falls for eight to ten hours, and ceases completely when digestion is at an end. The first rise which accompanies the introduction of food into the stomach, is certainly brought about by nervous agencies of a similar nature to those of the stomach, the secretion of which follows closely upon mastication. The second accompanies the passage of the undigested food through the small intestines, and may be most conveniently explained as the result of reflex nervous stimulation of the gland-cells.

Nervous mechanism:—The great complexity of the *nervous mechanism* of the glands of the intestinal tract makes it difficult to ascertain the exact channels traversed by the afferent and efferent impulses. The following observations, if accurate, would tend to prove that certain inhibitory impulses pass from the stomach along the vagus to the medulla, and are thence reflected to the gland by its vaso-motor nerves. During vomiting, or when the central end of the divided vagus is stimulated, the secretion of the pancreas ceases. Section of the nerves which surround the blood vessels distributed to the pancreas causes considerable (paralytic) flow of secretion which stimulation of the vagus cannot check.

No nerve-channels have been demonstrated to carry exciting impulses direct to the glands, as the chorda tympani does to the submaxillary; but the direct stimulation of the gland itself or of the medulla oblongata, induces active secretion.

Histological changes in the cells during secretion:—During the period of rest, *i.e.*, no secretion flowing from the duct, and the gland being pale, the gland-cells in the acini undergo a change which may be compared with that observed in the cells of the serous salivary glands. The division of the row of cells lining the acinus, into a central granular and outer clear zone has already been mentioned (p. 144).

Immediately after very active secretion, the central granular ›ne is reduced to a minimum owing to the paucity of granules; ıd the outer zone occupies the greater part of the cell, the ıtire substance of which stains readily and looks like ordinary ·otoplasm. After rest, however, the granules re-appear, and ter the lapse of a short quiescent period, the inner granular ›ne has again encroached on the outer, owing to the accumu- tion of granules, which, rapidly increasing, fill the greater ırt of the cells, and cause them to bulge inwards and occlude ıe lumen of the gland. As digestion proceeds, the cells

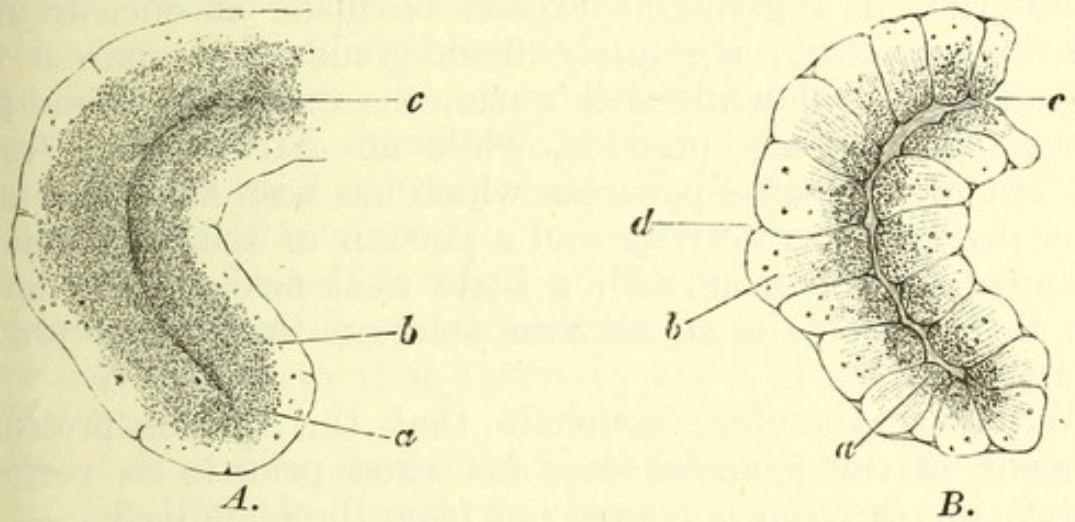


Fig. 74.—One Saccule of the Pancreas of the Rabbit in different states of activity.

After a period of rest, in which case the outlines of the cells are indistinct, and the inner zone, *i.e.*, the part of the cells (*a*) next the lumen (*c*), is broad and filled with fine granules.

After the gland has poured out its secretion, when the cell outlines (*d*) are clearer, the granular zone (*a*) is smaller, and the clear outer zone is wider. (Kühne and Lea.)

ıdergo a slight change in form, so that each individual cell is ›re distinctly seen, and its angles are retracted, giving a ›tched appearance to the margin of the acinus. The blood pply during this period is much increased, red arterial blood ›wing from the veinlets of the gland. At the same time the anules are diminished in number, escaping at the free central ırgin of the cells into the lumen, towards which they appear crowd, leaving the outer zone once more clear and free from anules, while the lumen of the saccule and of the ducts is led with secretion.

The examination of a single cell shows that during the riod of rest, with a comparatively poor supply of blood, it

receives its normal nutrition, which is accompanied by an accumulation of granules in the protoplasm next the free side of the cell. During secretion these granules are pushed out of the cell, and seem in some way to form the secretion.

It will be seen presently that one of the most important functions of the pancreatic juice is the formation of proteoses from proteid, which operation is carried out by a special ferment called *trypsin*. It has been found that this ferment can only be obtained from the active pancreas, and that the wider the inner granular zone of the cells is, the richer in ferment is the glycerine extract made from the gland. But it has also been found that if a glycerine extract be made at once from an actively secreting, absolutely fresh gland, *i.e.*, removed from the dead animal while still warm, the extract is found to be quite inert towards proteids, while an extract made from a portion of the same pancreas which has been kept some hours after death is very active ; and a portion of the fresh pancreas pounded in a mortar with a little weak acid so as to develop the trypsin acts in an alkaline solution and forms proteose energetically.

We must therefore conclude that the special proteolytic ferment of the pancreas does not exist prior to the period at which the secretion is poured out from the gland-cells.

Although a definite relation seems to exist between the amount of granules in the active cells and the degree of efficacy of the secretion, the ferment does not appear in full force for some time after the height of the gland activity has been established.

It has therefore been assumed that the granules of the gland-cells give rise, not to the proteolytic ferment, but to a ferment producing substance which is called a *Zymogen* (*trypsinogen*).

So that, if we trace the history of the pancreatic proteolytic ferment, we shall find that, so far as this trypsin is concerned there can be no question as to whether it pre-exists in the blood and is removed thence by the gland or not, because by studying the process, the final elaboration of the secretion is seen to take place after it has got into the ducts or into the intestinal cavity. Thus the blood gives nutriment to the protoplasm of the gland-cells. The protoplasm of the cells, by its intrinsic chemical processes, manufactures peculiar granules. These granules give rise, among other things, to a zymogen which in the presence of an acid begets trypsin.

Pancreatic Digestion.

The pancreatic juice is, of all digestive fluids, the most neral solvent. It acts upon the three great classes of food-uffs which require modification to enable them to pass through e barrier that intervenes between the intestinal cavity and e blood current. It changes proteids into peptones, emulsifies ty substances, and converts starch into soluble sugar. The ments to which its activity is due may be separately described.

I. *Action on proteids.*—The ferment which produces peptone *trypsin.* Some of the conditions required for its perfect eration are the same as those necessary for the action of the stric ferment *pepsin;* namely, a certain degree of dilution, d a temperature of about 40° C. But it differs from pepsin the most important characteristic of its action. Whilst the esence of an acid is absolutely necessary for peptic proteolysis, find that alkalinity aids this action of the pancreatic ferment. he presence of sodium carbonate seems to play a part which sely corresponds to that taken by the hydrochloric acid in stric digestion.

A series of bodies similar to those already described under stric digestion, is found to occur in tryptic hydrolysis, mely, primary and secondary proteoses and peptones, but re associated with alkali-albuminate in place of the acid uminate of the gastric digestion.

This change as accomplished by the trypsin, is not accom-nied by any swelling of coagulated albumin such as occurs stomach digestion, but the proteid is gradually eroded from e surface and thus diminished in size.

Besides these differences between the mode of action of psin and trypsin in producing proteoses and peptones, trypsin s a peculiar power upon proteids, which has no analogue in e peptic action. After the pancreatic peptone has been duced, a further change occurs, which gives rise to the mation of two crystallizable nitrogenous bodies known as *cine* and *tyrosine*, the former belonging to the fatty acid, and e latter to the aromatic acid group. These substances, which e commonly found together as a result of the septic decom-sition of peptones, seem inseparable from pancreatic digestion ere they depend in part on the action of the trypsin.

The amount of proteose and peptone produced reaches a ximum in about four hours, after which the proportion of

the different decomposition products appears to increase at the expense of the peptone.

This breaking-up of the surplus proteid food into bodies which cannot be of much utility in the economy, and which as will appear hereafter (compare Chap. XXIII.), are but a step in the direction of their elimination, is probably an important part of the pancreatic function, as it relieves the economy of a surcharge of albuminous substances.

II. *Action on Fat.*—The action of the pancreatic juice on fats is of two kinds. (*a.*) Saponification.—By the action of a special ferment (*steapsin*) a small proportion of the neutral fat is split up into glycerine and the corresponding fatty acids. The acids thus produced readily unite with the alkali present to form soap. The chemistry of the change will be found at p. 62, but may here be shortly stated, taking oleine as an example. Oleine is a compound of oleic acid and glycerine. Oleine in presence of this ferment and soda gives glycerine and oleic acid, and the latter combines with soda to form sodium oleate or soap. This process materially aids in the next (*b.*) Emulsification.—Which means that the fat is reduced to a state of very fine sub-division, as it exists in milk. The production of this condition is facilitated by (1), the albumin in solution; (2), the alkalinity of the fluid; (3), the presence of soap alluded to above; and (4), the motion of the intestine. This process of emulsification may be imitated by adding about one quarter volume of rancid linseed-oil to a solution of sodium carbonate and shaking in a test-tube. It will be found that the addition of a little soap and albumin, (to complete the analogy with the intestinal contents, where emulsification normally takes place,) will make the emulsion more perfect and more permanent.

III. *Action on Starch.*—The amylolytic power of the pancreatic juice depends on a separate ferment (*Amylopsin*). Its action is identical with that of the saliva, converting the starch into dextrines and maltose (see p. 129) with the exception that it is more rapid and energetic, and affects raw as well as boiled starch. In fact, this is the most active ferment in the body. It is found to exist in the extract of the gland, whether it has been removed from a fasting or from a recently fed animal: the ferment therefore exists in sufficient quantity in the gland whether engaged in active secretion or not. This pancreatic ferment is not found in the pancreas of children for a period about equal to that of their suckling.

Bile.

The Liver has many important functions which may be thus enumerated.—(1.) Formation of urea, uric acid, &c. (2.) Formation of glycogen. (3.) Elimination of some injurious constituents from the blood. (4.) Secretion of Bile. The last must be treated of in this section concerning digestion, the others belong to a future chapter.

Method of obtaining Bile.—For most practical purposes the bile from the gall-bladder of recently killed animals is sufficient. The bile pigments and cholesterin may be conveniently obtained from the gall-stones so often found in the human gall-bladder.

In order to investigate the composition of the bile as it comes from the ducts, before it has been modified by its sojourn in the gall-bladder, it is necessary to make a biliary fistula, communicating either with the gall-bladder or better with the bile-duct. In this way the rate, pressure, and other points concerning the mode of secretion may be determined.

Composition of Bile.—The bile of man and carnivorous animals is of a deep orange-red colour, turning to greenish-brown on oxidation of its colouring matter. In herbivorous animals it has some shade of green when quite fresh, but turns to a muddy brown after a time. It is transparent, and more or less viscid according to the length of time it has remained in the gall-bladder. It has a strong bitter-sweet taste, and a peculiar aromatic odour. It is neutral or faintly alkaline, but after remaining for some time in the gall-bladder it becomes more strongly alkaline. Its specific gravity is about 1010 when taken from the bile-ducts directly, but it may rise to 1030 after prolonged stay in the gall-bladder, owing to the absorption of some of its fluid and the addition of mucus.

The following table gives approximately the proportions of the chief constituents of bile :—

Water	85·0 per cent.
Bile-salts	10·0 „
Colouring matter and mucus . .	3·0 „
Fats	1·0 „
Cholesterin	0·3 „
Inorganic salts	0·7 „
	100·0

Bile contains no structural elements nor any trace of albuminous bodies.

I. The *bile-acids* are two compound acids, glycocholic and taurocholic, which exist in the bile in combination with sodium. The amount of each varies in different animals and at different times in the same animal. The bile of the dog and other carnivora contains chiefly taurocholate of soda. In the ox the glycocholate of soda is greatly in excess. In man both are present, the proportion being variable, but the glycocholate greatly preponderates.

To separate these acids, bile is evaporated to one-fourth its volume, rubbed to a paste with animal charcoal to remove the pigments, and carefully dried at 100° C. The black cake is extracted with absolute alcohol, which dissolves the bile-salts. From the strong alcoholic solution, after partial evaporation, the bile-salts can be precipitated by ether. They first appear as an emulsion, and then form glistening crystals which are soluble in water or alcohol, but insoluble in ether.

From a solution of the two salts the glycocholic acid may be precipitated as lead glycocholate, by neutral lead acetate. This is collected on a filter, washed and dissolved in hot alcohol. The lead is then removed, as lead sulphide, by passing a stream of sulphuretted hydrogen through the solution, and filtering. To the filtrate water is added, when the glycocholic acid separates in a crystalline form. The taurocholate remaining in the filtrate, is precipitated as lead taurocholate by the addition of basic lead acetate, and ammonia. Taurocholic acid is obtained from this in a manner similar to that used in the preparation of glycocholic acid.

Glycocholic acid when boiled with weak acids, alkalies, or baryta water, takes up an atom of water, and splits into cholalic acid and glycine. (See p. 49.)

Taurocholic acid, under similar treatment, splits into cholalic acid and taurine. (See p. 49.)

In the intestine the bile-salts are decomposed by the acid gastric chyme, bile acids being precipitated. The bile-acids apparently are also split up into cholalic acid, glycine, and taurine, but these are largely absorbed from the intestine, for we find only small quantities of them in the fæces.

In experimenting on an animal with a biliary fistula, when all the bile is removed we find that in a short time the specific gravity of the bile collected falls considerably, and this has been shewn to be due to a greatly diminished secretion of bile

alts. If such an animal be now fed with bile—the specific ravity of the secretion again goes up and the bile contains a arge quantity of bile salts.

So there is apparently a continuous circulation of these roducts. The cholalic acid, glycine, and taurine absorbed from ie intestine are converted into bile acids again by the liver, nd re-secreted as bile salts.

Bile salts have not been detected in the normal blood and there no accumulation of them in the body after the removal of the ver : hence it is concluded that they are manufactured by the ver, chiefly from their factors absorbed from the intestine.

II. The substance in bile that gives it its characteristic iscid and slimy properties has been shewn to consist chiefly of nucleo-albumin, not altogether of mucin as was formerly ated, though a small quantity of mucin is always present. It probably secreted by the numerous glands in the walls of ie ducts and the gall-bladder.

III. The pigments present in the bile are named *bilirubin* id *biliverdin*. The latter preponderates in the bile of many erbivora. Both are present in human bile, but it is generally ated to contain more bilirubin. Neither contain any iron. n oxidation bilirubin is first converted into biliverdin, and ien passes through other stages, finally becoming yellow ; is final product is termed *choletelin*. It is insoluble in water, ly slightly soluble in alcohol, but very soluble in chloroform. iliverdin on the other hand is insoluble both in water and loroform, but very soluble in alcohol. With the spectroscope lirubin shows considerable absorption of the violet end, and liverdin of the red end of the spectrum. If solutions of either these pigments be treated with reducing agents (sodium nalgam) they are converted into hydrobilirubin, a substance lied to, but not identical with *stercobilin*. Bilirubin is entical, in chemical composition, with *hæmatoidin*, a deeply loured material found, in rhombic crystals, by Virchow in old travasations of blood within the body. Bilirubin is also und in the crystalline form. The bile pigments increase in iantity if the colouring matter of the blood be injected into e portal vein. Hence the bile pigment is said to be derived om the colouring matter of the blood (*hæmoglobin*). Probably e hæmoglobin of red corpuscles which have been broken in the spleen or other organs is converted into bile-pigment the liver.

IV. *Fatty matters*, the principal of which are lecithine,

palmitine, stearine, oleine, and their soda soaps in small quantities.

V. *Cholesterine* ($C_{26}H_{43}.OH$) is an alcohol, and crystallises in clear rhombic plates, insoluble in water but held in solution by the presence of the bile salts. It can be obtained from gall-stones, the pale variety of which are almost entirely composed of it. The cholesterine leaves the intestine with the fæces.

VI. Among the *inorganic salts* are sodium and potassium chloride, calcium phosphate, some magnesium, and iron. This latter is present in the form of a phosphate. The quantity is small in proportion to the amount of hæmoglobin destroyed to form the bile-pigments which we saw were iron-free. The rest of the iron is stored, as a proteid compound, in the liver cells.

Tests for Bile.—The most important constituents of the bile viz., the bile acids and pigment, may be detected by appropriate tests, which are in common practical use :—

1. Pettenkofer's test for the bile-acids :—To a fluid containing either or both bile-acids, or any solution of *cholalic acid*, add a very small quantity of cane-sugar and then slowly drop by drop, strong sulphuric acid. The solution turns to a cherry-red and then changes to purple. As other substances, such as albuminous bodies, give under this treatment a similar colour, in order to make the reaction a decisive test for bile salts, the two characteristic absorption bands shown by the spectroscope should also be observed.

   The following is said to be a characteristic method :—Rinse out a porcelain capsule successively with the fluid to be tested, and with a weak solution of sugar, and then add strong sulphuric acid, on standing or heating to 70° C. the acid turns purple.

2. Gmelin's test for the bile-pigments depends upon the fact that during the stages of oxidation the bilirubin undergoes a series of changes in colour which follow the familiar sequence of the solar spectrum. Place a few drops of the fluid to be tested on a white surface (capsule or plate), and allow a drop of nitric acid yellow with nitrous acid fumes which make it more oxidising, to run into it ; as they mingle together the rainbow-like play of colour appears. This, when watched, will be found to consist of a series

changes to green, (biliverdin) blue, violet, red, and yellow (choletelin).

This can also be observed by allowing the acid to trickle gently down the side of a test-tube fixed in an inclined position so that it cannot be shaken : the play of colour can then be seen starting from the point of junction of the two fluids.

Method of Secretion of Bile.

The secretion of the liver varies less in the amount formed at ifferent times than that of other digestive glands. Although he changes in the rate of its secretion are not so marked, they ollow the same general rule as those of other glands connected ith digestion, *i.e.*, after food is taken there is a sudden rise, hen a gradual fall, followed by a second rise in the rate of ecretion. This is not so well seen as in the case of the ancreas. Want of food is said to check the secretion of bile, ut only does so in a slight degree, for the more important ork of the liver is continuous, as is the activity of all glands hose duty it is to eliminate noxious substances or otherwise nfluence the composition of the blood. At the end of a period f fasting, the gall-bladder is always found greatly distended, ecause the secretion has continued to flow into that receptacle, nd there has been no call for its discharge into the duodenum.

The amount of bile produced by dogs is much influenced by heir diet. It is very great when meat alone is consumed, less ith vegetable, and very small with a diet of pure fat. As a eneral rule bile is more abundantly produced in herbivorous, han in carnivorous animals.

The rate of secretion is much influenced by the amount of lood flowing through the organ, which probably explains the ncrease during digestion. Ligature of the portal vein causes rrest of the secretion, and death. After ligature of the epatic artery the secretion continues, but soon diminishes rom malnutrition of the tissue of the liver, which ultimately auses death if the entire vessel be tied.

These variations in the rate of secretion may depend on lirect nervous influence, but no special secretory nerve nechanism has been discovered for the liver, and it is quite ossible that the changes in the activity of the gland, which ccompany the different periods of digestion, may be accounted

for by changes in the intestinal blood-supply, which give rise to corresponding differences in the amount of blood flowing through the portal vein.

The force with which the bile is secreted is very small. That is to say, the pressure in the ducts never exceeds to any great degree that of the blood in the portal vein : but, on the contrary, when a pressure of about 16mm. mercury is attained, (that of the portal blood being normally not more than 10mm.) the flow of the bile ceases, and with a little increase of opposing force the fluid in the manometer falls and finds its way into the blood. This is made obvious by experiment, by which it can be shown that with a comparatively low pressure, about 8 in. of water for a guinea-pig, fluid can be forced into the circulation from the bile-ducts, viâ lymphatics. The fact that the flow in the gall-ducts stops at this low pressure does not imply any want of secretory power on the part of the liver-cells, but merely, that there exists a great facility of communication between the duct-radicles and the lymphatics. The liver-cells continue to secrete and the animal becomes jaundiced.

This is seen also in stoppage of the bile-ducts in the human subject, when some of the bile-constituents continue to be formed, and pass into the blood, where their presence is demonstrated by the yellow colour characteristic of jaundice. The ready evacuation of the bile is a matter of great importance for health, the least check to its free exit causing the secretion to be forced into the lymphatic system instead of into the gall-passages. Under normal circumstances, the large receptacle of the gall-bladder being always ready to receive the bile, ensures its easy exit from the ducts, but the forces which cause its flow are extremely weak. The smooth muscle in the walls of the duct seems rather for the purpose of regulating than aiding the flow.

When food from the stomach begins to flow into the duodenum, the muscular coat of the gall-bladder contracts and sends a flow of bile into the intestine, which action is doubtless brought about by a reflex nerve impulse, for it is only when this part is stimulated that the bile flows freely from the bladder. The acid gastric contents seem to be the most efficacious stimulus.

In the human subject the quantity of bile secreted has been found to be about 600 cc. (21 oz.) per diem in cases where there were biliary fistulæ. This would equal about 13 grms. per kilo of the body-weight.

In the guinea-pig and rabbit, it has been estimated to be bout 150 grms. per kilo of body-weight.

Functions of the Bile.

1. *Neutralising and precipitating gastric chyme.*—When the id contents of the stomach are poured into the duodenum and eet with a gush of alkaline bile, a copious cheesy precipitate formed which clings to the wall of the intestine. This recipitate consists partly of compounds of the bile salts with e unaffected albumen, proteoses, &c., and partly of bile-acids, e salts of which have been decomposed by the hydrochloric id of the gastric juice, the soda at the same time neutralising e acid. With the bile-acids the pepsin is mechanically arried down, peptones are however not precipitated. The recipitated albumen, &c. is viscid and probably adheres to the ucous membrane, allowing the useless matters to pass on while remains.

Thus, immediately on their entrance into the duodenum the eptic digestion of the gastric contents is suddenly stopped not nly by the precipitation of the albumin and proteose, but also y the removal of the pepsin itself, and the neutralisation of e gastric fluid by the bases of the bile. By thus checking e action of the gastric ferment the bile prepares the chyme r the action of the pancreatic juice.

2. *As a stimulant*, the bile is of considerable use, in that it xcites the muscles of the intestine to increased action, and ereby aids in absorption and promotes the forward movement f food, and more particularly of those insoluble materials hich have to be evacuated per anum. This stimulation may mount to mild purging.

3. *Moistening and lubricating.*—The bile adds to the ingesta a abundant supply of fluid and mucus, much of which passes long the intestine to moisten and lubricate the fæces and cilitate their evacuation. In cases of jaundice, or when the ile is removed by a fistula, the fæces are hard and friable, and ith difficulty expelled, owing to the deficient fluid and mucus, s well as to the weaker peristaltic movements.

4. *As an aid to absorption.*—The bile having some soap in lution has a close relationship to both watery and oily fluids, nd possibly on this account, as well as owing to a peculiar ower possessed by the bile-salts, a membrane saturated with ile allows an emulsion of fat to pass through it much more

readily than if it were kept moistened with water. This ca
be seen experimentally with filter-paper. The bile thus acts a
an important adjunct to the pancreatic juice.

In practice the influence of the bile on the absorptio
of fats can be recognised by the fatty fæces which occur i
fats be eaten when the ducts are occluded so that the secretio
cannot enter the intestine.

5. *As excrement.*—Although much of the bile is reabsorbe
from the intestinal tract into the blood, and again used in th
economy, some of its constituents pass off with the fæces, an
are no doubt simply excrementitious matters that must be go
rid of. Thus all the cholesterine, mucus, nuclein, and colourin
matter are normally eliminated, and some of the cholalic-acid
glycine, and taurine are found in the fæces.

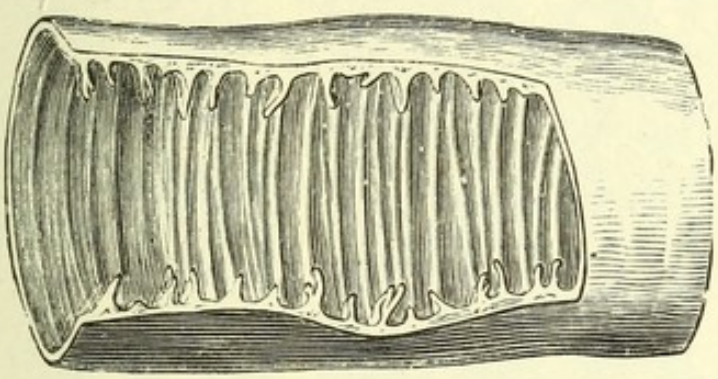
6. *Emulsification of fats.*—The bile has some share in formin
an emulsion, but far less than the secretion of the pancreas
however, the mixed secretions are probably more efficacio
than either separately, from the presence in the bile of free fatt
acids, which form soaps and so aid in forming the emulsion.

7. *As an antiseptic,* bile has been said to have some functio
to perform. Possibly it restricts the formation of certain o
the bye-products, such as the indol resulting from pancreati
digestion; but it is certainly not *antiseptic*, since bacteri
abound and thrive in it, both when removed from the body, an
in the duodenum.

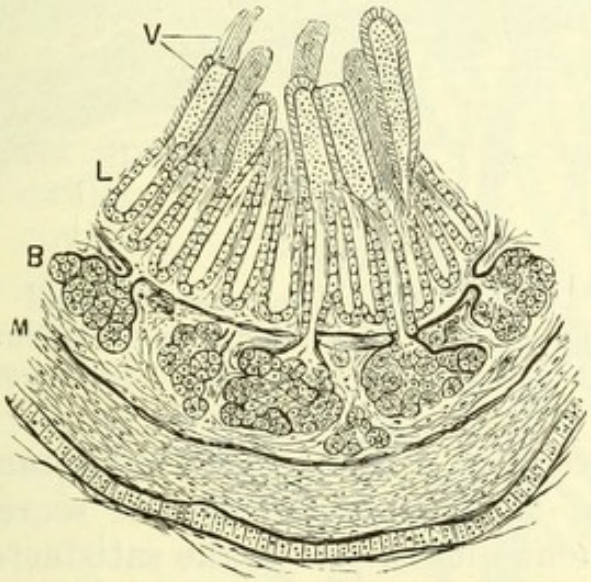
CHAPTER X.

FUNCTIONS OF THE INTESTINAL MUCOUS MEMBRANE.

Two distinct varieties of glands are found in the small ıtestine. Those known as Brunner's glands, are localised to



ig. 75.—Portion of the Wall of the Small Intestines laid open to show the valvulæ conniventes. (Brinton.)



'ig. 76.—Drawing of transverse section of the duodenum showing Brunner's Glands. (B) Opening into Lieberkühn's follicles (L), (V) villi, (M) muscular coats.

he submucosa of the duodenum. They are insignificant in ıumber when compared with the second variety, called

Lieberkühn's follicles, which are distributed over the entire intestinal tract and are closely set in the mucous membrane.

Brunner's glands form, in some animals, a dense layer in the submucous tissue of the beginning of the duodenum ; they are

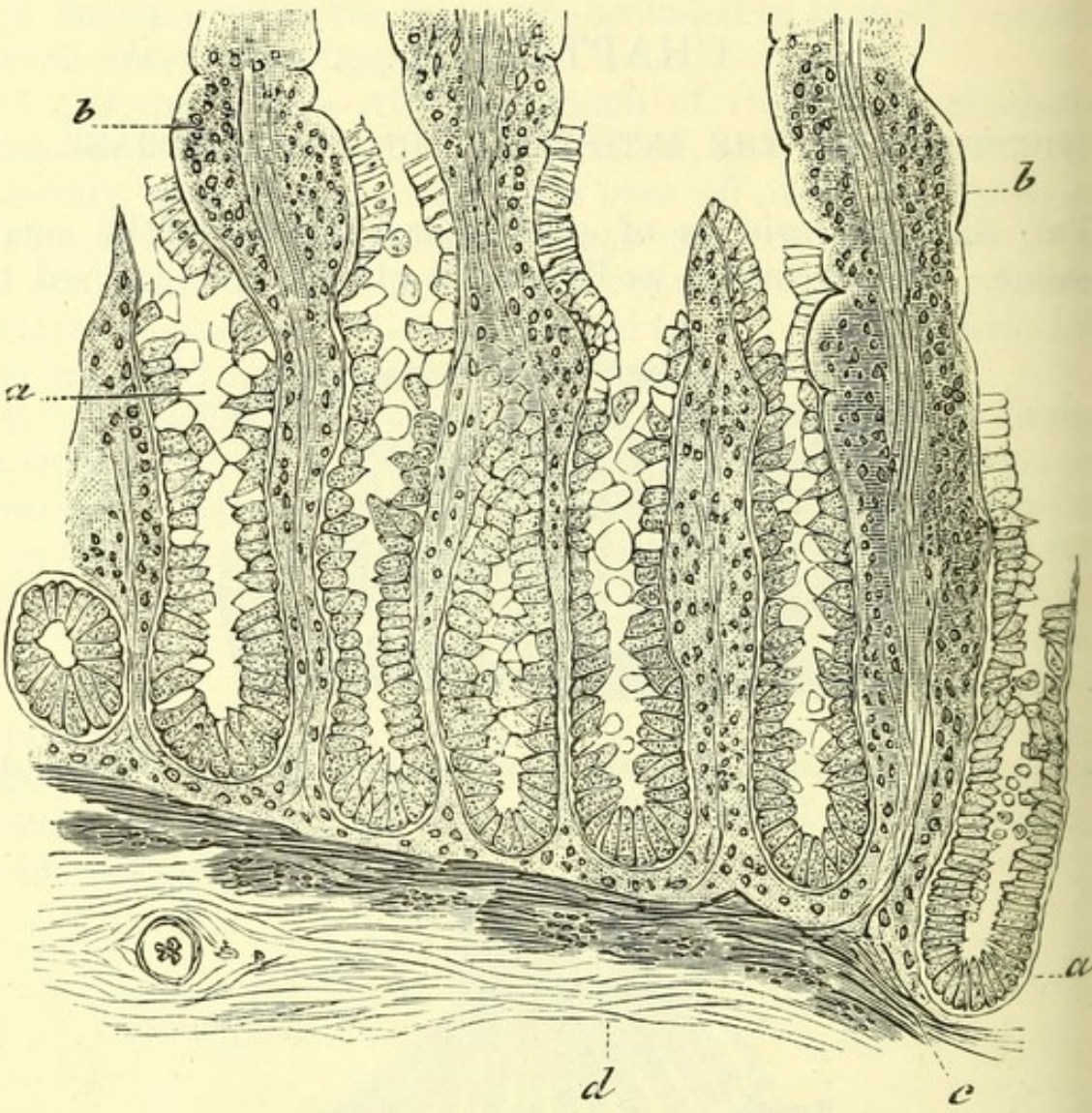


Fig. 77.—Section of the Mucous Membrane of small intestine, showing Lieberkühn's follicles (*a*) with their irregular epithelium and the villi (*b*) passing out of view ; (*c*) Muscularis mucosæ ; (*d*) Submucous tissue. (Cadiat.)

small branched saccular glands resembling mucous glands in structure. Owing to their small size the secretion cannot be obtained in sufficient quantity to make satisfactory experiments in respect to its properties. It is said to dissolve albumin and to have a diastatic fermentative action, so that probably the secretion is analogous to that of the pancreas, as Brunner originally supposed. The quantity of fluid secreted by these glands is so small that its existence is not taken into account in speaking of the intestinal juice, by which is meant the fluid

oured out by the in-
umerable short tubes
r follicles of the in-
estine.

These *Lieberkühn's*
llicles belong to a very
mple form of gland,
ach one being a single
raight cavity in the
ucous membrane
ardly deep enough to
eserve the name of a
ube. In the small
ntestine they are set
s closely as the villi
ermit. (Fig. 77.) In
ne large intestine,
here the villi are
bsent, they are more
osely set and are also
eeper. They are
ounded by a thin
asement membrane
hich is embraced by a
ose capillary network
blood-vessels, and
e lined by a single
yer of cylindrical or
herical epithelial cells.
The epithelial cover-
g of the processes
nown as villi, which
e studded all over the
ucous membrane of
e small intestine, pro-
uces some mucus.

ETHOD OF OBTAINING
TESTINAL SECRETION.

Considerable difficulty
s been found in obtain-
g the proper intestinal

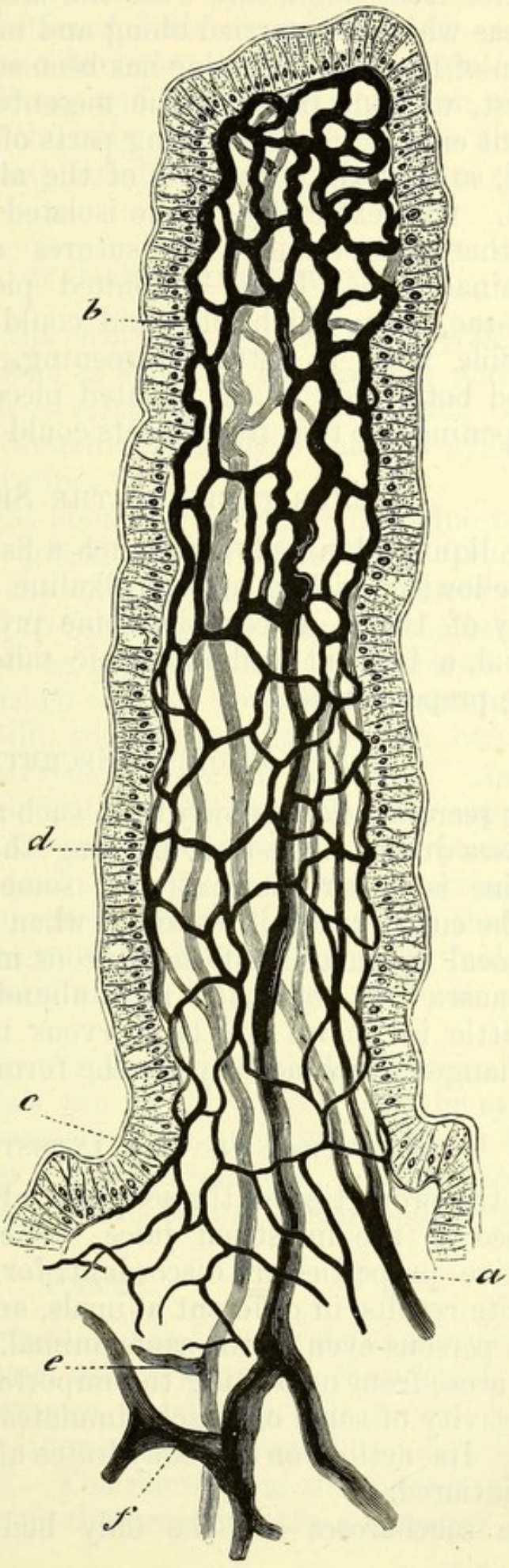


Fig. 78.—Villus with the capillaries injected showing their close relation to epithelium, some of the cells of which are distended with mucus. (Cadiat.)

juice free from admixture with the secretions of the liver and pancreas which are carried along and mixed with it. A short portion of the small intestine has been successfully isolated from the rest, without injuring the mesentery or its blood-vessels. The cut ends of the remaining parts of the intestine were first united, so that the continuity of the alimentary tract was preserved. One extremity of the isolated portion was closed, and the other was retained by sutures at an opening in the abdominal wall. Thus, a limited piece of gut, forming a cul-de-sac, from which the fluid could be collected, was made accessible from a fistulous opening. (Thiry.) By another method both ends of the isolated piece were attached to fistulous openings, so that its contents could be washed out. (Vella.)

Characters of the Secretion.

The liquid obtained from such a fistula is thin, opalescent and yellowish, with a strong alkaline reaction and a specific gravity of 1011. It contains some proteid and other organic material, a ferment and inorganic salts in which sodium carbonate preponderates.

Mode of Secretion.

The secretion flows slowly from such a fistula, but the amount increases during digestion, showing that the secretion of the intestine is under the control of some nerve centre which can call the entire tract into action when one part is stimulated. The local stimulation of the mucous membrane makes it red and causes it to pour out a more abundant secretion. Beyond this little is known of the nervous mechanism or the local cell-changes which accompany the formation of the secretion.

Functions of the Intestinal Juice.

All the properties of the secretion of the pancreas have been ascribed to the intestinal juice. The observations as to its digestive properties are discordant, for experiments have given opposite results in different animals, and in the hands of different persons even in the same animal. This discordance probably arose from neglecting the important influence of bacteria, the activity of some of which simulates the action of pancreatic juice. Its action on carbohydrates alone, has been definitely substantiated.

The saccharoses are the only bodies affected. Starches

extrines, &c., remaining unaltered. Cane-sugar is inverted, *i.e.* hanged into equal quantities of dextrose and lævulose.

Maltose is converted into dextrose. This is important, as we ave seen that both salivary and pancreatic digestion change :arch into maltose, yet the only sugar found in the blood is extrose. This can be explained by the above action of the ıccus entericus.

Function of Large Intestine.

In the large intestine the secretion of the long, closely-set ieberkühn's follicles alone is found. Its reaction and that the mucous membrane is alkaline, but the contents of the)lon are acid, owing to certain fermentative changes which go ı in this part of the intestine.

Of the changes brought about in the large intestine by the gency of the digestive juices we know but little. Judging om the large size of the cæcum and colon in herbivorous ıimals, we are prompted to conclude that vegetable substances fficult of solution, such as cellulose, can be dissolved here. robably this is accomplished only by fermentative action.

Although devoid of villi, the large intestine can certainly)sorb readily such materials as are in solution. As the soluble materials pass along the small intestines the supply of ıid is kept up to about the same standard, the absorption and cretion being nearly equal ; but in the large intestine, the)sorption of the fluid so much exceeds the secretion that the ıdigested materials are gradually deprived of their fluid, and e converted into soft solid masses which pass on to be added the fæces.

Owing to its absorbent power, the large intestine forms a ready ıannel by which materials can be introduced into the system cases in which the stomach is too irritable to retain food. e know nothing of the special mechanism of digestion or sorption, if any such exist, in this part of the alimentary tract.

Fæces.

The quantity of fæces evacuated in the day depends upon the nd of diet, being greater with a vegetable than meat diet, eraging about 150 grammes a day (60–250 grms.). This ıount may be greatly increased by partaking largely of digestible forms of food. The more rapid the passage of the gesta through the intestine the greater is the amount of fluid

remaining with the fæces, so that any stimulant to the intestina movements reduces the consistence of the fæces and facilitate the evacuation. The fœtor depends in a great measure on th presence of indol, which is an outcome of bacterial activit and also upon the presence of certain volatile fatty acids. Th colour depends upon the amount of the bile pigment and th degree of change the latter has undergone.

The fæces are composed of (1) the undigested parts of th food, and (2) the useless or injurious parts of the secretions o the various glands. In the first category we find perfectl indigestible stuffs, such as, yellow elastic tissue, horn structures, portions of hairs, from animal food, and wood fibre, spiral vessels (cellulose) from plants, and also masses o digestible substances which have been swallowed in too larg pieces to be thoroughly acted on by the secretions. All form of food may thus appear in the fæces, but vegetable substanc are most conspicuous.

In the second category—which with medium diet is far i excess of the other—we find a variable quantity of muci and the decomposed colouring matter of the bile, together wit some cholalic acid, cholesterin, &c.

A few inorganic substances are found, mainly those whic diffuse with difficulty, as calcium salts and ammonio-magnesiu phosphate.

Putrefactive Fermentations in the Intestine.—Wi the air and saliva which are swallowed mixed with the foo large numbers of the lower organisms existing in them a introduced into the alimentary canal.

The effect of these organisms is to produce certain ferme tative changes quite distinct from the action of the spec ferments of the digestive fluids.

Large numbers of the bacteria swallowed with the food a destroyed by the acid of the gastric juice, hence no fermentati occurs normally in the stomach. Though fermentation vigorous in the alkaline pancreatic juice, it is in the la intestine that putrefactive ferments have greatest effect, the a reaction being caused by the various acids thus produced.

On the carbohydrates their chief effect is the production lactic acid followed by the butyric acid fermentation. Cellul is split up by them, CO_2, CH_4, and other products be produced. This is probably the only change cellulose underg in the intestinal tract.

On fats the action of these ferments surpasses that of eapsin, since lower acids are produced.

Proteids are hydrated, but the process does not stop at the tage of peptones. Hemipeptone is the substance chiefly ffected, leucine, tyrosine, indol, skatol, cresol, phenol, ulphuretted hydrogen and ammonia being found among the roducts of the change.

It is probable that the bacteria bring about some results that re useful to the economy, for it appears that some injurious ubstances (*e.g.* the very poisonous body choline, which appears uring the digestion of lecithin) are converted into harmless roducts such as marsh-gas and CO_2.

The gases of the intestine consist of CO_2, CH_4, H, N and H_2S.

The CO_2 is produced from carbonates, acetates, and alcoholic ermentation of glucose, by the putrefaction of cellulose, and rom choline.

The CH_4 comes from the decomposition of cellulose, choline, c. The H is formed during the butyric acid fermentation of actic acid. The N is derived from the swallowed air. The H_2S comes from the decomposition of proteids. Only small uantities are found, as it rapidly diffuses through the mucous nembrane and is carried away by the blood.

Summary of Intestinal Digestion.

From the foregoing account of the intestinal secretions it ay be seen that the changes which the various kinds of food ndergo on their way through this part of the alimentary tract re numerous ; a short review may therefore be useful.

When the acid gastric chyme escapes into the duodenum a ow of bile takes place from the gall-bladder, and at the same me the secretions of the pancreas, Brunner's glands, and ieberkühn's follicles are poured copiously into the intestine. he bile meeting with the turbid fluid chyme causes it to hange to a soft cheesy granular mass, the appearance of which epends chiefly on the precipitation of the albumins, proteoses, c., in combination with the bile salts. The pepsin is rendered owerless, both it and the bile acids being carried down with ne precipitate. Gastric digestion is thus arrested and the nward flow of the fluid chyme checked. As the alkaline pan- reatic and intestinal juices meet this semi-fluid cheesy mass

the conversion of starch into sugar proceeds rapidly, even th raw starch granules being changed. The small oil globule come in contact with the alkaline mixture of bile and pancreati juice, and the pancreatic ferment *steapsin* splits up some of th fat separating the fatty acid from the glycerine radicle. Som of the soda of the bile salt is substituted for the latter, an uniting with the fatty acid forms a soap. In such a mixtur as this—an alkaline fluid with proteid and soap in solution— fine emulsion is readily formed.

The precipitated and finely divided proteids are presented t the pancreatic juice in a form which it can easily attack, an thus their hydration goes on rapidly.

How far the peculiar action of trypsin on proteids, convertin a part of them into leucine and tyrosine, goes on in norma digestion is not known. It is supplemented by the action o putrefactive bacteria, and it is probable that the production o leucine and tyrosine is increased with the over-abundant inges tion of proteid or a purely meat diet, and is useful as a means o preventing the injurious effects of too great proteid ingestion.

The gastric chyme is therefore completely changed in th duodenum, and throughout the small intestine we find, in i stead, a creamy fluid which clings to the mucous membran coats over its folds and surrounds the long villi of the jejunun &c. This intestinal chyme is the form in which the food presented to the mucous membrane for absorption. resembles somewhat by its whiteness the fluid called chy which flows in the lacteals, and formerly was considered to b identical with it. This creamy coating is the chief materi found in the upper part of the small intestine, the coarser par of the food being hurried onwards by peristaltic action to th large intestine.

Self-Digestion.

To the interesting question, why the digestive juices do n dissolve the tissues of the organs in which they are containe we cannot give a positive answer. If a piece of the gastric wa be ligatured within the stomach, and thus cut off from its bloo supply, it is rapidly digested, but not because of the loss of th alkalinity of the blood, suggested as normally checking the ac gastric secretion, for this could have no preventive effect the duodenum. We can no longer say, with John Hunte that "the vital principle" has a protective influence, for v

now that the fact of a tissue being alive, is not sufficient o ward off the digestive action of the alimentary juices. The eg of a living frog (Bernard) or the ear of a rabbit (Pavy) are igested when introduced through a fistula into the stomach f a dog. When the gastric juice trickles from a fistula, the neighbouring skin soon becomes eroded, the snout and tongue of the animal, owing to its licking the fluid, are rapidly ligested, so as to destroy the skin and even expose the blood-vessels.

We must then modify John Hunter's statement by saying hat it is not owing to an abstract vital principle, but a pecial resisting power dependent upon the specific character of he vital processes of those textures which manufacture, and re habitually exposed to the influence of the juices. Can we guess wherein this resisting power lies? There are present in ll active protoplasmic units substances which are not readily ffected by the digestive juices, viz., nucleo-albumin and nuclein. May not the manufacture of a constantly-renewed protective coating, be part of the functional activity of the epithelial cells hroughout the alimentary canal?

CHAPTER XI.

ABSORPTION.

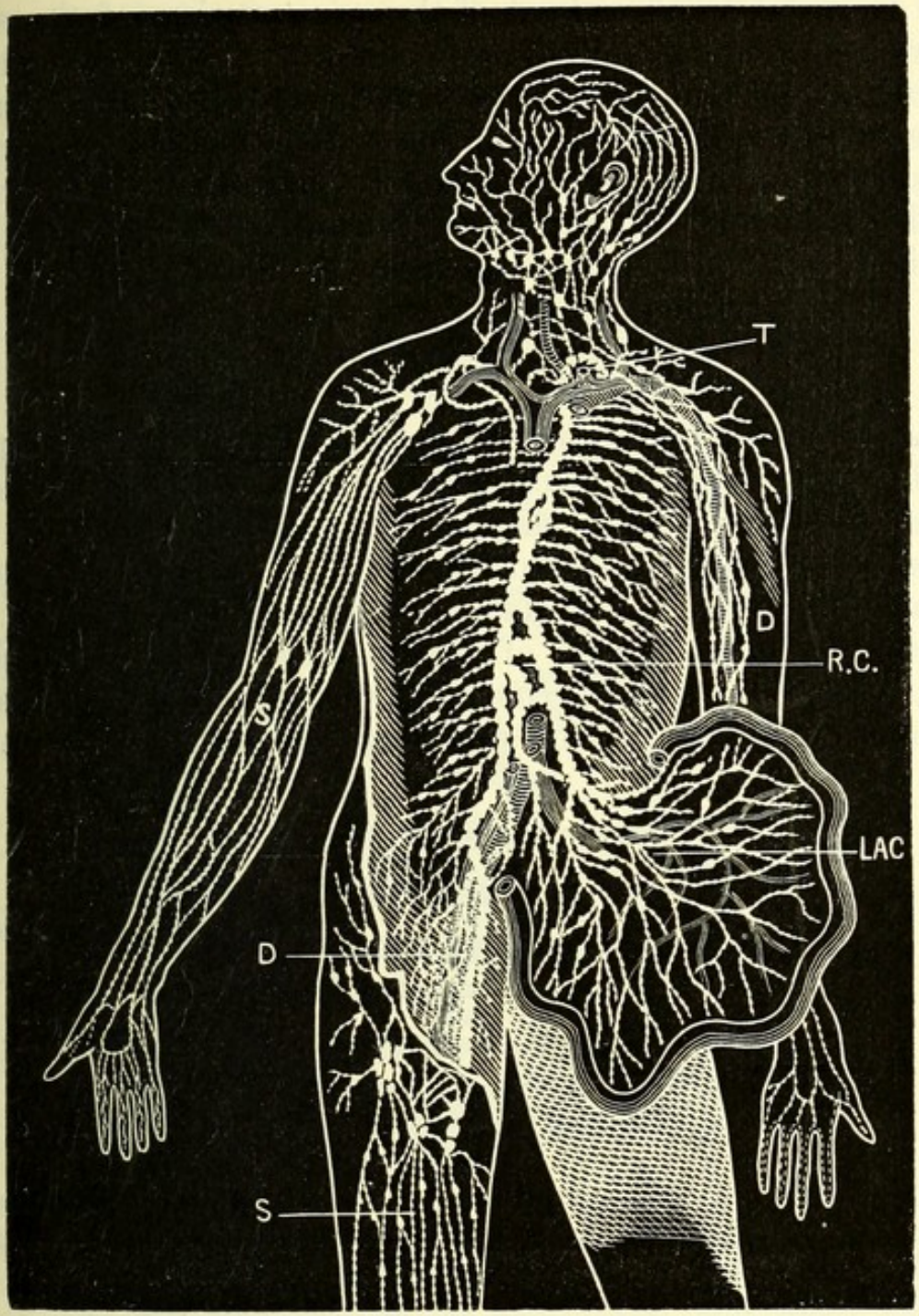
THE nutritive materials must be taken up and distributed t the textures and organs, in order that the various processes described under digestion of the food-stuffs, may be of any us to the economy. For this purpose they must pass through th lining membrane of the alimentary canal and gain access to th blood, which is the common mode of intercommunication be tween the various parts of the body.

The nutrient part of the food has then to be *absorbed* out o the alimentary canal by the surrounding tissues, and mixe with the general circulating fluids, lymph and blood.

But the blood is separated from the intestinal contents b barriers, which, as far at least as the blood is concerned, are im passable, although it exerts considerable pressure, and thereb tends to escape from the blood-vessels.

The question then arises—How does the elaborated chym make its way through this barrier, which is sufficient to preven the flow of blood into the intestinal tract ?

The general answer is easily given, viz. :—the blood canno pass through an animal membrane. But this is not a satis factory solution of the question, for under certain abnorma circumstances, the blood does pass through the wall of th vessels, and normally the plasma escapes from the capillarie into the tissues, in order to nourish them. We must furthe remember, in considering this point, that the wall of the vessel and the membrane lining the intestine are both made up o living cells which are endowed with a capability, co-inciden with their lives, of controlling any passage through or betwee them. Some of these cells, which we might call secretin agents, do allow, or rather cause a passage of fluid from th blood to the intestinal cavity, and, as we shall presently se others of them induce a passage of the nutritious materials fro the intestinal canal into the surrounding tissues.



ig. 79.—Diagram showing the course of the Main Trunks of the Absorbent System. The lymphatics of lower extremities (D) meet the lacteals of intestines (LAC) at the receptaculum chyli (R. C.), where the thoracic duct begins. The superficial vessels are shown in the diagram on the right arm and leg (S), and the deeper ones on the left arm (D).

The glands are here and there shown in groups. The small right duct opens into the veins on the right side. The thoracic duct opens into the union of the great veins of the left side of the neck (T).

In order clearly to understand the method by which absorp-on is accomplished, it is necessary to have some idea of the bsorbent system generally ; it may be well, therefore, at this

place to give a brief account of the construction of the speci apparatus which carries on this function. Although the ab sorbent vessels form one continuous system, they may b conveniently divided into two departments, namely, interstiti and surface absorption. A certain modification of the latte called the lacteal system, occurs in the alimentary canal, and described under intestinal absorption.

I. *Interstitial Absorption.*

The blood flowing through the body in the delicate capilla vessels yields to the various tissues a kind of irrigation strea of plasma, which leaving the capillaries permeates every tiss and saturates them with nutrient fluid. The surplus of th irrigation stream is collected and carried back to the blo current by a special set of fine narrow vessels with slend walls, called the *lymph vascular system*, which acts as t drainage of the tissues, and pours its contents into the veins.

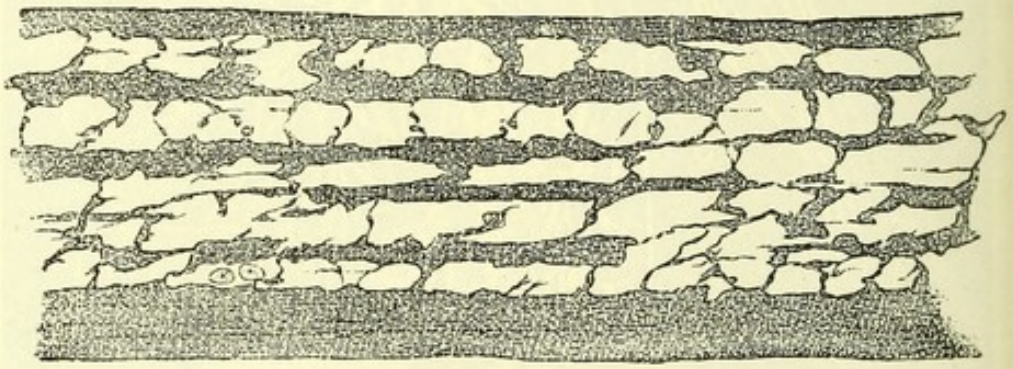
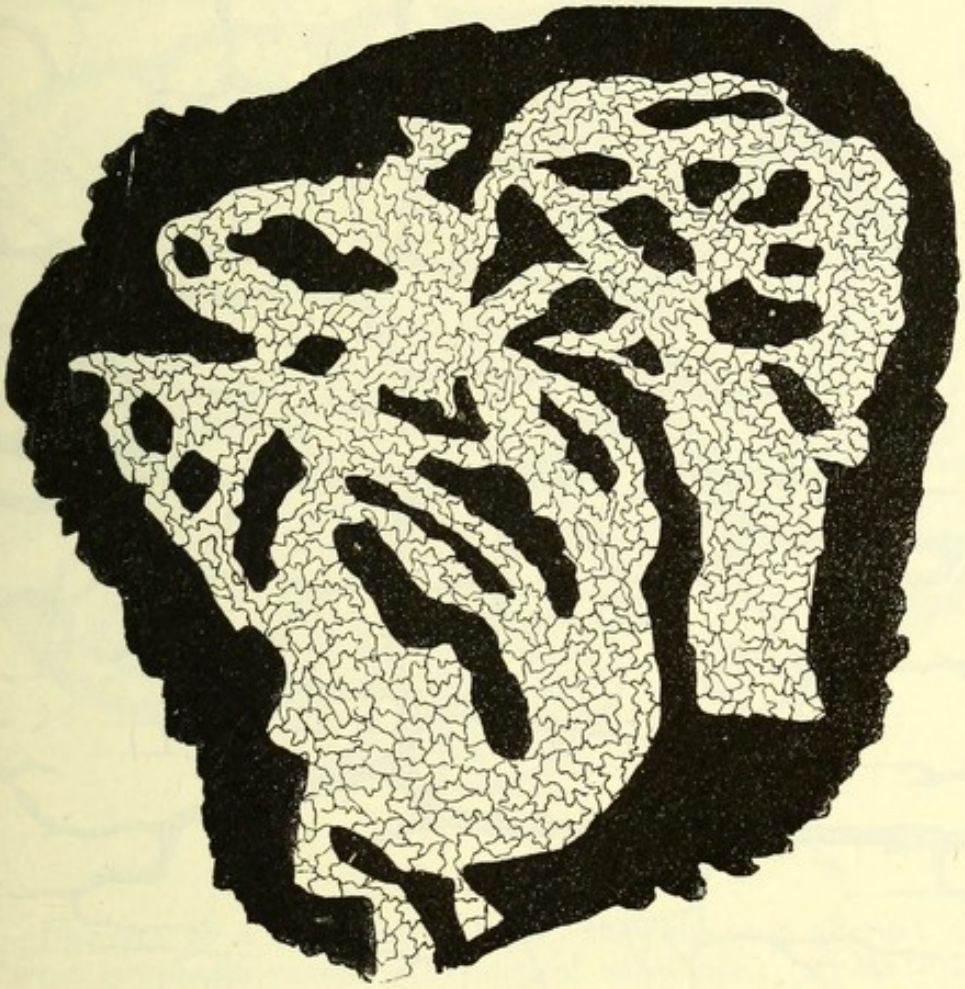


Fig. 80.—Tendon of Mouse's Tail treated with nitrate of silver, show clefts, or cell-spaces, around the bundles of fibrils as white patc These interstices may be called the smallest lymph-channels or spa (Schäfer.)

When the nutrient fluid escapes from the capillaries, it l in the interstices between the tissue elements, and here bat the cells which commonly occupy these *lymph spaces*. (F. 80.)

Communicating freely with the interstices of the tissues irregular anastomosing flattened channels, which convey lymph or any fluid forced between the tissues into vessels w definite boundaries. These vessels, which are lined w characteristic endothelium, form a more or less dense netw of lymphatic capillaries, from which spring the tributaries f the lymph vessels. (Figs. 81 and 82.)

The lymphatic vessels are throughout slender thin-walled hannels with close-set valves, usually in pairs, and frequent hastomoses. They lie embedded in the connective tissue, and hen empty are difficult to see, owing to the extreme thinness their coats. They converge towards a central vessel called he thoracic duct, which, passing from the abdominal cavity,



ig. 81.—Lymph Channels from the thoracic side of the central tendon of the diaphragm of the rabbit, treated with silver nitrate. The fine lines indicate the boundaries of the endothelium cells lining the lymph channels. The dark part shows the islets between the lymphatic network. (Klein.)

hrough the thorax, reaches the left side of the neck, and opens nto the angle of junction of the two great veins from the head nd upper extremity. (Fig. 79.) On the right side a smaller runk conveying the lymph from the right arm and that side f the head, chest, and neck, opens into the corresponding enous trunks.

The thoracic duct is much larger than any of the numerous ributaries which enter it at close intervals from all directions.

Its lower extremity or point of origin is an irregular dilata-

tion called the *receptaculum chyli*, because the lymphatic vessels from the small intestines, or *lacteals* as they are called, pour their contents into it. The chyle from the intestines thus flows into the same main channel as the lymph which is derived

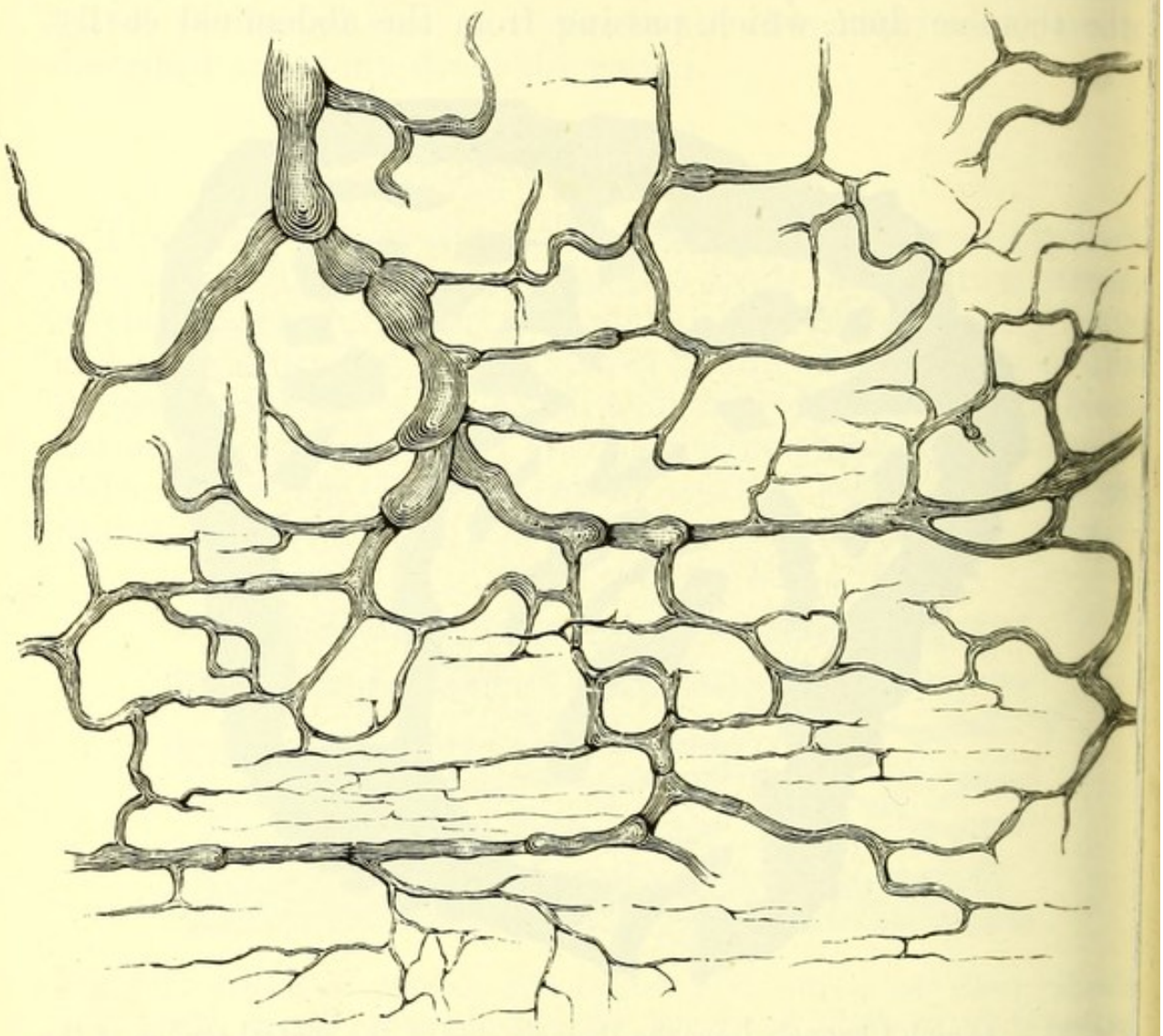


Fig. 82.—Lymphatic Network from between the Muscle Coats of the Intestinal Wall with fine vessels and many valves, causing the walls to bulge. (Cadiat.)

from the drainage of the tissues, and organs of the lower extremity, the trunk and left side of the head, neck and arm and the two fluids are mixed in the receptaculum chyli, and other parts of the thoracic duct.

LYMPHATIC GLANDS, &c.—Along the course of the lymphatic vessels numerous small bodies called *lymphatic glands* or *follicles* are found, which are composed of a delicate trellis-work of adenoid tissue, packed with nucleated protoplasmic cells called lymph corpuscles, the combination making what is

nown as *lymphoid tissue.* (Fig. 83 (*l h*) and 84 (*a*).) These nasses of cells and their delicate supporting reticulum are nclosed in a fibrous case or capsule from which branching rabeculæ pass into the gland and separate the portions of lym-

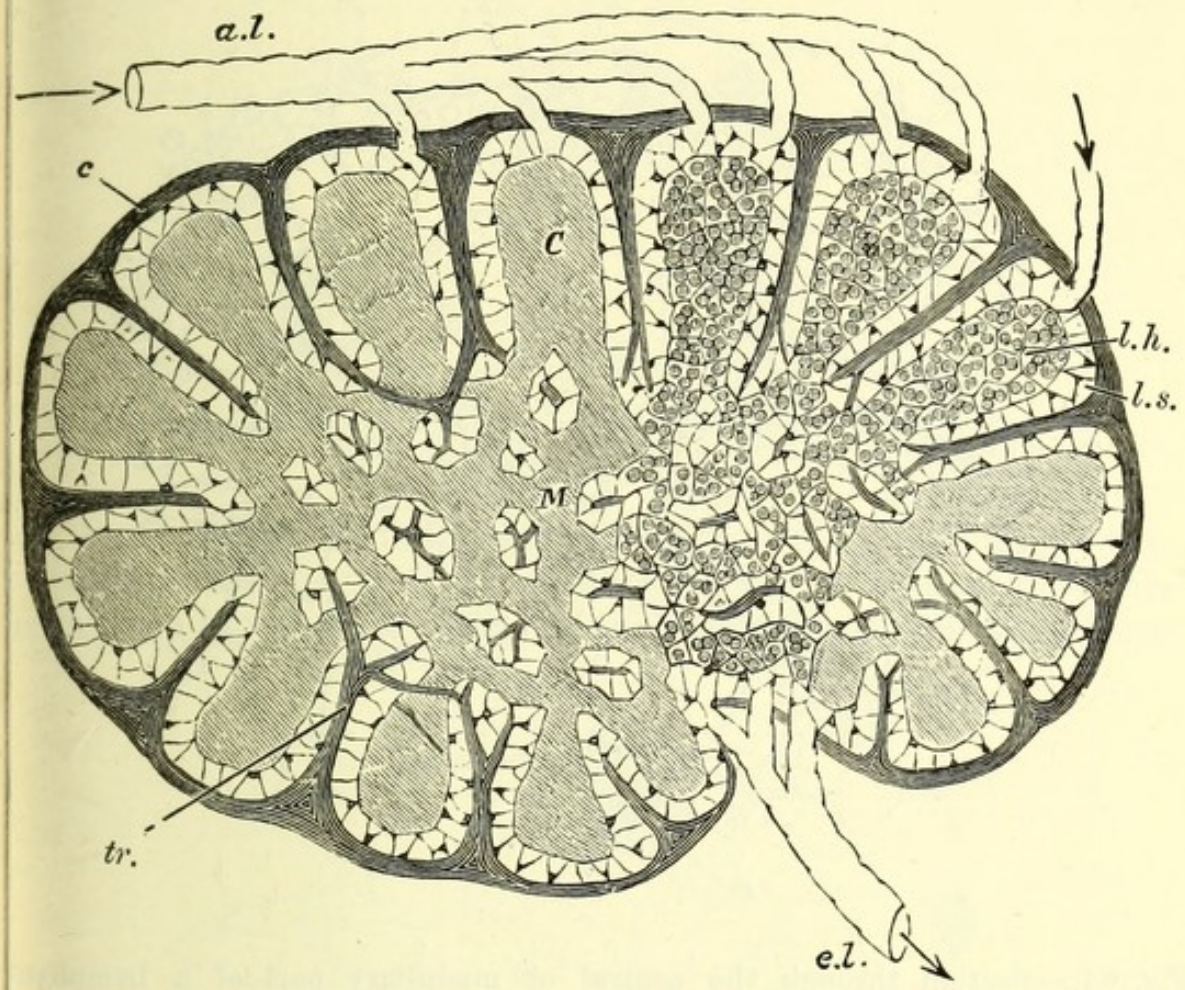


Fig. 83.—Diagram of a Lymphatic Gland, showing (*a l*) afferent and (*e l*) efferent lymphatic vessels; (c) Cortical substance; (M) Medullary substance; (*c*) Fibrous coat sending trabeculæ (*t r*) into the substance of the gland, where they branch, and in the medullary part form a reticulum, the trabeculæ are surrounded by the lymph path or sinus (*l s*), which separates them from the adenoid tissue (*l h*). (Sharpey.)

phoid tissue from one another. The lymph channels enter and pour their contents through the convex side of the capsule. The lymph then flows through irregular paths, which lie between the lymph follicles next to the capsule and trabeculæ, and lead to the concavity of the gland from which the efferent vessel escapes.

These lymph glands occur in groups in the flexures of the limbs, the recesses of the neck, and the thoracic and abdominal cavities, a large number being placed in the mesentery, in the course of the intestinal lacteals.

In the submucous tissue of the intestine this lymphoid tissue is widely diffused, and here and there arranged in small follicles, which doubtless have a function similar to that of the lymph-glands found elsewhere.

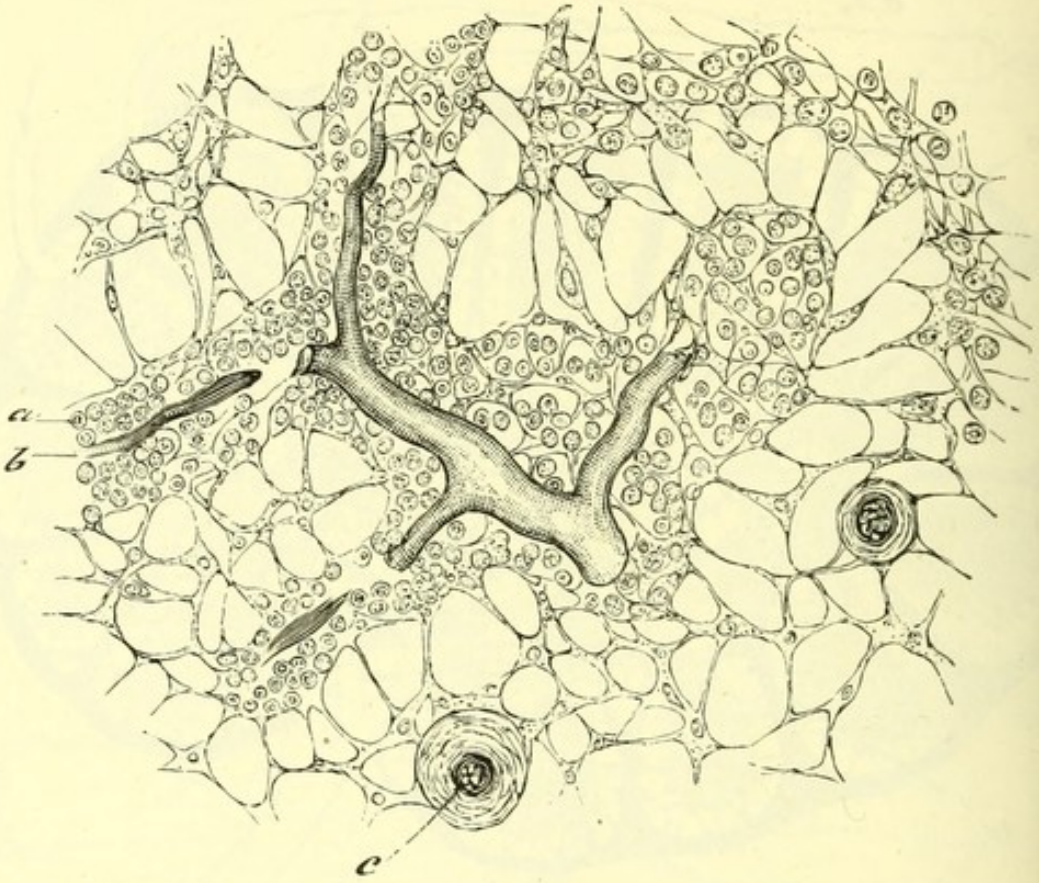


Fig. 84.—Section through the central or medullary part of a Lymphati Gland, showing adenoid tissue (*a*) containing capillaries (*b*) and fibrous trabecula (*c*) cut across showing a central artery. (Cadiat.)

Lymphatic Vessels.—There are various modes of origin o the lymphatic vessels which are more or less characteristic o the different parts in which they occur.

In the connective and allied tissues there are variously formed fissures or clefts which can be filled with fluid force into the tissues by puncturing the skin with the nozzle of fine syringe, such as is used for hypodermic injection.

These fissures contain the protoplasmic units of the tissue and transmit the ordinary transudation stream for nourishin the tissues. They freely communicate with one another, an lead into the beginnings of the network of the lymphat capillaries.

The lymph capillaries run midway between the bloo

pillaries, and are made up of a single layer of nucleated ndothelial cells, which can be brought to light by staining ith silver nitrate.

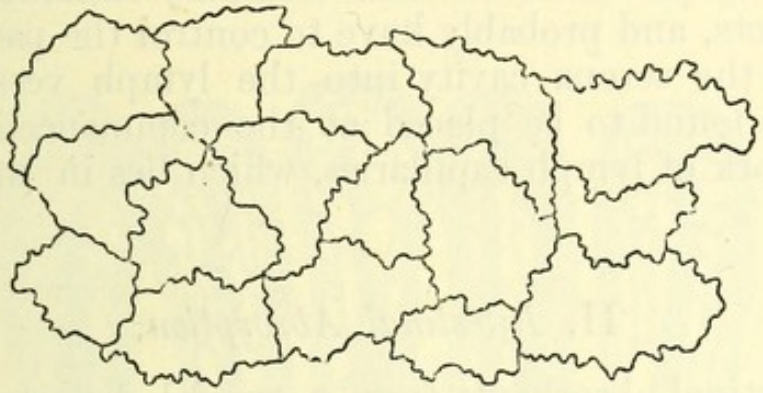
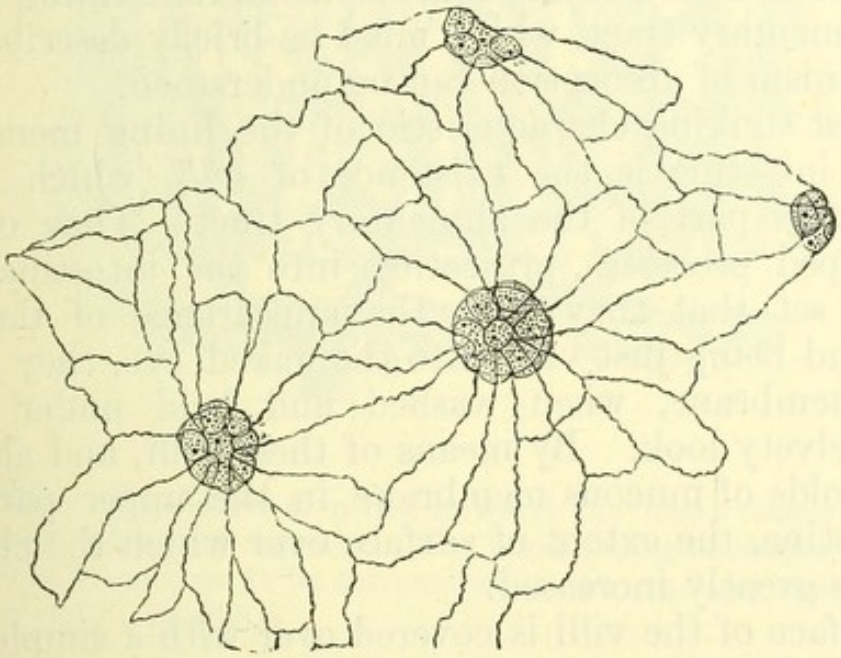


Fig. 85.—Endothelium from serous surface without stomata (nitrate of silver).

In some tissues, such as that of the central nervous system, er and bone, the lymph vessels commence as channels en-cling the blood-vessels, or perivascular lymph spaces. Here



ig. 86.—Endothelium from serous surface with stomata surrounded with granular protoplasmic cells.

e lymph channels form a kind of sheath for the minute lood-vessels, and pass along to the connective tissue of the aventitia of the larger.

The lymph vessels may also be said to commence on the s face of serous membranes which are intimately connected h the lymphatic system, and may indeed be regarded as

nothing more than inordinately developed lymph spaces. In most parts of the endothelial surface of serous cavities are a number of so-called *stomata*, or small apertures surrounded by a few cells, which differ from the ordinary endothelial cells in many respects, and probably have to control the passage of the fluid from the serous cavity into the lymph vessels. These stomata are found to be placed at the commencement of the dense network of lymph capillaries, which lies in the subserous tissue.

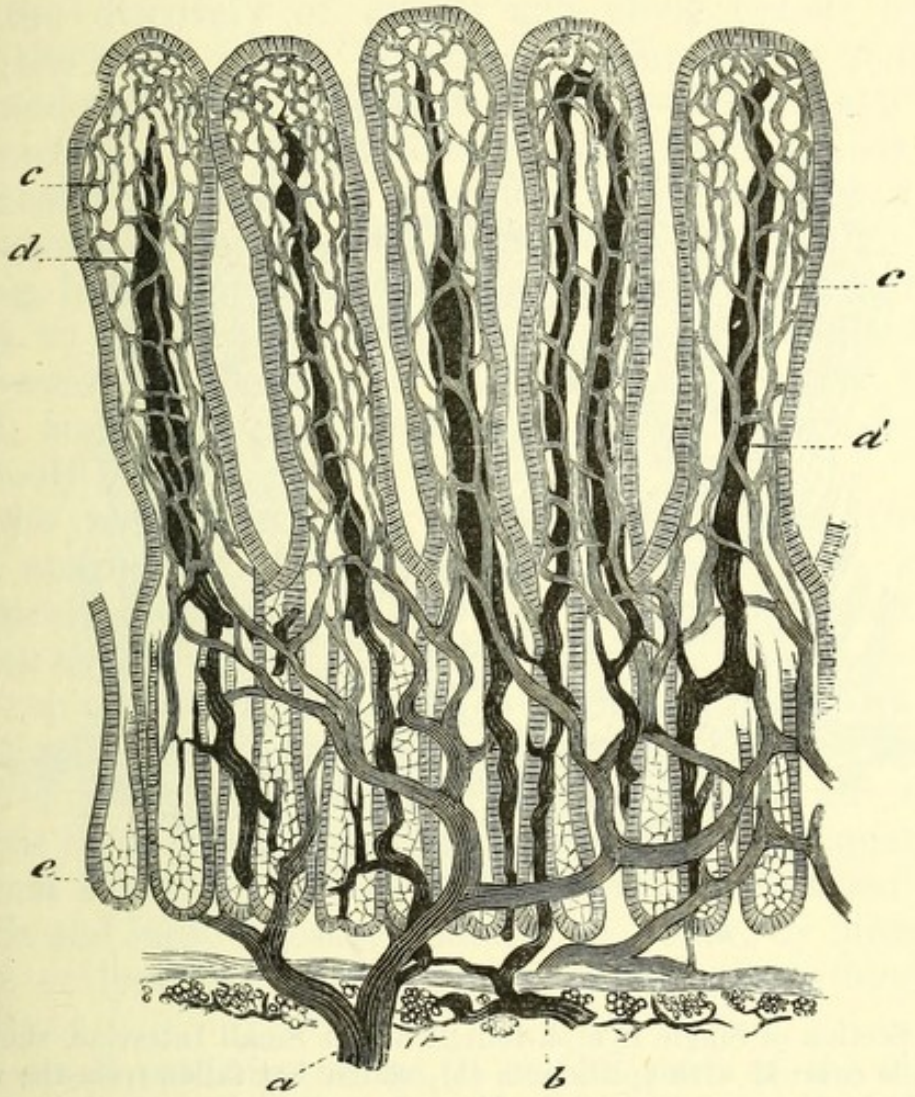
II. *Intestinal Absorption.*

The intestinal absorbents form a special department of the lymphatic system aiding nutrition. On account of the white chyle seen as a milky fluid through their transparent walls, they have been called *lacteals*. Their functions are to take up the nutrient fluid from the intestinal cavity, and to drain the tissue in which they lie. In order to fulfil these functions, they are arranged in a particular way, especially adapted to the peculiar construction of the mucous membrane lining this part of the alimentary tract, which must be briefly described before the mechanism of absorption can be understood.

The most striking characteristic of the lining membrane of the small intestine is the existence of *villi*, which are only found in this part of the alimentary tract. They consist of nipple-shaped processes, projecting into the intestinal cavity so closely set that they have the appearance of the pile of velvet ; and being just visible to the naked eye, they give the mucous membrane, when washed and held under water, a peculiar velvety look. By means of these villi, and also of the ring-like folds of mucous membrane in the upper part of the small intestine, the extent of surface over which the chyme has to travel is greatly increased.

The surface of the villi is covered over with a simple layer of columnar epithelial cells in continuity with the epithelium lining the rest of the intestinal tract. The free surface of these cells is marked by a clear striated margin composed of a series of minute channels placed closely together, while the deep-seated end of the cells is truncated, and appears to be separated by a basement membrane from the supporting retiform tissue. Some of the cells are seen to swell upon the addition of certain re-agents, owing to their containing mucus which gives them a peculiar goblet shape ; hence they are

lled goblet cells. These occur at intervals, and some bservers consider that they form a distinct variety, differing om the neighbouring cells just as the border-cells of the omach-glands differ from the central-cells. (Fig. 78, p. 161.)



F 87.—Section of Intestine of a Dog in which the blood-vessels (*c*) and the lacteals (*d*) have been injected. The blind ending or simple loop of the black lacteal is seen to be surrounded by the capillary network of the blood-vessels. (Cadiat.)

The body of the villus is composed of a very delicate kind of connective tissue, forming a slender frame in which a little cage-like network of blood-vessels surrounds a central lacteal radicle. The interstices of this connective tissue are filled with pale protoplasmic cells, like those formed in the lymph. Under the basement membrane forming the foundation of the epithelium are some unstriated muscle cells which embrace the villus and are able to squeeze it and empty the vessels that lie

within it. The lacteal radicles which lie in the villi are sometimes double, and have a communication with the lymph spaces of the connective tissue. They frequently branch as they pass down from the villi to reach the dense network of lacteal vessels which lies beneath the mucous membrane.

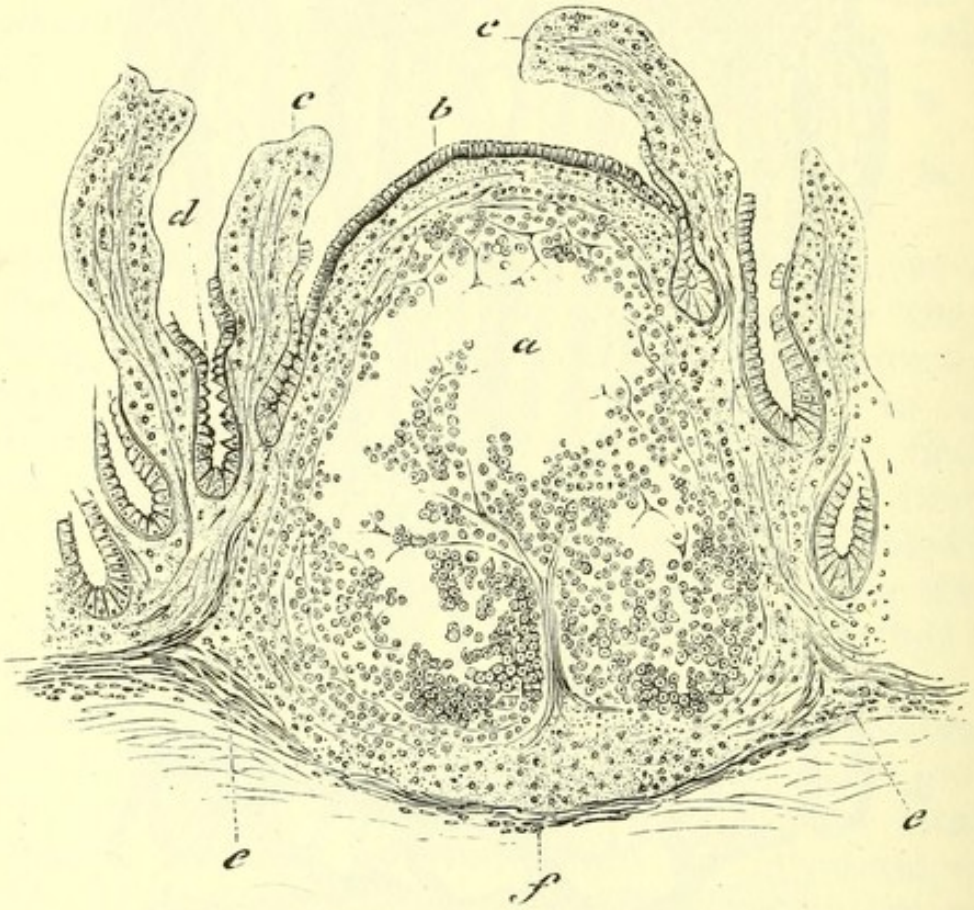


Fig. 88.—Section of Single Lymph-follicle of the Small Intestine, showing (*a*) follicle covered with epithelium (*b*), which has fallen from the villi (*c*); (*d*) Lieberkühn's follicles; (*e*) Muscularis mucosæ. (Cadiat.)

The richness of the lymphoid tissue all through the digestive mucous membrane is most remarkable. At irregular intervals throughout the submucous tissue are found masses of lymphoid tissue similar to those seen in packets within a lymph gland or in other lymph follicles. These are either isolated (solitary glands) and scattered through the entire alimentary tract, or collected into groups (agminated glands or Peyer's patches) which are restricted to certain parts of the small intestine. Though called glands by anatomists, it should be borne in mind that they are in no way connected with the secretion of any of the intestinal juices, but belong to the absorbing arrangements of the intestine. Around these solitary and

grouped lymph follicles are spaces and networks from which the lacteal vessels arise.

MECHANISM OF ABSORPTION. — Formerly absorption was supposed to take place by means of the blood-vessels alone. After the discovery of lymph and chyle vessels by Casper Aselli, the belief in the direct absorption by the blood-vessels was abandoned, and all the work of absorption was attributed to the lymphatics. Now, however, ample evidence exists to show that substances capable of absorption make their way into the blood-vessels of any part not protected by an impermeable covering, like the horny layer of the skin, and are thus carried directly to the general circulation. The share taken by the blood-vessels in interstitial absorption in the tissues is not defined, and when no impediment to the lymph-flow exists is probably small.

In the absorption from the alimentary tract the blood-vessels appear to take the most important part, as recent experiments seem to show that the thoracic duct carries little else than the fatty part of the food.

We can easily imagine that a surface covered by a single layer of epithelial cells, with numerous blood-vessels and a good supply of absorbents beneath them, is capable of absorbing materials in solution ; and we know that large quantities of fluids and solutions of various materials are absorbed from the stomach and large intestine, partly, no doubt, by means of the lacteals or lymphatics, and partly by the minute blood-vessels themselves.

The small intestine seems to be the part of the alimentary tract which is especially adapted for taking up the materials elaborated from the food.

In the upper part of the small intestine the valvulæ conniventes are most marked, and the villi are long and set closely together. It is here we find the thickest layer of creamy chyme covering the mucous membrane, but seldom any masses of undigested food. All these points tend to show that the upper part of the small intestine is the part specially adapted for absorption. The chyme which clings to the mucous membrane contains all the substances destined to pass into the economy. Into this mixture the villi dip, so that each villus is bathed in chyme. From what has been said of the construction of the villi it is obvious that such an arrangement is well adapted to the absorption of the nutrient material,

which is in the closest proximity to the lacteals and blood-vessels.

Absorption of the several Food-stuffs.

The various food-stuffs in the chyme differ in the degree of readiness with which they are absorbed. Hence the mode of absorption of its principal ingredients must be examined separately in detail.

Salts and H_2O.—Water can be absorbed from the intestinal tract in almost unlimited quantity, but not solutions of salts. The amount of the solution of any salt capable of absorption seems to depend on its endosmotic equivalent. The lower the endosmotic equivalent the more readily the solution passes into the blood-vessels. In those cases where the equivalent is very high, such as magnesium sulphate, there is a tendency of the fluid to pass out from the blood-vessels into the intestinal cavity ; this has been supposed to explain the watery stools caused by this and other saline purgatives.

Sugars.—Among the carbo-hydrates, we need only take into account the sugars, for unchanged starch is but little if at all absorbed. Only a certain quantity of sugar can be taken up by the intestinal absorbents, since some is found in the fæces when the amount taken with the food exceeds a certain quantity. Some of the sugar in the intestine undergoes fermentation, by which it is converted into lactic and butyric acid. The quantity of sugar converted into lactic and butyric acid has not been determined, but the amount of sugar found in the portal vessels or lacteals does not correspond with that which disappears from the cavity of the intestine.

We have seen that starch is converted into maltose, and this again into glucose before absorption. Cane sugar and lactose are also converted into glucose. So that the form of carbohydrate absorbed is almost entirely glucose. This enters chiefly into the capillaries and it is only when a large excess has been taken that some of it finds its way into the lacteals, so entering the blood viâ the thoracic duct.

Proteids.—Proteids, we have seen, are changed into albumoses and peptones in the stomach and intestine, and it is in this form that they are chiefly absorbed. The absorption of albuminous bodies begins in the stomach, and is completed in the small intestine, as only a small quantity of proteid is found

in the large intestine even after an excessive meat diet. The more concentrated the solutions of albumose the more rapidly are they absorbed, and the rate of absorption is greatest at first and then, by degrees, diminishes. The presence of free alkali is said to facilitate this absorption. It is a curious fact that neither in the lacteals nor in the portal blood can any proteose or peptone be found, even during active proteid digestion. It is further known that albumoses and peptones introduced directly into the blood stream are most violent poisons, consequently they must be converted into other proteids before entering the circulation.

The only evidence that albumoses, as such, are absorbed into the blood, is that they are taken up by the lymph corpuscles of the alimentary tract, and carried by them to the lymph glands, &c., at least the lymph and blood cells are said to contain albumose during proteid digestion. The lymph cells thus seem to be the means of transport of the albumoses in the blood current, and possibly require this special form of proteid for their own nutrition and proliferation.

We know that soluble forms of albumin are to some extent diffusible (when a solution of salt is used) through a dead animal membrane. Even were they quite indiffusible this fact would not preclude the possibility of their passing through the intestinal wall, which is a living structure, and therefore not restricted by the physical difficulties controlling diffusion through an inanimate membrane. If a large amount of egg-albumin be taken into the stomach, it is stated that some of it appears, still as egg-albumin, in the urine ; so that it has entered the blood and left it again as egg-albumin.

Again, proteids are absorbed from the large intestine under conditions which preclude the possibility of their being first converted into proteoses. Here again we must attribute the absorption to the vital action of the intestinal epithelium, and we may conclude that some proteid is absorbed as ordinary soluble albumin. But in whatever form the albumin leaves the intestinal tract it normally becomes converted into special blood albumins before it joins the circulation. Where the final stages of this conversion take place is not certainly known, but there is good evidence that it is effected by the vital activity of the cells of the mucous membrane. The absorbed albumins pass by the portal vessels to the liver.

A certain limit to proteid absorption exists, so that if an amount of albuminous material above the maximum that can

be absorbed be eaten, the albumins are either converted into leucine and tyrosine, or thrown off with the fæces.

Fats.—In the absorption of water, watery solutions of salts, sugars, and even proteids, there are no great physical difficulties to be overcome, so that we speak confidently about the mechanism of their absorption, though in all probability many circumstances connected with the life of the epithelial cells, &c., of which we are ignorant, co-operate in bringing about the results. With the fatty foodstuffs the difficulty is more obvious. A small quantity of these may, no doubt, be split up into soluble glycerine and fatty acids, which are at once changed into soluble soaps, and in this condition are capable of simple osmotic transmission into the blood-vessels or lacteals. But we know that the greater portion of fat appears in the lacteals in the condition of a fine emulsion, *i.e.*, as solid particles. This process is difficult to reconcile with our physical experiences; for however finely divided, emulsified fat does not pass through an animal membrane more freely than ordinary fluid fat.

The view that all the fat is changed into a soluble form before its absorption, and then reconverted by the epithelial cells, seems not to be supported by adequate evidence.

The fat emulsion is chiefly taken up by the villi of the small intestines, for in the stomach fat exists only in large fluid masses, and the amount found in the large intestine is small, unless it be eaten in great excess. This can be seen in examining the absorbent vessels after a fatty meal, when those which carry materials from the stomach and large intestine are clear and transparent, while those coming from the small intestines are filled with the white milky fluid from which the name of lacteals is derived. There is a limit to the absorbent capacity of the intestine for fatty matters, for when a great excess of fat is eaten it appears with the excrement, sometimes giving rise to adipose diarrhœa, thus showing that the amount eaten has exceeded the limit that the cells will absorb.

The important question remains, how does the fat emulsion make its way through the intestinal mucous membrane? That it really does so there can be no shadow of doubt; for it disappears from the intestinal cavity, and can be detected in the lacteals more easily than any other of the absorbed materials.

By means of osmic acid, which renders the fat granules black, they may be demonstrated to occur in the following situations during the active digestion of fat. 1. In many of

the epithelial cells lining the villi, &c. 2. In lymph-cells lying in close relation to the epithelium and others in the lymphoid tissue of the villi. 3. Between the epithelial cells.

It has been shown that while a membrane moistened with water acts as a complete barrier to a fat emulsion, and only after prolonged exposure under high pressure allows traces of fat to pass, the same membrane when saturated with bile will without much pressure permit the passage of a certain amount. It has, therefore, been suggested that the epithelial cells of the mucous membrane are more or less moistened with bile, and the particles of fat in the emulsion are also coated, as it were, with a film of bile or soap. Thus they are enabled to pass into the epithelial cells, in which they can be detected. This coating may, no doubt, aid the fat particles in their transit through the various obstacles met with on their way to the lacteal radicles, but their passage out of the intestine cannot be explained in this way. Many circumstances tend to the conclusion that the vital activity of the protoplasm of the epithelial cells is the only explanation we can rely upon. The fat particles are, then, taken up by the epithelial cells from the cavity of the intestine, and passed into the lymph channels.

Another view supposes the fat to be seized by protoplasmic processes of the lymph-cells, which, for that purpose, pass between the epithelial cells to reach the surface. As the great bulk of the fat is free in the fluid chyle, and much can be seen in the epithelium, this cannot be the only method.

When the fat is lodged in the protoplasm of these cells their amœboid properties may convey it into the delicate connective tissue of the villi and the lacteal radicle. During this transit it is changed, for in the lacteal radicle we notice that the fat is in a far finer state of division than it was before being taken up by the epithelial cell or leucocyte, and it is in this very minute state of division that it enters the blood. So that through all the stages of digestion and absorption of fats the process of progressive subdivision is at work.

Other forces, such as the contraction of the villi, aid in its further progress to the other lacteal vessels.

The exact utility of the marginal bands of rods or pores which characterize the surface of the intestinal epithelium is not known, though it has been supposed to be connected with the absorption of fats.

We may conclude, then, that the passage through the

intestinal wall of the materials taken as food cannot be accomplished by mere physical processes, but that the absorption of all food-stuffs is probably controlled by the vital activity of the epithelial cells. The passage of the fat can only be explained by the direct activity of cells which by amœboid movement take up the fine particles and pass them on to the interstices of the connective tissue of the villi.

Lymph and Chyle.

As these two fluids are generally mixed in the thoracic duct, whence the lymph is commonly obtained for examination, we may discuss them together, though the lymph might more properly be considered with the distribution of the nutrient materials to the tissues.

The fluids coming from the tissue-drainage, from the lymphatic glands and from the lacteals of the alimentary tract, when mingled in the thoracic duct, form an opaque mixture which holds a considerable quantity of proteid in solution, and contains a number of morphological elements, viz.: (1), protoplasmic cells similar to those found in the lymph follicles, and in most essential points identical with the pale cells found in the blood; (2), some red-blood corpuscles which give the fluid in the thoracic duct a pinkish colour; (3), a quantity of very finely divided fat, which varies in proportion to the amount of fat recently digested; (4), other minute particles of unknown composition and origin.

When removed from the body and allowed to stand, the lymph becomes converted into a soft jelly. This coagulation, no doubt, depends upon some chemical changes in the lymph which give rise to fibrin, the formation of which will be discussed more fully in a future chapter. The amount of fibrin formed in the lymph is small, and therefore the clot is very soft, and shrinks considerably.

The lymph of the thoracic duct contains three forms of proteid; (1), serum albumin, which can be coagulated by heat; (2), alkali albumin precipitated by neutralization; and (3), globulin. It also contains soap in solution, cholesterine, grape-sugar, urea, leucine, and some salts, particularly sodium chloride, and the sulphates and phosphates of the alkalies.

The quantity of *chyle* which can be obtained from the lacteals is small, and, therefore, its thorough investigation is difficult. The fluid from the lacteals differs from the mixed

lymph in appearance and constitution only during digestion, and then chiefly in containing a greater amount of fat and solids derived from the intestinal cavity, and relatively less waste products.

On their way to enter into the blood-current both the lymph and chyle undergo changes. Before passing through the lymphatic glands the fluid contains much fewer lymph corpuscles than after it has traversed the glands: from this fact and from the structure of the lymph glands we may conclude that they are the chief sources of these white cells. The chyle of the lacteal vessel of the mesentery contains particles of fat which greatly exceed in size those found in the thoracic duct, so we may infer that the fat emulsion undergoes a further subdivision or modification on its way through the glands and the lymphoid tissue of the intestinal wall.

Lymph which has been collected from the lymph channels of the extremities is an almost clear colourless fluid, rich in the waste products of tissue change, but containing less albumin than that coming from the main trunk, and no fat. After long fasting the lymph from the thoracic duct has the same characters.

Lymph contains a considerable quantity of carbonic dioxide, about 50 vol. per cent., some of which is readily removed by the air-pump, and is therefore said to be absorbed by the fluid, while some can only be removed by the addition of acids, and therefore must be present in chemical combination. Only mere traces of oxygen have been found in the lymph.

The quantity of chyle and lymph poured into the blood varies so much that any estimation of the amount entering in a given time is unreliable.

The following circumstances upon which the variations may depend are instructive:—

1. The ingestion of liquid and solid food causes a great increase in the amount of chyle. This is obvious from the change in the state of the lacteal vessels, which, from being transparent and almost empty, become widely distended and white.
2. The activity of any organ causes an increase of lymph to flow from it.
3. Impediment to the return of the venous blood from any part, increases the irrigation, and hence the amount of lymph.

4. Increase of the amount or the pressure of the blood flowing through any part augments the lymph flow.
5. The administration of curara increases the amount of lymph.

The history of the structural elements or *lymph-corpuscles*, which exist in such numbers in the large lymph-channels, requires some further discussion, as these cells are composed of active protoplasm destined for some important function, and must be produced by some vital process.

The origin of the lymph corpuscle is not restricted to any one part of the body or to any special organ. It has been already said that the lymphatic glands are the most important source of these cells, because the follicular tissue is filled with them, and the lymph contains a much larger number after it has passed through some lymph glands. In the lymphoid tissue of the spleen and of the intestinal mucous membrane, they are very numerous, and, no doubt, many have their origin in the follicular tissue of the spleen and intestine. They are said also to be formed in the red marrow of the bones. Although their number is relatively small, lymphatic cells occur even in those lymph-channels that have not yet met with a lymphatic gland, and these cells, no doubt, come from the blood, which contains many cell-elements, identical with the lymph-cells found in the lymphatic duct. These cells, when they arrive at the minute blood-vessels sometimes leave the vessels and creep by amœboid movements into the interstices of the tissue with the irrigation stream (*diapedesis*). They may abide in the tissue, or be washed into the larger lymph-channels with the surplus stream of lymph. When the abnormal increase of activity in a tissue, known as inflammation, occurs, this escape of the white cells from the blood takes place with great rapidity, and the stages in the process can be watched under the microscope.

Still another source of the lymph-cells may be from proliferation of the cells which lie in the tissues. The fixed tissue-cells are said to be capable of producing elements, identical with lymph-cells, which by division possibly multiply and may be carried along by the lymph-stream as lymph-cells.

The cells which accumulate in enormous numbers, as pus, when an abscess forms, are structurally identical with lymph-cells, and probably arise from these combined sources, viz.,

escape from the blood-vessels and proliferation of the tissue-cells.

The lymph-cells, therefore, whether they have their origin in lymphoid, splenic, or connective tissue, perform a kind of circuit, going with the lymph into the blood, and are distributed with the latter to the tissues, whence they may be once more carried into the lymph-stream.

Movement of the Lymph.

In some of the lower animals small muscular sacs occur in the course of the main lymph-channels, which pump the lymph into the great veins by contracting rhythmically much in the same way as the heart.

In man and the higher animals no such *lymph-hearts* have been found; the onward movement of the fluid therefore depends on the pressure under which the irrigation stream leaves the blood-vessels. The fluid in the blood-vessels, as we shall presently see, is under considerable pressure, which causes a nutrient fluid to leave the capillaries. Hence, if a lymphatic trunk be tied, its tributaries are filled with lymph until a considerable pressure (8—10 mm., soda solution) is developed in their radicles.

While the pressure exerted on the small tributaries of the lymph channel may become considerable, that in the thoracic duct is invariably very low for the following reasons. The blood in the large veins into which the duct opens is under less pressure than in any other part of the vascular system, owing to the thoracic suction, or negative pressure in the thorax, caused by the elastic traction of the lungs. In fact, the pressure in the large veins, *e.g.*, brachial, &c., varies from 0 mm. to −5 mm. Hg., and that in the venæ cavæ is always negative, except in sudden or forced expiration, and varies, according to the period of the respiratory rhythm, from −8 mm., in inspiration, to −3 mm. in expiration.

The fact that the lymph at the origin of the small channels may attain a pressure of 8 to 10 mm. of water, whilst at the entrance to the vein it is a minus quantity, would be sufficient to explain the movement, even if there were no other force aiding it.

It must be remembered that every lymph-vessel is furnished with closely set valves, which prevent the fluid it contains from

being forced backwards, so that any accidental local pressure exercised on the exterior of a lymph-channel must help the fluid onwards to the veins. Along their entire extent these vessels are subject to certain pressures which materially aid the flow of the lymph-stream. The first of these is the pressure exerted on the small vessels by the movement of the muscles in the neighbourhood. The second is the unequal distribution of atmospheric pressure, which has full force on the peripheral channels, but is kept off the thoracic duct and its termination, as already mentioned, by the rigidity of the thoracic wall, which, together with the tendency of the elastic lungs to shrink, causes a permanent negative pressure in the thoracic cavity through which the duct passes. And lastly, the thin-walled lymphatics are everywhere surrounded with very elastic textures, enclosed in an elastic skin, which exert an amount of pressure, sufficient to empty and press together the walls of the vessels after death, and therefore during life must have considerable influence upon the fluid they contain.

The movements of the chyle depend on the same forces, with the addition of the power used in the contraction of the villi, which pump the chyle from the lacteal radicles into the network of valved vessels in the submucous tissue.

The commencements of the thoracic duct and the lacteals are placed in the abdominal cavity, and therefore are constantly under the influence of the positive pressure exerted by the abdominal wall on the contained viscera. The rest of the duct is in the thorax, where the pressure is habitually negative. Certain variations coincident with inspiration and expiration take place in both these cavities, and must aid the onward flow of fluid in a vessel containing valves so closely set.

Although no difficulty exists in explaining the onward flow of lymph and chyle on purely physical grounds, there are some points connected with pathological slowing of the flow, *œdema*, which tempt us to believe that chemical or perhaps vital processes have also a share in the perfect drainage of the tissues.

CHAPTER XII.

THE CONSTITUTION OF THE BLOOD.

In all animals, except those which form the lowest class (Protozoa), the distribution of the nutritious materials to the various parts of the body, as well as the collection of the effete matters prior to their expulsion, is carried on by the medium of a fluid which circulates throughout the different parts of the body. This fluid is the blood.

In vertebrate animals the blood passes through a closed system of elastic pipes and is kept in constant motion by the action of a muscular pump. It is first forced through strong, branching canals called arteries, whose walls gradually become thinner as the branches get smaller, and end in a network of delicate channels (capillaries), through which it slowly trickles into the wide soft-walled veins by means of which it flows gently back again to the heart. In its course it receives the nutritive materials from the stomach and intestines during digestion, the specially elaborated substances from the liver, spleen, and lymph glands, and the oxygen absorbed from the air in the lungs. In short, it contains and bears to their destination all the materials required for the chemical changes of the economy. While passing through the capillary networks of the various tissues, it takes up the waste materials resulting from the tissue-changes and bears them to their proper point of exit from the body; at the same time the nutriment oozes through the delicate vessel walls and is diffused in the tissues.

General Characteristics of the Blood.—The blood of vertebrate animals is of a bright scarlet colour when exposed to the oxygen of the air, but when deprived of oxygen it becomes a dark purplish red.

The blood is remarkably opaque, as may be seen by placing a thin layer on a piece of glass over the page of a book. This opacity depends on the fact that the blood, as will presently be seen, is not a red *fluid*, but owes its colour to the presence of

solid red particles or corpuscles which float in a clear pale fluid. The blood has a peculiar smell (halitus), distinct in different animals and man, dependent on certain volatile fatty acids. Its specific gravity varies from 1045 to 1075, the average being 1055. The solid parts (corpuscles) are heavier (sp. gr. 1105) than the liquor sanguinis (1027).

When first shed the blood has a slippery feel, which it soon loses, becoming viscous as it passes into the first stage of coagulation.

Amount of Blood in the Body.—The total amount of blood has been estimated to be from $\frac{1}{13}$ to $\frac{1}{14}$ of the body-weight for an adult man, and somewhat less for a new-born child.

Much difficulty has been found in arriving at an accurate estimation of the amount of blood in the body. In the first place, all the blood cannot be made to flow out of the vessels of an animal when it is killed. Secondly, the quantity and quality of blood are constantly varying with the capacity of the blood-vessels. Thirdly, when slowly withdrawn from the body during life it is rapidly replaced by more fluid passing into the blood-vessels. This explains the enormous quantity of blood occasionally reported to be shed in cases of bleeding to death. In these cases, as quickly as the blood is lost, fluid is absorbed by the blood vessels, so that if the bleeding be gradual the standard quantity is still kept up in the vessels. Thus the very sudden loss of a comparatively small quantity of blood may cause death, whereas, if the bleeding go on sufficiently slowly and gradually, as much or even more in quantity than normally exists in the entire body may escape without fatal result. Of course much of this is fluid which has only recently entered the vessels.

Weber's Method.—The percentage of solid matters in the blood is first carefully estimated. The absolute quantity of solids in all the blood that can be drawn is then ascertained and added to the solids obtained by washing out the blood-vessels. Here an error arises from the fact that, in washing out the blood-vessels, much solid matter besides that belonging to the blood is taken from the tissues and thus an excess is found.

Valentine's Method.—A small measured quantity of blood is drawn from a vein and its percentage of solids accurately estimated; a known quantity of water is then injected into the

vessels. When some time has been allowed for the distribution of the water a sample of the diluted blood is taken and its solids estimated. The difference in solid contents of the two samples shows the degree of dilution caused by a known quantity of water introduced into blood of ascertained strength, and thus the amount of the diluted fluid (the blood) may be calculated and added to the amount of the first sample to make the absolute quantity.

This method cannot give accurate results, because in the time necessary for the distribution and mixture of the water the density of the circulating blood is readjusted, some water being excreted by the kidneys and skin, and the second sample of blood is more concentrated than it should be from such dilution.

Welcker's Method depends upon the estimation of the colouring matter of the blood. He connected the carotid with a small T piece, and allowed the animal to bleed into a bottle in which the blood could be defibrinated by shaking with pieces of glass. One cubic centimetre of this defibrinated blood was carefully measured off and saturated with carbon mon-oxide (CO), which gives a permanent and equally bright red colour independently of the oxygen of the air. It was diluted to 500 c.c. with distilled water and kept as a standard colour-solution. The blood-vessels of the animal were then washed out with ·6 per cent. solution of sodium chloride until the solution flowing from the jugular vein was colourless. The tissues of the animal were chopped up, steeped in water and pressed. The washings of the vessels and the infusion from the tissues were added together and diluted until they had the same colour-intensity as a layer of the standard solution of the same thickness. Every 500 c.c. of these diluted washings corresponds to 1 c.c. of blood.

By this method the following estimates have been made of the relation of the blood to the body weight :—

Mouse	$\frac{1}{12} - \frac{1}{13}$
Guinea Pig	$\frac{1}{17} - \frac{1}{22}$
Rabbit	$\frac{1}{15} - \frac{1}{22}$
Dog	$\frac{1}{11} - \frac{1}{18}$
Cat	$\frac{1}{21}$
Bird	$\frac{1}{10} - \frac{1}{13}$
Frog	$\frac{1}{15} - \frac{1}{20}$

Only approximate estimates of the distribution of blood in the body during life can be made, since there can be no

accurate method of investigation, and the amount varies considerably according as the organ or part is in a state of rest or activity. It is supposed that a quarter of the entire amount is habitually flowing through each of the following regions :—

1. The heart, great vessels, and lungs.
2. The skeletal muscles.
3. The liver.
4. Skin and other tissues.

PHYSICAL CONSTRUCTION OF THE BLOOD. — As already stated the blood is not really a red fluid. It is seen with the microscope to be made up of a clear fluid called *plasma* or *liquor sanguinis*, which contains an immense number of little disc-shaped bodies—red corpuscles—and some colourless protoplasmic cells—white corpuscles—so that the living blood may be physically tabulated, giving approximately an estimation of the relative amounts, thus :—

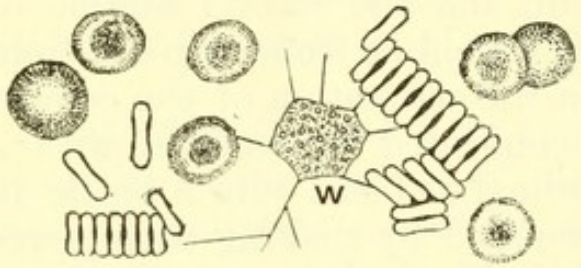


Fig. 89.—Human Blood after death of the elements. The red corpuscles are seen in different positions showing their shape. Some also are seen in rolls. Only one white cell (w) is seen, misshapen and entangled in fibrin threads.

$$\text{Blood} \begin{cases} \text{Plasma or Liquor Sanguinis} \text{ ——— } \frac{3}{5} \\ \text{Solid or Corpuscle} \begin{cases} \text{Red discs} \\ \text{Cells} \end{cases} \text{ — } \frac{2}{5} \end{cases}$$

PLASMA.

The fluid part of the blood, or *plasma*, is of a pale straw colour, when pure and free from the colouring matter of the corpuscles.

Unless special precautions have been taken the plasma is altered when removed from the blood-vessels and coagulation of the blood takes place, so that plasma does not come under observation, except when suitable methods are employed to separate it from the corpuscles. It was first separated from the corpuscles by the filtration of frog's blood to which strong syrup had been added to delay coagulation and destroy the flexibility of the corpuscles, so that they were caught in the meshes of the filter and the clear plasma passed through.

To obtain mammalian plasma free from corpuscles it is

necessary to use some other method, as the small elastic corpuscles easily run through the meshes of the finest filter-paper.

The blood of the horse is chosen, because it coagulates more slowly than that of most mammals, and delay in the coagulation or postponement of the change in the plasma is the chief object to be obtained. To increase this delay the blood is drawn from a vein into a cylinder surrounded with ice. The cold, however, must not be so intense as to completely freeze the blood, for the wished-for subsidence of corpuscles could not go on if the blood became solid. It is then left quite motionless for 24 hours, after which time it will be found that the heavy corpuscles have fallen and left a clear supernatant fluid, which is plasma containing a few white cells. This can be removed with a cool pipette and passed through an ice-cold filter to remove the cells; thus tolerably pure plasma is obtained which soon coagulates at the ordinary room temperature.

Another method of checking coagulation consists in letting the blood flow into a 25 per cent. solution of magnesium sulphate (about four volumes of blood to one of the solution). This, if left in a cool place, will not coagulate, and the corpuscles will separate, by subsidence from, the plasma and salt solution, which form an upper layer of clear fluid. If the salt be removed by dialysis, or weakened by dilution with water, coagulation commences.

A third method consists in receiving the blood, as it is shed, into a solution of potassium oxalate. This precipitates the calcium as oxalate of lime and so prevents coagulation.

The coagulation of plasma can be seen with the microscope to depend upon the appearance of a close network of exquisitely delicate, finely granular elastic fibrils, which pervade the entire fluid and cause it to set as a soft jelly. The substance forming the meshes is called *fibrin*.

Some time after the plasma has gelatinised, the threads of fibrin break away from their attachment to the vessel in which the coagulum is contained, and owing to their elasticity, the general mass of fibrin contracts, squeezing out of its meshes clear drops of a fluid termed *serum*.

The fibrin clot gradually shrinks to small size and floats in the abundant fluid serum.

The separation of the serum is accelerated by agitation of the soft clot; and if brisk agitation, such as whipping, be kept up for a few minutes in recently drawn blood, the plasma does

not form a jelly, but the fibrin firmly adheres to the stirring rods and at once contracts around them.

Chemical Composition.—The specific gravity of plasma is about 1027. It is alkaline in reaction. It contains about 10 per cent. of solid matter, of which three quarters are of a proteid nature. It also contains gases in solution. In 100 vols. of plasma there were found of—

Oxygen	... ...	0·26 vols.
Nitrogen	...	2·24 „
Carbonic acid	...	35·26 „

The proteids consist of fibrinogen, serum-globulin, and serum-albumin.

1. *Fibrinogen.*—This may be prepared from plasma or from serous effusions in the following ways :—

(*a*) The solution containing fibrinogen is mixed with an equal volume of saturated sodium chloride. This precipitates the fibrinogen, which is collected on a filter, and washed with a half saturated solution of sodium chloride. The precipitate is then dissolved by the addition of distilled water ; sufficient sodium chloride adheres to the precipitate to enable the distilled water to dissolve it.

(*b*) Plasma is diluted with 15 times its volume of water, and a stream of CO_2 gas passed through. This precipitates serum-globulin, which is filtered off. The filtrate is further diluted and CO_2 again passed through it ; the precipitate which now forms is fibrinogen, but not in so pure a condition as that attained by method (*a*).

It is found to have the following properties :—

(*a*) The addition of fibrin ferment causes the formation of fibrin, *i.e.* coagulation.

(*b*) It is coagulated by heat at the low temperature of 56° C.

(*c*) It is a globulin, *i.e.* it shews the following characteristics :

(i.) Insolubility in distilled water.

(ii.) Solubility in weak solutions of neutral salts.

(iii.) Precipitation by saturating the solution with Na_2SO_4, NaCl, or $MgSO_4$.

(iv.) Coagulation by heat.

It is important to note that half saturation with NaCl is sufficient to precipitate fibrinogen.

The quantity of fibrinogen present in blood is only about $\frac{1}{20}$th of the total amount of proteid.

2. *Serum-globulin.*—This may be obtained from plasma, after the removal of fibrinogen by method (*a*), by complete saturation of the filtrate with sodium chloride. This precipitate is collected, washed with a saturated solution of sodium chloride, and dissolved by adding distilled water. It is usually however, prepared from serum, where it occurs unaccompanied by fibrinogen, and its preparation is consequently easier. The following are some of the methods used :—

(*a*) Dilute serum with a very large bulk of distilled water. This lowers the percentage of salts so considerably that the globulin is precipitated.

(*b*) Dilute serum with 15 times its bulk of water, and then pass a stream of CO_2 through. The globulin is precipitated.

(*c*) Saturate with neutral salts, such as $MgSO_4$, Na_2SO_4 or NaCl. This is the most useful and generally employed method.

Serum-globulin as thus obtained shews the characteristic properties of a globulin.

The temperature at which it coagulates is 75° C.

3. *Serum-albumin.*—This is the proteid remaining in solution after the complete precipitation of fibrinogen and serum-globulin from plasma. It may be obtained from such a solution by the following methods :—

(*a*) If the filtrate is already saturated with $MgSO_4$, Na_2SO_4 is now added to saturation. The double salt, sodio-magnesic sulphate ($Na_2SO_4.MgSO_4.6H_2O$) is formed, and this precipitates the serum-albumin, which is caught on a filter, washed with a saturated solution of the double salt, and then dissolved in distilled water.

(*b*) Plasma freed from the globulins, by any method, is saturated with ammonium sulphate $(NH_4)_2SO_4$. The serum-albumin is then precipitated.

Serum-albumin has the following properties :—

(*a*) It gives the ordinary proteid reaction.

(*b*) It is soluble in distilled water, or in solutions of neutral salts.

(*c*) It is not precipitated by saturation with either Na_2SO_4, $MgSO_4$, or NaCl, singly.

(*d*) It is precipitated by saturation with the double salt, $Na_2SO_4.MgSO_4.6H_2O$, or with $(NH_4)_2SO_4$.

(*e*) It is coagulated by heat.

(The above reactions show that it belongs to the class of albumins.)

(*f*) It is not precipitated by ether.

(*g*) It is precipitated by strong HCl, but the precipitate dissolves on adding excess of acid.

(*h* If its solution be heated, a coagulum appears at 73° C. If this be filtered off and more heat applied, a second coagulum appears at 77° C., and again a third at 84° C.

The *Extractives* found in plasma consist of :—

(i) Urea and uric acid, in small quantities.
Kreatine and hippuric acid, in still smaller quantities.

(ii) Dextrose, in small quantities.

(iii) Fatty matters, which may be extracted by ether. These are far more abundant after a meal rich in fat. Small quantities of cholesterin and lecithin are also present.

The *Salts*.—Of these sodium chloride is by far the most abundant ; potassium chloride, sodium carbonate, phosphates of Ca, Mg, and Na, and small amounts of sulphates also occur. It should be remembered that the amount of sodium salts present in plasma is about 10 times as great as that of the potassium salts.

Fibrin.

Fibrin may be procured either from (1) plasma, (2) serous effusions, *e.g.* hydrocele fluid, (3) solution of pure fibrinogen, by adding fibrin-ferment, or (4), blood by whipping, and then washing the insoluble product with water. When fresh it has a pale yellow or whitish colour, a filamentous structure, and is singularly elastic. It is not soluble in water, weak saline solution, or ether. It is soluble with difficulty in a 10% solution of sodium chloride, or of magnesium sulphate. Alcohol makes it shrink by removing its water. When quite dry it is brittle and hard, and can be reduced to a powder. It swells in 1 per cent. hydrochloric acid, and if

warmed is converted into acid albumin and after some time albumoses. It is readily dissolved by gastric or pancreatic juice.

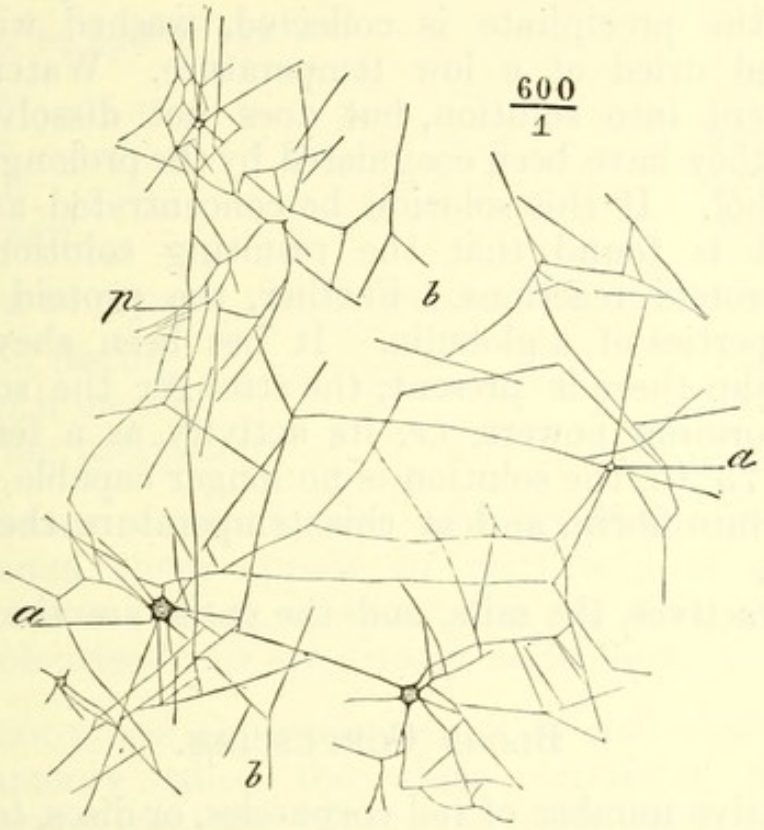


Fig. 90. —Fibrin threads after staining has made them visible. The network (*b*) appears to start from granular masses, the remains of cells; or blood-platelets (*a*). (Ranvier.)

The amount formed varies very much even in the blood drawn from the same animal at the same time, but is always very small compared with the size of the blood-clot. It never reaches as much as 1 per cent., commonly varying from 0·1 per cent. to 0·4 per cent. of the entire mass of blood.

Serum.

This name is given to the clear fluid which oozes out of the clot of plasma. It is a clear straw-coloured alkaline fluid of 1026—1027 sp. gr. After a full meal the serum is slightly milky from the presence of finely divided fat.

It contains about 10 per cent. of solid matters, of which three quarters are proteids.

The *Proteids* are :

1. *Serum-globulin.*
2. *Serum-albumin.* These have been described under Plasma.
3. *Fibrin-ferment.*—This is prepared by Schmidt in the

following manner :—Serum is mixed with about 15 times its bulk of absolute alcohol, which precipitates all the proteids fibrin-ferment among them. This mixture is kept for six weeks, and then the precipitate is collected, washed with absolute alcohol, and dried at a low temperature. Water takes the fibrin-ferment into solution, but does not dissolve any other proteid, if they have been coagulated by the prolonged standing under alcohol. If this solution be concentrated at a low temperature it is found that the resulting solution gives the ordinary proteid reactions. Further, the proteid present has all the properties of a globulin. It has been shewn that the more globulin there is present, the stronger the solution is in its fibrin-forming powers, *i.e.* its activity as a ferment. By heating to 73° C., the solution is no longer capable of changing fibrinogen into fibrin, and at this temperature the globulin is coagulated.

The extractives, the salts, and the gases are the same as in plasma.

Blood Corpuscles.

The relative number of red corpuscles, or discs, to the colourless cells is said to be, on the average, 350 to 1. This is true of the blood drawn from the fine vessels by puncture. While in the vessels the blood must contain a greater proportion of the colourless cells, for by the ordinary method of obtaining blood for examination, they do not flow out of the punctured capillaries as readily as the red discs, and many of them are said to become disintegrated very shortly after they are removed from the circulation. Although the number of red discs normally alters but little, the proportion of white to red varies much, on account of the constant changes occurring in the number of the white cells. It has been found to differ according to the observer, the situation, and other circumstances, as shown in the following table, which gives the number of red corpuscles to one colourless cell :—

Observer's estimate of normal proportion :—

	Red. White.
Welcker	335—1
Moleschott	357—1

In various parts of the circulation :—

Splenic vein	60—1
Splenic artery	2260—1

	Red. White.
Hepatic vein	170—1
Portal vein	740—1
According to age or sex :—	
Girls	405—1
Boys	226—1
Adult	334—1
Old age	381—1
According to general conditions :—	
When fasting	716—1
After a meal	347—1
During pregnancy	281—1

In a disease of the spleen and lymphatic glands called Leucocythæmia there appear to be nearly as many white cells as red discs. Here, however, the red discs are deficient, while the colourless cells are greatly multiplied.

The Colourless Corpuscles.—The colourless cells of the blood, commonly called the white corpuscles, differ in no essential respect from the pale round cells which are found in most of the tissues of the body. They occupy a great part of the lymphatic glands and thymus, and exist in large numbers in the lymph, which carries them from those organs into the blood (Hewson). They are often spoken of as lymphoid cells, leucocytes, elementary, or formative cells, on account of their being so widely distributed throughout the tissues.

When fresh blood is examined with the microscope these cells can generally be seen adhering to the glass slide, or cover-glass, and lying singly, apart from the groups of red discs. They can be recognised by their absence of marked colour, finely granular structure, spherical shape, and the nuclei which may often be recognised near the centre of the cell. Though not always visible in fresh preparations, the nuclei can be brought to light by the action of many reagents—*e.g.*, acetic acid. If examined while being moved by the blood-current in the capillary vessels, they are seen to pass slowly along in contact with the vessel wall, while the red corpuscles rush rapidly past them down the centre of the channel.

This may partly be due to their peculiar adhesiveness, which also causes them to stick to the glass slide, whilst the red discs

are washed away when a gentle stream of saline solution is allowed to flow under the cover-glass. These cells show all the manifestations of activity characteristic of independent living beings. If kept in a medium suitable to them, and at the temperature of the body, they will soon be seen to alter their appearance ; their outline becomes faint, they are no longer spherical, but very irregular in shape, and constantly change their form by sending out and retracting processes, by means of which they change their position, so that they may be said to perform locomotion. These movements are rendered more active by a slight increase of temperature, and are checked by cold. For continued observation about 38° C. is the best temperature for mammalian blood. The blood of the Frog is generally used to observe the motion of the white corpuscles, as warming is unnecessary in cold-blooded animals.

While in motion these amœboid movements are absent, but when an arrest of the flow in the capillaries occurs, the cells change their form and position ; and if there be no onward flow of blood for some little time, they creep out of the capillaries, passing through the delicate vessel-walls. This *emigration* of the blood-cells is possibly a common event when a tissue is in need of textural repair. It forms one of the most striking of the series of events occurring in inflammation.

No doubt they continually absorb fluid nutriment from the surrounding medium, as is shown by the effect of poisons on them ; and, by the repeated contractions and relaxations of parts of their substance in the form of pseudopodia, they take into their protoplasm solid particles, which after some time are ejected after the manner of amœbæ (p. 78).

The colourless cells of the blood have been variously classified from time to time. Recently they have been divided into two varieties with supposed functional differences. The (α) corpuscles, or *phagocytic cells*, make up nearly two-thirds of the whole number. Their nucleus is irregular, and their protoplasm finely granular. Their function is said to be mechanical, since they are capable of taking up and transporting foreign particles, carmine, bacteria, &c. They do not stain readily with eosin. The (β) corpuscles (eosinophile-cells) have regular nuclei, and their cell body is filled with coarse granules that stain with eosin. The granules are discharged from the cells from time to time. These cells do not pick up foreign particles, and are not phagocytic. They may be regarded as free unicellular glands.

ORIGIN OF THE COLOURLESS BLOOD-CELLS.—Since such an ordinary circumstance as a hearty meal can materially influence the number and size of the white corpuscles, it would appear that they must be usually undergoing rapid variations in their number—probably by being constantly used up and continuously replaced by new ones. The places in which they occur in greatest number are the lymphatic glands, the spleen, and the lymph follicular tissue in the intestinal tract.

There is no doubt that the lymph contains a much larger proportion of these cells after it has passed through the lymph-glands, and the blood coming from the spleen contains an excessive proportion of them.

It is then not unreasonable to suppose that many of the white cells found in the blood have their origin in these organs.

They may also be developed from similar cells in any tissue, but their reproduction by *division*, other than that which probably occurs in the lymph follicles where it cannot be seen, is a circumstance of the greatest rarity, and few observers have been fortunate enough to witness the phenomenon.

The destiny of the white blood-cells is probably manifold. From the readiness with which they escape from the capillaries and wander by their amœboid movement through the neighbouring tissues to reach any point of injury, it would appear that they take an active part in the repair of a tissue whose vitality has in any way suffered. During the growth of all tissues these cells seem to contribute active agents to their formation ; thus in the formation of bone it has been stated that escaped blood-cells or their immediate offspring help to lay down the calcareous material, and some even settle themselves as permanent inhabitants of the lacunæ.

Further, they are in all probability the means of renewing the red discs. Their protoplasm either takes up the colouring matter from its surroundings, or forms it within itself from suitable ingredients. Certain it is that cells are found, recognisable as white blood-cells, which have more or less of the red colouring matter embedded in their substance. As this increases the cell gradually loses its distinctive characters, and assumes those of a red corpuscle.

THE COLOURED CORPUSCLES.—The red discs were discovered in the human blood by Leeuwenhoek, about 1673. They give the red colour which characterises the blood of all

vertebrated animals (except the amphioxus), but are not found in the blood of the invertebrata, which only contains colourless cells. When the blood of the invertebrates has a colour, it owes it to the fluid, not to the corpuscles. The individual discs when viewed singly under the microscope appear to be pale orange, but when in masses the red becomes apparent.

The shape of the corpuscles differs in different classes of animals. In man and most other mammalia they are discs, concave on each side, and rounded off at the margin. The only class of mammals which forms an exception to this rule is the camelidæ, whose red corpuscles are elliptical in shape, like those of non-mammalian vertebrates.

The corpuscles of birds, amphibia and fish are flattened elliptical plates, slightly convex on each side, and containing a distinct oval nucleus in their centre.

The size of the corpuscles varies greatly in different classes of animals, but is strikingly constant in the same class. A glance at the following diagram, in which the corpuscles are drawn to scale, will give an idea of their relative sizes, in examples of the different classes of animals, and will make the following points more rapidly obvious than mere description.

The size of the animal has no general relation to the size of the corpuscles. The human red discs are of a fair average size when compared with those of other mammals, and therefore man's blood cannot be distinguished from that of the other mammalia by the discs.

The mammalian corpuscles are, on the whole, small when compared with those of the other vertebrates. The batrachians are distinguished by the great size of the corpuscles. Those of the Amphiuma tridactylum are visible to the naked eye.

The following measurements are given by Welcker for the human discs :—

Diameter	·0077 of a millimetre (7·7μ*) = $\frac{1}{3200}$th of an inch.
Thickness	·0019 of a millimetre (1·9μ) = $\frac{1}{12400}$th of an inch.
Volume	·00000077 of a cubic millimetre.
Surface	·000128 of a square millimetre.

The last measurement would give a surface of about 2,816 square metres for the corpuscles of an adult. A surface of 11 metres square is exposed every second in the lungs for the absorption of oxygen.

* The Greek letter μ is used by histologists to denote $\frac{1}{1000}$ of a millimetre, which is taken as a convenient unit of measurement.

When circulating in the vessels, or immediately after removal, the red corpuscles are very soft and elastic, being bent and altered in shape by the slightest pressure, and easily stretched to twice their diameter. But the moment pressure

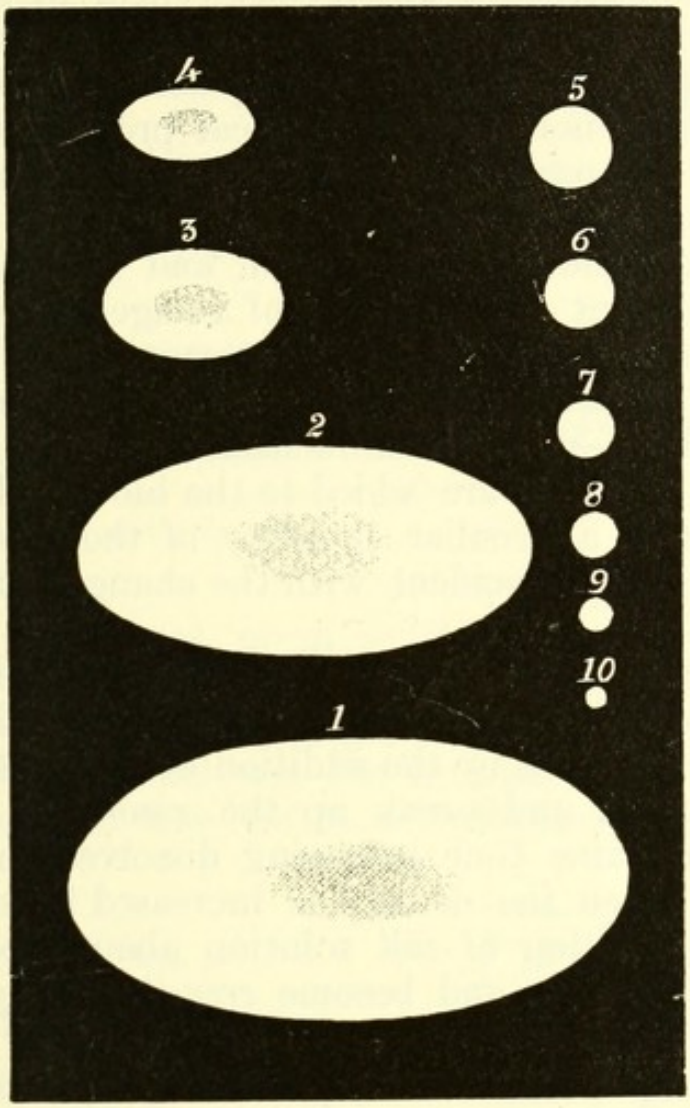


Fig. 91.—Diagram of the relative sizes of red corpuscles of different animals. The measurements below are in fractions of a millimetre.

1. Amphiuma	$\frac{1}{16} \times \frac{1}{30}$	6. Man	$\frac{1}{126}$
2. Proteus	$\frac{1}{18} \times \frac{1}{44}$	7. Dog	$\frac{1}{139}$
3. Frog	$\frac{1}{45} \times \frac{1}{66}$	8. Horse	$\frac{1}{181}$
4. Pigeon	$\frac{1}{225} \times \frac{1}{120}$	9. Goat	$\frac{1}{253}$
5. Elephant	$\frac{1}{108}$	10. Muskdeer	$\frac{1}{483}$

or traction is removed, they return to their normal biconcave disc-shape, if the medium in which they lie continue of the normal density.

Changes take place in the blood shortly after it is removed from the body, which seem to be associated with the loss of function (death) of the red discs, as shown by their rapid destruction if re-introduced into the circulation.

The changes are checked by cold, and facilitated by heat, a temperature above that of the body causing them to take place almost immediately. Associated with the loss of function of the discs is observed a change accompanied by an apparent increase of adhesiveness, which causes them to stick together, commonly adhering by their flat surfaces, so as to form into rolls or *rouleaux*, like so many coins placed side by side. That this adhesion is not a mere physical process, independent of the chemical properties of the corpuscles themselves, seems proved by the following facts :—(1) It does not occur immediately after the blood is drawn, and it disappears after a few hours without the addition of re-agents ; (2) while the blood is in the living vessels under normal conditions there is no adhesion, but it appears when any standstill in the circulation takes place—as in inflammation ; (3) it does not occur when saline solutions are added to the blood. It seems to be dependent upon a peculiar property of the discs, which only exists for a time coincident with the changes that accompany their death.

The shape of the discs changes when the density of the medium in which they are suspended is altered. When the density is reduced, as by the addition of water, they swell and become spherical, and break up the *rouleaux*, the colouring matter at the same time becoming dissolved in the medium. (Fig. 92.) When the density is increased by slight evaporation, or the addition of salt solution about 1 per cent., they cease to be concave, and become *crenated* or spiked like the green fruit of the horse-chestnut. (Fig. 93.) The addition of strong syrup causes the corpuscles to shrivel and assume a great variety of peculiar bent or distorted forms. (Fig. 94.) Elevation of temperature or repeated electric shocks cause a peculiar change in shape, but since the change is associated with the death of the element, it cannot be attributed to vital activity comparable with that seen in the white cells.

The discs show no signs of structure under the microscope ; they are perfectly homogeneous, transparent bodies of a pale orange colour ; the recent efforts to restore the importance of the limiting membranes, formerly supposed to surround them, have not been convincing, and give no explanation of their shape. Their behaviour when certain re-agents are added to the blood shows that the corpuscles have two constituents : (1) the colouring matter, *Oxyhæmoglobin ;* and (2) the *Stroma.* The colouring matter may be removed from the corpuscle, as

above stated, by water, and leaves a perfectly colourless transparent foundation or groundwork, but no evidence of a vesicular boundary or capsule. This either holds the colouring

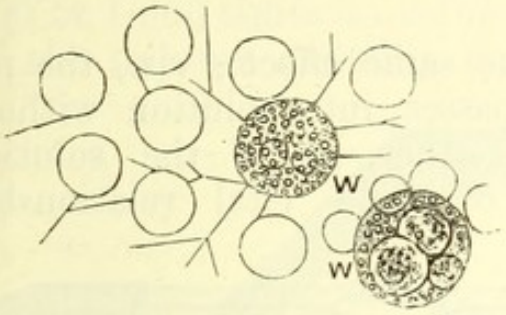


Fig. 92.—Microscopic appearance of the blood after the addition of distilled water. Red Corpuscles become colourless or pale, separate, and spherical. The white are seen to be swollen round and granular with clear nuclei.

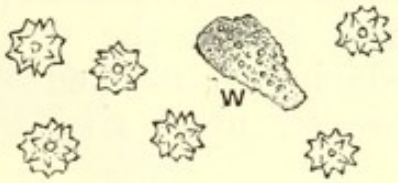


Fig. 93.—Showing effect of evaporation. Six Red Corpuscles crenated. (w) White cell changing shape.

matter in its interstices, or in a vital chemical combination. The effect on the naked eye appearance of the blood produced, by the removal of the colouring matter from the stroma, is to alter the colour and increase the transparency of the fluid. The oxyhæmoglobin now forms a transparent dark-red, *lakey*

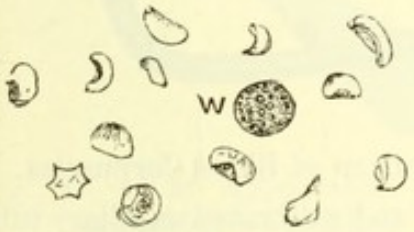


Fig. 94. — Red Corpuscles, shrivelled by the addition of strong syrup. (w) White Corpuscle.

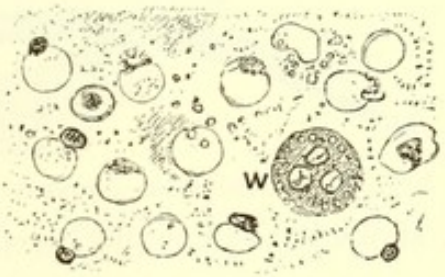


Fig. 95.—Blood Corpuscle after the addition of tannic acid. ($\frac{1}{2}$%.)

solution, and the corpuscles, being quite colourless, are practically invisible. This transparency of the fluid does not depend on any change in the oxyhæmoglobin, but merely on its being dissolved out of the discs, which become transparent and can no longer reflect the light. This process, which is commonly spoken of as rendering the blood "lakey," may be brought about by the following means. (1) The addition of about $\frac{1}{4}$ of its bulk of distilled water, to wash the colouring matter out

of the stroma, which may then be rendered visible by a weak solution of iodine. (2) By the addition of chloroform, ether, or alkalies. (3) By passing repeated, strong induction shocks through the blood. (4) By rapidly freezing and thawing the blood several times.

All these processes produce the same effect ; viz., the red matter leaves the stroma and passes into solution without producing a marked change in either, as if the solution depended upon the destruction of some vital relationship

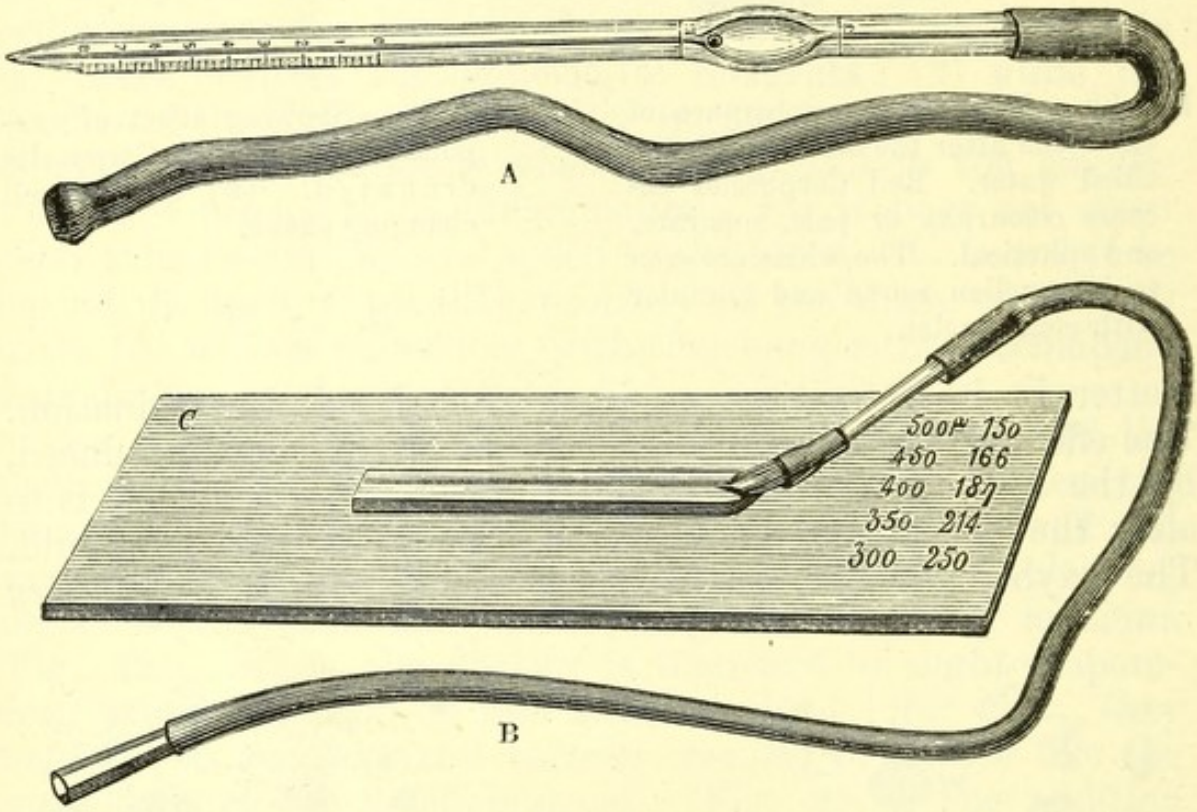


Fig. 96.—Malassez' Apparatus for the Enumeration of Blood Corpuscles.

A. Measuring and mixing pipette. B. Flattened and calibrated capillary tube.

between the stroma and the oxyhæmoglobin which prevented the diffusion of the latter in the living blood.

Solutions of urea, bile acids and heat of about 60° C. seem to destroy the discs, and thus remove the colouring matter. Carbolic, boracic, and tannic acids cause the colouring matter to coagulate and become localised either at the centre or margin of the corpuscle. (Fig. 95.)

The number of discs in the blood of man is enormous, namely, in a cubic millimetre of blood, about 5 millions for males, and 4½ millions for females, or about 250,000 millions for one pound of blood. The number varies much, not only through disease, but also as a result of the many physiological

processes, such as changes in the amount of plasma, which alter the relative proportion of discs to the fluid.

In order to count the corpuscles the following method is employed. The blood is diluted with artificial plasma to 100 or 1,000 times its volume, and the corpuscles in a portion of the mixture carefully measured off by a capillary tube, and

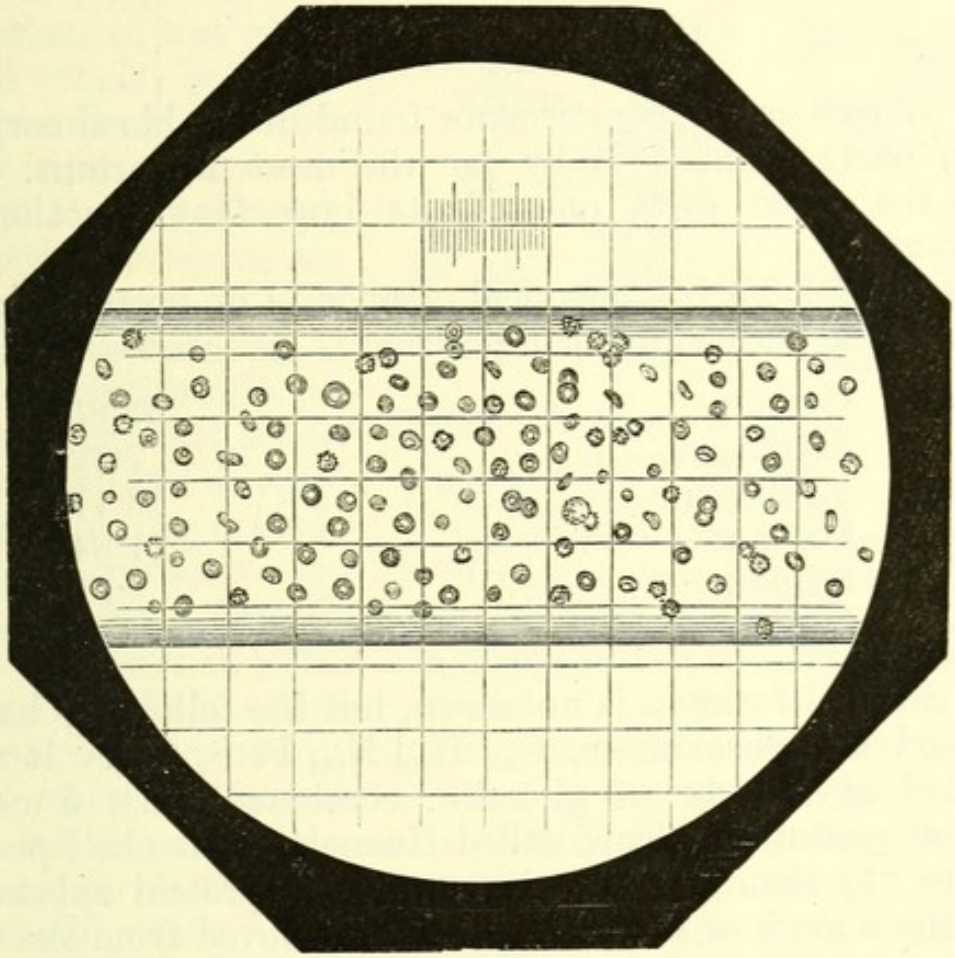


Fig. 97.—The appearance presented by the Capillary Tube of Malassez' Apparatus when filled with diluted blood and examined under a microscope magnifying 100 diameters, provided with an eye-piece micrometer.

counted. This operation requires great care and delicate apparatus. One of the best-known methods is that of Malassez, the details of which are as follow :—

Blood is drawn into the capillary tube of a specially prepared delicate pipette (Fig. 96, A) up to a mark which indicates $\frac{1}{100}$ part of the capacity of the pipette. This known quantity of blood is then washed into the bulb of the pipette by drawing up artificial serum to fill the bulb, where the fluids are mixed by shaking about a glass bead contained in its cavity. Some of this mixture is then allowed to pass into a flattened capillary tube of known capacity fixed on a slide, and the number of

corpuscles in a given length of this tube is carefully counted at two or three places.

The important question, how much oxyhæmoglobin exists in a given sample of blood, can be determined by diluting some of it until the colour equals that of a standard solution of known strength.

Oxyhæmoglobin.

Of the chemical constituents found in the blood corpuscles, the colouring matter is by far the most important. To it alone the blood owes one of its important functions—the respiratory.

Oxyhæmoglobin is a chemical compound of great complexity, of which the per-centage composition is given as—

Carbon	53·85
Hydrogen	7·32
Nitrogen	16·17
Oxygen	21·84
Sulphur	·39
Iron	·43

Its rational formula is unknown, but the following has been proposed as approximate, $C_{600}\ H_{960}\ N_{154}\ Fe\ S_3\ O_{179}$. It may be regarded as a form of globulin, combined with a coloured material containing iron, called Hæmatin. Its chief peculiarities are (1) that although it contains a proteid substance, it crystallises more or less readily, when removed from the stroma of the corpuscles of most vertebrates; (2) the considerable amount of iron it contains (0·4 per cent.); (3) the remarkable manner in which it combines with oxygen to form an unstable compound; and (4) the ease with which it yields its oxygen to the tissues and takes it from the air.

The readiness with which the *oxyhæmoglobin crystals* are formed varies much in different animals and under different circumstances, as may be seen from the following list—

Most readily—rat, guinea pig, mouse.
Readily—cat, dog, horse, man, ape, rabbit.
With difficulty—sheep, cow, pig.
Not at all—frog.

The presence of oxygen causes the crystals to form more rapidly, so that a stream of oxygen passed through a strong

solution of hæmoglobin causes small crystals of oxyhæmoglobin to form.

The crystals always belong to the rhombic system, being most frequently plates (man, &c.) or prisms (cat), and rarely tetrahedra (guinea pig) or hexagonal plates (squirrel). (Fig. 98.)

The colour of the crystals and their solution varies according to the light by which they are looked at. By reflected light they are greenish red in colour, and by direct light, scarlet.

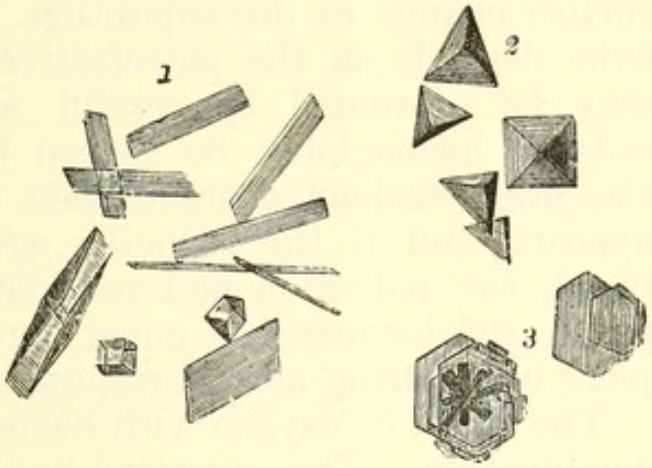


Fig. 98.—Crystals of Hæmoglobin from different animals :—

1. Showing the ordinary form of crystals.
2. Tetrahedra from Guinea Pig.
3. Hexagonal plates from Squirrel.

The *preparation of oxyhæmoglobin* crystals is accomplished by first separating the colouring matter from the corpuscles by freezing, or the addition of water or ether, and then rendering it less soluble by evaporation, cold, and the addition of alcohol.

For microscopic observation it generally suffices to kill a rat with ether, and expose a drop of the blood diluted with distilled water on a slide until half dried, and then cover. Crystals appear in the fluid as it becomes concentrated.

The combinations which hæmoglobin enters into are numerous, and throw much light upon the function of the corpuscles.

As already stated, the colouring matter, when exposed to the air, combines with oxygen to form a loose chemical compound called oxyhæmoglobin. This is the condition in which the colouring matter of the blood is generally found. Although so prone to combine with oxygen, the oxyhæmoglobin very readily parts with some of it. In the circulation it is always united with oxygen, normally leaving the lungs in a state of saturation. On its way through the capillaries of the tissues, it parts with some of its oxygen, part becoming reduced to hæmoglobin, but even the most venous blood always contains some oxyhæmoglobin.

The oxygen can be removed by reducing the pressure under an air pump, or by exposing the solution to a mixture of nitrogen and hydrogen. Various reducing agents rob the

oxyhæmoglobin of its oxygen; and if blood or a solution of oxyhæmoglobin be sealed in a glass tube so as to exclude the air, the loose oxygen is taken up by some of the other constituents of the blood, and the oxyhæmoglobin becomes gradually reduced to hæmoglobin, after which it undergoes no further change or decomposition. The reduction in the sealed tube depends on the putrefactive changes in the proteids, and may be prevented by careful aseptic precautions. If the reduced hæmoglobin be shaken for a few moments with air, the bright colour characteristic of oxyhæmoglobin soon reappears, and if the reducing agent be not injurious to the blood, the reduction and reoxidation may be repeated several times, the hæmoglobin going through the changes which take place in it during normal respiration.

The union of oxygen with hæmoglobin is a definite chemical combination. This is proved by the following facts :—

(1.) When the pressure is reduced the oxygen does not come away from the solution in accordance with the law which governs the escape of gases dissolved in a liquid, but nearly all comes off suddenly when the pressure is lowered to about $\frac{1}{25}$ of an atmosphere at the body temperature (*vide* p. 318). One gramme of oxyhæmoglobin crystals yields 1·59 c.c. of O.

(2.) The two substances give a different absorption band when examined with the spectroscope. The reduced hæmoglobin gives one wide diffuse band, which lies between the D and E lines of the solar spectrum, and much of the violet and of the red are cut off. The single band, characteristic of reduced hæmoglobin, is replaced by two when the hæmoglobin combines with oxygen—one broad band in the green near E, and a narrow one, more clearly defined, in the yellow close to the D line; both bands lie between D and E. With strong solutions the spectrum is still more darkened at either extremity, and the two bands become wider and tend to fuse into one (see Frontispiece).

(3.) Further, the oxygen may be replaced by other substances which unite with the hæmoglobin. One of the most important of these is carbonic oxide, which forms a much more stable compound with hæmoglobin than oxygen. It is of a bright cherry-red colour, and has two absorption bands in the spectrum resembling those of oxyhæmoglobin; but more equal in width and more sharply defined, that in the yellow being separated further from the D and E lines respectively.

It is this compound which is formed in poisoning with carbonic oxide. The CO occupying the place of the oxygen,

[*To face* p. 210.

EXPLANATION OF THE PLATE OF SPECTRA.

(*FRONTISPIECE.*)

1. Spectrum of diffused daylight with some of the principal lines of Fraunhofer.

2. Spectrum of *oxy-hæmoglobin* in a moderately dilute solution, p. 210.

3. Spectrum of *reduced hæmoglobin* in solution of same strength, p. 210.

4. Spectrum of *methæmoglobin*, got by adding a solution of potassium permanganate to a solution of sheep's blood in water, p. 211.

5. Spectrum of *alkaline methæmoglobin*, got by treating the last solution with a little ammonia.

6. Spectrum of *acid hæmatin*, prepared by treating blood with acetic acid and agitating with ether, p. 212.

7. Spectrum of *alkaline hæmatin*, got by treating blood with rectified spirit and caustic soda, p. 212.

8. Spectrum of *reduced hæmatin* or *hæmochromogen*, prepared by adding sulphide of ammonium to the solution of alkaline hæmatin.

9. Spectrum of *acid hæmatoporphyrin*, p. 212.

10. Spectrum of *alkaline hæmatoporphyrin.*

11. Spectrum of *myohæmatin*, from alar muscle of a meat fly. The spectrum is practically the same throughout the whole animal kingdom, p. 412.

destroys the function of the blood corpuscles. CO-hæmoglobin may be distinguished from O-hæmoglobin by not being reduced by reagents greedy of oxygen, and by the bright red colour which persists when a 10 per cent. solution of caustic soda is added, and the mixture heated. O-hæmoglobin gives a muddy-brown colour under the same treatment.

When a solution of oxyhæmoglobin is exposed to the atmosphere for a few days its colour changes to a dingy brown, owing to the production of a new substance which is called *methæmoglobin*. This is now regarded as of the same chemical composition as oxy-hæmoglobin, only the oxygen is more firmly united to the hæmoglobin, as may be shown by the facts, that it cannot be removed by passing other gases (CO, &c.) through the liquid, or by exhaustion with an air-pump. Met-hæmoglobin gives an absorption spectrum which shows a distinct band in the red between C and D and two other faint bands between D and E which closely correspond to the position of the bands of oxy-hæmoglobin. A fourth indistinct band in the blue has also been described.

This substance can also be formed by the addition of potassium permanganate, ferro-cyanide of potassium or alkaline nitrites to hæmoglobin. A solution of methæmoglobin, though unaltered when placed in vacuo, may be reduced to hæmoglobin by ammonium sulphide. It then regains its red colour, shows the spectrum of reduced hæmoglobin, and when shaken with air it forms oxyhæmoglobin.

Decomposition of Hæmoglobin.—Hæmoglobin may easily be broken up into two constituents—namely, (*a*) a colourless substance which is nearly related to the class of proteids called globulins, and (*b*) a blackish red amorphous material called *Hæmatin*, which contains all the iron of the hæmoglobin.

This change is brought about by several methods, such as the addition of acids, strong alkalies, heat above 70° C., &c.

Hæmatin, &c.—Hæmatin is a secondary product, being the result of the oxidation of a substance called *hæmochromogen*, which is the first outcome of the decomposition of the hæmoglobin by acids or alkalies. Hæmochromogen or *reduced hæmatin*, as it may be called, can be obtained from hæmatin by reducing agents, *e.g.* ammonium sulphide, but it can only be preserved in an atmosphere of hydrogen or nitrogen, as it immediately takes up oxygen to form hæmatin on exposure

to the air. The formula $C_{68}\ H_{70}\ N_8\ Fe_2\ O_{10}$ has been given for hæmatin. It dissolves in weak alkaline or acid solutions, but not in water or in alcohol.

Hæmatin is readily prepared by mixing acetic acid with a strong solution of hæmoglobin, which then becomes a dark-brown colour. The dark hæmatin can be removed by ether. But if the acid used be strong, the solution of hæmatin is found to be free from iron. This iron-free hæmatin is called *hæmatoporphyrin* or *hæmatoin*. If now the *acid-hæmatin* solution be saturated with ammonia, the iron again becomes united with hæmatoin, forming *alkali-hæmatin*.

If acid-hæmatin be removed from its watery solution by ether, and examined spectroscopically, four bands are seen; the 1st. in the red between C and D, but nearer C; the 2nd. a narrow faint band close to D; the 3rd. a broad band between D and E; and the 4th. broad and faint between *b* and F (see Frontispiece).

If the fluid be made alkaline with ammonia, we see the spectrum of alkali-hæmatin, viz. one broad band in the red near D; and a 2nd broad and faint band extending either side of E in the green. There is complete absorption beyond this.

Hæmatoporphyrin in its acid solution shows two absorption bands, the 1st narrow and faint in the red close to D; the 2nd broad and dark in the yellow between D and E.

HÆMIN.—Hæmatin unites with hydrochloric acid to form a crystallisable body called *hæmin* or hydrochlorate of hæmatin (Teichmann's crystals).

Fig. 99.—Hæmin Crystals.

If blood or dry hæmatin be mixed with a small quantity of common salt, a drop of glacial acetic acid added, and the mixture boiled, small characteristic crystals appear which have been found to be produced by the union of two molecules of hydrochloric acid with the hæmatin.

The formation of these crystals is very easily accomplished with a small quantity of old dried blood; therefore this substance becomes, in medico-legal inquiries, an important test for blood-stains.

HÆMATOIDIN.—Crystals of a substance called *Hæmatoidin*

are formed only in old blood-clots retained in the body. It does not contain any iron, and has the chemical formula $C_{32} H_{36} N_4 O_6$. It is closely related to if not identical with *bilirubin*, one of the colouring matters found in bile.

GLOBIN.—This name has been given by Preyer to the proteid derived from the hæmoglobin when the hæmatin is separated. It differs slightly from a globulin, though it resembles it in being precipitated by the weakest acids, even carbon dioxide, and it leaves no ash on ignition.

THE STROMA.

The stroma forms only about 10 per cent. of the solid parts of the corpuscles, the rest being hæmoglobin. The proteid basis of the stroma is probably made up of a globulin, also containing lecithin, cholesterin and fats in minute proportions. There is little more than one-half per cent. of inorganic salts in the red blood corpuscles, of which more than half consists of potassium phosphate and chloride.

DEVELOPMENT OF THE RED DISCS.

In the early days of the embryo the blood-vessels and corpuscles appear to be formed, about the same time, from the middle layer of the blastoderm (mesoblast). They first appear as round, nucleated, coloured masses, within colourless branching cells, *angioblasts*, the rest of the original mass of protoplasm of which forms a rudimentary blood-vessel. These round embryonic corpuscles subsequently lose their nucleus, and assume the characteristic shape of the red corpuscles.

In the later stages of embryonic life the red corpuscles are said to be formed in the liver, possibly out of protoplasmic elements which are made in the spleen and thence carried to the liver by the portal circulation.

In the connective tissue of rapidly growing animals—tadpole (Kölliker), rabbit (Ranvier), rat (Schäfer)—certain cells can be seen connected in the form of a capillary network, and within the protoplasm of these cells red colouring matter is developed, and the particles of colour can soon be recognised as characteristic blood corpuscles, arranged in rows within the newly-formed networks. Thus, isolated small networks of capillaries, consisting of a few meshes filled with blood corpuscles, are formed independently of the general circulation.

These corpuscles and their hæmoglobin are manufactured by isolated protoplasmic elements in the connective tissue, and subsequently added to the general mass of blood, by the growth of the network bringing it into continuity with the neighbouring vessels.

In the adult the formation of red blood corpuscles is much less active, but never ceases to take place in health, for the corpuscles must be renewed as they become worn out, and incapable of performing their function. This reproduction can go on with considerable rapidity, as we see after severe hæmorrhage, when the normal richness in hæmoglobin and corpuscles is soon regained. Their formation is, however, probably confined to a few special organs—red medulla of bones, spleen—where transitional forms are found in such numbers as to point to the probability of the red corpuscles being the offspring of the colourless cells, whose protoplasm either manufactures anew or collects the necessary hæmoglobin, and then loses its nucleus and ordinary cellular characters.

We can only guess at the fate of the discs, but there are many things which point to the spleen as the organ in which they are destroyed. In the spleen an enormous number of protoplasmic elements are produced, and the blood comes into relationship with the nascent cells in a way unknown in any other part of the body. Further, various unusual elements, some like altered red corpuscles, others like white cells containing hæmoglobin, are found in this organ.

The blood corpuscles on coming to the spleen are possibly submitted to a kind of preliminary test of general fitness, some elements of the spleen pulp having the faculty of examining their condition and deciding upon their fate. Many, no doubt, pass the trial without any change, being found in good working order. Others that are found totally unfit are broken up, and their effete hæmoglobin carried to the liver to be eliminated as bile pigment. Some possibly undergo a form of repair : a white cell taking charge of a weakly disc renews its stroma, adds to its hæmoglobin, and carries it through the final proof in the liver, where it is chemically refreshed before going to the lungs for the load of oxygen which it has to carry to the systemic capillaries.

The Gases of the Blood.

These are present in two conditions: (1) dissolved in accordance with well-established physical laws, and (2) chemically

combined. But since those present in the latter state are but loosely combined they may be separated by the same means as the former, and thus the oxygen, carbon dioxide, and nitrogen can all be removed by reducing the pressure with the air-pump. For this purpose a mercurial pump must be used, by means of which a practically perfect vacuum can be formed and all the gases obtained. Together they are found to measure about 60 volumes for every 100 volumes of blood.*

The following table shows the average amount of each gas—

	O. Vol. %	CO_2 Vol. %	N. Vol. %
Arterial blood	20	39	1—2
Venous	8—12	46—50	1—2

Oxygen.—The amount of oxygen in the blood is found to vary much with circumstances. In arterial blood the quantity is much more constant, and always exceeds that in venous blood. It is estimated (at 0° C. and 760 mm. pressure) that every 100 volumes of arterial blood yield 20 volumes of oxygen, whilst, in venous blood, the amount of oxygen varies from 8 to 12 volumes, in every 100 of blood.

The oxygen which comes off in the Torricellian vacuum exists in the blood in two distinct states :—(1) a very small quantity simply absorbed,—about as much as water absorbs under atmospheric pressure ; (2) chemically combined, in which state nearly all the oxygen exists, forming with the hæmoglobin the loose combination called oxyhæmoglobin. This oxygen therefore does not follow the laws of absorption by leaving the blood in proportion as the pressure is reduced, but when a certain point of reduction of pressure (20—30 mm. mercury, according to the temperature) is reached, the oxygen suddenly comes off, almost completely.

Carbon Dioxide (CO_2).—The amount of carbon dioxide also varies more in venous than in arterial blood, for under certain

* I. At the same temperature the *volume* of a gas varies inversely with the pressure, so that with twice the pressure, a given volume of a gas is twice the *weight* of the same volume at the original pressure.

II. A given liquid absorbs the same *volume* of a given gas, to which it is exposed, independent of the pressure exercised by that gas.

III. Therefore the amount *by weight* of gas absorbed by a liquid, at a given temperature, depends directly on the pressure, being *nil* in vacuo.

IV. The weight of a given volume of a gas decreases and the coefficient of absorption of a liquid diminishes, as the temperature increases.

V. Therefore the amount of gas absorbed is in inverse proportion to the temperature, being practically *nil* at boiling point.

circumstances (suffocation) it may rise to over 60 volumes per cent., although ordinary venous blood on an average contains only 46 volumes in every 100 of blood. On the other hand, the amount of this gas in arterial blood varies little from 39 volumes per cent.

Nearly all the carbon dioxide exists in the plasma, where some of it appears to be chemically combined with soda salts.

Nitrogen.—The amount of nitrogen does not vary much, being in both venous and arterial blood about 1·5 volume per cent., and it would appear to be simply absorbed.

For further details about the gases of arterial and venous blood, see Respiration.

CHAPTER XIII.

COAGULATION OF THE BLOOD.

In speaking of the chemical relationships of the plasma (see p. 197), the formation of fibrin has been mentioned as the essential item in coagulation. It was there explained that the presence of the red corpuscles was only an incidental part of the spontaneous coagulation of the blood. This was first shown by William Hewson, whose experiments, published some 120 years ago, form the basis of our present knowledge of the subject, and enable us to understand the various characteristics of the *clot*, which forms when blood is shed into a vessel.

The great importance of the coagulation of the blood in arresting bleeding, and in certain pathological processes, makes it expedient to consider more closely the steps of the process and to enquire into the various circumstances which facilitate its occurrence, after the blood is shed, as well as in the living vessels.

I. Coagulation of Shed Blood.

Before the formation of a perfect clot, blood may be seen to pass through three stages: 1, viscous; 2, gelatinous; 3, contraction of clot and separation of serum.

The first stage is commonly very short, and in thin layers of blood passes immediately into the second. In cold weather considerable quantities of blood if contained in deep vessels, take a much longer time to stiffen, so that the first stage may occupy from one minute to some hours.

The second stage, when the mass has been turned into a firm jelly, may be arrived at within the varying limits just named, and occupies a corresponding period: only a few minutes if the mass be small, spread out or shaken, but many hours if a large quantity be kept motionless and cool.

The third stage therefore begins sometimes as soon as ten to

fifteen minutes, but generally after some hours. Clear drops of serum appear about the clot. After several hours this contracts until it forms but a comparatively small mass floating in the serum. If the jelly-like clot be disturbed, the serous fluid makes its appearance much sooner than the time just stated.

During the formation of the clot under ordinary circumstances the corpuscles are entangled in the meshwork of fibrin, so that the gelatinous mass has throughout a dark-red colour.

If the coagulation takes place slowly—as it does in very cold weather, in horses' blood, or in human blood if removed from a person during fever—then the heavier red corpuscles have time to subside to the lower layers of the clotting plasma, while the white cells remain and are caught in the meshes of the fibrin in the upper layer of the clot, which then has the pale colour familiar to the physician in the old days of bleeding as the "buffy coat," or *crusta phlogistica*. This buffy coat contains a greater proportion of the elastic fibrin and soft white cells than the rest of the clot, and encloses but few red corpuscles, therefore the fibrin can contract more completely in this upper layer than in the deeper part of the clot which includes the red corpuscles. The effect of this is, that the upper surface becomes concave, and a "cupped" clot is formed. The contraction of the clot proceeds for days, and in order to see the characters described above, the blood should be kept in a cool place and perfectly motionless.

The contraction of the fibrin, and separation of the serum, can be made to take place much more quickly by gentle agitation, by causing the ends of the fibrin threads to separate from the sides of the vessel, but by thus disturbing the clot, during its formation, the corpuscles are displaced and escape into the serum, which is then stained and cannot be seen in its clear transparent state.

If brisk agitation with a glass rod—or better, a bundle of twigs—be commenced the moment the blood is drawn, the fibrin is formed more rapidly, but the corpuscles are not entangled in its meshes, for as quickly as the elastic threads are formed they adhere to, and are removed by the rod or twigs. Thus the fibrin is formed very rapidly, and the ordinary stages in the formation of a blood-clot, consisting of fibrin and the corpuscles, do not occur, for the fibrin is separated from the corpuscles as quickly as it is formed. We then have what is spoken of as "defibrinated blood," which does not give a blood-clot. Not that the coagulation has been prevented, but

the material essential for the formation of a clot has been removed as quickly as formed, and instead of catching the corpuscles in the meshes of its delicate fibrils to form the clot in the ordinary way, the stringy shreds of fibrin cling around the beating-rod as a jagged mass. The following tables show the relation of the different constituents of *coagulated* and *defibrinated* blood respectively :—

$$\text{Living blood} = \left\{\begin{array}{l}\text{Plasma}\\ \text{Corpuscles}\end{array}\right\} = \left\{\begin{array}{l}\text{Serum (appearing as clear fluid).}\\ \left.\begin{array}{l}\text{Fibrin +}\\ \text{Corpuscles}\end{array}\right\} = \text{Blood-clot.}\end{array}\right.$$

$$\text{Living blood} = \left\{\begin{array}{l}\text{Plasma}\\ \text{Corpuscles}\end{array}\right\} = \left\{\begin{array}{l}\text{Fibrin (removed on the rod).}\\ \left.\begin{array}{l}\text{Serum +}\\ \text{Corpuscles}\end{array}\right\} = \left\{\begin{array}{l}\text{Defibrinated}\\ \text{blood.}\end{array}\right.\end{array}\right.$$

Many circumstances influence the rapidity with which a blood-clot is formed. Speaking generally, circumstances which tend to injure the corpuscles or the plasma, and give rise to changes resulting in their death, promote coagulation ; while, on the other hand, conditions which protect the corpuscles and impede fibrin formation must retard coagulation.

These may be arranged categorically, viz.

A. Circumstances promoting coagulation :—

1. *Contact with foreign bodies* is of the first importance in hastening coagulation. The greater the surface of contact with the vessel or the air, the more the corpuscles are exposed to injury, and the more rapid are the destructive chemical changes inducing fibrin formation. Thus a drop or two of blood falling on any surface so as to spread out in a thin layer clots almost instantly.
2. *Motion*, by renewing the points of contact between the blood and the moving agent, hastens fibrin-formation. Thus, by whipping fresh blood, all the fibrin can be removed in a few minutes, and the defibrinated blood left without a clot.
3. *Moderate heat.* The formation of the fibrin generators and the action of the ferment seem to go on more rapidly at 38°—40° C. than at any other temperature.
4. *A watery condition of the blood* causes rapid coagulation but a soft clot. This is seen in repeated bleedings or hæmorrhages ; the blood which flows last clots first.

5. The addition of *a small quantity of water*, by setting up rapid changes in the corpuscles, accelerates coagulation.
6. *A supply of oxygen.*—Oxygen is used up in the chemical changes attendant upon the death of the blood, and its presence aids the formation of firm clots, such as are produced in arterial blood. Exposure to the air in a shallow vessel facilitates coagulation, partly by extensive contact and partly by a free supply of oxygen. But exposure to air is not necessary, because blood collected over mercury, without ever coming in contact with the air, coagulates very rapidly.

B. Circumstances which retard coagulation :—

1. Constantly renewed and close inter-relationship with the *lining of healthy blood-vessels*, alone affords the requirements essential for the preservation of the living corpuscles and plasma, in their normal condition.
2. When the blood is surrounded by *healthy living tissues* interchanges may occur between them, and if the oxygen supply is deficient, coagulation is much delayed. Thus considerable quantities of blood effused into the tissues may remain liquid and black for many days. This dark blood clots on removal and exposure to the air.
3. *Low temperature.*—The rate of coagulation decreases below 38° C., and the process is checked at 0° C.
4. The addition of concentrated *solutions of neutral salts* (about one third volume of a 30 per cent. solution of magnesium sulphate) quite prevents coagulation.
5. The introduction of albumose into the blood.
6. An extract of the mouth of the leech has a remarkable power of preventing coagulation.
7. *A great quantity of water* seems to render the action of the fibrin factors weak.
8. The addition of *egg albumin, syrup,* or *glycerine.*
9. The addition of *small quantities of alkalies.*
10. The addition of *acetic acid* until a very slight acid reaction is obtained.
11. The addition of *a small quantity of a solution of potassium oxalate.*
12. Increase in the amount of *carbon dioxide.* This,

together with the want of oxygen, explains why venous blood clots more slowly and loosely than arterial, and why the blood in the distended right side of the heart is frequently liquid after death from suffocation.

13. The blood of persons suffering from inflammatory disease coagulates slowly, but forms a very firm clot, which is "buffed and cupped."

Theories of Coagulation.

The chemical changes comprehended under the term coagulation, beginning when plasma is deprived of its means of vitality, and ending in the production of fibrin and serum, are naturally of the first importance in studying the chemical relationships of living plasma. They can best be followed out in the coagulation of plasma when separated from the corpuscles, for although the stages in the coagulation of blood are the same, (the appearance of an insoluble proteid—fibrin—being the one essential in either case) the corpuscles complicate the process and modify the appearance of the clot.

Not only is the fibrin not present, as such, in the living plasma, but it requires, for its production, the presence of other substances, which either do not exist in the living plasma, or are there so chemically associated as not to bring about the change which occurs when the plasma dies.

The reasons for believing this are the following. Fluids which sometimes collect by a slow process in the serous cavities of the body, *e.g.*, hydrocele fluid, pleural effusion, &c., if kept quite clean do not generally undergo spontaneous coagulation. If, to one of these, some serum or recently washed blood-clot be added, coagulation takes place just as in plasma (Buchanan). The "buffy coat" of a clot, or a piece of washed blood-clot, shows this power still better, hence Buchanan argued that it resided in the white corpuscles which are so plentiful in the buffy coat. He compared coagulation to the curdling of milk by rennet, shewing that two substances were required to form fibrin, one was present in hydrocele fluid, the other present in greatest abundance in dead white corpuscles.

The next worker who increased our knowledge of this subject was Denis, who shewed that if pure plasma be treated with sodium chloride to saturation, proteid substances are pre-

cipitated, which readily dissolve if water be added to weaken the salt solution. This Denis termed *plasmin*, and we now know it is made up of serum-globulin, fibrinogen, and fibrin-ferment. After some time the solution undergoes spontaneous coagulation, while the plasma from which it has been made has lost that power.

Schmidt shewed that from hydrocele fluid, or from blood serum, substances could be precipitated by passing a stream of carbon dioxide (CO_2) through the fluids. Both precipitates readily re-dissolve in weak saline solutions. The solution prepared from the hydrocele fluid causes blood serum to coagulate; that prepared from the blood serum causes the hydrocele fluid to coagulate; and when mixed together the mixture of the two solutions coagulates; while the serum and hydrocele fluid from which the substances have been removed no longer have the power of exciting coagulation in each other or in like fluids. Here, then are two materials: one, obtained in considerable quantity from serum after coagulation, is called *fibrino-plastin* or *paraglobulin* (Schmidt), *serum-globulin* (Hammarsten); the other, occurring in serous fluids, is named *fibrinogen*. Both these substances are present in the dying plasma of the blood prior to coagulation.

In preparing fibrinogen and serum-globulin Schmidt found that the more carefully he operated, the weaker and more uncertain their action as fibrin factors became; and finally he made solutions which, when added together, did not produce coagulation, but which, when added to less pure solutions, gave good firm clots. From this he suspected that a third agent, which acted as a ferment, was necessary to put into operation the fibrin-producing properties of the other two factors. He further succeeded in preparing the third agent, to which he gave the name of *fibrin-ferment*. By treating serum with strong alcohol the proteids are precipitated; the ferment is carried down with them, and after standing under alcohol some weeks is extracted with water. This extract, added to the mixture of the pure fibrin factors, which previously did not clot, caused rapid coagulation.

Hammarsten determined the properties of these substances more thoroughly, and shewed that the serum-globulin is not indispensable to the formation of fibrin, because (1) a solution of fibrinogen may be made to coagulate without its presence; (2) the *fibrinoplastic* property of serum-globulin is shared by casein and calcic chloride; (3) no fibrin can be obtained from

pure serum-globulin, (4) pure serum-globulin made from ferment-free fluids is not fibrinoplastic.

Fibrin ferment is influenced by those circumstances which affect the activity of ferments in general : it has a minimum, 0° C., optimum, 38° C., and maximum 80° C. temperature for its activity, with various gradations of rapidity of action between each, and is destroyed if heated above 80° C. An active solution having the properties of the ferment can be extracted from whipped fibrin, preserved in alcohol, by an 8°/₀ solution of common salt (Gamgee). Halliburton has shewn that it is a cell-globulin, though ferment-like in action, *i.e.* producing changes without being itself changed.

It has further been shewn by Green that the presence of a calcium salt is indispensable for the formation of fibrin. This explains the fact that a small quantity of potassium oxalate added to blood, directly it is shed, prevents its coagulation, for all the lime salts are precipitated, as insoluble calcium oxalate, consequently there is no calcium salt left to aid in the formation of fibrin.

II. Coagulation within the Vessels.

Since the blood coagulates spontaneously when removed from the body, the question now arises, how does it remain fluid in the blood-vessels ?

Though this question has long occupied much attention, it is still difficult to formulate a definite answer. Nor can we expect to find any adequate explanation until we are better acquainted with the exact details of the origin of the fibrin generators. It must be remembered that the blood may be regarded as a tissue, made up of living constituents requiring constant assimilation and elimination for the maintenance of its perfectly normal conditions and life. We can confidently say that coagulation is the outcome of certain chemical changes concomitant with the death of the blood, and that while it lives no such changes take place. But such an answer adds little to our knowledge of the matter.

Since constant chemical interchange between the blood and its enclosing vessel wall must be kept up in order to sustain the complex chemical integrity essential for its life, we can understand why it soon dies when shed. The formation of a solid and the separation of a liquid form of proteid is in no way unusual as a first step in the decline from exalted chemical construction, for similar changes occur in other tissues, and in

protoplasm itself. The soft contractile substance of muscle during its contraction probably tends to, and at its death certainly does, undergo almost exactly the same kind of change as the blood in coagulation.

If we knew accurately the nutritive process necessary for the blood itself, the answer to the question would be much simplified. But we have in the blood three elements that probably have different modes of assimilation and elimination, viz., plasma, white cells, and red discs. We practically know nothing of the changes they undergo during their nutrition ; or what relation their chemical processes have to those of the neighbouring tissues. We do know, however, that there exists some very intimate relation between the membrane lining the vessel walls and the contained blood. They seem to require frequently repeated contact one with the other in order that the normal condition of both may be maintained in perfect vital integrity. That fresh supplies of blood are required by the vessel wall, may be shown by the fact that when deprived of its nutriment by a stoppage of the blood-flow, it soon loses its power of retaining the blood, and admits of extravasation. And that renewed contact with the vessel wall is equally necessary for the integrity of the blood, is seen from the fact that the colourless cells become active and congregate, the discs adhere together, and the plasma coagulates when stasis interferes with its intercourse with fresh parts of the intima. The chemical changes going on in the one, seem to be useful for the nutrition of the other, and they mutually supply one another with some material essential for their life.

We probably gain most knowledge concerning the normal non-coagulation of the blood during life by studying the conditions under which it does form clots in the living blood vessels. This study is also of great practical interest, because to the surgeon the mutual nutrition of intima and blood, is of the utmost importance in attaining the occlusion of vessels, for it is upon this fact he has mainly to depend for the stoppage of hæmorrhage from a wounded artery. A tightly-tied ligature either injures the inner coats mechanically, or starves the intima by checking the flow of blood through the vessel up to the next branch, and that portion of the vessel is filled with stationary blood, which clots and forms an adherent plug. But if the ligature be applied too loosely, a slight blood current passes through the point where the vessel is tied, and this suffices for the nutrition of the intima by the renewal of

the blood's contact, so that no clot is formed, the vessel is not closed, and most probably when the ligature has cut through the outer coat, "secondary hæmorrhage" occurs.

Coagulation does not occur so long as the intima of the vessel is perfect, and the blood-flow constant, but it follows lesion of this delicate membrane, whether caused by injury or mal-nutrition.

The gradual occurrence of this impairment of function of the intima can be watched under the microscope in the small vessels of a transparent part, during the initial stages of inflammation. Owing to the arrest of the flow of blood, the walls of the small vessels suffer from defective nutrition, and may be seen to allow some elements to escape, while the discs adhere together and the plasma coagulates.

In the larger vessels the same thing occurs when inflammation of their lining membrane destroys its capability of keeping up the necessary nutritive equilibrium. Thus clots form on the inner lining of the walls of an inflamed vein, often growing so as to fill the entire vessel, and give rise to a condition called *thrombosis*.

On the valves of the left side of the heart and in the arteries, where the delicate intima is subjected to great mechanical strain, it is common enough to find slight injuries of it covered over with thin clots.

It has also been shown that if any foreign substance, such as a thread, be introduced into the blood while circulating, the colourless corpuscles collect on it and soon a coagulum forms around it. From this it would appear that the presence of a substance which cannot carry on the necessary chemical interchange with the blood will excite irritation in its elements, and so effect slight local death of the plasma and the production of fibrin.

The time required for the production of intravascular coagulation as a result of mere stasis is happily long, for it has been found that the blood current may be stopped in a limb, by pressure or otherwise, for many hours without coagulation occurring. Indeed, cases have occurred where a tight bandage has stopped the circulation for an entire day without injurious consequences. This is explained by the fact that so long as the intima lives, the blood remains fluid; in short, the tissues die before the blood clots in the vessels.

The tissues continue to live for some time after the animal is dead, and so we see the blood remains fluid in the vessels a

considerable time, in fact, as long as the vessel wall can nourish itself and live. Thus it has been shown that the blood in a horse's jugular vein separated by ligature from the circulation, and removed from the animal, will remain fluid for fully twenty-four hours. (Lister.)

In cold-blooded animals the tissues live for even a longer time. The heart of the tortoise, if kept under suitable conditions, will beat for two days when removed from the body, and as Brücke has shown, blood contained in it will remain fluid until after the heart is dead.

If the details of the fibrin formation within the blood-vessels be followed, it is found that the injured spot or foreign body first becomes covered over with white corpuscles, around which threads of fibrin appear attached to the rough surface. As more fibrin is formed and the layer thickens, only a few cells can be seen in its meshes, but a great number always exist on the surface of the new fibrin, forming a layer between it and the blood. It is further remarked that coagulation has some relation to the abundance of white cells in all spontaneously coagulated fluids. The more cells, the firmer the clot. In pathological exudations also, and those acute serous collections which coagulate on removal from the body, fine granular threads of fibrin seem to start from the white cells, and radiate from them in a stellate manner. (Fig. 90.)

When white cells congregate at a point of a vessel from which the intima is stripped, their more active exertion possibly produces the ferment, &c. And at the same time they remain at the injured part of the vessel wall, and the removal of the fibrin factors cannot occur at the place of injury, since the intima is destroyed. Thus, local clots are formed which extend over the injured surface, and by a process of organisation, the repair of the denuded patch is accomplished.

Some believe that a great number of white blood-cells undergo chemical disintegration the instant the blood is shed, and consider that the fibrin ferment, and probably other fibrin generators, are the result of the destruction of these weak cells, and exclude the red corpuscles from taking any share in the process.

In this connection may be mentioned the fact that in dog's blood, rendered incoagulable by the addition of 1 part per 1000 of potassium oxalate, and kept cool in a sterile vessel, the colourless corpuscles have retained their vitality for *twenty-four days* (Sherrington).

If some fresh blood be allowed to flow into a fine capillary tube, the white cells can be seen to move away from the red discs, and the formation of the clot—a delicate fibrin network enclosing the discs—may be watched. Here some at least of the white cells exhibit manifestations of life for a considerable time after the clot has been formed, and their death could not have been the source of the fibrin factors.

In conclusion, then, we can only suppose that, as in other tissues, some chemical changes must go on in the elements of the blood in order to preserve its integrity. A cessation of these changes gives rise to new products which produce fibrin, and hence cause coagulation. But so long as the elements of the blood are frequently brought into close relationship with a healthy vessel-wall, the fibrin factors are either produced in such small quantity as to be ineffectual, or they are altered, destroyed, or taken up by the intima and possibly utilised for its nutrition. When the blood is removed from the vessels, the production of the fibrin factors proceeds effectually, either on account of the blood elements undergoing destructive changes, the products of which accumulate ; or owing to the impossibility of re-integration, the fibrin factors appear as a product of lethal chemical change, or decomposition.

In accepting the first view, we only adopt the theory of John Hunter, who thought coagulation was an act of life. If we adopt the other view, we must needs say it is an act of death. But, after all, this is a mere difference in degree, for how can we distinguish between the unsuccessful attempt of a living tissue to re-integrate, or regain the chemical properties upon which its life depends, and the inevitable result of failure, which, if prolonged beyond a certain point, must cause its death ?

CHAPTER XIV.

CIRCULATION OF THE BLOOD.

THE course taken by the blood on its way to the various parts of the body is called the *circulation*, on account of its having to make repeatedly the circuit of vessels leading to and from the heart. The heart is the great motor power which drives the blood through all the vessels, of which there is one set belonging to the circulation in the organs of the system generally, and another belonging to that of the lungs.

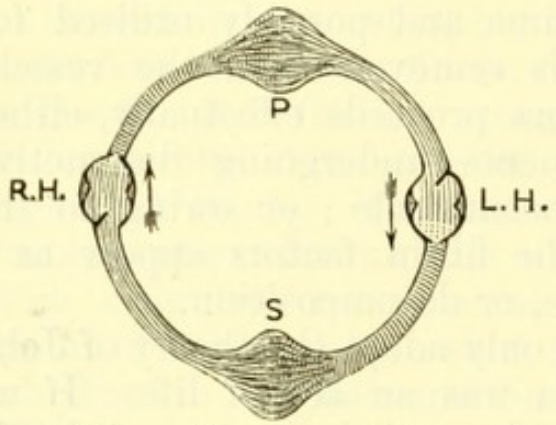


Fig. 100. — Diagram of Circulation, showing right (R.H.) and left (L.H.) hearts, and the pulmonary (P) and systemic (S) sets of capillary vessels.

Anatomists speak of two circulations—the greater or *systemic*, and the lesser or *pulmonary*. However, if we follow the course of the blood we see that both these sets of vessels really belong to the one circulation, and in fact form but one circuit. In all the higher animals the heart forms a single organ, but it really is composed of two muscular pumps which are anatomically united, though distinct in function. These functionally distinct hearts work at different parts of the circuit traversed by the blood. The blood on its way through the pulmonary and systemic vessels requires to be pumped twice, in order to acquire the force necessary to overcome the resistance of these two sets of vessels. The right heart is the agent for pumping the blood through the lungs. The left heart pumps the blood through the body generally. Thus anatomically there appear to be two circulations and but one heart ; physiologically there is one circulation and two hearts ; or two separate points of resistance and a distinct pumping organ to drive the blood through each.

The circulation might then be represented by a simple diagram (Fig. 100) in which the direction of the current is indicated by the arrows. L. H. shows the position of the left or systemic pump, and S. the resistance in the systemic vessels. R. H. represents the pulmonary pump and P. the second obstacle in the circuit, viz., the vessels of the lungs. This functional distinction must be kept in view in studying the dynamics of the circulation, although the two pumping organs are fused into one, with two distinct and separate channels for the passage of the blood.

In each system of blood vessels we have the same general arrangement for the distribution and re-collection of the blood.

In passing from either the right or left side of the heart the blood flows into tubes called *arteries*, which divide and subdivide until the branches become microscopical in size. From the very minute arteries the blood passes into the *capillaries*, which cannot be said to branch, but to form a network of delicate tubes with meshes of varying closeness according to the tissue.

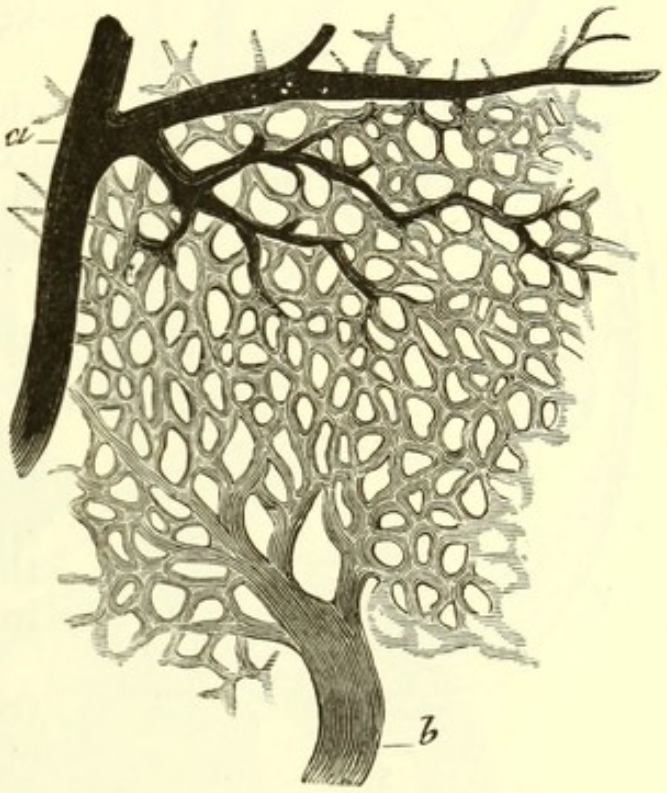


Fig. 101.—Capillary Network of the Choroid of Child of a few months old. (Cadiat.)
(*a*) Artery. (*b*) Vein, and capillary network intervening.

Connected with the meshes of the capillaries are the small *veins* which collect the blood from the networks (Fig. 101). These unite, gradually forming larger vessels, which again are but the tributaries of the large veins which convey the blood back to the heart.

Little more than three hundred years ago the true course of the blood current, through the systemic and pulmonary heart, arteries and veins, so as to form one circle, was demonstrated by Harvey. Before his time only the so-called "lesser" or pulmonary circuit was known. The magnifying glasses at his disposal did not enable him to see the capil-

laries, which were first described by Malpighi some fifty years later.

In the hope of making their different functions appear more obvious, the various parts of the circulatory apparatus may be enumerated as follows, and roughly illustrated by a diagram :—

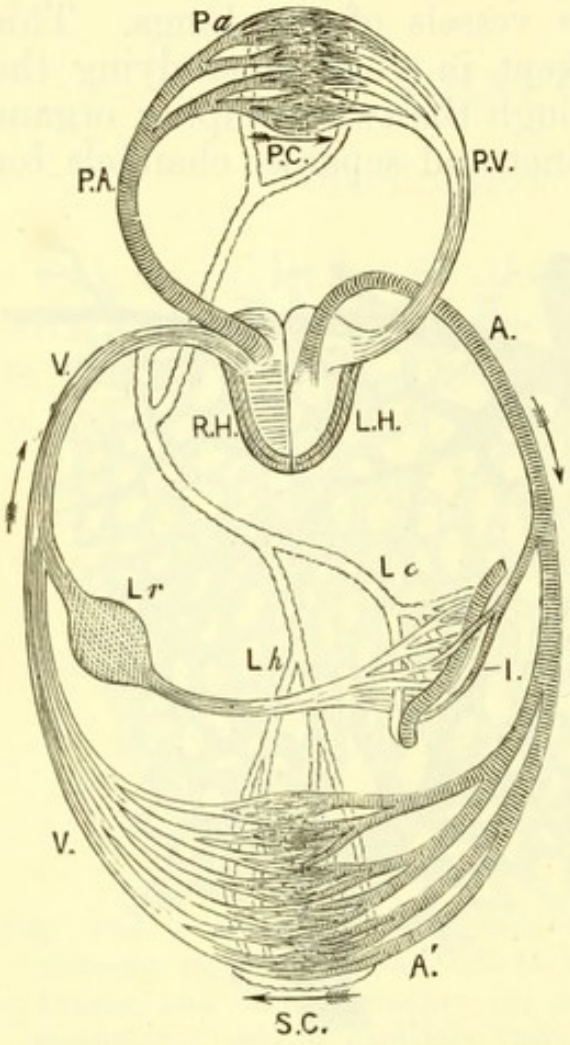


Fig. 102.—Diagram of the Circulation of the Blood and the absorbent vessels. For details see text.

1. The left (systemic) heart (L. H.) pumps the blood into the systemic arteries, and thus keeps these vessels over-filled.

2. The larger systemic arteries (A.), by their elasticity, exert continuous pressure on the blood, with which they are distended.

3. The smaller systemic arterioles (A′.), by their vital contractility check and regulate the amount of blood flowing out of the larger arteries into the capillaries, and thus keep up a high pressure in the larger arteries (A.).

4. In the systemic capillaries (S. C.) the essential operations of the blood are carried out, viz., the chemical interchanges between it and the tissues.

5. The wide systemic veins (V.) are the passive channels conveying the venous blood to the pulmonary heart.

6. The right (pulmonary) heart (R.H.) pumps the blood into the pulmonary arteries and distends them.

7. The pulmonary arteries (P.A.) press steadily upon the blood and force it through the lungs.

8. The small pulmonary arterioles (P*a*), which regulate the flow into the capillaries of the lungs.

9. In the pulmonary capillaries (P.C.) the blood is exposed to the air, and undergoes active gas-interchange.

10. The pulmonary veins (P.V.) carry the blood to the left heart, and thus complete the circuit.

11. L*h* indicates the lymphatics, which drain the tissues,

and *Lc* the lacteals, which absorb from the stomach and intestines (I.).

Although the blood enters the arteries by jerks, its motion through the capillaries is even and continuous, because the walls of the arteries being distended by the pumping of the heart, which fills the aorta and arteries more quickly than they

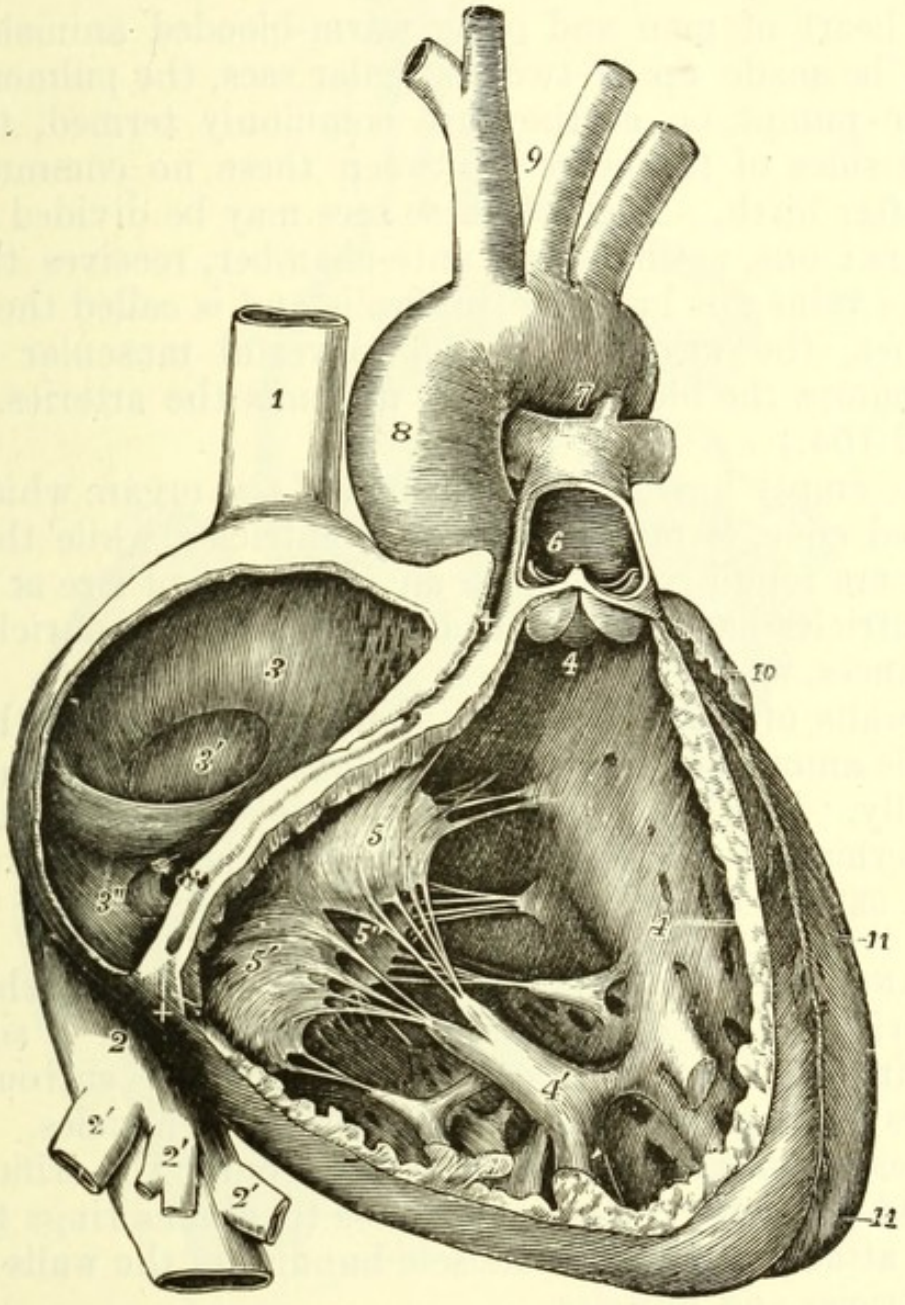


Fig. 103. —Interior of Right Auricle and Ventricle exposed by the removal of a part of their walls. (Allen Thomson.)

1. Superior vena cava.
2. Inferior vena cava.
2′. Hepatic veins.
3, 3′, 3″. Inner wall of right auricle.
4, 4. Cavity of right ventricle.
4′. Papillary muscle.
5, 5′, 5″. Flaps of tricuspid valve.
6. Pulmonary artery, in the wall of which a window has been cut.
7. On aorta near the ductus arteriosus.
8, 9. Aorta and its branches.
10, 11. Left auricle and ventricle.

can empty, exerts a continuous pressure on the blood and forces it evenly into the capillaries. The very minute arterioles are the chief agents in resisting the too rapid outflow. By contracting they keep up the arterial pressure.

I. The Heart.

The heart of man and other warm-blooded animals may be said to be made up of two muscular sacs, the pulmonary and systemic pumps, or, as they are commonly termed, the right and left sides of the heart ; between these no communication exists after birth. Each of these sacs may be divided into two chambers : one, acting as an ante-chamber, receives the blood from the veins ; it has very thin walls and is called the *auricle* ; the other, the *ventricle*, is the powerful muscular chamber which pumps the blood into and distends the arteries. (Figs. 103 and 104.)

In the empty heart the great mass of the organ, which forms a blunted cone, is made up of the ventricles, while the flaccid auricles are found retracted to an insignificant size at its base. The ventricles have a capacity of about six, the auricles about four, ounces, when distended.

The walls of both the auricles are about the same thickness, while the amount of muscle in the walls of the ventricles differs materially. The wall of the left ventricle, including that part which forms the interventricular septum, is nearly three times as thick as that of the right or pulmonary ventricle.

Arrangement of Muscle Fibres.—At the attachment of each auricle to its corresponding ventricle there is situated a dense ring of tough connective tissue, which surrounds the openings leading from the auricles to the ventricles. Similar tendinous rings (zona tendinosa) exist around the orifice of the aorta and pulmonary arteries. These tendinous rings form the basis of attachment for the muscle bundles of the walls of both the ventricles and auricles.

In the ventricles many layers of muscles can be made out. The outer fibres pass in a twisted manner from the base towards the apex, where they are tucked in so as to reach the inner surface of the ventricular cavity. They then pass back to be attached at the base ; some passing into the papillary muscles are connected with the cardiac valves through the medium of the chordæ tendineæ ; and the others forming

irregular masses of muscle on the inner surface of the cavity, pass in various directions towards the base, to be fused with the tendinous rings around the arterial orifices. Another set of layers passes transversely around the ventricle, lying between

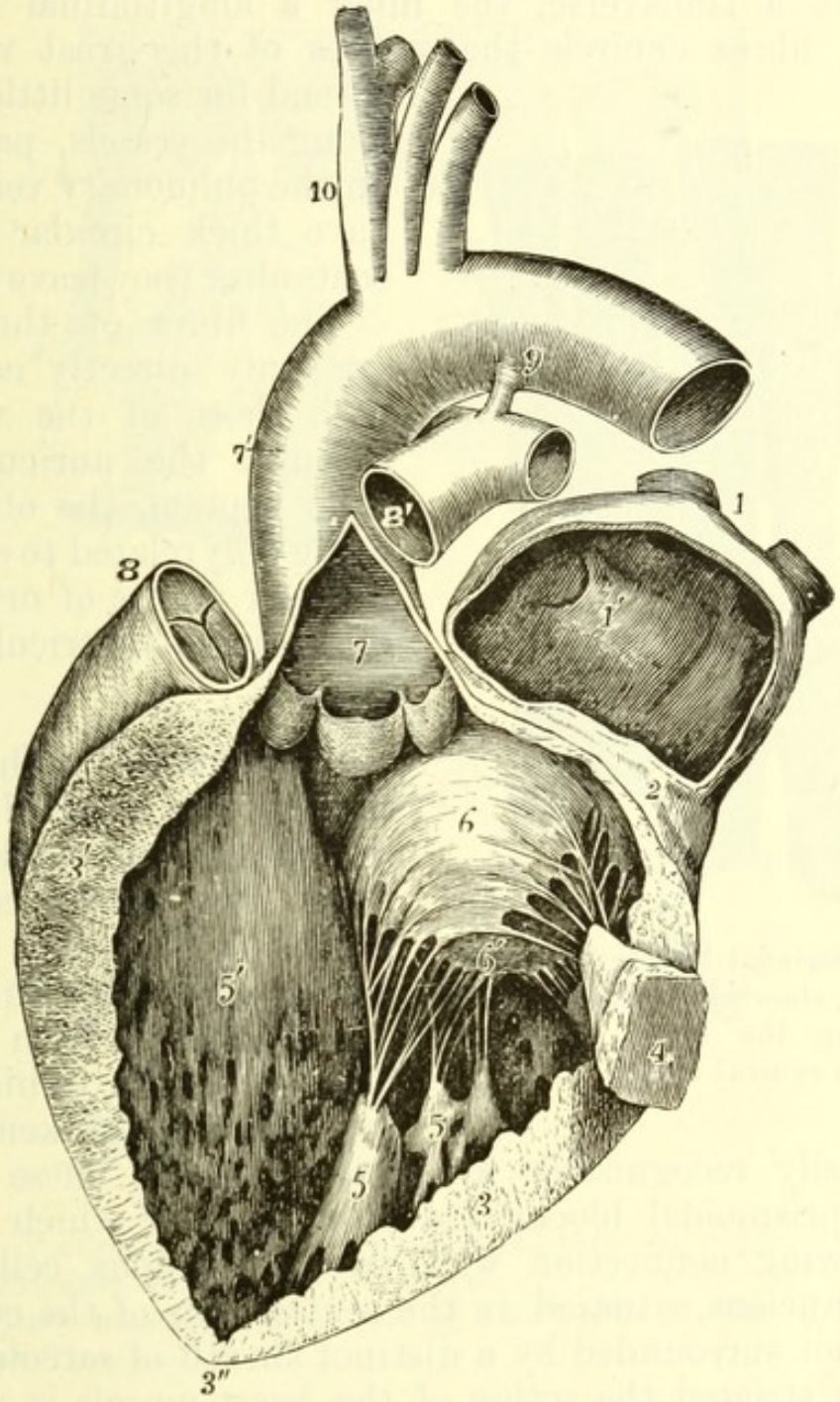


Fig. 104.—The left Auricle and Ventricle opened and part of their walls removed to show their cavities. (Allen Thomson.)

1. Right pulmonary vein cut short.
1′. Cavity of left auricle.
3, 3″. Thick wall of left ventricle.
4. Portion of the same with papillary muscle attached.
5. The other papillary muscles.
6, 6′. The segments of the mitral valve.
7. In aorta is placed over the semi-lunar valves.

the inner and outer sets, and passing nearly at right angles to them.

The muscular fibres forming the thin auricular walls have their origin from the zones of the auriculo-ventricular orifices, and pass very irregularly around the cavities. The outer set of fibres have a transverse, the inner a longitudinal direction. Bands of fibres encircle the orifices of the great veins, and extend for some little distance along the vessels, particularly on the pulmonary veins, which have thick circular muscular coats after they leave the lungs.

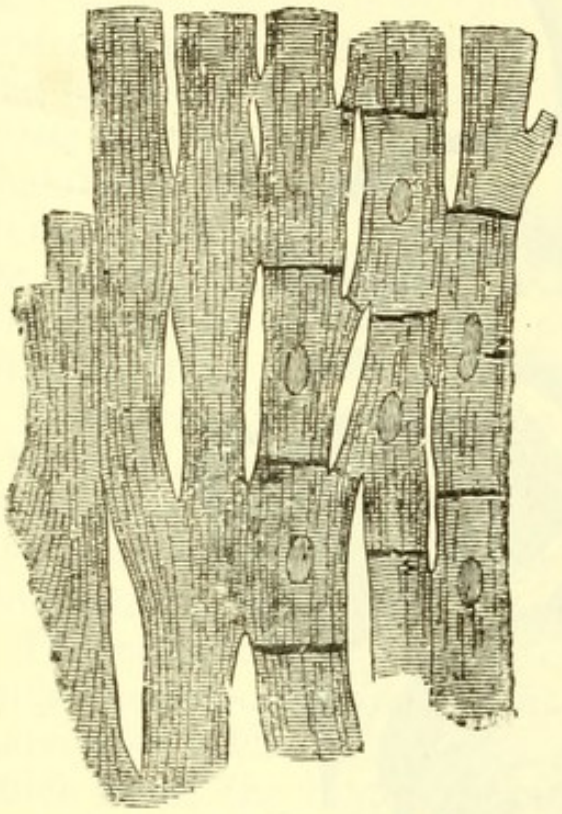


Fig. 105.—Striated Muscle Tissue of the Heart, showing the trellis-work formed by the short branching cells, with central nuclei.

The fibres of the auricles are only directly continuous with those of the ventricles, through the auriculo-ventricular septem, the other fibres being only related to each other by their points of origin, viz., the auriculo-ventricular fibrous zones.

Structure.—The muscle tissue of the heart differs both in structure and mode of action from the other contractile tissues of the body. The elements are firmly united with one another to form irregular close networks, which, however, can be broken up into masses easily recognisable as peculiar cells. These cells are irregular prismoidal blocks, the blunt ends of which are often split, allowing connection with two contiguous cells. They contain a nucleus, situated in the central axis of the cell. The cells are not surrounded by a distinct sheath of sarcolemma.

Though striated the action of the heart muscle is peculiarly independent of the higher nervous centres, being quite involuntary; it is characterised by a definite periodicity, and is incapable of tetanus. The duration of its contraction is very long when compared with that of the skeletal muscles, but is much shorter than that of the contracting tissues of most hollow viscera.

Valves.—The orifices which lead into and out of the

ventricles have peculiar arrangements of their lining texture, forming valves which allow the blood to pass only in a certain direction. These valves, which form a most interesting and important part of the mechanism of the heart, are of two kinds,

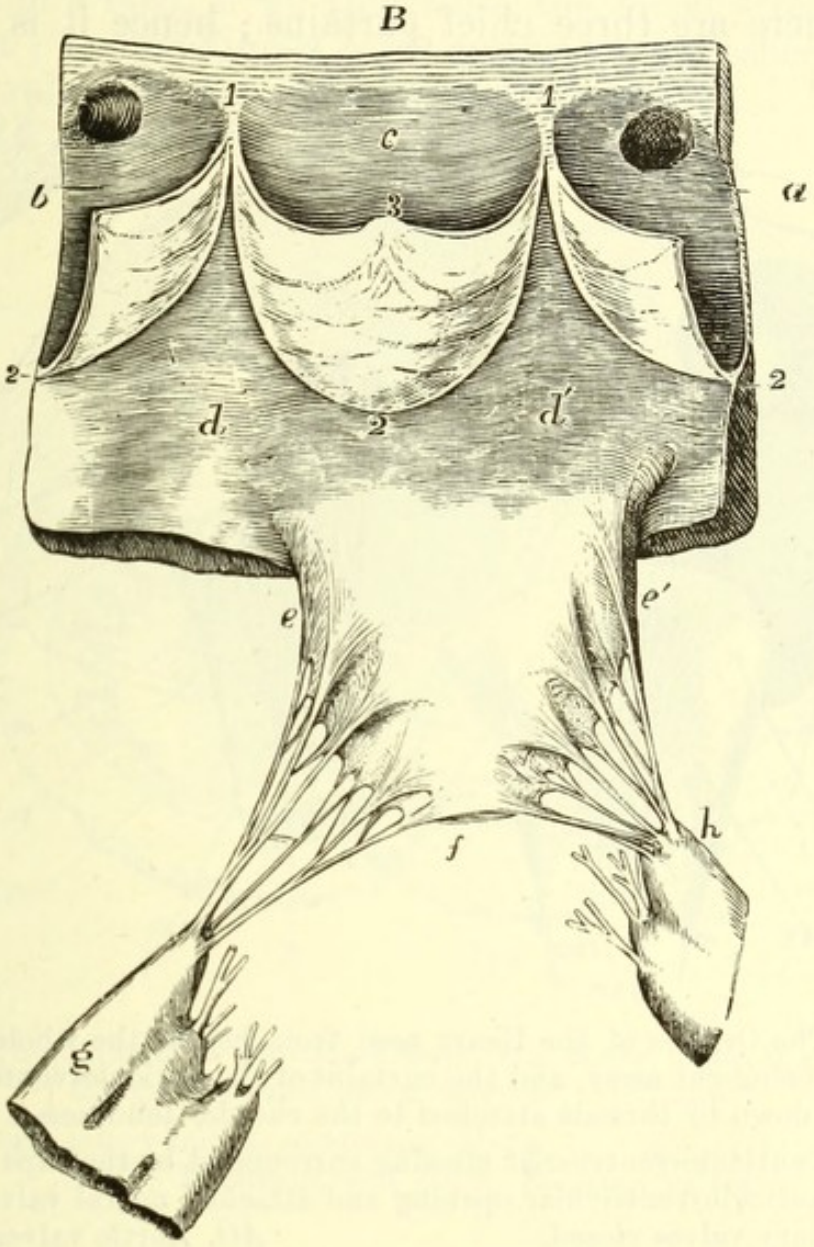


Fig. 106.—Portion of the Wall of Ventricle (*d d'*) and Aorta (*a b c*), showing attachments of one flap of mitral and the aortic valves; (*h* and *g*) papillary muscles; (*e*, *e'*, and *f*) attachment of the tendinous cords. (Allen Thomson.)

each differing in their mode of action. One prevents the passage of the blood from the ventricles to the auricles, the other guards the openings into the great arteries.

The *auriculo-ventricular valves* have a sail-like action. They are made up of delicate curtains, formed of thin sheets of connective tissue, arising from the margins of the auriculo-ventricular openings, which form the fixed attachment of each

of the curtains of the valves. The free edges and ventricular surfaces of the curtains are blended with the tendinous cords coming from the papillary muscles, and thus give points of tendinous attachment to some of the bundles of muscle fibres in the wall of the ventricle. At the right auriculo-ventricular opening there are three chief curtains; hence it is called the

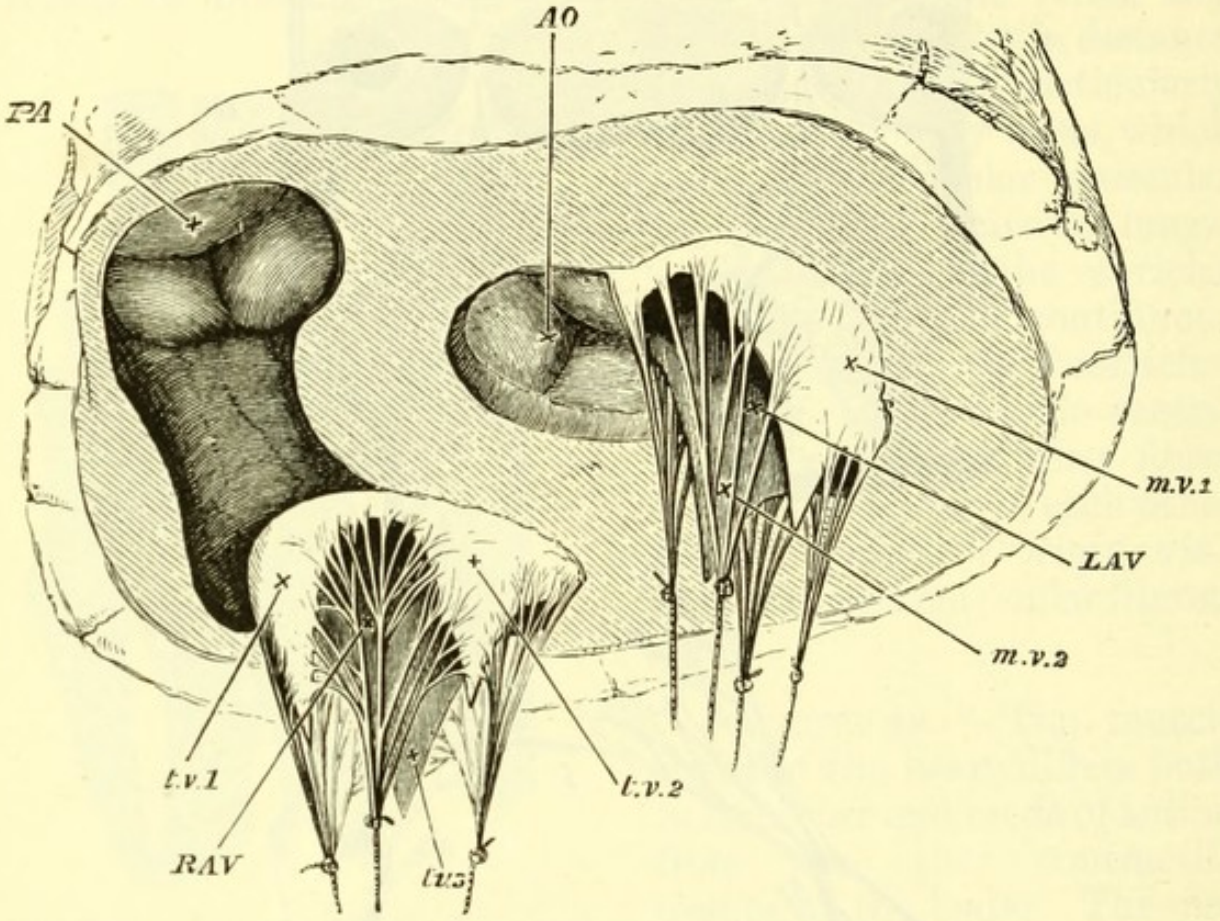


Fig. 107.—The Orifices of the Heart seen from below, the whole of the ventricles being cut away, and the curtains of the auriculo-ventricular valves drawn down by threads attached to the chordæ tendineæ. (Huxley.)

RAV. Right auriculo-ventricular opening surrounded by the flaps of tricuspid.
LAV. Left auriculo-ventricular opening and attached mitral valve.
PA. Pulmonary valves closed. *AO.* Aortic valves closed.

"tricuspid" valve (Fig. 107, *RAV*). The opening from the left auricle to the left ventricle, which is about one-third smaller, is guarded by two large valvular flaps, and is hence called the "bicuspid," or more commonly "mitral" valve (Fig. 106).

The *aortic* and *pulmonary valves* are made up of three deep *semi-lunar pockets* with free margins looking towards the vessel. The convex base of each pocket is attached to the arterial orifice of the ventricle, with the lining membrane of which it is continuous.

II. Action of the Valves.

Auriculo-ventricular Valves.—The mode of action of the flaps of the tricuspid and mitral valves is like that of a lateen sail of a boat, if we substitute the blood stream for the air current ; the tendinous cords acting as the "sheet" or rope which restrains the sail when filled with wind.

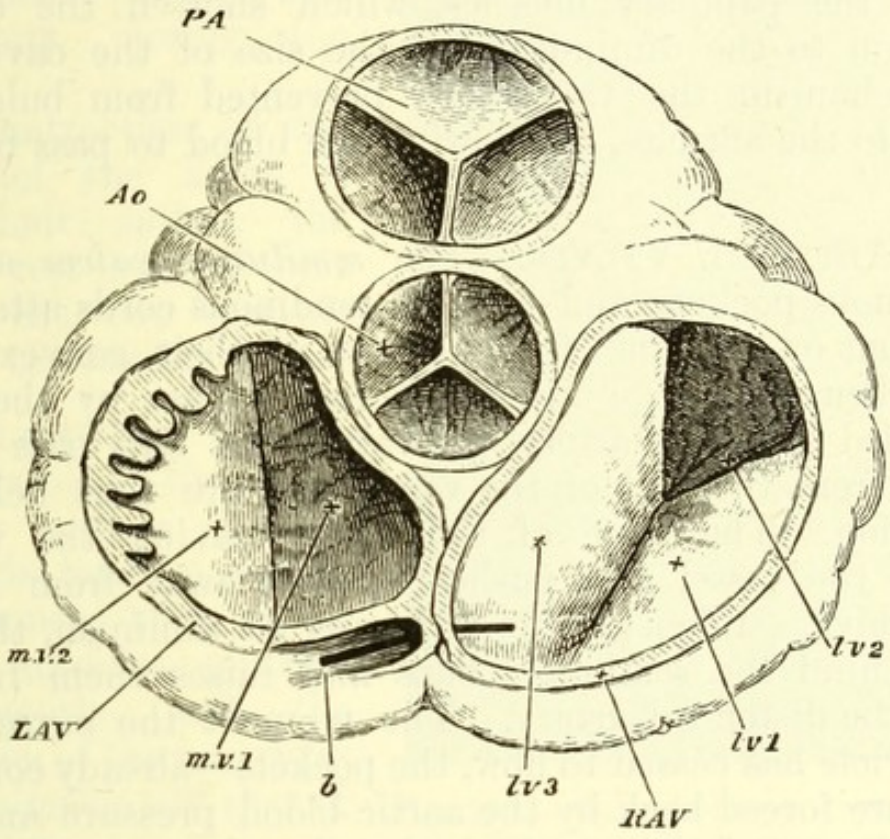


Fig. 108.—The Orifices of the Heart seen from above, both the auricles and the great vessels being removed. (Huxley.)

PA. Pulmonary artery and its semilunar valves. *Ao.* Aorta and its valves. *RA V.* Tricuspid, and *LA V.* Bicuspid valves.

The curtains of the valves may at first be considered as lying close to the ventricular wall. As the ventricle gradually becomes filled, the flaccid muscular wall is moved away from the valves, which are held close together in the midst of the fluid by the tendinous cords from the papillary muscles. When the auricle contracts, a column of blood is driven into the ventricle, which, though not distended, is already filling with blood. This sudden central inflow gives rise to lateral back-eddies behind the flaps which carry the valves over the auricular orifice. By the time the auricle has emptied itself into the ventricle, the flaps of the valves are in contact

with each other and the orifice is closed. When the ventricle begins to contract upon its contained blood, the pressure makes the valves tense and the fluid bellies out the sail-like flaps towards the auricles, so that their convex sides come into still closer and more extended apposition with one another. Their free margins are held firmly in position by the tendinous cords and the papillary muscles. The flaps are kept at much the same tension while the ventricle empties itself by the contraction of the papillary muscles, which shorten the cords in proportion to the diminution of the size of the cavity. By this mechanism the valves are prevented from bulging too much into the auricles, or allowing the blood to pass back into them.

The Arterial Valves.—The *semilunar valves* are mere membranous pockets, and have no tendinous cords attached to them ; but on account of the extent of their convex attachment, when their free margin is made tense by the pocket being filled from the artery, the valves can only pass a given distance from the wall of the vessel, and are thus held firmly in position. The force of the blood leaving the ventricle distends the vessel and pushes its wall away from the less elastic valve. When the force begins to diminish, the blood passes behind the semilunar flaps and raises them from the wall of the distended artery. The moment the current from the ventricle has ceased to flow, the pockets—already containing blood—are forced back by the aortic blood pressure and bulge into the lumen of the vessel, so that the convex surface of the lunated portions of each valve is pressed against corresponding parts of its neighbours. Their union, which is accomplished by the overlapping of their surfaces down to the edge of the lunulæ, forms three straight radiating lines, and is a perfectly impervious barrier to any backward flow of blood (Fig. 108, *PA.* and *Ao.*).

III. The Cardiac Cycle.

The blood, flowing from the systemic and pulmonary veins, passes unopposed into the right and left auricles respectively. Immediately the auricles are filled, their walls suddenly contract and press the blood into the right and left ventricles, and the ventricles then instantly contract, and force it into the great arteries.

The blood cannot pass back into the veins from the auricles when they contract, because the auricular contraction commences at the orifices of the great venous trunk, which are surrounded by heart-muscle for some distance. It cannot flow back to the auricles, because the blood-current on its entry into the ventricles, closes the valves. A backward flow from the large arteries is prevented by the current distending the semilunar pockets, and thus firmly closing the valves.

The contraction of the cavities of the heart is called their *systole*, the period of rest is called their *diastole*, the two periods make up the *cardiac cycle*.

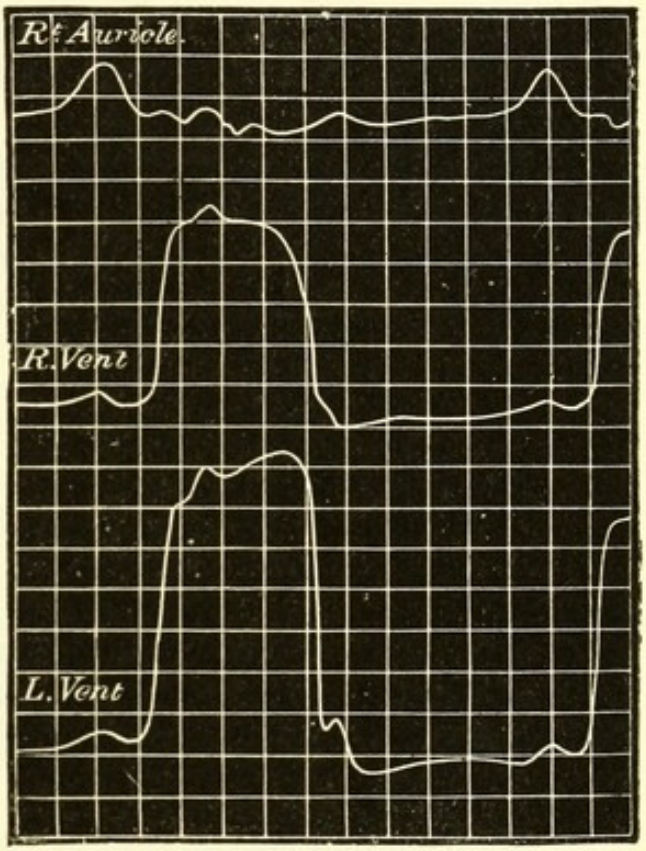


Fig. 109.—Curves drawn on a moving surface by three levers, which are connected with the interior of the heart, viz. :—

Upper line shows the changes of pressure occurring in the right auricle ;

Centre line shows the pressure changes within the right ventricle ;

Lower line shows the changes of pressure occurring in the left ventricle.

(The smoked surface is moved from right to left.) (After Chauveau.)

Systole of the Heart. —The systole of the corresponding cavities of both sides of the heart is exactly synchronous ; that is to say, the auricles contract simultaneously, and the contraction of the ventricles follows immediately that of the auricles.

While the auricles are contracting, the ventricles are relaxed, and the relaxation of the auricles commences immediately after the ventricular contraction begins.

The entire cycle of the heart-beat, occupying nearly a second in the healthy adult, may be divided into three stages :—

Auricular systole.
Ventricular systole.
General Diastole.

The exact time occupied by each phase of the cycle can be

calculated by registering graphically the motions of the auricles and ventricles directly communicated to levers brought into contact with their surface, or by recording graphically the pressure changes which occur within the cavities, by introducing into them little elastic sacks filled with air, whence the pressure changes are communicated to a "tambour," and registered on a smoked surface.

The diastole or pause is the longest and the most variable. Next in duration is the ventricular systole, while the shortest is the auricular systole.

The following figures give approximately the proportion of time occupied by each part of the cycle in the case of a horse, whose intracardiac tension was registered, in the manner just referred to, while his heart was beating about fifty times in the minute :—

	Proportion of cycle.		Duration in seconds.
Auricular systole . . .	$\frac{1}{6}$	=	0·2″
Ventricular systole . . .	$\frac{2}{6}$	=	0·4″
Passive interval . . .	$\frac{3}{6}$	=	0·6″

Or if we assume the human heart to beat some seventy times a minute, which is about the normal rate, each cycle would occupy about $\frac{8}{10}$ of a second, made up as follows :—

Auricular systole	= $\frac{1}{10}$	of a second.
Ventricular systole . . .	= $\frac{3}{10}$	,,
Pause	= $\frac{4}{10}$	,,

The duration of the auricular and ventricular systole varies little except under abnormal circumstances, but the pause is constantly undergoing slight changes. In fact, the rate of the heart-beat depends upon the duration of the diastole, which is less in proportion as the heart beats more quickly.

IV. Cardiac Movements.

If the thorax of a recently killed frog be opened, the heart can be observed beating *in situ*, and the different acts in the cycle studied without difficulty.

In mammalia, in order to see the heart in operation, it is necessary to keep up artificial respiration, during which the heart continues to beat regularly, though the thorax be opened. A careful inspection of the beating heart shows that during its

cycle of action certain changes take place in the shape and relative position of its cavities. This is owing partly to the change in the amount of their blood contents, and partly to the form assumed by the muscular wall when contracting.

During the diastole the auricles are seen to swell gradually on account of the blood flowing into them from the veins : when the auricular cavities are nearly full, a contraction, commencing in the great venous trunks near the heart, passes over the auricles, and gives rise to their rapid systolic spasm. The auricles suddenly diminish in size, and appear to become pale. When the blood is being propelled through the auriculo-ventricular openings, the flaccid walls of the ventricles appear to be drawn over the liquid mass by the contraction of the muscular walls of the auricles (just as a stocking is drawn over the foot by the hands), and the base of the ventricles is thus drawn upwards. The instant the ventricles have received their full charge of blood from the auricles they contract, becoming *shorter* by the movement of the base towards the apex, and *thicker* by their elongated cone becoming rounder. The great arteries are at the same time distended with the blood from the ventricle and elongated, their elastic walls being drawn down over the liquid wedge. The soft elastic tissues are thus in turn made to slide, as it were, over the incompressible fluid that forms the fulcrum, which the muscular walls use as a purchase.

During the systole, when the thorax is open, the ventricles rotate slightly on their long axis, so that the left comes a little forwards, and the apex also forwards and towards the right. When the systole of the ventricles ceases, they become flaccid and flattened, and the gradual refilling of the cavities begins, the blood flowing readily from the veins through the auricles into the ventricles, where the pressure, as in all parts of the thorax, is negative. The semilunar valves being closed, the large arteries grasp firmly the blood, and by their steady resilient force press it on towards the distal vessels. During this period the arteries seem to become shorter and to draw the base of the heart up again by lengthening the flaccid ventricles.

The part of the heart which changes its position most is the line between the auricles and ventricles, while the apex remains fixed in one position, only making a very slight lateral and forward motion, which probably does not take place within the closed thorax. If a thin needle with a straw attached be made

to enter the apex through the wall of the chest, the straw does not move in any definite direction during the systole, but simply shakes. If, on the other hand, the needle be made to pierce the base of the ventricles, the straw moves up and down with each systole and diastole.

V. Heart's Impulse.

The heart communicates its motion to the chest-wall, and the movement can be felt and seen over a limited area, which varies with the thinness of the individual. This *cardiac impulse*, as the stroke is called, can best be felt in the fifth

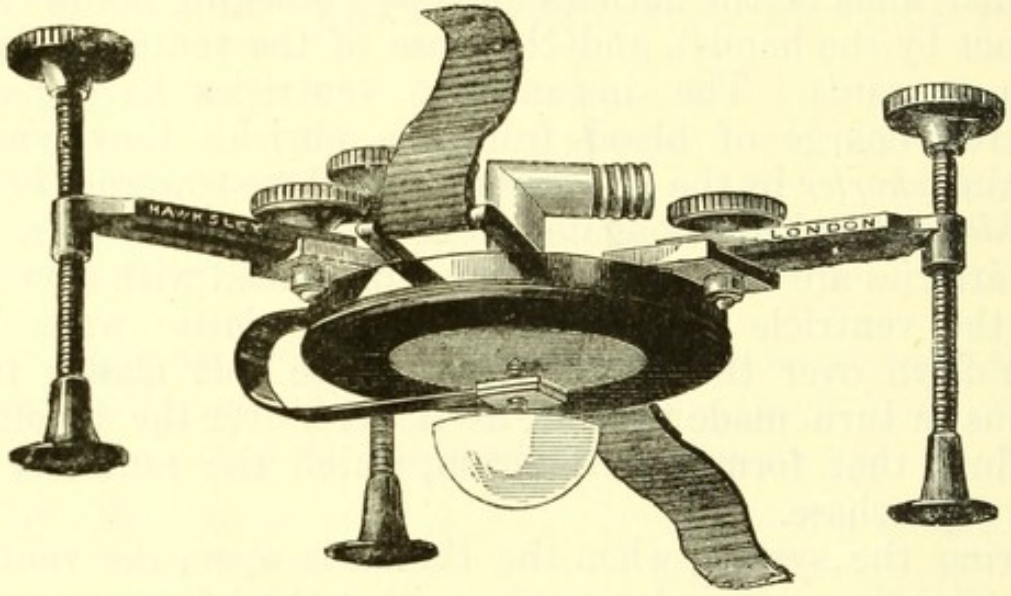


Fig. 110.—Cardiac Tambour, which can be strapped on to chest-wall, so that the central button lies over the heart-beat, and the pressure may be regulated by the screws at the side. To the tube bent at right angles is attached the rubber tube which connects the air cavity with that of the writing tambour shown in Fig. 111.

intercostal space, a little to the median side of the left nipple. It is found to be synchronous with the ventricular systole. During this period—ventricular systole—the base of the ventricles moves downwards and they become thicker. The flaccid cone formed by the ventricles during diastole, is somewhat flattened by the chest-wall, but during systole it becomes rounded and bulges forwards, pushing the chest-wall before it. This change in shape is the chief cause of the cardiac impulse.

If the ventricles be held gently between the fingers during their systole, a most striking sensation is felt, on the change

of shape and the sudden hardening of the muscle. The mass in the ventricles, from being quite soft and compressible during diastole, suddenly acquires a wooden hardness owing to the tightness with which the muscle grasps the fluid, and the greater firmness of the contracting tissue.

This hardening gives the sensation of a sudden enlargement. No matter on what surface the finger be placed, the heart seems to give a slight knock in that direction. Thus, when grasped between the fore-finger placed below the diaphragm and the thumb on the antero-superior aspect, the impulse is equally felt by each digit.

The important items in causing the impulse are then, the change in shape of the ventricles from a flattened to a rounded cone, and their simultaneous hardening, which no doubt helps to make the movement more distinctly felt through the wall of the chest.

The point at which the impulse is best felt corresponds to the anterior surface of the ventricles at a considerable distance above the apex; it is therefore erroneous to call the impulse the "apex beat."

The cardiac impulse is a valuable measure of the strength of the systole, and hence is of great importance to the clinical physician. It may be registered by means of an instrument called the Cardiograph. Many such instruments have been devised, most of which work on the same principle, and make a record on a moving surface with a lever attached to a *tambour*, to which the movements of the chest wall are transmitted from a somewhat similar drum by means of air tubes. In using

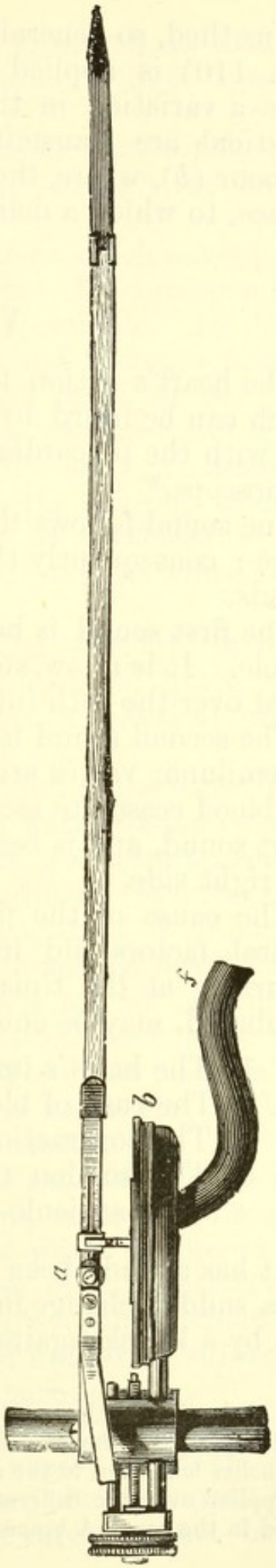


Fig. 111.—Writing Lever and Tambour. (*a*) Axis of the lever; (*b*) Air chamber; (*f*) Rubber tubing connecting it with cardiac tambour shown in Fig. 110.

this method, so generally employed by Marey, one air tambour (Fig. 110) is applied over the heart, the motions of which cause a variation in the tension of the air it contains ; these variations are transmitted by a tube *f*, (Fig. 111) to the other tambour (*b*), where they give rise to a motion in its flexible surface, to which a delicate lever is attached (*a*).

VI. Heart-Sounds.

The heart's action is accompanied by two distinct sounds, which can be heard by bringing the ear into firm direct contact with the precardial region, or indirectly by the use of the stethoscope.*

One sound follows the other quickly, and then comes a short pause ; consequently they are spoken of as the *first* and *second* sounds.

The first sound is heard at the beginning of the ventricular systole. It is a low, soft, prolonged tone, and is most distinctly heard over the fifth intercostal space.

The second sound is heard at the moment when the two sets of semilunar valves are closed and made tense, that is, when the blood ceases to escape from the ventricles. It is a sharp, short sound, and is best heard at the second costal cartilage on the right side.

The cause of the first sound is not so evident. Possibly several factors aid in its production. The principal events occurring at the time of the first sound, to which it has been attributed, may be enumerated thus :—

1. The heart's impulse.
2. The rush of blood into the arteries.
3. The contraction of the heart-muscle.
4. The sudden tension of the ventricular chambers and the auriculo-ventricular valves.

It has already been seen that the heart's *impulse* is caused by a sudden change in the shape and density of the muscle, and not by a knock against the chest. The first sound is heard

* A flexible stethoscope to listen to one's own heart-sounds can easily be made by fitting the mouthpiece to one end of a piece of rubber tubing about 18 inches long, and to the other end the bowl of a wooden pipe. The bowl is applied over the different regions of the heart, and the mouthpiece firmly fitted in the ear. A binaural clinical stethoscope is the best.

more clearly when the chest wall is removed, so that the ventricle, beating against the thorax, cannot help to cause the sound.

The character of the sound is quite unlike that which could be produced by the *passage of the blood* through the arterial orifices.

The sound is not unlike the *muscular tone* which accompanies the contraction of the skeletal muscles. It corresponds in time with the contraction of the cardiac muscle. In disease where the heart muscle is weak, the sound becomes faint, or inaudible, although the valves are made tense by an intra-ventricular force sufficient to overcome the pressure in the arteries. Otherwise the circulation would cease. An abnormal præsystolic sound, like in character to the systolic sound, is now supposed by some physicians to be produced by the auricular systole ; but this cannot depend on the vibration of valves.

All this evidence tends to show that the sound is produced by the contraction of the muscle tissue of the heart, or, in short, that it depends upon some sudden physical change occurring during the cardiac muscle contraction.

Against the view that the muscular sound is the cause of the first sound is urged the supposition that only tetanus causes a muscle-sound, and a single contraction is not accompanied by any sound. Though in many ways it differs from the single contraction of other muscles, yet the heart-beat is no doubt a single contraction. But the sound, which may be heard during the voluntary contraction of skeletal muscle, has not been proved to depend on regularly recurrent contractions, such as occur in the tetanus produced by an interrupted current ; and a kind of thud very like the first sound of the heart may be heard with the single stimulation of a skeletal muscle.

On the other hand the *auriculo-ventricular valves are made tense* at the beginning of the sound, and injury or disease of these valves is often associated with a weak or altered first sound : this is often observed in disease of the mitral valve. The blood is said, by some, to be necessary for the production of the sound, because the gentle closure and immediate subsequent tension of these valves have a share in causing it.

As before remarked, the valvular tension would not account for the præsystolic sound occasionally heard, and there is no doubt that the first sound can be heard in an empty heart removed from the animal, in which the valves cannot become

tense. It may even be heard in the ventricles after they are separated from the valves.

The sound has been analysed with suitable resonators, and two distinct tones made out : one high and short, corresponding to the tension of the valves ; the other long and low, corresponding in duration with the muscle contraction.

The reasons given for thinking that the heart muscle cannot produce a sound, suggest that the sudden state of tension of the ventricular wall when tightened over the blood may give rise to vibrations, and be an important item in causing the first sound. This would explain the faintness of the sound, both when the valves were injured and the muscle weak, and when the blood was prevented from entering. It would also explain the præsystolic sound, which requires a certain auricular tension for its production.

From the foregoing statements it would appear probable that both the tension of the valves and the muscle are concerned in the production of the first sound.

The production of the *second sound* is more easily explained. Occurring just after the ventricle is emptied, it is synchronous with the closure and sudden tension of the semilunar valves at the aorta and pulmonary orifices. The blood in the aorta forcibly closes the valves as soon as the ventricular pressure begins to wane. This sudden motion causes a vibration of the valves, which is rapidly checked by the continuous pressure of the column of blood.

VII. Innervation of the Heart.

A most interesting phenomenon in the heart's action is the wonderful regularity of its rhythmical contractions under normal circumstances, and the extreme delicacy of the nervous mechanism by which it is regulated.

The vast majority of the active contractile tissues of the higher animals is under the immediate direction of the central nervous system. Thus the skeletal muscles are connected with the cerebro-spinal axis by means of nerves, along which impulses, stimulating the contractile tissue to action, pass.

Some muscular organs, as has been seen in the pharynx, œsophagus, &c., though not under the control of the will, are governed altogether by the cerebro-spinal axis ; while others, of which the most striking example is the heart, can contract

characteristically without excitation from the central nervous system.

It will materially help us in comprehending the nervous mechanisms of the heart, if we bear in mind the fact that the muscle tissue of the heart of some animals has—quite independently of any nervous influences—an inherent tendency to rhythmical contraction. This is shown by the following facts. The heart-muscle cannot, under any circumstances, remain contracted like a skeletal muscle in tetanus, or like an unstriated muscle in tonus, except when its tissue is spoiled by deficient nutrition, &c. The heart of many of the invertebrate animals contracts rhythmically without any nerve elements being found in it by the most careful microscopic examination. A strip cut from the ventricle of the tortoise can, by rapid gentle excitations, be made to beat with an automatic rhythm without the help of any known nerve mechanism (Gaskell). The lower part of the frog's ventricle—which is admitted not to contain any nerves—beats quite rhythmically if stimulated with a gentle stream of serum under a certain pressure. In the embryonic chick the heart beats rhythmically before there is a vestige of nerve tissue to be seen. There is no reason to assume that we cannot concede to muscle tissue, as we do to nerve cells, the property of acting with an automatic rhythm.

Although the heart-muscle may itself have this tendency to rhythmical contraction, there is no doubt that in all vertebrate animals the rhythm is controlled and regulated by nerves. These may be divided into an *intrinsic* and *extrinsic* set.

Intrinsic Nerve Mechanisms.

In cold-blooded animals, such as a frog or tortoise, the heart will beat for days after its removal from the animal, if it be protected from injury and prevented from drying. In warm-blooded animals the tissues lose their vitality very soon after they are deprived of their blood supply ; however, spontaneous rhythmical movements can be seen in the mammalian heart if removed at once after death. The hearts of oxen, rapidly slaughtered, give several beats after their removal from the thorax. A cat's heart, if kept in warm blood, beats for half an hour after removal. If a blood current be caused to flow through the vessels of the mammalian heart tissue this spontaneous contraction will go on for some time, or will even recommence after having ceased.

The hearts of criminals after being hanged have been found to continue to beat for four to seven minutes after the spinal cord and the medulla had been separated.

These facts prove conclusively that the stimulus which causes the heart to beat rhythmically arises in the muscle tissue of the organ or in close relation to it. Upon physiological grounds alone we might conclude that in the heart tissue of the vertebrata there exist nerve elements capable of sustaining the rhythmical action, even if we had not anatomical proof of the existence of the ganglionic cells with which we are familiar.

Such collections of nerve elements are called *automatic* centres, and are made up, like all other origins of nerve force, of ganglionic cells.

Since the heart of mammalian animals soon ceases to beat, it forms an unsatisfactory subject for experimental inquiry. The heart's innervation is, therefore, best studied in a cold-blooded animal, where also the mechanisms are probably more simple.

The frog's heart may, for our present purpose, be regarded as consisting of three parts, viz. (1) sinus venosus ; (2) auricles, and (3) ventricle.

The heart continues to beat after removal from the animal. If the lower two-thirds of the ventricle be separated, and not stimulated in any way, it remains motionless, while the auricles continue to beat. But it responds, by an ordinary single contraction, to short direct stimulus, and if gentle stimulus be kept up, it may beat rhythmically. If the ventricle and auriculo-ventricular groove be removed from the auricles and sinus, both parts continue to beat, but each beats with a different rhythm, and, under like conditions, the auricles, &c., continue to beat longer than the ventricles. If the heart be cut into zig-zag strips, by partial transverse incisions, the rhythm of the sinus is carried by the muscle tissue to the very apex (Engelmann).

The auricles beat even when subdivided. The sinus venosus, when quite separated from the rest of the heart, continues to beat longer and more regularly than any other part. When the entire heart is intact, the sinus seems to be the starting point of the heart-beat.

This experimental evidence of the presence of nerve centres in certain parts of the heart-muscle of the frog is supported by the results of anatomical investigations, for the microscope shows that there are many ganglionic cells distributed throughout the heart-tissue, and that they are located just where we should expect from the above facts. That is to say, there are

none in the substance of the ventricles, while there are several groups of cells scattered around its base in the auriculo-ventricular groove (Bidder). There are others in the walls of the auricles, particularly in the septum, and the greatest number are found in the walls of the sinus venosus (Remak).

The ganglia in the sinus venosus are probably those which habitually act as automatic centres. They take the initiative and regulate the rhythm of the auricles and ventricles, and therefore include some inhibitory as well as exciting cells.

This seems proved by the following facts :—1. The ordinary contraction wave starts from the sinus venosus. 2. This part beats longer and more steadily than the others, when separated from the animal. 3. When cut off from the sinus, the rest of the heart stops beating. After some minutes the auricles and ventricle begin to beat, but at a slower rate than the sinus, and with uncertain and changeable rhythm. 4. When the sinus venosus is functionally separated, by a ligature, from the auricles and ventricle, both the latter cease to contract, while the motions of the sinus continue. If a slight stimulus, such as the touch of a needle, be then applied to the auriculo-ventricular margin, it gives rise to a series of rhythmical contractions. Or, if the ventricle be separated from the auricles by incision through the auriculo-ventricular groove, the former commences to beat rhythmically while the auricles commonly remain motionless.

These latter experiments (Stannius) have been explained by supposing the ligature either (1) to excite some inhibitory nerve mechanism, or (2) to cut off the exciting influence of the sinus. The latter is the more probable explanation. When cut off by ligature from the sinus, the heart fails to contract because the stimulus from the sinus, can no longer pass the "block" in the tissues. When the ventricle is cut away from the auricles, the incision is sufficient stimulus to the cells in the groove to make them excite its rhythmical contractions.

Although we cannot adequately explain the relationships borne by the different sets of ganglia in the frog's heart to one another, there seems no doubt that the following conclusions may he accepted and are applicable to the hearts of mammals. That nerve centres exist in the muscle tissue of the heart, some of which are capable of originating stimuli for the rhythmically contracting muscle. That there exist other ganglionic groups which help to regulate and distribute the stimuli in sequence throughout the several cavities.

Extrinsic Cardiac Nerves.

The intrinsic nerve mechanism of the heart just described is under the immediate control of the great nervous centres, through the medium of fibres passing from the medulla oblongata, by (1) the vagus and (2) the sympathetic chain.

The vagus fibres *check* the action of the intrinsic ganglia, and cause the heart to beat more slowly ; hence they are called *inhibitory*. The sympathetic fibres *quicken* the beat, and are called *acceleratory*.

Inhibitory Nerves of the Heart.—It was observed by Weber (1) that electric stimulation of the distal end of the cut vagus nerve caused a slowing of the heart's rhythm, and if

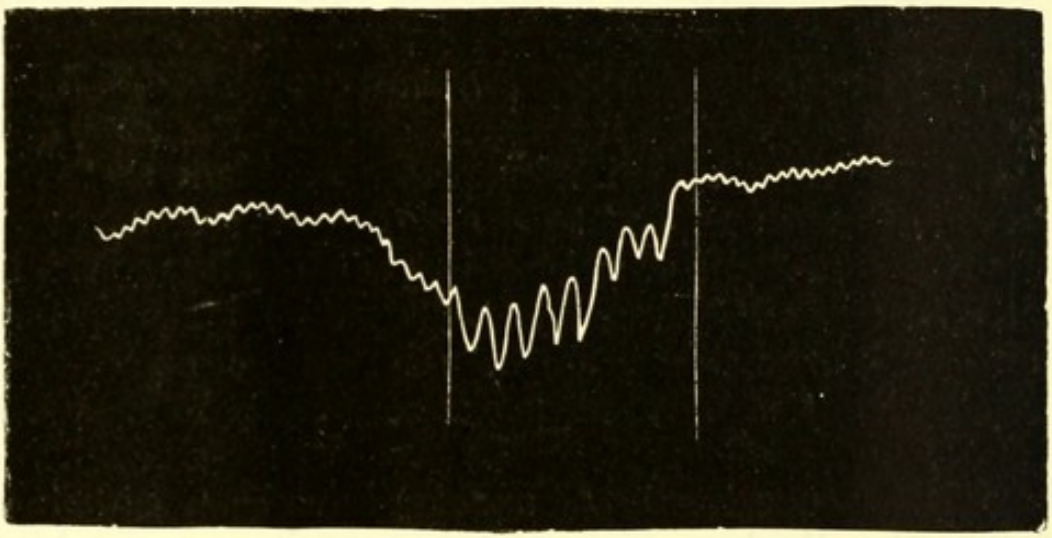


Fig. 112.—Tracing, showing the effect of Weak Stimulation of Vagus Nerve. Stimulus applied between vertical lines. (Recording surface moved from left to right.)

increased, gave rise to a standstill of the heart in diastole ; (2) that the normal rhythm of the heart-beat returned soon after the stimulus had been removed.

On the other hand (3) section of both vagi produced an increase in the rapidity of the heart-beat, varying according to the kind of animal experimented upon. Section of only one vagus, however, has not this effect.

From these experiments it would appear—1. That fibres of the vagus constantly bear inhibitory impulses to the intrinsic nerves of the heart, or in other words, the vagi exert a tonic inhibitory influence on the rapidity of the heart-beat. 2. The action of one vagus is sufficient to regulate the heart's rhythm.

Vagus inhibition is increased during life by the following circumstances—(*a*) certain psychical phenomena such as terror, which may produce a temporary standstill ; (*b*) deficiency of arterial blood in the medulla oblongata ; (*c*) increase of the blood pressure within the cranium ; and (*d*) reflexly by the stimulation of many afferent nerves, particularly those bearing impulses from the abdominal viscera to the medulla, and the afferent fibres of the opposite vagus.

THE ACCELERATOR NERVES.—It has been found that stimulation of the cervical portion of the spinal cord causes quickening of the heart-beat. This occurs even after the possibility of increase of blood pressure has been removed by section of the splanchnic nerves, and the tonic inhibition of the vagi has been cut off by their section. In the cervical portion of the spinal cord nerve channels must exist which cause the heart to beat more quickly. These accelerator fibres pass from the cord through the communicating branches to the upper dorsal sympathetic ganglia and thence to the heart.

Stimulation of these ganglia, or of the branches passing thence to the heart, quickens its beat. The effect of stimulus begins to show itself a comparatively long time (10 secs.) after it has been applied, and the acceleratory effort continues for a considerable time after the stimulus is removed. It therefore probably acts through the intrinsic nerve cells. The accelerator nerves have a less powerful influence than the inhibitory fibres of the vagus, as the vagus can be made to slow the beat whether the accelerators are stimulated or not, but the action of the accelerators is suspended so long as the vagus is being stimulated.

In the frog the cardiac sympathetic runs in the vagus, so the accelerator and inhibitory influences are excited together in it. The vagus alone may be excited in the cranium, before their junction. The accelerator effect can be demonstrated after the vagal fibres are tired out, or by stimulating the cervical sympathetic.

An analogy exists between the nervous mechanism of the heart and that of the blood-vessels (to be described in a future chapter) which may help in their better comprehension. Both the heart and vascular muscles can work automatically ; though no ganglionic cells can be found in the latter. Both are normally regulated by central influences. The heart receives constant inhibitory (dilator) impulses by the vagus, and occasional motor (accelerator) impulses by the sympathetic,

The vessels receive constant motor (constrictor) impulses by the sympathetic, and occasional inhibitory (dilator) impulses, usually passing to them by other nerves, though the fibres really belong to the sympathetic, as do also the cardiac fibres of the vagus.

AFFERENT NERVES.—Besides the nerve impulses to the heart, others pass from the heart to the medulla ; probably having their origin in the inner lining of the heart, which is the part most sensitive to stimulus.

These impulses appear to be of two kinds. One, travelling by the vagi, affects the cardio-inhibitory centre and diminishes the heart's rate ; the other, the depressor, affects the vaso-inhibitory centre and lowers the blood pressure. Increase of the intra-ventricular pressure stimulates both these sets of fibres. Over-filling of the heart causes retardation of its beat, and a fall of arterial pressure. Thus an equilibrium is sustained between the general blood pressure and the force of the heart-beat.

Cardiac Poisons.

The following drugs affect the cardiac nerve mechanisms :— *Muscarin* produces diastolic standstill of the heart, by exciting the local inhibitory ganglia, or vagus terminals. *Atropin* causes quickening of the heart's action by paralysing the endings of the vagus, and also those intrinsic mechanisms which are supposed to have an inhibitory effect. *Nicotin* produces at first a slowing of the heart by stimulating the inhibitory endings of the vagus. This is soon followed by exhaustion of the terminals and a consequent quickening of the heart-beat. Large doses of *curare* paralyse the inhibitory fibres. *Digitalis* excites the vagus centre in the medulla, and thereby reduces the rapidity of the heart's beat.

CHAPTER XV.

CIRCULATION.

I. The Blood Vessels.

The channels which carry the blood through the body form a closed system of elastic tubes, which may be divided into three varieties :—

1. Arteries.
2. Capillaries.
3. Veins.

The arteries and veins serve merely to conduct the blood to and from the capillaries, where the essential function of the blood, *viz.*, its chemical interchange with the tissues, is carried on.

Arteries.—The *arteries* are those vessels which carry the blood from the heart to the capillaries. The great trunk of the *aorta*, which springs from the left ventricle, gives off a series of branches, which in turn sub-divide more and more freely in proportion to their distance from the heart. Arterial twigs of considerable size here and there form connections with those of a neighbouring trunk (*anastomoses*) ; but these unions are simple junctions of single branches, never so complex as to be worthy of the name of a network or plexus, such as those seen in the capillaries or in the veins.

The *walls* of the arteries are made up of three coats :—

1. An *external* tough layer of white fibrous tissue, which gives strength to the vessels, restricts their elasticity like the webbing in the wall of rubber water-hose, and also acts as a bond of union between them and the neighbouring tissues. This coat (*tunica adventitia*) carries the minute vessels necessary for the nutrition of the vessel wall, and nerves.

2. The *middle* coat (*tunica media*) forms the more characteristic part of the arterial structure, being a mixture of elastic tissue and unstriated muscle. It is much thicker in the

arteries than in the veins, where its special functions are not required. It differs in character in arteries of different

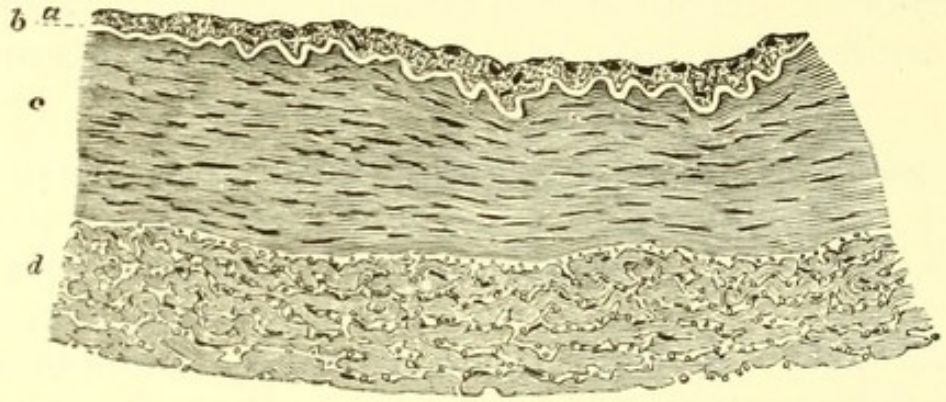


Fig. 113.—Transverse Section of part of the Wall of the Posterior Tibial Artery (man). (Schäfer.)

(*a*) Endothelium lining the vessel, appearing thicker than natural from the contraction of the outer coats.
(*b*) The elastic layer of the intima.
(*c*) Middle coat composed of muscle fibres and elastic tissue.
(*d*) Outer coat consisting chiefly of white fibrous tissue.

calibre, being relatively much thicker in the large vessels. The middle coat differs essentially both in structure and in function, in the large arteries and the arterioles, in each class of vessel it forms the most important part for the due performance of their respective functions. In the large vessels it is made up of fibres and sheets of elastic tissue woven into a dense felt-work, interspersed with a few muscle cells. In the smallest arteries or arterioles, on the other hand, the great mass of the middle coat is made up of muscle cells, the elastic tissue being but sparsely represented. Between the large arteries and the capillaries every grade of transition may be found; the elastic tissue gradually becoming less abundant, and the muscle elements relatively more numerous, in proportion as the capillaries are approached.

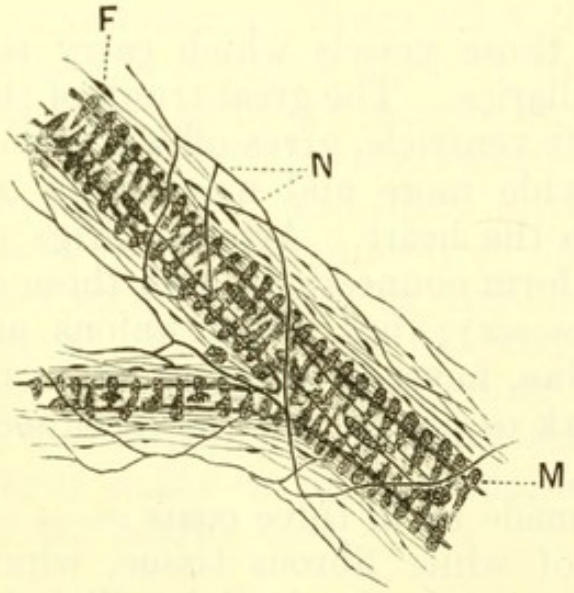


Fig. 114.—Portion of Small Artery from Submucous Tissue of Mouse's Stomach, stained with gold-chloride, showing the nuclei of the muscle cells (M) passing transversely around the vessel to form the middle coat, outside which is the fibrous tissue of the outer coat (F). Around the vessel several fine nerve fibrils form a network (N).

3. The *internal* lining (*tunica intima*) of the arteries is composed of a delicate, elastic, homogeneous membrane, lined with a single layer of endothelial cells. The intima may be said to be continuous throughout all the vessels and the heart cavities.

It is thus seen that the large arteries have extremely elastic and firm walls, capable of sustaining considerable pressure. The smaller the calibre of the arteries becomes the more the general property of elasticity and resiliency is reinforced, by that of *vital contractility*, due to the greater relative number of muscle cells contained in the middle coat.

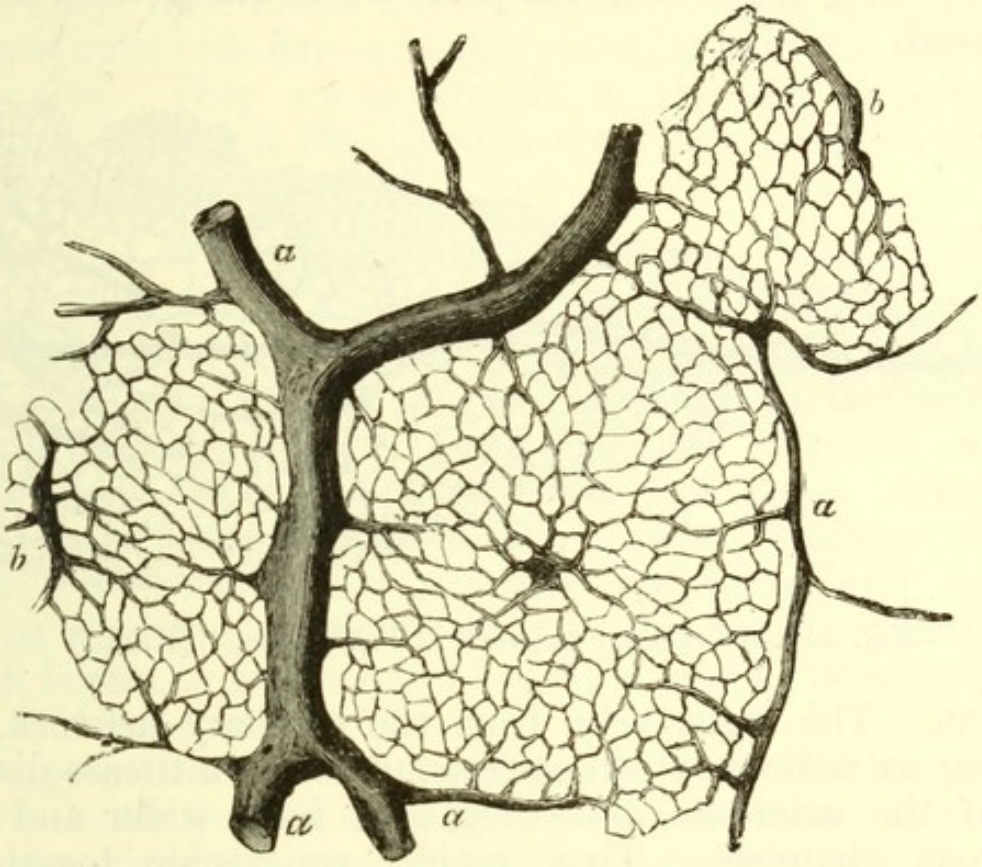


Fig. 115.—Capillary network of a Lobule of the Liver.
(*a*) Interlobular veins. (*b*) Intralobular veins.

CAPILLARIES.—The frequently branching arterioles finally terminate in the *capillaries*, in which distinct branches can no longer be recognised, but the thin canals are interwoven into a network of blood channels, the meshes of which are made up of vessels, all having about the same calibre. They communicate indefinitely with the capillary meshworks of the neighbouring arterioles, so that any given capillary area appears to be one continuous network of tubules, connected here and there with the similar networks from distinct arterioles, and thus any given capillary area may be fed with blood from several different sources. The walls of the capillaries are com-

posed of a single layer of elongated endothelial cells (possibly lining an invisible membrane) cemented edge to edge to form a tube. They are soft and elastic, and permeable not only to the fluid portion of the blood, but also, under certain circumstances, to the corpuscles. Thus a free interchange between the tissues and the blood can be maintained.

The characters of the capillary network vary in the different tissues and organs ; the closeness and wideness of the meshes may be said to be in proportion to the functional activity or inactivity of the organ or tissue in question, a greater amount of blood being required in the parts where energetic duties are performed.

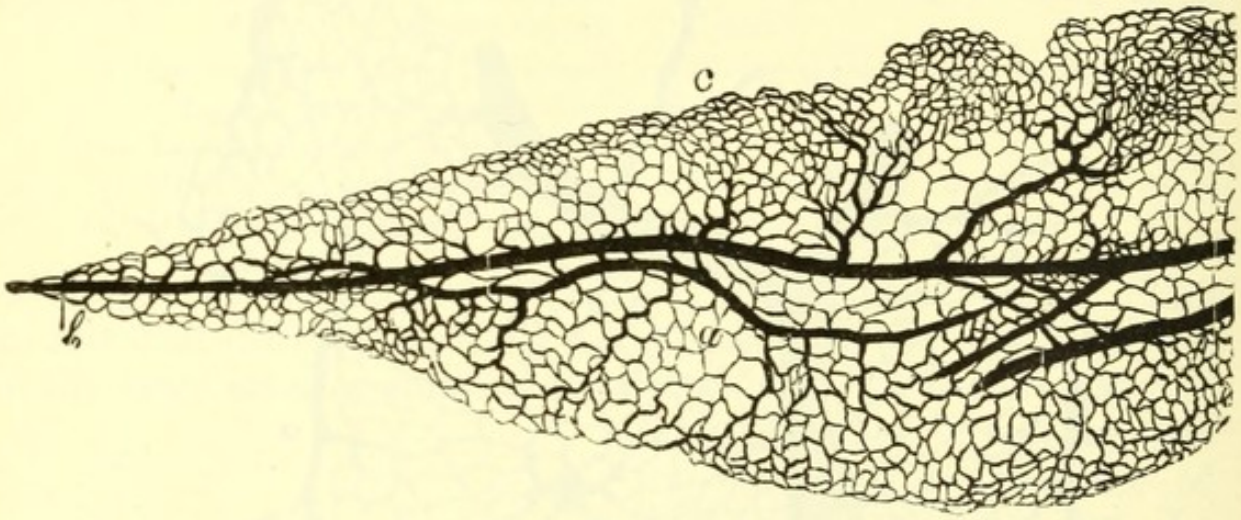


Fig. 116.—Capillary network of Fat Tissue. (Klein.)

VEINS.—The veins arise from the capillary network, commencing as radicles which correspond to the ultimate distribution of the arterioles, but they soon form wider and more numerous channels. They rapidly congregate together to make comparatively large vessels, which frequently intercommunicate and form coarse and irregular plexuses. The general arrangement of the structures in the walls of the veins is like that of the arteries ; they also have three coats, the *external*, *middle*, and *internal ;* the tissues of each differing but little from those of the arteries. The *external* coat is like that of the arteries, but is not quite so strong. The *middle coat*, however, in the large veins, is easily distinguished from that of the large arteries by being much thinner, owing to the paucity of yellow elastic tissue. It is also characterised by its relative richness in muscle fibre. The structure of the middle coat of the small veins can be distinguished from that of the arterioles by the comparative sparseness of the circular muscle cells.

The inner coat of the veins is practically the same as that of the arteries.

The veins are capable of considerable distension, but, though possessed of a certain degree of elasticity, they are much inferior to the arteries in resiliency.

In all those veins where the blood moves against gravity, *valve-like folds* of their lining coat exist, which prevent the backward flow of blood to the capillaries and insure its passage towards the heart. These valves resemble in their general plan the pocket valves that protect the great arterial orifices of the heart. They vary much in arrangement, there being two or sometimes only one flap or pocket entering into the formation of the valve. They are closely set in the long veins of the extremities, in which the blood current has to move against the force of gravity.

AGGREGATE SECTIONAL AREA OF THE VESSELS.—The general aggregate diameter of the different parts of the vascular system varies greatly. The combined calibre of the branches of an artery exceeds that of the parent trunk, so that the aggregate sectional area of the *arterial* tree increases as one proceeds from the aorta towards the capillaries. After the muscular arterioles are passed the general diameter of the vascular system suddenly increases immensely, and in the *capillaries* it reaches its maximum, the aggregate sectional area of which is said to be several (5 to 8) hundred times as great as that of the aorta.

The aggregate sectional area of the *veins* diminishes as the tributaries unite to form main trunks, and reaches its minimum at the entrance of the vena cava into the right auricle.

The capacity of the veins is, however, everywhere much greater than that of the corresponding arteries, the least difference being near the heart, where the calibre of the venæ cavæ is more than twice that of the aorta.

After this brief anatomical sketch the most important properties of each part of the vascular system may be summarised thus :—

1. The structure of the walls of the large arteries shows them to be capable of sustaining considerable pressure, and of exerting powerful and continuous *elastic recoil* on the blood.
2. In the small arteries, as well as this elasticity, frequent variation in their calibre occurs, dependent on the

contraction of their muscular coat, which regulates the blood-flow.

3. In the capillaries we find extreme thinness, elasticity, and *permeability* of their wall, which presents an *immense surface*, so as to allow free interchange between the blood and the surrounding textures.

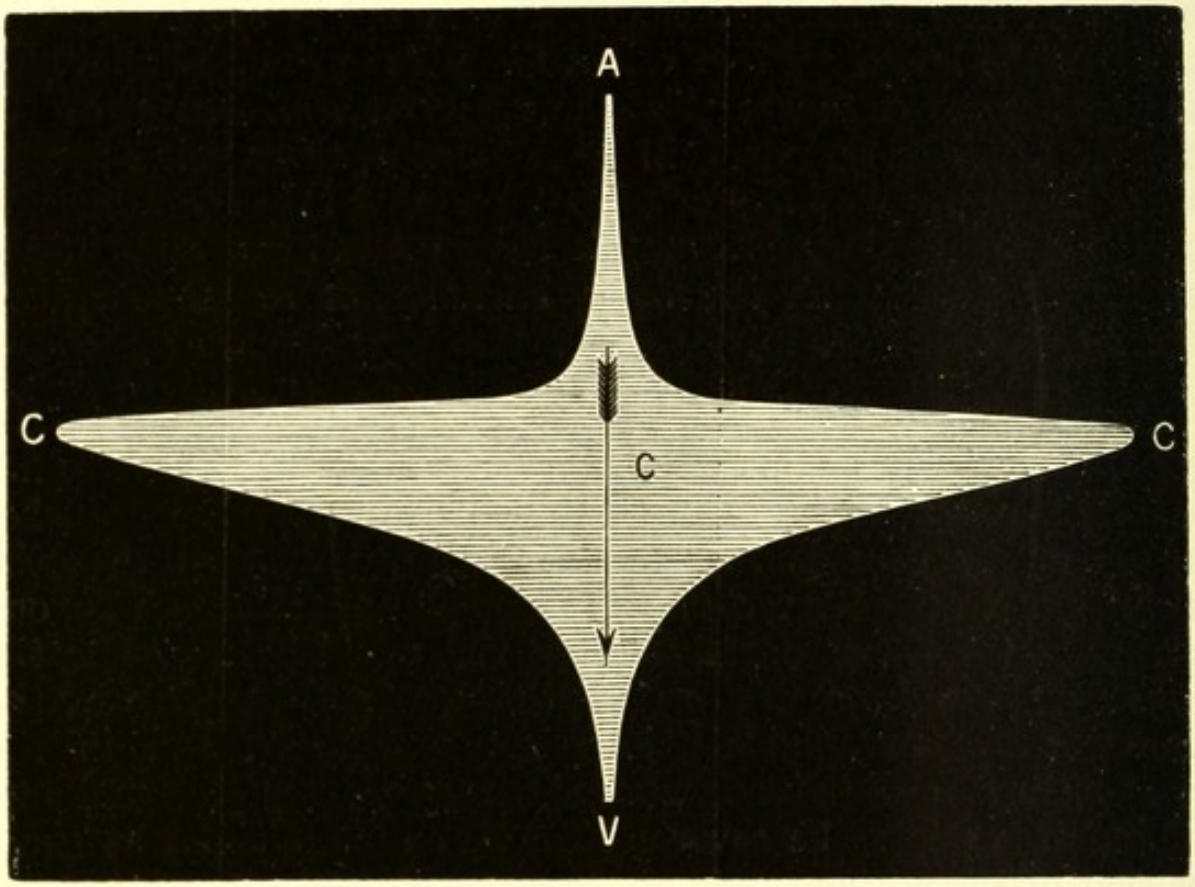


Fig. 117.—Diagram intended to give an idea of the aggregate sectional area of the blood-vessels in the different parts of the vascular system.

A. Aorta. C. Capillaries. V. Veins.

The transverse measurement of the shaded part may be taken as the width of the various kinds of vessels, supposing them fused together.

4. The veins have yielding and distensible walls, capacity to accommodate a large quantity of blood, and *valves* to prevent its backward flow upon the capillaries.
5. The aggregate sectional area of the systemic capillaries is about three hundred times that of the great veins, and seven hundred times that of the aorta, so that the current of the blood must be proportionately slower in the capillary network.

II. Physical Forces of the Circulation.

A liquid flows through a tube as the result of a difference of pressure in the different parts of the tube. The liquid moves from the part where the pressure is higher towards that where it is lower, except where sudden and great variations of calibre occur.*

The rate of flow corresponds with the difference in the pressure, and varies in proportion to it, continuing so long as the pressure is unequal in different parts, and ceasing when it is equalised throughout the tube.

If liquid be forcibly pumped into one extremity of a long tube, such as a garden-hose, a pressure-difference is established, the pressure becoming greater at the end into which the liquid is pumped, a current consequently takes place towards the open end. So long as the free or distal end of the tube is quite open and on the same level as the rest, no very great pressure can be brought to bear on the walls of the tube, no matter how forcibly the pumping may go on, as the liquid easily escapes, and therefore flows the more quickly as the pumping becomes more energetic. If, however, the outflow be impeded by raising the distal end of the tube to any considerable height, or by partially closing the orifice with a nozzle or rose, then the pressure within the tube can be greatly increased by energetic pumping, and the tube if elastic will be distended.

It can be further observed, in this common operation, that the smaller the orifice of the nozzle the greater the pressure in the tube with a given rate of working the pump; and, the orifice remaining the same, the pressure will increase in proportion as the pump is more energetically worked. Or in other words, the pressure within the tube will depend on (*a*) the energy used at the pump, and (*b*) the degree of impediment offered to the overflow.

If the tube be resilient, and the nozzle have a small orifice so that a high pressure can be established within the tube, it will be found that the liquid will flow from the nozzle in a con-

* Although in the whole course of any system of tubes the flow of liquid must take place from the part of higher to that of lower pressure, yet if a narrow tube open abruptly into one the diameter of which for a short length is much greater, the diminution of velocity in the wide tube may cause the local pressure in it to exceed that in the narrower tube immediately preceding; so that the liquid would be actually flowing, for a short distance, from a point of lower to a point of higher pressure.

tinuous stream, and will not follow the jerks communicated by the pump. That is to say, the interrupted energy of the pump is stored up by the elastic tube and converted into a continuous *pressure* exerted on the fluid. But if the tube be quite rigid, or the orifice too wide to allow the pressure within the tube to be raised sufficiently high, then the fluid will flow out of the end of the tube in jets which correspond with the strokes of the pump; *i.e.*, the outflow will follow closely the pressure difference caused by the pump at the point of inflow.

These simple facts, which can be verified experimentally with an ordinary enema bag, a yard of elastic tubing, and a short glass tube drawn to a point, form the key to the most important dynamic principles of the circulation.

Blood-Pressure.—The cause of the blood's motion is simply a difference in the pressure within the various parts of the vascular system, for the heart acts as the pump filling the tube represented by the large elastic arteries, which can be more or less distended, according as (1) the outflow is impeded, or facilitated by the contraction or relaxation of the muscular arterioles which form the outlet, or as (2) the inflow is increased or diminished by the greater or less activity of the heart's action.

From the foregoing facts, and from what has been said of the direction of the blood current, namely, that it flows from the arteries through the capillaries into the veins, it would appear that the pressure in the arteries exceeds that in the capillaries, and that in the capillaries must in turn be greater than that in the veins, the blood flowing in the direction in which the pressure becomes less.

The different manner in which blood flows from a cut artery and a cut vein, shows that a great difference exists in the pressure within the two sets of vessels.

When a small artery is cut and the orifice directed upwards the blood spurts out two or three yards in jerks. When a vein is cut, the blood only trickles gently from the orifice, the force of the flow depending much upon the position of the part. It is well to remember that bleeding from a vein in the leg or arm can be stopped by placing the limb in a position more elevated than the rest of the body, so as to prevent the force of gravity from acting on the blood.

By means of a special form of gauge (the mercurial manometer),—which will presently be described—the exact differ-

ence in the pressure exerted by the blood against the vessel-walls in the different parts of the circulation can be accurately estimated, and it has been found by direct experiment that the *pressure* varies, just as one would be led to expect from a consideration of its physical relationships, namely, with the *direction* and *rate* of the current and the varying *width of the bed* in which it flows.

The fall in pressure observed in the vessels when passing from the left ventricle to the right auricle is not even. In the arterioles it falls suddenly, and a great difference always exists between the arterial and venous pressure (v. p. 266). It is on account of the permanent high pressure in the arteries and comparatively low pressure in the capillaries and veins, that there is a continuous and permanent flow through the capillaries from arteries to veins.

Sustentation of the arterial blood-pressure.—The fundamental problem that must be clearly understood in studying the dynamics of the circulation is, how the high pressure in the arteries is kept up, or, in other words, how the arteries can exert so much pressure on the blood when the capillary out-flow is so free.

From the description already given of the action of the heart, it appears that each *beat of the ventricle* pumps some six ounces of blood into the aorta. Though coming to the left ventricle from the pulmonary circulation, the blood may for brevity be regarded as being pumped out of the systemic veins. This pumping occurs some seventy times a minute, so that a great quantity of blood is removed from the veins and forced into the arteries. The ventricles in filling the arteries have to work against considerable pressure, and may be said to pump up the blood from the low-pressure veins into the high-pressure arteries, the result of which is a permanent difference of pressure in the two sets of vessels.

The second important factor in enabling the high arterial blood-pressure to be kept up, is the *resiliency of the middle coat of the arteries*. It is only on account of the great elasticity of their arterial walls, that these vessels are capable of being so over-filled, and because of the perfect resiliency of the elastic coat, that they are able to exert such powerful pressure on the blood for such an unlimited time.

Each contraction of the ventricle further stretches the elastic artery. The act of injecting the blood into the aorta only occupies about one quarter of a cardiac cycle. During the

diastole the arteries are closed at their cardiac end by the aortic valves, and open at their distal end to the capillaries. The force of the ventricle is only used to cause arterial distension, the vessels do the rest by pressure.

As the result of this, the blood flows constantly out of the distended arteries, through the capillaries, into the veins.

But why does not this constant outflow allow the pressure in the arteries to fall to the level of that in the veins? Or in other words, what is the impediment offered to the escape of the blood that thus keeps the arteries distended?

This peripheral *resistance* is made up of several items. The great *increase of surface* and consequent enormous *friction* in the capillaries, and the pressure exercised upon them by the *surrounding elastic tissues*, offer much resistance. But the *contractility of the arterioles* is the most powerful agent, as may be seen from the following consideration. The resistance offered by the capillaries is less than the force exercised by the arterial blood-pressure, for the increase of friction, accompanying their greater extent of surface, is nearly counterbalanced by the decrease of resistance dependent upon the extensive area of the capillaries in comparison with that of the arterioles. The capillary resistance alone is not sufficient to restrain the blood from rushing into the veins. This is seen when the arterioles are paralysed by the destruction of the nervous mechanism controlling them. The blood then readily overcomes the capillary resistance, the veins become engorged, and the arterial blood-pressure falls. Further, as will presently be seen, beyond the arterioles the pressure diminishes suddenly, and in the capillary network it is always very low.

The four great factors in keeping up the arterial blood-pressure may be thus enumerated; 1, the heart-beat; 2, perfect aortic valves; 3, the elastic resiliency of the large arteries; 4, the resistance offered by the contraction of the muscular arterioles.

Heart-beat.—If any factor fail, the mechanism of the circulation is at once impaired. For example, the heart's beat may be stopped by the stimulation of the inhibitory nerve fibres of the vagus, in which case the blood-pressure rapidly falls, as shown by the curve taken by the graphic method, (p. 250.) Or weakness of the heart-beat may arise from disease (fatty degeneration) of the muscle, when signs of low arterial tension can be recognized in the human subject.

Valves.—Any insufficiency of the aortic valves that permits

the blood to flow backward into the ventricle, allows the arterial pressure to fall between each ventricular systole, and gives rise to the characteristic "pulse of unfilled arteries."

Elasticity of Arteries.—The resiliency of the arterial coats may also be destroyed to a certain extent by degeneration of the tissue, in which case the large arteries become greatly distended, and unable to exert their normal steady pressure on the blood.

Contractile Arterioles.—Injuries of certain nervous centres may bring about paralysis of the muscular arterioles, and fall of blood-pressure. The effect upon the blood-pressure of dilatation of the small arteries can be best seen by experimenting on the nerves that control their contraction. If paralysis or inhibition of the vasomotor mechanisms be experimentally produced, a sudden fall of pressure is the result.

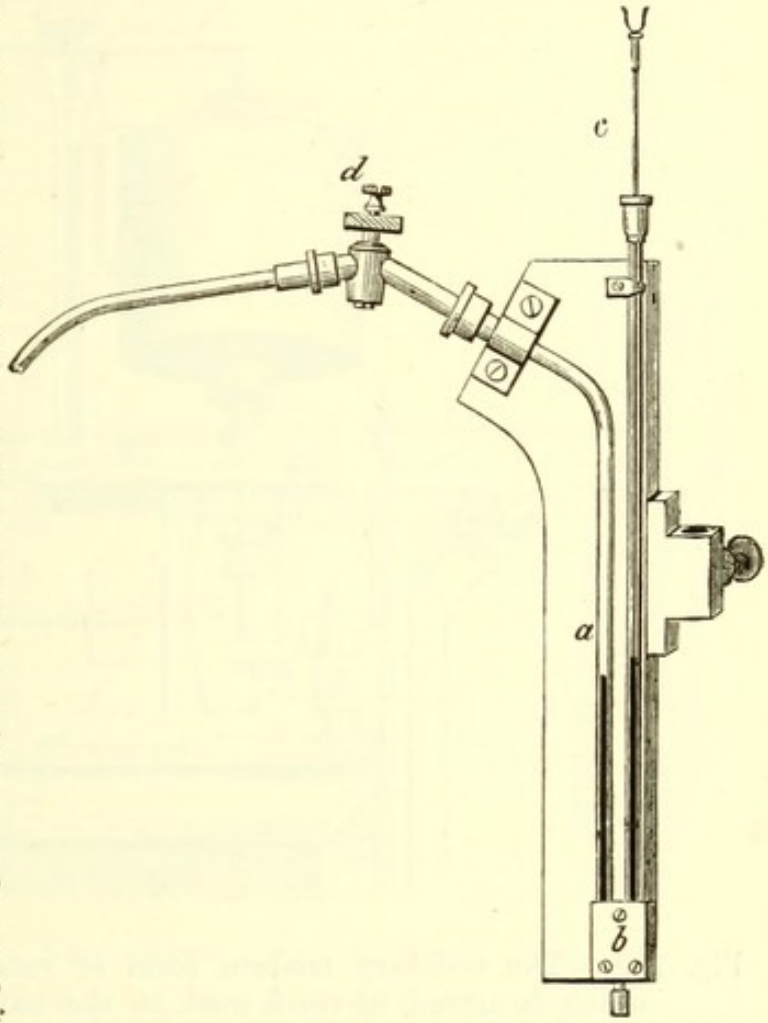


Fig. 118.—Mercurial Manometer for measuring and recording the blood pressure.

a. Proximate limb of manometer.
b. Union of two limbs of manometer.
c. The rod floating on mercury and carrying the writing point.
d. Stop-cock through which the sodium bicarbonate can be introduced between the blood and mercury of manometer.

MEASUREMENT OF THE BLOOD-PRESSURE.—The first attempt at direct measurement of blood-pressure was made by the Rev. Stephen Hales about the middle of the last century, who, wishing to compare the motion of fluids in animals with that in plants, connected a tube with an artery of a living animal, and found that the blood was ejected with considerable force. When the artery of a horse was brought into union with a long upright tube, the blood reached a height of about three yards.

The column of blood is not now used as a measure, because so much blood leaving the vessels tends to empty them, and to reduce the pressure in the arteries; besides the coagulation of the blood soon stops the experiment. We now employ the mercurial manometer, which consists of a column of mercury in a U-shaped tube. To prevent coagulation, the tube between

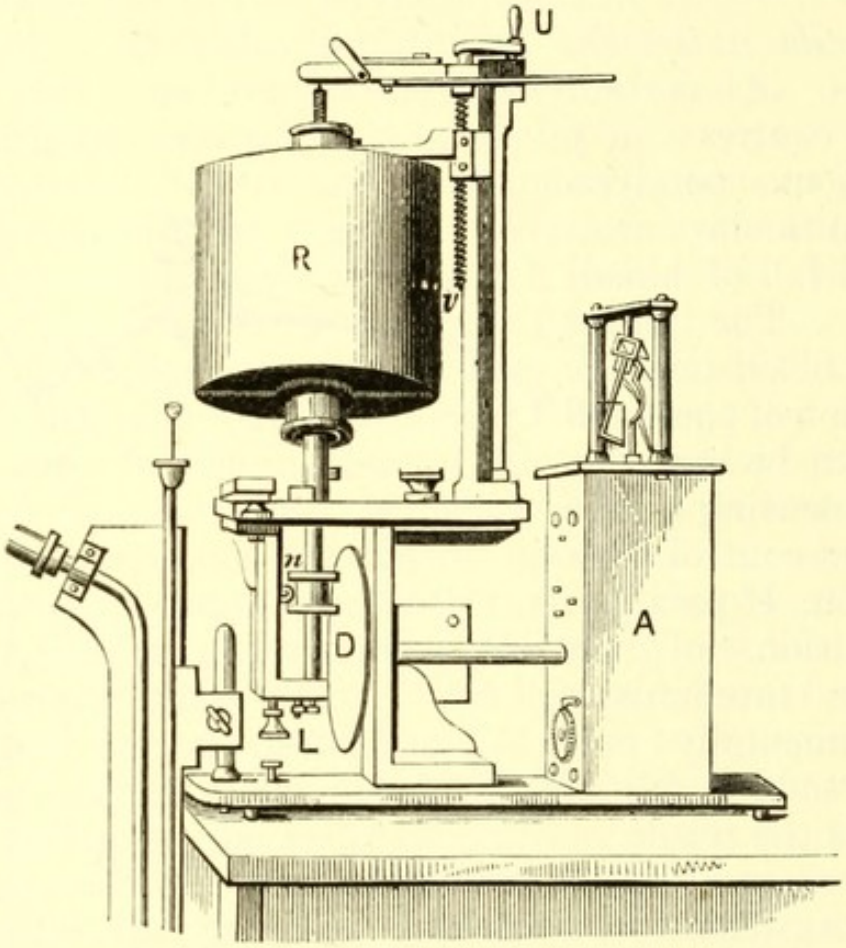


Fig. 119.—The ordinary modern form of rotating blackened cylinder (R), which is moved by clock work in the box (A) by means of the disc (D) pressing upon the wheel (*n*), which can be raised or lowered by the screw (L), so as to come in contact with any part of the disc more or less near the centre, and thus rotate at different rates. The cylinder can be raised by the screw (*v*), which is turned by the handle (U). (Hermann.)

the mercury and blood is filled with a solution of sodium carbonate, the pressure being previously regulated to equalise as nearly as possible that of the blood. A rod is made to float upon the mercury, in the open side of the tube, and to the upper extremity of this a writing apparatus can be attached, so that by the movements of the mercury, a graphic record of the blood-pressure and its variation can be traced on a regularly moving surface. This instrument, known as Ludwig's Kymo-

graph, is that used in all ordinary measurements and experiments on blood pressure.

In order to overcome the inertia of the mercurial column, another manometer has been devised which will be mentioned in speaking of the character of the curve (p. 269). When an experiment of long duration has to be made, a recorder with a continuous roll of paper can be employed (Fig. 120).

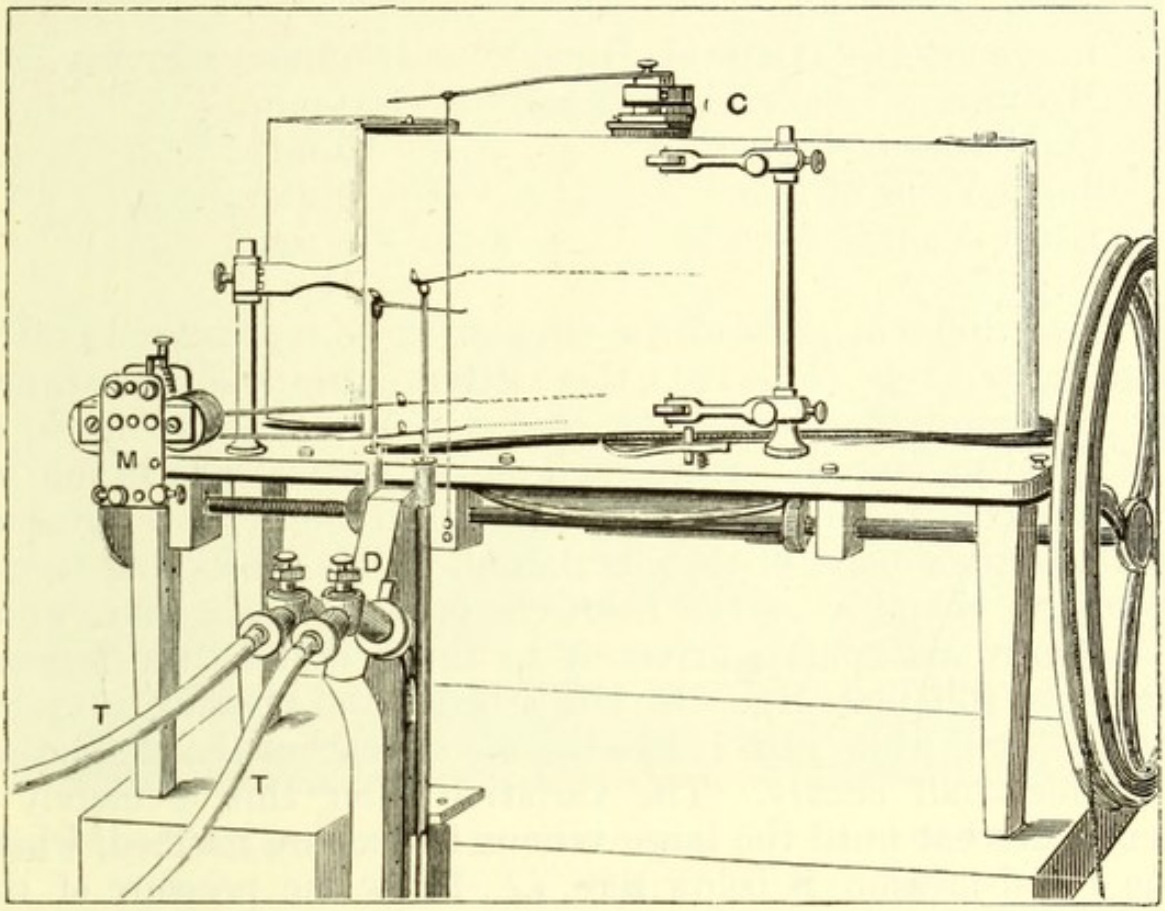


Fig. 120.—Ludwig's Kymograph with continuous paper.

The instrument consists of an iron table, above which the receding surface is slowly drawn past the writing points from an endless roll of paper on the left by the motion of the cylinder (c), and rolled up on a spindle next the driving-wheel on the right. The mercurial manometers are so fixed on (d) that the open ends come in front of the firm roller upon which the paper rests. The writing style can be seen rising from those tubes while the other limbs of the manometers lead through the stop-cocks to the tubes which are in communication with the blood-vessels. The time is recorded by means of a pen attached to the electro-magnet (m), which by a "breaking" clock, is demagnetised every second. The moment at which a stimulus is applied is marked on the zero line by a key to which another pen is attached near the time-marker.

The modern accurate methods of research have taught us the differences in pressure that exist in the various parts of the vascular system. However, direct measurement can only be

accomplished in vessels of such a size as to admit a cannula, hence the pressure in the capillaries in the very minute arteries and veins can only be estimated indirectly. The pressure in all parts of the vascular system is subject to frequent variations, to be presently mentioned, but the following table may be useful in giving a general idea of the average permanent differences that exist in the different vessels of large animals and man.

Large arteries (Carotid, Horse)	+ 160 mm.,	mercury.
Medium ,, (Brachial, Man)	+ 120 mm.,	,,
Capillaries of Finger	+ 15 mm.,	,,
Small Veins of Arm	+ 9 mm.,	,,
Large Vein of Neck	− 3 to − 8 mm.,	,,

If the different parts of the circulation be represented on the base line H. A. C. V. (Fig. 121), these letters corresponding to heart, arteries, capillaries, and veins respectively, and if the height of the blood-pressure be represented on the vertical line in mm. of Hg. the curve *h*, *a*, *c*, *v*, would give about the relative pressure in the various parts of the circulation. This shows that in the receiving chamber of the heart the pressure is negative, while the ventricular pump drives it to the height of the arterial pressure, 160 mm. Hg. In the arteries the pressure is everywhere high, while just before the blood reaches the capillaries, a sudden fall occurs. The variation after this is merely a gentle descent until the large venous trunks are reached, where the blood-pressure is below zero, *i.e.*, below the pressure of the atmosphere, so that air rushes into them if opened.

From this diagram the following points can be gathered :—

1. The great difference in the pressure on the arterial and venous sides of the circulation.
2. The comparatively slight difference in pressure in the different parts of the arterial or of the venous systems respectively.
3. The suddenness of the fall in the pressure between the small arteries and the capillaries, where the great resistance to the outflow is met with.
4. In the large veins the pressure of the blood is habitually below that of the atmosphere, only becoming positive during forced expirations.

From a purely physical point of view the ventricle may be

regarded as pumping the blood up to an elevated high-pressure reservoir of small capacity (the arteries), from which it rapidly falls, by numerous outlets, into an expansive low-lying irrigation basin (the wide capillaries), while it slowly trickles through wide channels (veins), back to the well (the auricle), which lies below the surface pressure.

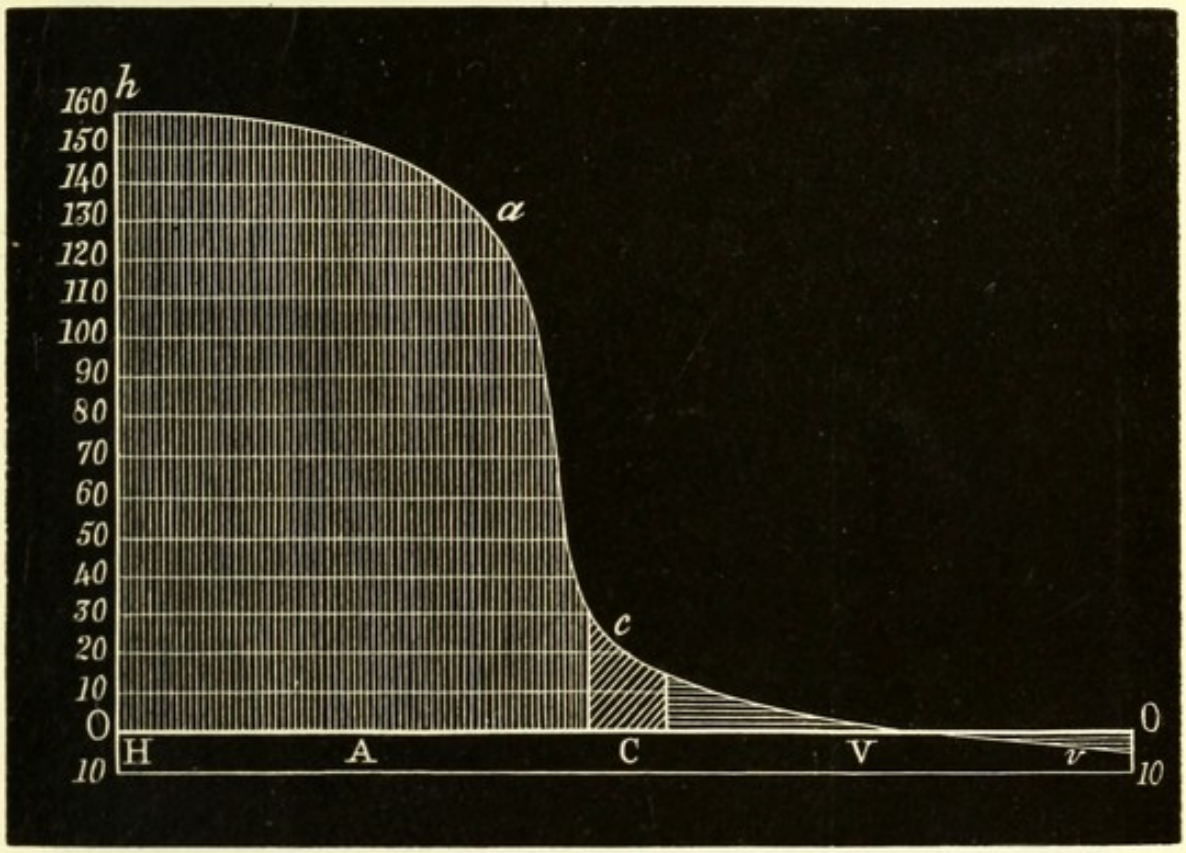


Fig. 121.—Diagram showing the relative height of the blood-pressure in the different regions of the vessels.

H. Heart. *a*. Arterioles. *v*. Small veins.
A. Arteries. *c*. Capillaries. V. Large veins.
H. V. being the zero line (= atmospheric pressure) the pressure is indicated by the height of the curve. The numbers on the left give the pressure (approximately) in mm. of mercury.

VARIATIONS IN THE BLOOD-PRESSURE.—If the blood-pressure be recorded with a Kymograph, a tracing will be obtained, which shows that the pressure undergoes periodic elevations and depressions of two different kinds. The smaller oscillations correspond with the heart-beat, the larger waves have the same rhythm as the respiratory movements, and the average elevation of the mercurial column is spoken of as the *mean pressure*. In the large arteries of the warm-blooded animals, this mean pressure varies with the size of the animal from 90 mm., mercury, to more than 200 mm. In cold-blooded

animals it is comparatively low, from 22 mm. in the frog, (Volkmann), to 84 mm. in a large fish.

The general mean pressure in the arteries is increased by: (1), increased action of the heart; (2), increased contraction of the muscular coat of the arteries; (3), sudden increase in the

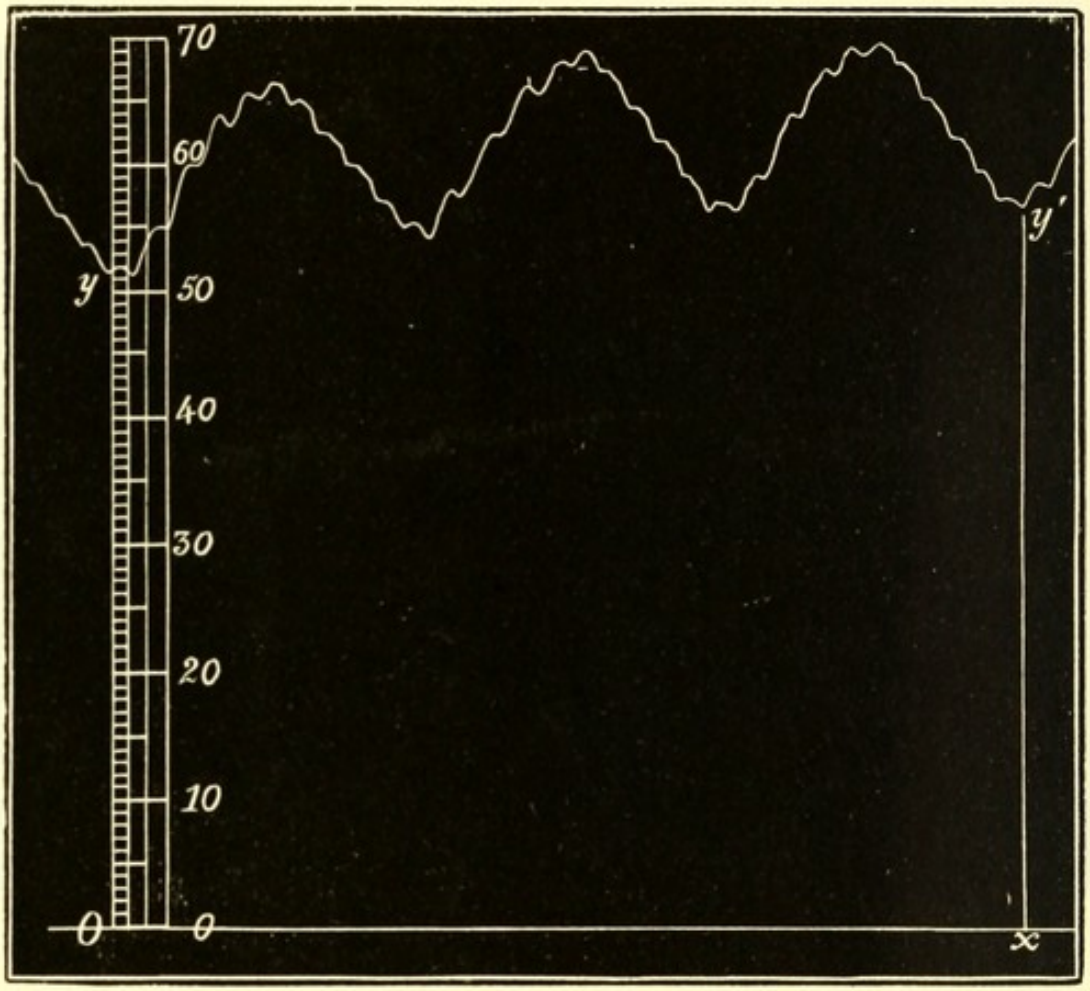


Fig. 122.—Blood-pressure Curve, drawn by mercurial manometer. O – x = zero line y – y' = curve with large respiratory waves and small waves of heart impulse. A scale is introduced to show height of pressure.

quantity of blood. When the change is gradual, the vessels adapt themselves to the increase.

The opposite of these conditions may be said to have a contrary effect.

The character of the change in pressure which accompanies the heart's systole, is not shown exactly in the tracing obtained by the mercurial manometer, owing to the sluggishness of the movement of the mercurial column which, as it were, rubs off the apices of the curves. But with the metallic *spring manometer* of Fick (Fig. 123), or Hürthle's rubber manometer, in which the inertia is small, the details of these oscillations can be recognized. (See Fig. 124.)

INFLUENCE OF RESPIRATION ON BLOOD-PRESSURE.—The explanation of the respiratory undulations in the tracing of the

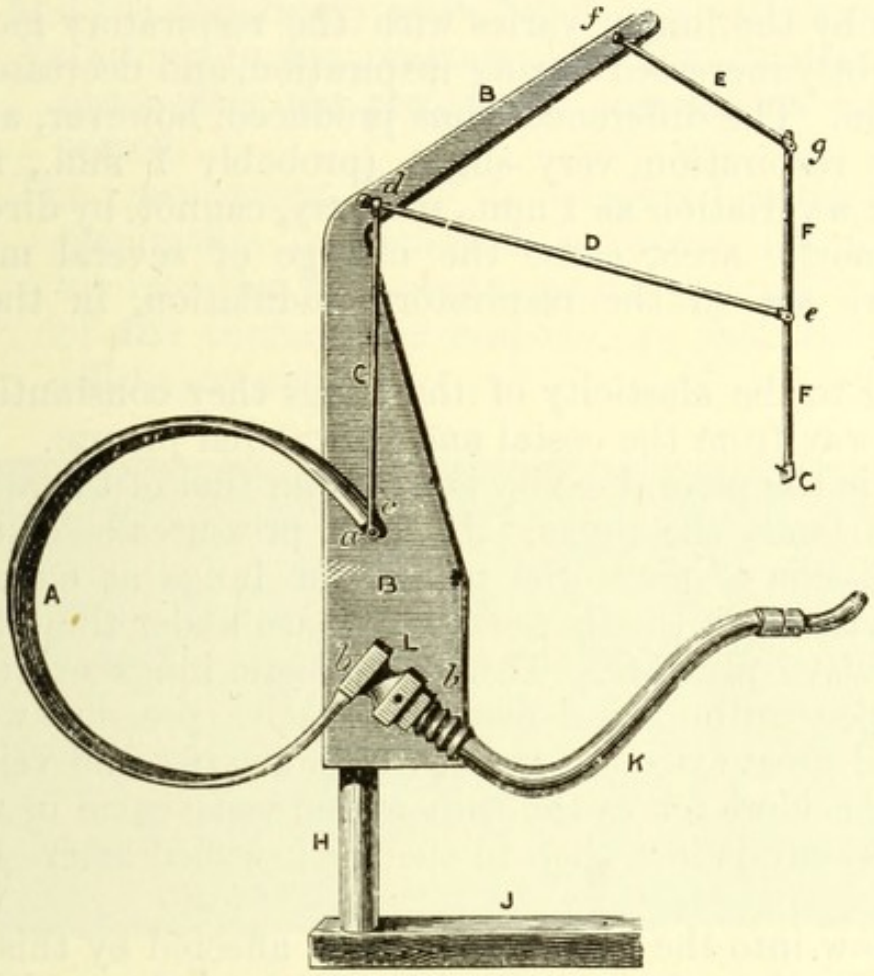


Fig. 123.—Fick's Spring Manometer.

A hollow C-shaped spring (A), made of extremely thin metal, is fixed at (*b b*) where its cavity communicates with the tube (K). The top of the C. is connected at (*a*) with the writing lever. Any increase of pressure in the tube (K) causes the spring to expand and move the writing (G) up and down.

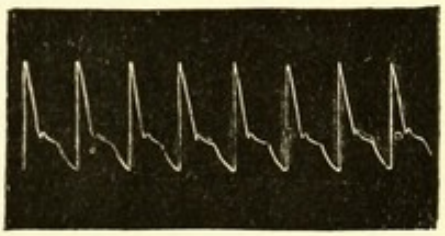


Fig. 124.—Tracing of blood-pressure taken with Fick's manometer.

blood-pressure is difficult. Though many causes have been assigned, no single one appears to explain adequately all the changes that may occur in this phenomenon. At first sight the respiratory movements, and consequent pressure changes within the thorax, would seem to give a simple *mechanical explanation* of the variation in pressure. But if the change occurring in the intra-thoracic pressure be examined carefully, it will be found not to correspond exactly with the so-called

respiratory wave of the pressure curve in the arterial system (Fig. 125.)

The amount of negative pressure exercised on the pericardial contents by the lungs, varies with the respiratory movements. It is slightly increased during inspiration, and decreased during expiration. The differences thus produced, however, are during ordinary respiration very slight (probably 1 mm., mercury). So slight a variation as 1 mm., mercury, cannot, by direct action on the aortic arch, cause the change of several millimetres which we see in the respiratory undulation, in the arterial pressure.

Owing to the elasticity of the lungs they constantly tend to shrink away from the costal and pericardial pleuræ. Thus the pressure in the pleural cavity is less than that of the atmosphere which distends the lungs. If these pressures be equalized by the admission of air to the pleuræ the lungs at once collapse. All the viscera in the thoracic cavity are under the influence of this negative pressure. Thus the elastic lungs exert traction on the pericardium, and cause a negative pressure within the heart and great systemic vessels, both arteries and veins. The influence is more felt by the thin-walled venæ cavæ in which the blood-pressure is low, than in the thick-walled arteries where it is high.

The flow into the left auricle is not affected by this negative pressure, as the pulmonary vessels are also influenced by it.

It has been suggested that inspiration, by *facilitating the flow* from the great veins, increases the amount of blood entering the right auricle, and thus the left ventricles may be better filled, and made to beat more actively, in rhythm with the inspiration.

Thus, while inspiration is taking place the lungs receive a larger supply of blood. From the relatively large amount of blood in these organs it is probable that this slight inspiratory excess has little influence on the amount entering the left side of the heart, too little, in fact, to mechanically influence the beat or the blood-pressure, but it may act as a nervous stimulus, and excite the nervous centres of the heart and the depressor nerve.

The rejection of this indirect mechanical explanation appears necessary from the following facts:—

(1.) The rise in pressure is not exactly synchronous with expiration or inspiration : (Fig. 125.)

(2.) The heart beats more slowly during expiration than inspiration :

(3.) This difference at once disappears if the vagi be cut, and the respiratory wave becomes greatly modified :

(4.) Variations in the pressure like the respiratory wave occur after the respiratory movements have quite ceased.

(5.) The respiratory wave is observed when artificial respiration is employed, in which the forcing of air into the lungs is the *cause*, and not the *result* of the thoracic movements, so that the pressure effects are *reversed*.

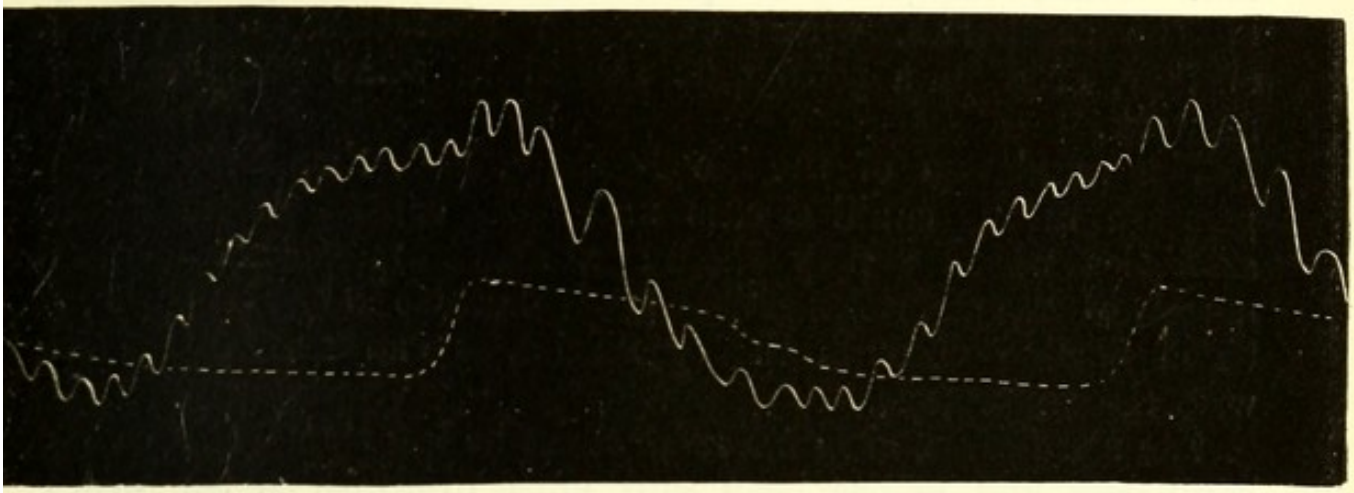


Fig. 125.—Blood-pressure and Respiratory Tracings recorded synchronously—recording surface moving from right to left—showing that the variations in pressure in the arteries (continuous line) and in the thoracic cavity (dotted line) do not exactly correspond, the latter continuing to fall after the blood-pressure has commenced to rise.

We may conclude then, from the variation in arterial pressure, which is rhythmical with the respiratory movements, that a sympathy in action exists between the respiratory, vascular and cardiac nerve mechanisms.

The undulations known as Traube's Curves occurring in curarised animals when no respiratory movements are performed, have been explained by referring them to a stimulation, by impure blood, of the vasomotor centre, which by rhythmical impulses increases the contraction of the arterioles and causes a rhythmical variation in the blood-pressure. This explanation when applied to the respiratory waves, seems to be rendered unsatisfactory by the fact, that these undulations go on even when the arterioles are cut off from their chief nerve centres, by a section of the spinal cord. So that if these undulations are

to be referred to nerve mechanism, we are ignorant of the course taken by the nerve impulses which influence the vessels.

Thus we seem forced to fall back upon the muscular coats of the arteries for an explanation of the respiratory variation in the blood-pressure, and to accord to this tissue automatic rhythmical contractility.

The blood-pressure in the capillaries cannot be directly measured by the means above described and it is difficult to estimate. It is said to vary from 10—20 mm. of mercury. The slightest change of pressure in the corresponding veins or arteries causes the pressure in the capillaries to rise or fall. Thus, variations in pressure are constantly occurring in the capillaries, which cause an alteration in the rate of flow, or even a retrograde stream in some parts of the network.

The regulation of the blood-supply, and, therefore, of the pressure in the capillaries, is under the control of the small arterioles which supply them; a slight relaxation of the muscle of the arterioles causes great increase in the amount of blood flowing through the capillaries, as can readily be seen with the microscope.

The blood-pressure in the veins must be less than that in the capillaries, and, as has been said, must diminish as the heart is approached, where in the great veins (superior cava) the pressure is said to be rather below that of the atmosphere (-3 to -8 mm., mercury). During inspiration the minus pressure may become further lowered, whilst on the other hand, it is only by very forced expiration that it ever becomes equal to or at all above that of the atmosphere.

This is a most important fact, as the suction, as it may be called, considerably helps the flow of blood from the veins, and also the current of fluid from the thoracic duct.

The pressure exerted by the walls of the veins on the blood may be said to be generally nil, since the veins are not filled with blood. The pressure, on the other hand, that can be registered and measured depends upon forces communicated from without, namely: (1) gravity; (2) the elastic pressure of the surrounding tissue; and (3) the pressure exerted by the muscle during contraction. This pressure is increased by any circumstance which impedes the flow of blood through the right side of the heart, through any large vein, or through the pulmonary circulation; but when no abnormal obstacle exists

in the venous blood-current the pressure in those vessels can never attain any great height, for, as we have seen, the large trunks are constantly being emptied by the heart's action.

Most circumstances which tend to lower arterial pressure also tend to raise the pressure in the veins, so that, when the heart's action is weak, or its mechanism faulty, the venous pressure rises.

In the veins of the extremities the pressure varies with gravity, as far as the valves and the alternating muscular pressure on the multiple venous routes will allow. Hence venous bleeding stops on elevation of the limb.

In the pulmonary circulation the direct measurement of the intravascular pressure is rendered extremely difficult, and possibly erroneous, by the fact that to ascertain it the thorax has to be opened. It has been found in the pulmonary artery to be in a dog 29·6 mm., in a cat 17·6 mm., and in a rabbit 12 mm. of mercury.

III. The Arterial Pulse.

Each systole of the ventricle sends a quantity of blood into the aorta, and thus communicates a stroke to the blood in that vessel. The incompressible fluid still further distends the tense arterial wall, and the shock to the column of blood is not transmitted directly onward by the fluid, but the elastic walls of the arteries yield locally, and thus a wave travels rapidly along those vessels. This distension in the walls of the vessel can be felt wherever the artery can be reached by the finger, but best, as is the case in the radial and temporal arteries, where the vessel is superficial and lies on the unyielding bone.

This motion of the vessel wall is called the *arterial pulse.* It consists of a simultaneous widening and lengthening of the artery. The arteries near the heart are more affected by the pulse wave than those more remote, the wave becoming fainter and fainter as it travels along the branching arteries. In the smallest arteries it is hardly recognizable, and under ordinary circumstances is quite absent in the capillaries and veins.

The *diminution in the pulse-wave* in the smaller arteries chiefly depends upon the fact that the force of the wave is used up in distending the successive parts of the arteries. In the small arteries the extent of surface to which the pulse-wave is communicated is great, and thereby the wave is much decreased.

It is probable that reflected waves pass from the peripheral end of the arterial tree—the contracted arterioles—and meeting the pulse-wave in the small arteries help to obliterate it. So long as the arterioles are contracted to the normal degree no pulsation is communicated to the capillaries, because any wave, reaching the arterioles, is reflected by them.

Pulse Rate.—The mean rate of the pulse (cardiac rhythm) varies in different individuals, seventy-two per minute being a fair average for a middle-aged adult. It varies also with many circumstances, which though purely physiological, must be borne in mind in taking the pulse as a clinical guide.

1. *Age.* At birth it is about 140 per minute, and is, generally speaking, quicker in young than in old people, commonly falling to 60 in aged persons.
2. *Sex.* It is more rapid in females than in males.
3. *Posture.* It is quicker standing than lying, particularly if a patient who has been lying down, stand or sit up, the pulse becomes more rapid.
4. *The time of day.* At its minimum at midnight, it gains in rapidity till 9 o'clock in the morning; falls in the day-time, and rises in the evening till 6 o'clock.
5. Muscular exercise quickens it.
6. It is quicker during inspiration than expiration.
7. It increases with increase of temperature.
8. It is variously affected by emotions.

Velocity of Pulse-Wave.—Near the orifice of the aorta the arterial distension occurs practically at the same time as the ventricular systole, but even with comparatively rough methods the pulse at the wrist can be observed to be a little later than the heart-beat. The difference of time between the pulse in the facial and the dorsal artery of the foot has been estimated to be one-sixth of a second, and the difference in the distance of these vessels from the heart is about 1,500 mm., so that the rate at which the pulse-wave travels is nearly 10 metres per second. The velocity of the wave is said to vary with the degree of elasticity of the walls of the vessels, decreasing with rigid walls. It would appear to be quicker in the lower than in the upper extremities.

Length of the Wave.—The time that the wave takes to pass any given point must be equal to the time taken to produce it, that is to say, the time the ventricle occupies in sending a new charge of blood into the aorta, which is about one-

third of a second. Knowing the rate at which the wave travels (10 metres per sec.) and the time it takes to pass any given point $\frac{1}{3}$ sec.), its length may be calculated to be about three metres, or about twice as long as the longest artery.

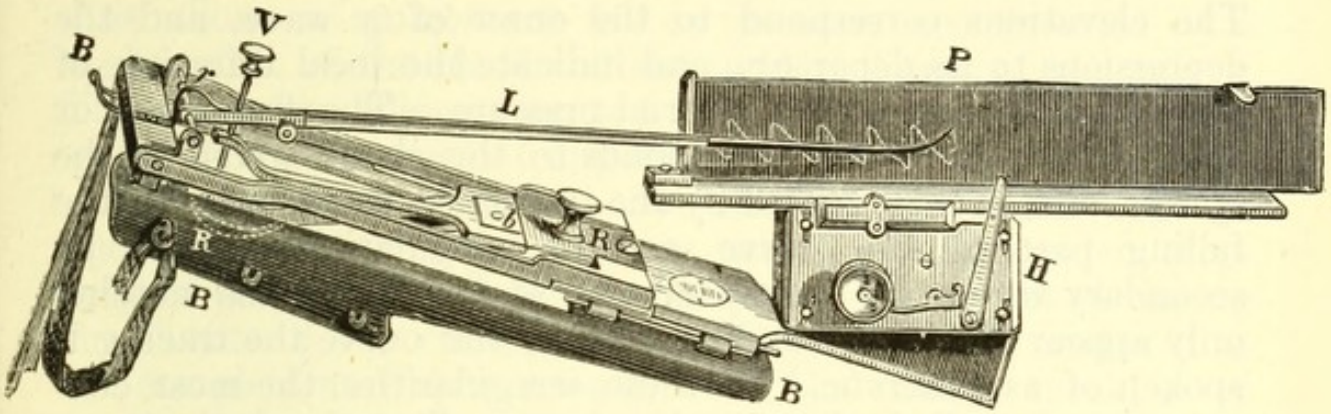


Fig. 126.—Marey's Sphygmograph.

The frame (B, B, B) is fastened to the wrist by the straps at B, B, and the rest of the instrument lies on the forearm. The end of the screw (V) rests on the spring (R), the button of which lies on the radial artery. Any motion of the button at R is communicated to V, which moves the lever (L) up and down. When in position, the blackened slip of glass (P) is made to move evenly by the clockwork (H) so that the writing point draws a record of the movements of the lever.

Thus the pulse-wave reaches the most distant artery in one-sixth of a second, or about the middle of the ventricular systole, and when the wave has passed from the arch of the aorta, its summit has just reached the arterioles.

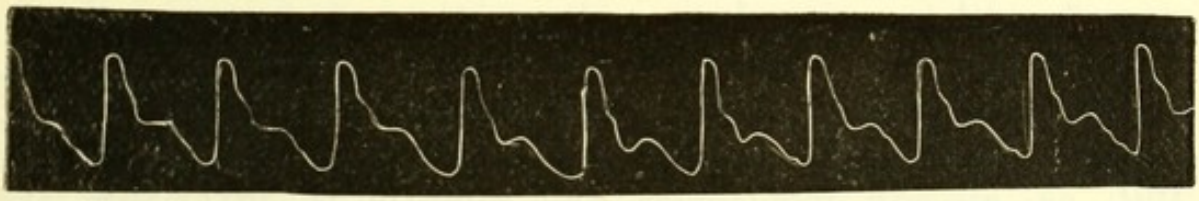


Fig. 127.—Tracing drawn by Marey's Sphygmograph. The surface moved from right to left. The vertical upstrokes show the period when the shock is given by the systole of the ventricle. The upper wave on the downstroke shows when the blood has ceased to enter the aorta. Then comes the dicrotic depression, which is a negative wave produced by the momentary backflow in aorta, and the dicrotic elevation caused by the closure of the valves.

PULSE CURVE.—Numerous instruments have been invented for the demonstration and graphic representation of the pulse in the human being. Of these the first perfected, is still in

general use —Marey's *Sphygmograph* (Fig. 126). A modification of Pond's American Sphygmograph, devised by Dudgeon, is a convenient form for clinical use. By means of these a graphic record of the pulse is made, in the form of a tracing which shows a series of elevations and depressions (Fig. 127). The elevations correspond to the onset of a wave, and the depressions to its departure, and indicate the local duration of the temporary rise of the arterial pressure. The first crest or apex of the pulse curve corresponds to the shock given by the systole, and is exaggerated by the inertia of the lever. In the falling part of the curve certain irregularities caused by secondary waves are nearly always seen. When the notches only appear on the descending part of the curve the tracing is spoken of as *catacrotic*. Of these irregularities, the most conspicuous is called the *dicrotic* wave. Sometimes there are several of these secondary waves, the most constant of which is a small wave preceding the dicrotic, called *predicrotic;* but the dicrotic is always more marked than any other. When several secondary waves exist in the pulse curve the smaller ones probably depend on oscillations partly due to the inertia of the lever of the instrument.

The dicrotic wave certainly does not depend on the instrument, because in many cases the skilled finger laid on the radial artery at the wrist can easily detect it, and it can be directly seen in the vessel when the pulsation in the arteries is visible, or when a jet of blood escapes from an artery.

The dicrotic wave has been explained as (1) a wave of oscillation, (2) a wave reflected from the periphery, or (3) a wave from the aortic valves.

(1) If the first, it should be less marked than the predicrotic, which by this theory is said to be the first wave of oscillation, for each succeeding oscillation is less than its forerunner. But, as already mentioned, the dicrotic is invariably the larger. It is therefore not due simply to oscillation.

(2) There are many reasons why it cannot be a wave of reflection from the periphery of the arterial tree; viz., 1. It is not found to get nearer to the primary wave in a series of tracings by which the peripheral vessels are approached. 2. The arterioles which form the peripheral resistance are at too irregular distances to give one definite wave of reflection. 3. It is seen in the spurting of an artery cut off from the periphery. 4. It increases with greater elasticity and low tension, which cause the reflected waves to diminish.

(3) When a new charge of blood is shot into the aorta the elastic wall of the vessel is suddenly stretched. At the same time a shock is given to the column of blood, and the fluid next the valves is moved forwards with great velocity. Owing to its inertia the fluid tends to pass onwards from the valves, and thus allows a momentary fall in pressure accompanied by a slight reflux of the blood and the sudden closure of the valves. These pressure changes cause a negative and a positive wave, which follow the wave of impulse.

We may conclude then that the dicrotic notch depends upon a negative centifrugal wave, caused by the sudden stoppage of the inflow and the momentary reflux of blood during the closure of the valve ; and the dicrotic crest is produced at the completion of their closure, when the sudden check, given to the reflux of the blood column by the valves, causes a positive centrifugal wave to follow the primary wave of the pulse.

The elasticity of the walls of the aorta by its resilient recoil no doubt accentuates the dicrotic notch and crest, and the subsequent indications of waves on the curve are altogether due to this cause.

The view that the reflux of blood and the closure of the valves produce the dicrotic wave is supported by the fact that the conditions which increase the dicrotism—viz. (1) sharp strong systole, (2) low arterial tension, and (3) perfect resiliency —promote the recoil and closure ; and, on the other hand, the conditions which interfere with the closure of the valves also diminish the dicrotic wave in the most marked degree, viz. (1) inefficiency of the aortic valves, and (2) a rigid calcareous condition of the arteries.

The amount of dicrotism, and therefore the form of the pulse, is greatly modified by the degree of tension of the arteries. When the tension is low the notch is deep. When high the notch is less, and the dicrotic crest may exceed in height the percussion wave. Such a curve seems to have a notch on its ascending part, and has been called *anacrotic*. This variation in the form of the curves is of clinical importance as a means of diagnosis, the anacrotic pulse usually depending on disease. It has been explained differently by various authorities.

It can be shown in an elastic tube, fitted with a suitable pump and sphygmographs, that when the outlet is closed a *positive* wave is reflected from the distal end back to the pump,

and when the outlet is opened, a *negative centripetal* wave is reflected. This fact assists in explaining the abnormal variations in the character of the pulse curve of the radial artery, where the equidistance of the derived arterioles enables the reflected waves to have considerable effect. When the arterioles are constricted (a condition corresponding to the closure of tube) a positive centripetal wave is reflected and is *added* to the pulse-wave so as to diminish the dicrotic notch, and give the curve known as characteristic of the "high tension" pulse, seen in Bright's disease. (Fig. 128, II.) On the other

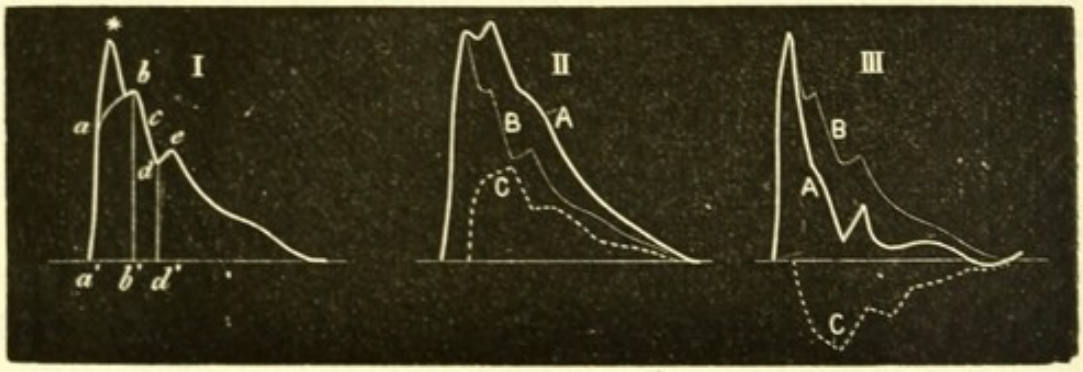


Fig. 128.

I. Scheme of Normal Pulse Curve: *a*, Entrance of ventricular stream into the aorta, the lever is jerked too high, reaching * ; *ab* shows real summit of waves ; *b*, point at which stream from ventricle ceases ; *c*, negative wave caused by sudden cessation of inflow and slight reflux of blood ; *d*, point of closure of aortic valves ; *e*, positive wave from valves (dicrotic wave). The time may be measured on abscissa at *a' b' d'*.

II. Scheme of High Tension Pulse Curve ; (constricted arterioles). **A** Curve of radial pulse, which is the resultant of *positive* reflected wave **C** added to the primary curve **B**.

III. Scheme of Low Tension Pulse Curve ; (dilated arterioles). **A**. Radial pulse curve, which is the resultant of the *negative* reflected wave **C** subtracted from the primary wave **B**. (After Grashey.)

hand, when the arterioles are widely dilated (corresponding to the open condition of the tube) a negative wave is reflected, and is *subtracted* from the force of the pulse-wave so as to exaggerate the dicrotic notch, and give the tracing characteristic of the "low tension" pulse seen in fever, &c. (Fig. 128, III.)

From comparisons of intracardiac with aortic pressures, it has been thought that the anacrotic pulse curve is formed when the increase of pressure within the aorta, caused by the systole, occurs gradually, owing either to prolonged, forcible systole, or very high pressure in the aorta. On the other hand when the peripheral resistance is small (low tension) the blood escapes more rapidly from the arteries, and the increase of pressure

caused by the systole soon attains its full height and rapidly begins to fall, giving the catacrotic pulse.

IV. Velocity of the Blood Current.

The velocity of the blood must not be confounded with the velocity of the pulse wave, which bears to it the same relation as the rapid surface waves on a river, do to the rate of the sluggish stream of water.

It has already been mentioned that the general bed of the blood increases from the aorta to the capillaries, and decreases from the capillaries to the vena cava. The branches of an artery, or tributaries of a vein, have collectively a larger sectional area than the vessel from which they spring, or to which they lead, respectively ; or, in other words, if we imagined the whole vascular system fused together into one tube it would form two somewhat irregular cones, one corresponding to the arteries and the other to the veins, with their bases placed at the capillaries and their apices at the heart. Between the two cones a still wider portion would represent the aggregate sectional area of the capillaries. (Fig. 117, p. 258.)

Since the same quantity of blood must pass through each section of these cones in a given time, the rate at which it flows must vary greatly in the different parts, being faster in proportion as the diameter of the part is narrower, in accordance with the well-known physical law that with the same *quantity* of liquid flowing, its *velocity* changes inversely with the square of the *diameter* of the tube $\left(V \propto \frac{q}{d^2}\right)$. Thus, the mean velocity of the flow in the arteries becomes slower as the capillaries are approached, and in the wide bed of the latter the rate of the current is reduced to the minimum. In the small veins the rate is slower than in the larger trunks, but on the venous side its rapidity never reaches that of the aorta, where it may be said to move at least twice as quickly as in the vena cava.

The following table may be useful in giving a general idea of the average velocity in different parts of the circulation :—

Near valves of aorta—while the ventricles are contracting it reaches	1200	mm. per sec.
Descending aorta	300—600	„ „
Carotid	205—357	„ „

Radial	100 mm. per sec.
Metatarsal	57 ,,
Arterioles	50 ,,
Capillaries	0·5 ,,
Venous radicles	25 ,,
Small veins on dorsum of hand	50 ,,
Venæ Cavæ	200 ,,

In the aorta, near the valves, the rapidity of the blood current varies with the flow through the aortic orifice, which is intermittent, and this variation is more or less communicated to the neighbouring arteries in the form of an increase of rapidity coincident with the beat of the arterial pulse. The variation in the rate of the blood-flow which is caused by the heart-beat, diminishes with the force of the pulse as the smaller arteries are approached, and finally ceases completely in the capillaries where under ordinary circumstances the flow is perfectly continuous. In the first part of the aorta the velocity of the blood-flow is reduced to nil after each ventricular beat, while in the capillaries no change is perceived. Between these two extremes, gradations which follow the same rules as the pulse may be found.

The general mean velocity varies directly with the blood-pressure, which bears a generally inverse relation to the calibre of the arteries. The velocity in any one artery, and its branches, will vary with the calibre of those vessels, which are constantly undergoing local changes in size.

Generally speaking, quick heart-beats increase the velocity of the stream, but no definite or invariable relation exists between the rate of the heart-beat and of the current of the blood. The vasomotor influences have, no doubt, much more effect than the heart-beat on the rate of the stream in the smaller vessels the calibre of which they control.

In looking at the blood passing through the small vessels of a transparent tissue, such as the frog's tongue or web, it appears that different parts of the column of fluid move with different velocities. Down the centre of the stream the red corpuscles are seen coursing rapidly, while between the central part and the vessel wall, on each side, a pale line of plasma can be recognised, which seems to flow more slowly and to carry with it only a few white corpuscles.

In the veins the velocity varies greatly with a variety of circumstances which have little or no effect on the arterial flow.

Thus, the position of the body or limb, the activity of the neighbouring muscles, and the respiratory movements alter it, but as a general rule the flow in the veins is pretty steady, there being no pulsation or corresponding variation of velocity. In the large vessels the onward flow is affected by the contraction of the auricles. During the auricular systole the veins cannot empty themselves, and therefore there is a slight check to the onward flow, and the velocity of the current is correspondingly reduced. In abnormal cases where the auricles are dilated and distended with blood this may cause a definite pulsation, which becomes visible in the great veins of the neck.

V. Work done by the Heart.

The amount of work done by any form of engine may be expressed as so many kilogrammetres per hour ; that is to say, the number of kilogrammes it could raise to the height of one metre in that time.

The left ventrical moves with each systole about 0·188 (Volkman) kilogrammes of fluid against an arterial pressure corresponding to 3·21 (Donders) metres height of blood, *i.e.*, 0·188 × 3·21 = 0·604 kilogrammetres for each systole. This at 75 per minute for 24 hours would be—

$$0{\cdot}604 \times 75 \times 60 \times 24 = 65{,}230 \text{ kilogrammetres.}$$

The right ventricle does about one-third as much work as the left, making a total of 86,970 kilogrammetres for the ventricles. Or, in other words, the heart of a man weighing twelve stone does as much work in twenty-four hours as would be required to lift his body 1248 yards into the air, *i.e.*, nearly ten times as high as the steeple of St. Paul's Cathedral.

Controlling Mechanisms of the Blood-Vessels.

Vaso-Motor Nerves.—That the arteries possessed elastic resiliency and vital *contractility*, which regulated the amount of blood flowing to any given part, was observed by John Hunter in studying inflammation.

The muscle cells have long since been clearly demonstrated in the middle coats of the arteries, but nothing was known of the nervous channels which bore the stimulus to the vessels, or

the nerve centres which regulated their contraction, until comparatively recent times.

The first definite knowledge concerning special nerves for the control of the muscular wall of the vessels is due to Claude Bernard. He showed that cutting the sympathetic nerve in the neck, was followed by an increase in temperature of that side of the head, and great dilatation of the arteries.

It was further observed that stimulation of the superior ganglion of the sympathetic brought about an opposite result, namely, a fall in temperature and contraction of the vessels on the side at which the stimulus was applied. If the stimulus was increased, the vessels contracted more than the normal, but on cessation of the stimulus they became dilated above the normal, and the temperature again rose ; the effects of the stimulus gradually passed off. From this it was concluded that the sympathetic in the neck contained *constrictor fibres* which conveyed impulses causing habitual *tonic contraction* of the vessel wall, corresponding to what was already recognised as *arterial tone*. On section of the nerve the tonic contraction disappeared, but on gentle stimulation it reappeared, and if more strongly stimulated an excessive contraction set in causing occlusion of many of the vessels.

Subsequent experiments have shown that all the vessels are supplied with similar vaso-motor (constrictor) nerves, section of which causes dilatation, while stimulation causes contraction of the vessels in the territory presided over by the stimulated nerve.

It has also been shown that the vaso-constrictor nerves for all parts of the body come from the cerebro-spinal axis, passing out from the spinal cord as extremely fine medullated fibres (white rami communicantes) by the anterior roots of all the spinal nerves between the 2nd thoracic and 2nd lumbar. They join the sympathetic, which may be regarded as a chain of vaso-motor ganglia, and are distributed to the vessels either as special nerves, branches of the sympathetic, as the splanchnics, or with the general peripheral nerve trunks.

Although stimulation of almost any nerve causes vascular contraction, it has been shown that in some parts stimulation gives rise to an opposite result, viz., vascular dilatation. Thus, stimulation of the chorda tympani or nervi erigentes is followed by dilatation of the arterioles of the submaxillary gland and penis respectively. This dilatation is caused by the nerve-impulses checking the normal contraction by inhibiting the

activity of the vascular muscles. It is believed that all arterioles may be influenced by such fibres, but the greater power of the constrictor fibres in most nerves prevents their demonstration.

These *vaso-dilator* fibres also come from the central nervous system, but those whose course is known, travel by quite a different route from that traversed by the vaso-constrictor fibres, and are not all connected with the sympathetic ganglia. Those coming from the spinal accessory pass out of the cranium with the vagus nerve, others leave the vertebral canal with the 2nd and 3rd sacral nerves. No vaso-inhibitory fibres have been found to pass by the other spinal roots.

VASO-MOTOR CENTRES.—The nerve cells which govern the majority of the vaso-motor channels, lie in the upper part of the medulla oblongata, in the floor of the fourth ventricle. This is proved by two facts : 1st, most of the brain may be removed without diminishing the arterial tone ; and 2nd, if the spinal cord be cut below the medulla (artificial respiration, of course, being kept up) the mean blood-pressure is found to fall immediately, almost to the level of the atmospheric pressure, owing to the relaxation of the smaller arteries consequent on the paralysis of their muscular coat.

The changes in the capillary circulation caused by vascular paralysis can be seen in the web of a frog, in which the medulla has been destroyed (pithed), while the circulation is being studied. The small arteries dilate and the pulse becomes apparent in the capillaries, and even in the veins.

It seems probable that in the medulla oblongata a *vaso-motor centre* exists, which can regulate the contraction of all the vessels, and keep them constantly more or less contracted. This slight general vascular constriction is spoken of as the arterial *tone*. The existence of such a centre in the medulla, and of nerve channels in the cord leading from it, is made certain by the fact that if a gentle stimulus be applied to a certain part of the medulla, or just below it, simultaneous general vascular constriction sets in, as indicated by a great and sudden rise in the blood-pressure.

Pressor Influences.—The action of the vaso-motor centre can be excited, the tone of the vessels increased, and the pressure raised, either by (1) direct or (2) reflex excitation. *Directly*, if the blood flowing through the medulla contain too little oxygen or too much waste products it stimulates the centre and

the blood pressure rises. This may be seen by temporarily suspending artificial respiration, during an experiment on blood pressure, when the pressure rises considerably. *Reflexly* the activity of the vaso motor centre can be increased by (1) the stimulation of any large sensory nerve, or (2) by sudden emotion (*fear*).

Depressor Influences.—The tone of the arteries may be diminished by inhibiting the activity of the vaso-motor centres by the stimulation of a certain afferent nerve, the anatomy of which has been made out in the rabbit, and some other animals, and probably has its analogue in man. It passes from the inner surface of the heart to the vaso-motor centre in the medulla. The effect of stimulation of this nerve in lowering the blood-pressure is so great that it is called the *depressor nerve*. Some emotions (*shame*) may also reduce the activity of the centre, as seen in blushing, which is simply dilatation of the facial vessels.

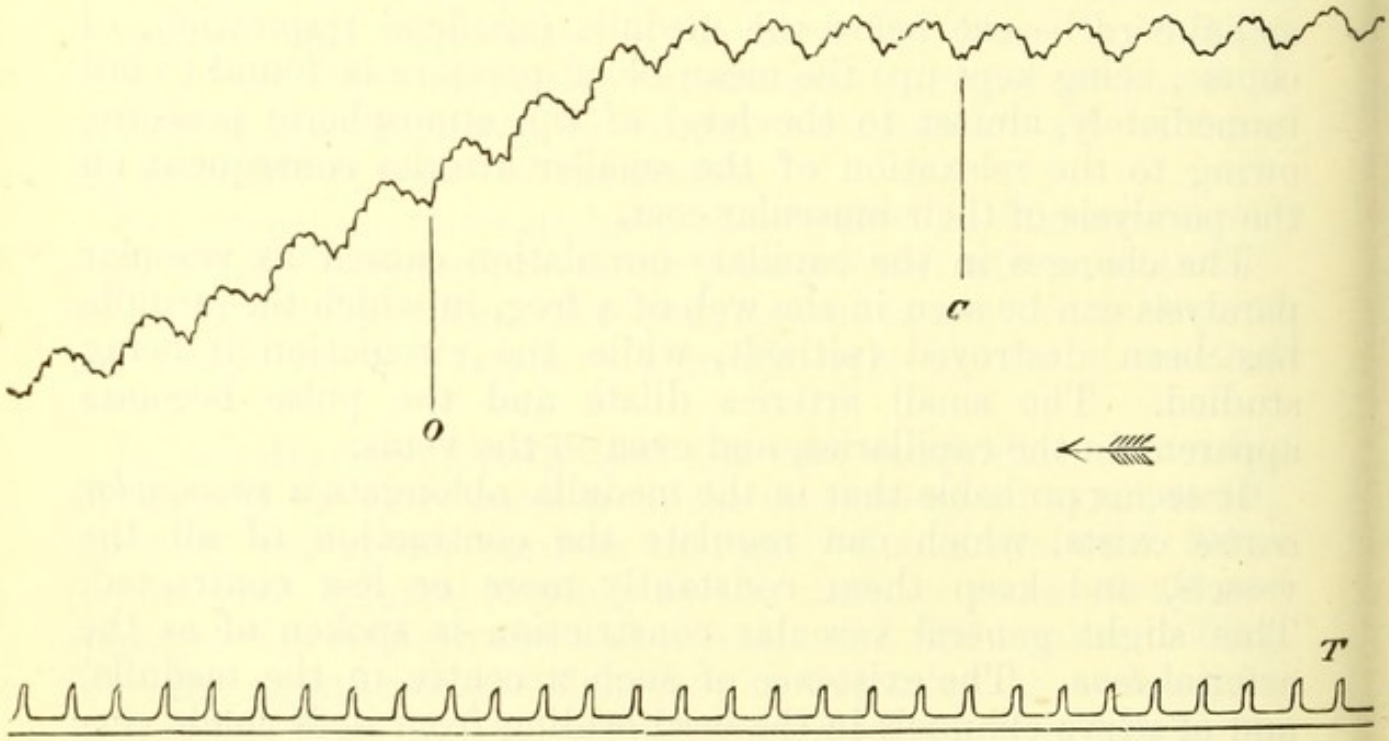


Fig. 129.—Kymographic tracing showing the effect on the blood- pressure curve of stimulating the central end of the depressor nerve in the rabbit. The recording surface moving from left to right. (c) Commencement and (o) cessation of stimulation. There is considerable delay (latency) in both the production and cessation of the effect. (T) Marks the rate at which the recording surface moves, and the line below is the base line. (Foster.)

Subsidiary Centres.—Besides this chief vaso-motor centre it is probable that in the higher animals, as certainly is the case

in the frog, other centres are distributed throughout the spinal cord which are able to take the place of the great primary centre. After the spinal cord has been cut high up, the hinder extremities more or less recover their vaso-motor power in a few days, and destruction of the lower part of the spinal cord causes renewed vascular dilatation. In frogs this recovery takes place rapidly, the centres being less confined to the medulla than is the case in the more highly organised animals, but in the rabbit and dog it has been observed to occur more slowly.

Regulation of the Distribution of the Blood.—Besides keeping up the normal blood pressure, the arterial muscles have the equally important function of regulating the amount of blood supplied to various organs at different times. Both *vaso-motor* and *dilator* impulses are probably employed for this purpose, but more particularly the latter.

The various experimental results recently obtained show that the vascular nerve mechanisms are very complex. The supposition of some such arrangements as the following may help the student.

1. The blood-vessels have muscular elements which, though commonly controlled by nerves, are capable of automatic activity. A supply of arterial blood is sufficient stimulus for their moderate action, and mechanical or other local stimulus is capable of exciting increased constriction. We know that such automatic contractility exists in the heart of many of the lower animals, and we have no reason to doubt its existence in mammals. Moreover, such a view obviates the necessity of supposing that local nerve elements exist, which cannot be recognised morphologically.

2. In the medulla oblongata there exist nerve cells which exert a constant influence over the activity of the vascular muscles. These groups of nerve cells, which compose the *vascular nerve centres*, may be divided into *motor* and *inhibitory*. From these centres impulses of two distinct kinds emanate, the one increasing the action of the contractile elements, and the other diminishing it. They are intimately connected with the centres which preside over the functional activity of the various viscera, and are also closely related to the nerves coming from all parts of the circulatory apparatus.

3. Direct communication between these *vaso-motor* and *vaso-inhibitory* centres and the blood-vessels is kept up by means of

efferent nerve-channels, some bearing exciting (vaso-constrictor) and others inhibitory (vaso-dilator) impulses.

4. The activity of the contractile elements of any given vascular area may be altered by influences from different sources. (*a.*) Local influences are brought but little into play, but, if the part be cut off from the nervous centres, they are capable of controlling the local blood supply by changing the degree of local arterial constriction. (*β.*) Central influences from the medulla are habitually in action, affecting all the vessels and keeping up the vascular tone. These impulses are variously modified by changes occurring in distant parts of the circulatory apparatus, and act as a general regulating mechanism. (*γ.*) Special influences, which are associated with the functions of the different parts and organs, are only called into operation during the performance of the function, whatever it may be. These impulses are probably conveyed by the same nerves as excite the various forms of functional activity.

These three modes of regulation have different powers in different parts, and thus we find that section, or stimulation of certain nerves, gives vaso-motor effects which appear contradictory.

Section of a sensory nerve causes temporary vaso-motor paralysis, owing to the chronic constrictor influence being cut off. Stimulation of the peripheral stump causes vaso-constriction from excitation of the fibres bearing these impulses.

The stimulation of a motor nerve causes an increase in the flow of blood through the muscle, *i.e.*, is associated with a vaso-dilator effect, probably dependent on the inhibitory influence of certain efferent fibres which check the local vascular agencies.

Thus we must suppose that there exist local agents under the control of the medullary centres, and that there are distinct sets of efferent, exciting and inhibitory fibres passing between the centre and periphery. One set of fibres lies in the ordinary functional nerve of the part, the other in the sympathetic, which to a great extent runs along the vessels themselves, and there forms intricate networks.

As far as we know anatomically there are no local agents other than the muscles in the wall of the vessels. Since the impulses from the centres which can stimulate or inhibit the activity of the local agents travel by different fibres, all the observed phenomena may be explained without supposing local nerve centres to exist.

CHAPTER XVI.

RESPIRATION.

The blood undergoes a series of modifications, and is constantly being altered as it passes from one part or organ to another.

It has already been seen that a quantity of nutrient material is taken up by the blood on its way through the capillaries of the alimentary tract, and a stream of lymph and chyle is poured into it when it reaches the great venous trunks ; so that from two sources the blood is materially increased in quantity. The most essential change that takes place in the circulatory fluid is the respiratory. All the blood passes through the lungs, in order to insure the elimination of the carbonic acid acquired in the general systemic capillaries, and the re-charging of the red corpuscles with oxygen.

These gas interchanges will form the subject-matter of the present chapter ; and the more especial modifications which the blood undergoes in the ductless glands, the spleen, the liver, &c., as well as in the kidneys and other excretory glands, will be considered subsequently.

As has already been pointed out (Chapter V.), an animal during its life may be said to use the substances supplied to it in food as fuel, and thus to acquire the energy which is bound up in them ; for the activities of the various tissues are really combustions, being as a rule associated with an oxidisation of some of the carbon compounds, so as to produce carbon dioxide and water. In order that the structures may be able to undergo this change they must have a ready supply of oxygen constantly at hand, and, moreover, the carbon dioxide which is formed in the process must be removed. The regular income of oxygen and the regular discharge of carbon dioxide are the first essentials to life ; hence we find in almost all animals special arrangements, known as the respiratory apparatus, by

means of which these gases can find their way to and from the tissues and external air respectively.

Here, as in the case of the nutritive materials, the blood acts as the carrier. The pulmonary half of the circulation is devoted to the gas interchange between the blood and the atmosphere, and is spoken of as *external respiration*. The gas interchange between the blood and the tissues which takes place through the walls of the general systemic capillaries, is spoken of as the *internal* or *tissue respiration*.

In mammalia the pulmonary apparatus is so far perfected that all the necessary gas interchange can be carried on by the lungs, and the respiratory influence of the external skin or the mucous passages may be regarded as insignificant. But it should be remembered that, whenever the blood is in close relation to oxygen, as in the case of swallowed air, the oxygen is soon absorbed by the blood.

In some of the lower animals the cutaneous surface aids very materially in respiration; for example, frogs can live by this cutaneous respiration alone for an almost indefinite time.

The change in the lungs consists in (1) oxygen being taken from the atmospheric air* by the blood and (2) carbon dioxide being given off from the blood to the air. In the capillaries, on the other hand, the blood takes the carbon dioxide from the tissues, and yields to them a great portion of its oxygen.

I. Respiratory Mechanism in Lower Animals.

In the lowest class of animals (*e.g.*, amœba), we find no special organs for the purpose of respiration, the gas interchange being sufficiently provided for by the exposure of the general surface of their bodies to the medium in which they live, namely, water.

All higher animals have some special apparatus for the purpose of respiration. This apparatus has always the same essential object, that of exposing their tissues to a medium containing oxygen, and of removing the carbonic acid gas.

* The composition of the atmosphere is everywhere remarkably constant, in spite of its oxygen being used up by living beings. It consists of—

Oxygen	21	vols. per cent.
Nitrogen	79	,, ,,
Carbonic acid gas (variable)	·04	,, ,,
Moisture (variable)	8	,, ,,

In some of the invertebrate animals the medium containing oxygen is distributed throughout the tissues of the animal by a system of tubes. Thus in the Echinodermata a water vascular system exists, which can carry on the function of respiration. An analogous method of distribution of gaseous oxygen takes place in insecta, in which delicately branching open tubes (tracheæ) distribute air to the tissues of the animal's body.

When more active changes occur in the tissues there is always a perfect blood vascular system. The blood is invariably used as the distributing and collecting agent of the gases in the tissues, and by flowing through some special organ exposed to the surrounding medium it ensures the gas-interchange between the body and the outer world. These organs are formed on two general types ; (1) external vascular fringes ; and (2) internal vascular sacs.

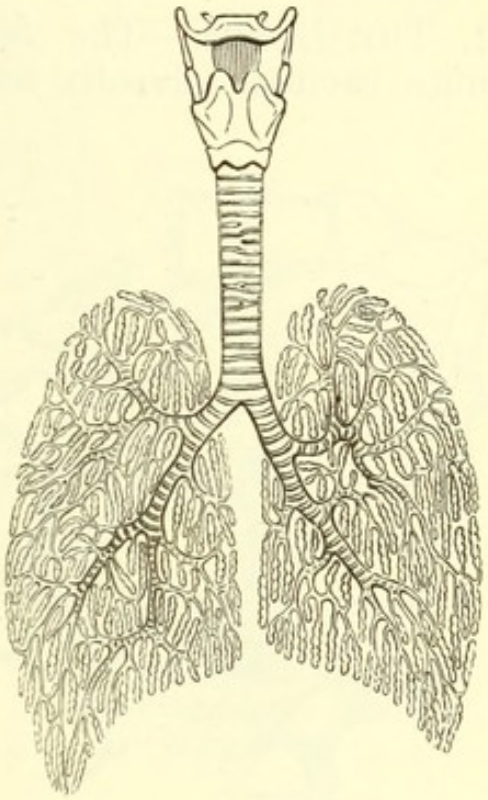


Fig. 130.—Diagram of the Respiratory Organs. The windpipe leading down from the larynx is seen to branch into two large bronchi, which subdivide after they enter their respective lungs.

Animals living in water have commonly the external fringe arrangement (gills) whilst those living in air have sacs (lungs). Some animals (Batrachia) have gills in the early stages of their life, and lungs when they are more fully developed. In frogs and serpents the lungs are simple sacs, with the inner surface increased by folds of the lining membrane, which gives it a honeycomb appearance ; into each sac opens one of the divisions of the air-tube. In crocodiles the air-tubes divide into several branches which open into a series of anfractuous vascular recesses communicating one with another.

In birds wide bronchial tubes pass through the lung tissue to reach large air cavities. The walls of the tubes are studded with the openings of innumerable air-cells, lined with capillary blood-vessels. The terminal air cavities are not vascular as in the mammalian lung.

II. Structure of the Lung and Air-Passages.

The respiratory apparatus of mammals consists of (1) vascular sacs filled with air, known as the lung alveoli ; (2) channels by which these sacs are ventilated—the air-passages ; (3) motor arrangements, which carry on the ventilation of the lungs—the thorax.

1. The Lungs.—The *lungs* are made up of innumerable minute cavities (alveoli), with thin septa springing from the inner surface so as to divide the space into several compartments or air-cells. Each of these cavities forms a dilatation on the terminal twig of a branching bronchus, and may be regarded as an elementary lung. The aggregate of these cavities, and the branches of the air-passages and vessels distributed to them, make up the structure of the lung.

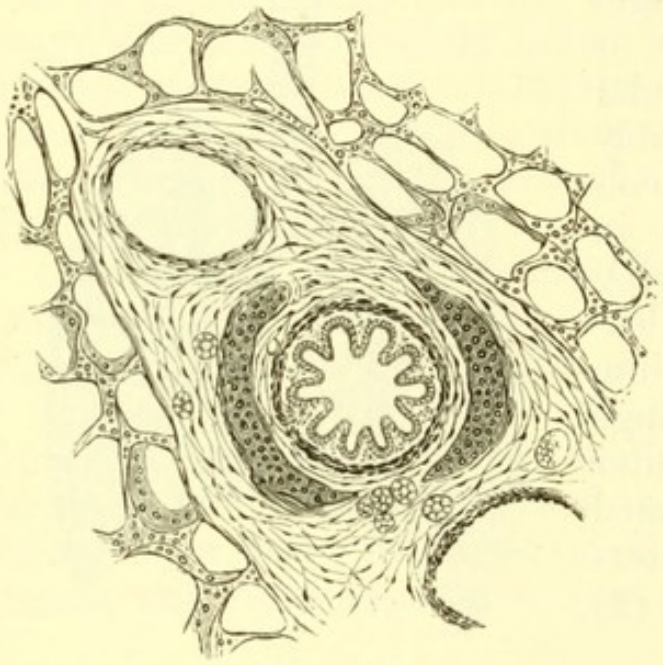


Fig. 131.—Section of small portion of Lung in which are seen a bronchial tube with its plicated lining mucous membrane in the centre, and the large blood-vessels at the sides cut across. Loose areolar tissue and numerous lymphatics surround the large vessels and separate them from the lung tissue.

The walls of the cavities are formed chiefly of fine elastic fibres, and the surface is lined with exceptionally delicate and thin celled epithelium. Supported in the delicate framework of elastic and connective tissue is the remarkably close-set network of capillaries, in which the blood is exposed to the air. The delicate wall of the vessel, and the thin body of the epithelial lining cell are the only structures interposed between the blood and the air.

Pleura.—The external surface of the lungs is invested by a serous membrane—the pleura, which is reflected to the wall of the thorax from the roots of the lungs, and completely lines the cavity in which they lie. Thus the lungs are only attached to the thorax where the air-passages and great vessels enter, the rest of their surface being able to move over the inner surface

of the thorax, and to retract from the chest-wall if air be admitted into the pleural sac.

2. AIR-PASSAGES.—The *bronchi* are kept permanently open

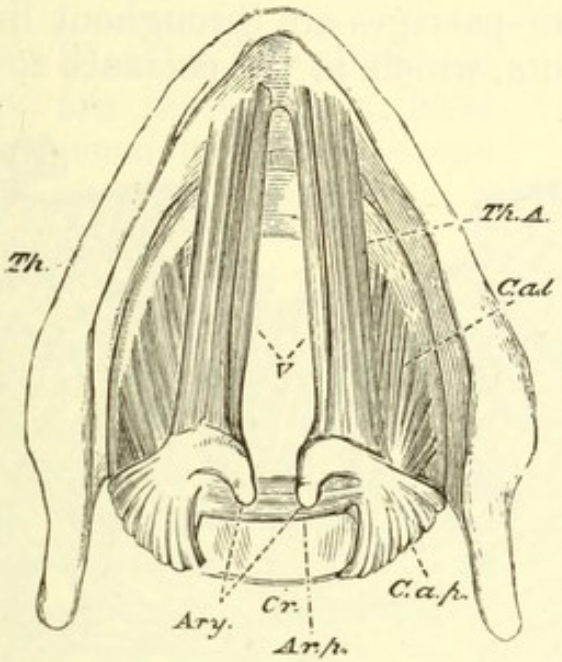


Fig. 132.—Muscles of Larynx, viewed from above.

Th. Thyroid cartilage.
Cr. Cricoid cartilage.
V. Edges of the vocal cords.
Ary. Arytenoid cartilages.
Th.A. Thyro-arytenoid muscle.
c.a.l. Lateral crico-arytenoid muscle.
c.a.p. Posterior crico-arytenoid muscle.
Ar. p. Posterior arytenoid muscle.

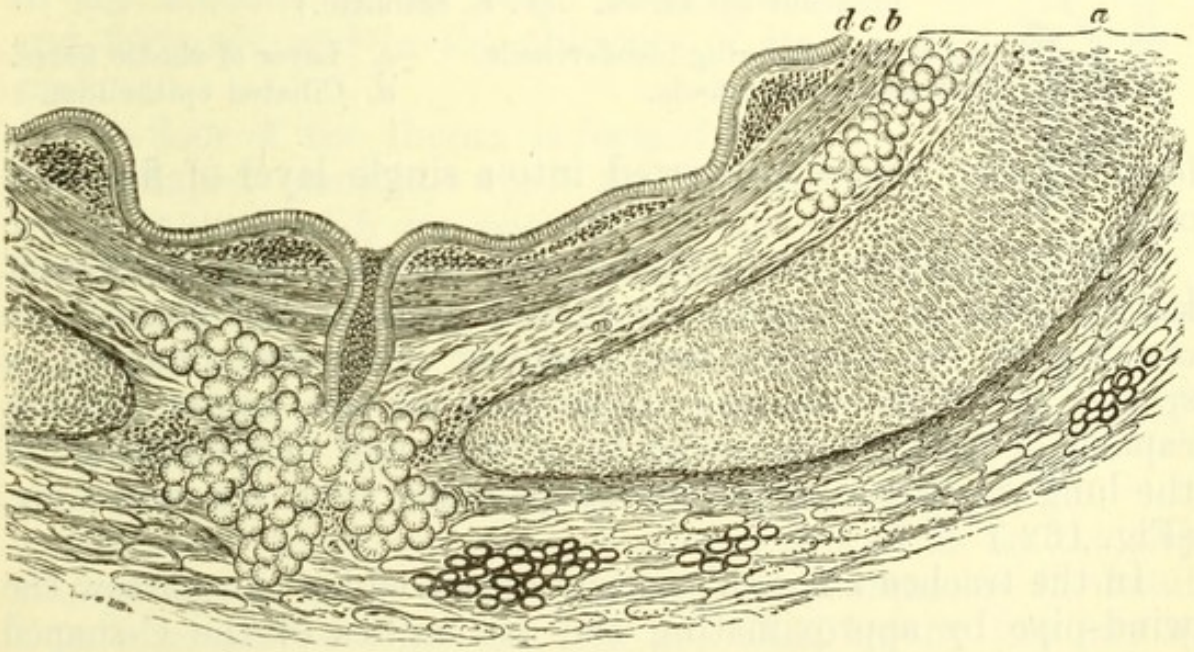


Fig. 133.—Transverse section of part of the wall of a medium-sized bronchial tube. × 30. (F. E. Schultze.)

a. Fibrous layer containing plates of cartilage, glands, &c.
b. Coat composed of unstriated muscle. *c*. Elastic sub-epithelial layer.
d. Columnar ciliated epithelium.

during ordinary breathing by the elasticity of their tissues. The trachea and bronchi have special cartilaginous springs for the purpose. These are closely attached to the fibro-elastic tissues which complete the general foundation of the walls of the tubes. The air-passages are throughout lined with ciliated columnar epithelium, which, at the entrance to the infundibula,

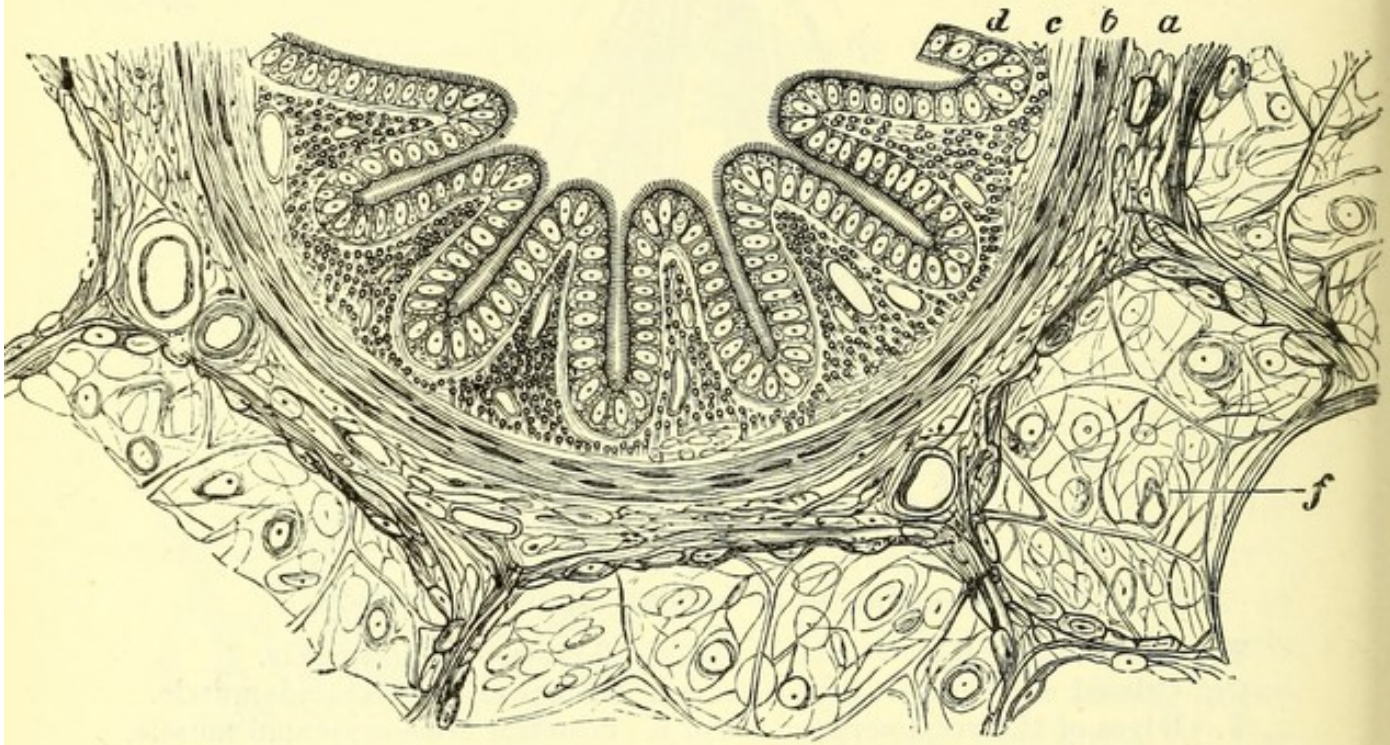


Fig. 134.—Section of a portion of Lung Tissue, showing part of a very small bronchus cut across. (F. E. Schultze.)

a. Fibrous layer containing blood-vessels.
b. Layer of unstriated muscle.
c. Layer of elastic fibres.
d. Ciliated epithelium.

loses its cilia, and is converted into a single layer of flattened cells.

The air-passages are supplied with muscle-tissue of different kinds. Besides the ordinary striated muscles that control the opening of the anterior and posterior nares and pharynx, a special set surrounds the upper part of the larynx, and is capable of completely closing the glottis, and thus shutting off the lung cavities, and proper air-passages from the outer air. (Fig. 132.)

In the trachea a special muscle exists which can narrow the wind-pipe by approximating the extremities of the C-shaped springs that normally preserve its patency.

In the bronchial tubes a large quantity of smooth muscle-cells exist, for the most part arranged as a circular coat, which is best developed in the small tubes (fig. 134, *b*). As we pass

from the large to the smaller bronchi the walls become thinner and less rigid, and the cartilaginous plates and fibrous tissue gradually diminish, while on the other hand the muscular and elastic elements become relatively more abundant.

3. The Chest Wall.—The *thorax*, in which the lungs are placed, is a bony framework, the dimensions of which can be altered by the muscles which close in and complete the cavity.

The framework is a rounded blunt cone composed of a set of bony hoops, the ribs, attached by joints to a bent pliable pillar, the vertebral column, and held together in front by the sternum, to which they are attached by resilient cartilaginous springs. The ribs slope downwards and forwards, and are more or less twisted on themselves about the middle of the shaft.

The first pair of ribs, which encircles the apex of the thoracic cone, forms part of a short flattened hoop. It slopes downwards in front to reach the sternum. Each succeeding rib, from above, increases in the amount of its slope downwards and forwards, and in the obliquity of its shaft.

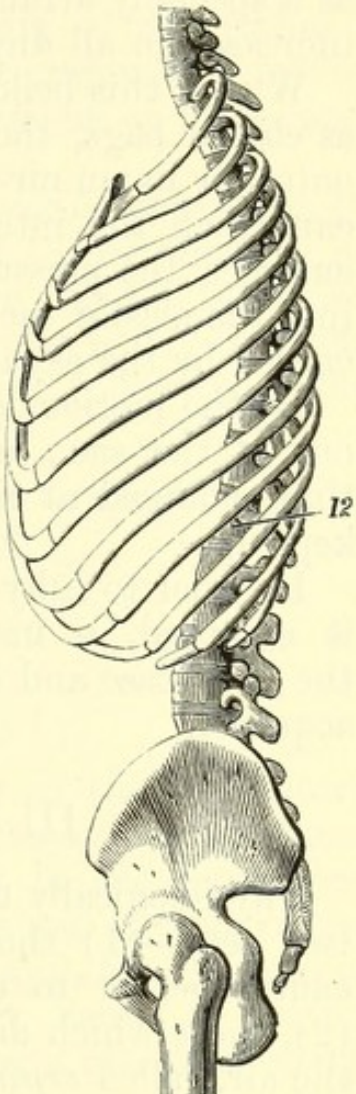


Fig. 135.—Drawing of the lateral view of Thorax in the position of gentle inspiration, showing the downward slope of the ribs.

The floor of the thorax is formed by a dome-shaped muscle, the diaphragm, which bulges with its convex side into the cavity, and separates the thoracic from the abdominal viscera. The upper outlet is closed around the trachea by several muscles, which pass obliquely upwards from the upper part of the thorax to the cervical vertebræ, and hold that part of the chest in position. These muscles can elevate as well as fix the first rib, as will be seen when speaking of the muscles in detail. The intervals between the ribs are filled up by two sets of muscular fibres, which cross one another at right angles, and are attached to the margins of the neighbouring ribs.

The base of the thorax is connected by a number of strong muscles with the pelvis and the spine, whence they pass upwards

to the lower ribs. The anterior muscles pull down the sternum and anterior part of the ribs. The posterior fix and extend the last rib.

From a mechanical point of view the thorax may be regarded as a specially arranged bellows, the dimensions of which can be increased in all directions.

Within this bellows are the lungs, which may be looked upon as elastic bags, the interiors of which communicate with the outer air by an air-pipe, the only way by which the atmosphere can reach the interior of the bellows. When the framework enlarges, the pressure of the atmosphere forces a stream of air into the elastic sac, so as to distend it, and thus fill the space caused by the expansion of the framework.

By the motions of the framework a stream of air passes in or out of the sac; a small quantity of the air in the bronchi is thus changed at each breath, and a certain standard of purity kept up.

In order to fully understand the motions by which the thorax is enlarged, a more detailed knowledge of the anatomy of the bony case and its muscles than can be given here must be acquired.

III. Respiratory Movements.

Physiologically the movements of the thorax are divided into two sets—(1) those which enlarge the thoracic cavity, and cause the air to rush into the lungs, called *inspiration;* and (2), those which diminish the size of the thorax and force out the air, called *expiration.*

No action of life is more familiar than the rhythmical movements of respiration. The slow quiet rise and fall of the chest and abdomen are the signs most commonly sought as indicative of life; for everyone knows that constant ventilation must go on in order that the blood may readily obtain the necessary amount of oxygen, and get rid of carbonic acid gas, the ordinary diffusion that takes place in the motionless chest being quite insufficient to remove the heavy carbonic acid gas from the lungs.

The rhythm of the respiratory movements may be represented graphically by recording the changes in the diameter or circumference of the thorax, the movements of the diaphragm, or the variations of the pressure in the air-passages. These methods, though not quite reliable, give curves of a similar character.

The rate of the respiratory movements is up to a certain point under voluntary control, and may be varied by the will, or stopped, as when one holds one's breath.

The voluntary control of the respiratory movements is, however, limited, for if we hold our breath for any length of time, a moment soon arrives when the "necessity of respiration" overcomes the strongest will. The usual respiratory movements are carried on without our being conscious of them, and are strictly involuntary.

The rate of the respiratory movements varies according to circumstances, being in an adult man about 18 per minute; in most of the lower animals it is much more rapid. It varies with age, being very rapid at birth, decreasing slowly to about 30, and slightly rising towards old age. The following Table (Quetelet) illustrates this :—

A new-born infant	. .	respires 44	times per minute.
5 years	. . .	„ 26	„ „
15—20 „	. . .	„ 20	„ „
20—25 „	. . .	„ 18·7	„ „
25—30 „	. . .	„ 16·	„ „
30—60 „	. . .	„ 18·1	„ „

Muscular exercise increases the rapidity of the respiratory movements, and, consequently, the effort of standing produces a more frequent respiration than is found in the recumbent posture. Emotions variously affect the rate and rhythm of the inspiration and expiration (*e.g.*, sighing); and, finally, morbid conditions, implicating the lungs, usually cause a greater frequency of respiration, sometimes attaining a rate of as many as 60—70 respirations per minute.

Inspiration.

The thorax is enlarged in all directions during inspiration, the motion being usually referred to the vertical, transverse, and antero-posterior diameters respectively.

The vertical diameter is increased by the descent of the lateral portions of the diaphragm, and the slight elevation of the parts about the apex.

The lateral diameter is widened by the side-droop of the ribs being lessened; each rib is rotated upwards upon the line uniting its extremities, and thus its lateral part is moved upward and outward.

The antero-posterior diameter is enlarged by the general elevation of the ribs and sternum, the anterior extremities of the ribs being drawn up from their general downward incline, push the sternum forwards.

The movements of the diaphragm depress the abdominal viscera lying beneath it, and thereby distend the elastic abdominal wall and compress the gases contained in the intestines. Thus the diaphragmatic movements cause a rhythmical heaving of the abdomen. Respiration depending chiefly on the action of this one muscle is therefore spoken of as *abdominal respiration*. On the other hand, when the ribs are the chief cause of expansion of the upper parts of the chest, it is called *thoracic or costal respiration*.

These two types of respiratory movements may be imitated voluntarily, and are variously combined in different individuals during ordinary respiration, and in the same individual under different circumstances.

In men the general character of the ordinary quiet respiration is abdominal, the movement of the thorax being insignificant in comparison with that of the abdomen.

In women the reverse is the case; the abdominal movements are slight when compared with those of the upper part of the thorax. This difference is only well marked during quiet unconscious breathing; any forced or voluntary respiratory effort changes the typical character of man's breathing, and the costal movements become more prominent. In a forced deep inspiration the upper part of the chest shows the greatest increase in the antero-posterior diameter in both sexes.

This difference in type between male and female respiratory movements has been ascribed to different causes. The most common of these is the change brought about by the costume ordinarily adopted by females. This can hardly be an adequate explanation of the phenomenon, for we find the same type existing when the tight garments are removed, and it is apparent in those who have never been constricted by tight clothing, and even in cases where no clothing has been used, as amongst the inhabitants of hot countries; so that, though the corset may induce an exaggeration of the costal respiration, by constricting the lower ribs and interfering with the action of the diaphragm, it does not seem sufficiently to account for the normal costal type of breathing found in women.

The occasional distension of the abdomen during pregnancy has also been assigned as a cause of the female type of breath-

ing, but it is very unlikely that pregnancy is the sole agency in producing it, since in childhood the costal type is marked in both sexes. That this type of breathing should be transmitted more markedly to females from our female ancestors is however quite possible. It is probable that the abdominal breathing of the male is also increased by hereditary transmission, but is originally due to the gradual increase in the development of the muscles of the upper extremities in males, causing a greater fixedness of the upper ribs from which they take origin.

Muscles of Inspiration.—The act of inspiration is not performed by any single muscle; indeed, even the most gentle and quiet inspiration requires the co-ordinated action of many sets of muscles. Most of the muscles have other duties to perform besides helping to produce respiratory movements.

The following are *inspiratory* in function:—

1. The Diaphragm with its accessory quadratus lumborum, fixing its origin from the last rib.
2. The Levatores costarum (including the scaleni) with their accessory intercostals, acting chiefly as regulators.
3. The Serratus posticus superior and the deep spinal muscles.

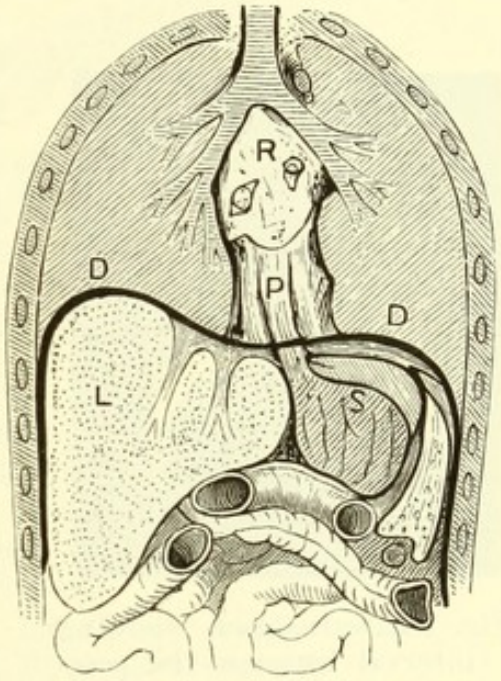


Fig. 136.—Diagram of a section made vertically from side to side through the thoracic and part of the abdominal cavities to show the position of the diaphragm, which is indicated by the dark line (D D) placed on the parts of the muscle that descend in inspiration.

P. Pericardial cavity.
L. Liver.
S. Stomach.
R. Roots of lungs cut through.

The Diaphragm is the most important inspiratory muscle. It is the only one which unaided can keep up the necessary thoracic ventilation, and in injury of the spinal cord, owing to its isolated nervous supply, the diaphragm may be called upon to do all the inspiratory work.

During ordinary quiet breathing in the male it does the greater share of inspiration.

When not in action, the edges of the muscular sheets of the diaphragm lies in direct contact with the inner surface of the

lower costal part of the thoracic wall, and the other (D) is higher than the central tendon which forms the floor of the pericardium, and is fixed in one position. During inspiration these lateral parts are separated from the ribs and drawn below the level of the central tendon by the contraction of the muscular fibres. The separation is aided by the abduction of the floating ribs, which is accomplished by the quadratus lumborum and the deep dorsal muscles.

In order that the diaphragm may act to the best advantage, it is necessary that its attachments be fixed by the other muscles; for when the quadratus lumborum, levatores and other fixing muscles are not acting, the lower floating ribs are drawn in by the diaphragm, and the power of that muscle is much diminished by the approximation of its attachments. This may be seen in spinal injuries when the inspiration is carried on by the diaphragm alone. In these cases a circular furrow marks the line of attachment of the muscle to the lower ribs and their cartilages, which are drawn inwards during each inspiration, the breathing being of course purely abdominal in type.

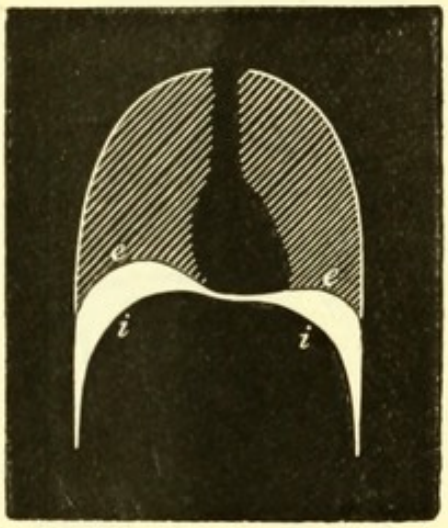


Fig. 137.—Diagram showing interval between the position of the diaphragm in expiration (*e*, *e*) and inspiration (*i*, *i*). The increase in capacity is shown by the white areas.

The *Quadratus Lumborum*, which passes from the pelvis to the last rib, has, besides the action in aid of the diaphragm just mentioned, the power of drawing down the lower outlet of the thorax, in which it is helped by other abdominal and dorsal muscles. In this action it may be regarded as the antagonist of the next group.

The *Scaleni muscles*, which pass down from the lateral aspects of the cervical vertebræ to the first two ribs, which they raise so as to draw up the upper outlet of the thorax. The quadratus and scaleni muscles thus act upon the thorax in the same way as the hands in extending a concertina.

The *Levatores Costarum* are small muscles, but on account of their number, their aggregate force is much greater than is commonly thought. They are short, thick muscles, which pass obliquely downwards and outwards from the transverse pro-

cesses of the dorsal vertebræ to the angle of the ribs. Their only action is to raise the angle of the ribs, and thus diminish their anterior and lateral downward slopes; by so doing they increase the intervals between the ribs and enlarge the lateral and the antero-posterior diameters of the chest. Thus they are purely muscles of inspiration, and probably, acting with the diaphragm and the scaleni, are the chief workers in ordinary breathing.

The *Intercostals* produce various effects on the ribs according to the different sets of muscles with which they act in association. They never act alone, and it is therefore idle to try to ascribe to them any constant specific inspiratory or expiratory action. Generally speaking, the intercostals approximate the ribs, and by this action they stiffen the thoracic wall and help to elevate the thorax when its upper part is fixed, or, when its lower part is fixed, to depress it.

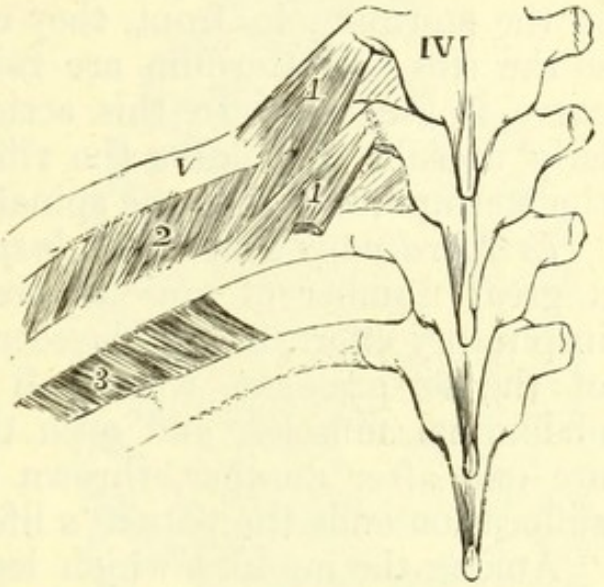


Fig. 138.—View from behind of four dorsal vertebræ and three attached ribs, showing the attachment of the elevator muscles of the ribs and the intercostals. (Allen Thomson.)

1. Long and short elevators.
2. External intercostal.
3. Internal intercostal.

Now, if both the upper and lower margins of the thorax be held firmly by strong muscles, as really occurs in inspiration—from the action of the quadratus and scaleni—the intercostals cannot approximate the ribs. Under these circumstances the results which follow their contraction will be twofold, viz. :—(1) the sternum will be pushed forwards, and the antero-posterior diameter of the thorax thus increased; and (2) the spaces between the ribs, which are widened by the other muscles, are kept rigid and prevented from sinking inwards when the intra-thoracic pressure falls. When acting with the elevators of the ribs both intercostal layers of muscle have an inspiratory effect. But when the elevators of the ribs are passive the intercostals, acting with the anterior abdominal muscles, draw down the ribs, and act as muscles of expiration.

The force of the little superior *serratus posticus* muscle is not great, but the deep *muscles of the back* have more influence on

inspiration than is generally ascribed to them. The scaleni, intercostals and quadratus lumborum, acting together, tend to bend the spine forwards. In this they are opposed by the dorsal muscles, which straighten the spine, and thereby help the scaleni to elevate the ribs, and tend to widen the intervals between them. This straightening of the dorsal curve occurs in quiet breathing, and has a still more important inspiratory influence in forced inspiration. Owing to the ribs being fixed to the sternum, in front, they can only be separated laterally, so the ribs and sternum are raised together, when the dorsal curve is lessened. In this action the intercostals are particularly useful ; by holding the ribs together they push forwards the sternum, and help the spinal muscles to enlarge the thorax.

Extraordinary Muscles of Inspiration.—For forced breathing a great number of muscles are called into play during the inspiratory effort, as may be seen during pathological occlusion of the air-passages, where all the thoracic, cervical, facial, abdominal muscles, and even the muscles of the extremities, are one after another, thrown into a recurring spasm before suffocation ends the patient's life.

Among the muscles which lend their aid when more energetic inspiratory movements are required, may be mentioned the *sterno-mastoid*, which helps the scaleni to elevate the front of the thoracic wall ; the *pectoral* muscles and the *great serratus*, which assist when the arms are fixed.

Expiration.

During quiet breathing *expiration* requires no muscular effort, the expulsion of the air from the chest being accomplished by the elasticity of the parts.

A powerful expiratory force is the *elasticity of the lungs*, which are on the stretch even after a forced expiration, and when distended by inspiration are capable of exerting considerable traction on the thoracic wall.

The ordinary shape of the *elastic walls* of the thorax when the muscles are not acting, corresponds with the position at the end of gentle expiration ; therefore the resiliency of the muscles, costal cartilages, and other elastic tissues which are stretched during inspiration, tends to restore the ribs to the position of expiration.

The *weight of the thorax* itself, and the elastic gases in the intestinal tract, which have been compressed by the diaphragm, may also help in expiration.

After death, when the elasticity of the expiratory muscles is lost, the traction exerted by the lungs on the thorax reduces it below the size its own elastic equilibrium would tend to assume ; when, therefore, air is admitted to the pleural cavity by puncture, the thorax expands slightly as the lungs shrink, and the pressure on the pleural surface becomes equal to that within the bronchi.

In forced expiration, or when the air is used during expiration for any purpose such as the production of voice, or any blowing movement, a number of muscles are called into action. The only muscles that could be called exclusively special muscles of expiration are the weak *triangularis sterni*, *serratus posticus inferior*, and parts of the intercostals ; but in all violent and forcible expiratory efforts these are aided by the *abdominal muscles* forming the anterior wall of the abdomen, which, associated with the *intercostals* and *quadratus lumborum*, are the most powerful agents in drawing down the thoracic walls and expelling the air.

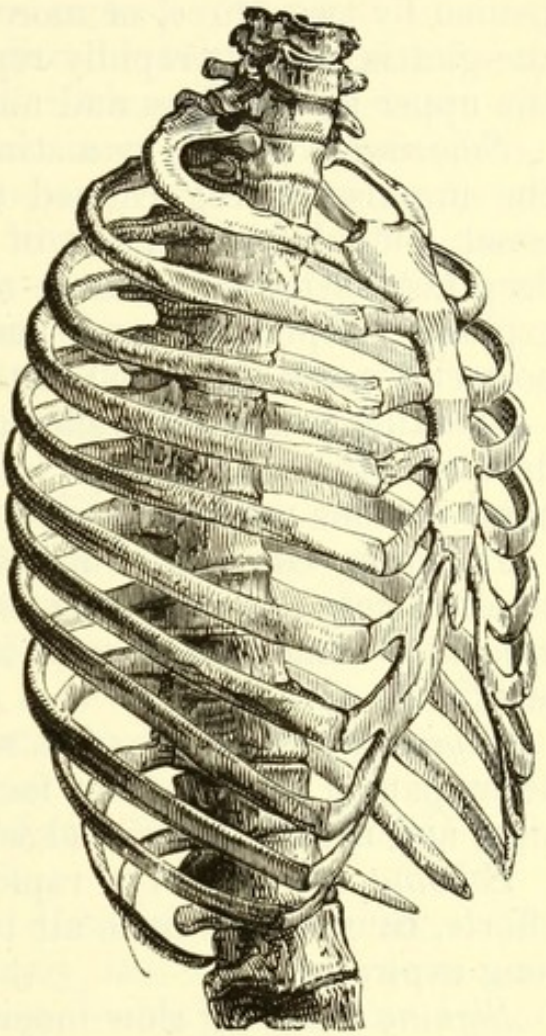


Fig. 139.—Shows the position of the Ribs and the Spinal Column in normal form of the thorax, *i.e.*, that assumed in inspiration.

Modified Movements of Respiration.

Besides the ordinary respiratory motions and the voluntary modifications made use of in speaking, singing, &c., the muscles of respiration perform a series of movements of an involuntary reflex nature indicative of certain emotions and mental states.

They will be seen to resemble each other in the mechanism of their production, though differing essentially in expression. The following are the more important :—

Coughing is caused by a stimulus applied to certain parts of the air-passages, but more particularly to the larynx; the stimulus passing along the superior laryngeal branch of the pneumogastric. It consists of a deep inspiration, closure of the glottis, and then a more or less violent expiratory effort, accompanied by two, three, or more sudden openings and closures of the glottis, so that rapidly repeated blasts of air pass through the upper air-passages and mouth, which is generally held open.

Sneezing is caused by a stimulus applied to the nose or eyes, the impulses being carried to the respiratory centre by the nasal and other branches of the 5th nerve. It consists of a deep inspiration and closure of the glottis, followed by a single explosive expiration and sudden opening of the glottis and posterior nares and facial distortion.

Sneezing is a purely reflex act, since it is impossible to produce it voluntarily, except indirectly by the stimulation of the nasal mucous membrane with some irritating substance.

Laughing consists of a full inspiration, followed by a long series of very short rapid expiratory efforts. The facial muscles are at the same time thrown into a characteristic set of movements.

Crying is made up of a series of short sudden expirations, accompanied by peculiar facial contortions, lachrymal secretion, and usually associated with the following.

Sobbing consists of a rapid series of convulsive inspiratory efforts, causing but little air to enter the chest, followed by one long expiration.

Sighing is a long slow inspiration, quickly followed by a corresponding expiration.

Yawning is a very long deep inspiration, completely filling the chest. It is accompanied by a peculiar depression of the lower jaw, wide open mouth, facial movements, and commonly stretching of the limbs.

Hiccough is an unexpected inspiratory spasm, chiefly of the diaphragm, the entrance of the air being checked by the sudden closure of the glottis.

Function of the Pleura.

From what has been already said it is obvious, that by far the greatest amount of inspiratory enlargement takes place in the lower part of the thorax, while the capacity of the apex changes but little. The increase of capacity in the chest

during inspiration takes place practically between the costal wall and the diaphragm (compare figs. 134, 135). If the lungs and the walls of the thorax were fused together, without the interposition of serous membranes, the different parts of the lungs would have to follow directly the movements of that part of the thorax to which they are attached. Thus the lower parts of the lungs would be much distended during inspiration, and the apices would expand but little. This condition is found when disease of the pleura leads to adhesion of the visceral and parietal layers. When such cases live for some time and the adhesions persist, the air-cells of the lower margins of the lungs are commonly found to be distended and bloodless (*i.e.*, local emphysema from habitual over-distension); while on the other hand, the apices become abnormally dense, and the alveoli are contracted and airless.

But normally the pleural lining of the thorax prevents this unequal distension of the lungs. The surface of the soft elastic lung tissue is quite free, being encased in a serous membrane, the smooth surface of which can slide uninterruptedly and freely over the similar lining of the costal wall. That this motion of the lung actually occurs may be seen from watching the lung through the exposed parietal pleura, or recognised by studying the sounds produced by a roughness of the pleura, such as occurs in inflammation, when a "friction sound" can be detected.

The lungs move in a definite direction. From the least movable points of the thorax, namely, the apex and vertebral margin, they pass towards the more moveable inferior costal and sternal regions. In short, the antero-lateral part of the lungs passes downwards and forwards to fill up the gap made by the descent of the diaphragm and by the passing of the costal wall upwards and forwards.

The position of the inferior margin of the lung may be easily recognised by percussion over the liver, and may thus be shown to move up and down with expiration and inspiration respectively. By percussion we also find that the space between the two lungs in front is increased during expiration and diminished during inspiration, so that the heart is more covered by the lungs, and the præcordial dulness is decreased every time we draw a breath.

By means of this free movement of the lungs in the cavities lined by serous membrane, the atmospheric pressure distends equally all the air-cells, whether they are situated in the

apex or base of the lung, and the alveoli are all equally filled with air.

If the pleural cavity be brought into contact with the air, either by puncture of the thoracic walls or by rupture of the visceral pleura, the lung, owing to the great elasticity of its tissue, shrinks to very small dimensions, and the pleural cavity becomes filled with air (pneumothorax).

If air be admitted to both pleural cavities so as to produce double pneumothorax, death must ensue, for if the opening remain free the motions of the thorax only alter the quantity of air in the pleural cavity, and cannot ventilate the lungs. This demonstrates the important fact that it is the atmospheric pressure which, having access to them only through the trachea maintains the distension of the elastic lungs, and keeps them pressed against the wall of the thorax.

The power with which the lungs can contract when the atmospheric pressure is admitted to the pleura, has been found after death, without inflation, to be four millimetres of mercury, which is undoubtedly much below the pressure exerted during life, when the smooth muscle of the bronchi is acting and the tubes are free from mucus, which rapidly collects in the minute air-tubes at death, and impedes the outflow of air.

When the lungs are inflated before the pleura is opened, the pressure can easily be made to rise to nearly $1\frac{1}{4}$ inches (30 mm. mercury).

From this it would appear probable, that when the lungs are stretched by inspiration, they exert a negative pressure equal to 30 mm., and when the lungs are in a position of expiration, they still tend to contract with a force of at the very least 6 mm. mercury.

Movements of the Air.

Volumes.—During ordinary respiration the volume of the inspiratory and expiratory stream of air is surprisingly small when compared with the volume of air sojourning in the lungs.

After an ordinary expiratory act we can force out a great quantity of air by a voluntary effort; but even after this is got rid of the lungs are still well filled. Some of this *residual* air which never leaves the chest during the life of the animal, is pressed out by the elasticity of the lungs when the pleura is opened. But a certain amount of air cannot be removed in

any way from the alveoli. Even when the lung is cut out of the chest and divided into pieces, enough air is retained in the air-cells to render it buoyant. This fact is relied on by medical jurists as an evidence that an infant has been born alive and distended its lungs with air, for except breathing has been well established, the tolerably fresh lung of an infant will sink in water.

In order to have a clear idea of the volumes of air at rest and in motion during pulmonary ventilation, it is convenient to follow the classification from which the nomenclature in common use has been borrowed.

Tidal air is the current which passes in and out of the air-passages in quiet natural breathing. It amounts to about 500 cc. (30 cubic inches).

Reserve air is that volume which can be voluntarily emitted after the end of a normal *tidal* expiration, and which, therefore, during ordinary respiration remains in the lungs ; it is estimated at about 1500 cc. (or nearly 100 cubic inches).

Complemental air is that which can be voluntarily taken in after an ordinary inspiration by a forced inspiration ; it also amounts to about 1500 cc. but is not used during ordinary breathing.

Residual air is the volume which remains in the lungs after a forced expiration, that is to say, which no voluntary effort can remove from the lungs ; it includes the air which leaves the lungs when the pleura is opened after death, and the air which persistently remains in them after they have collapsed. This amounts to about 2000 cc. (or about 120 cubic inches).

Vital capacity is a term meaning the greatest amount of air that can be emitted by a forced expiration immediately following a forced inspiration, so that it equals the sum of the tidal, reserve, and complemental air. The vital capacity is estimated by spirometers of different kinds, and gives an approximate measurement of (1.) The capacity of the chest. (2.) The power of the respiratory muscles. (3.) The resistance offered by the elasticity or rigidity of the walls of the thorax. (4.) The working capacity of the lungs, *i.e.*, their extensibility or freedom from disease. It therefore varies greatly according to the age, sex, position of the body, the occupation, weight, height, the fulness of the hollow viscera of the abdomen, and the pathological condition of the lungs. It can be much increased by practice, and this fact, apart from the injury

forced respirations may produce in a morbid state of the lung, renders it inapplicable as a gauge of progressive pulmonary disease.

PRESSURE-DIFFERENCES IN THE AIR-PASSAGES.—The immediate effect of the increase in capacity of the chest is, that a pressure-difference is established between the interior of the thoracic cavity and the atmosphere.

The change in pressure produced in the lungs and air-passages is very slight during ordinary quiet breathing with free air-passages. But the least impediment to the entrance or to the exit of the air at once makes the difference very noticeable.

It is difficult to obtain an accurate experimental estimate of the variations in the pressures in different parts of the air-passages during quiet breathing, because even the most careful attempt to measure the pressures causes an impediment which is still further magnified by the sensitive muscular mechanism of the air-passages.

The variations in pressure occurring in the pulmonary air are greatest in the alveoli, and gradually diminish towards the larger air-tubes, so that they disappear at the nasal orifice, where, if no impediment be placed in the course of the air, the pressure will remain very nearly equal to that of the atmosphere. By connecting one nostril with a manometer and breathing through the nose with the mouth shut, it can be shown that inspiration causes a negative pressure of about 1 mm. mercury, and expiration a positive pressure of 2 to 3 mm.; these results must be divided by two, since by plugging one nostril they shut off half the normal inlet. Forced inspiration and expiration give respectively − 57 and + 87 mm.

This great difference depends on the elastic forces against which the inspiratory muscles act in distending the thorax, all of which assist in expiration.

DIFFUSION.—From the foregoing it appears that the volume of air habitually sojourning in the lungs during natural respiration, or *stationary air*, is about 3,500 cc. (nearly 220 cubic inches), while the fresh air introduced by each inspiration is only a little over 500 cc. (30 cubic inches), or, in other words, about one-seventh of the air in the lungs is changed at each breath. Indeed, the 500 cc. of air is only just sufficient to fill the trachea and larger bronchial passages, so that the fresh air does

not reach the pulmonary alveoli, or directly replace any of the air they contain. The tidal stream is, however, brought into immediate relation with the stationary air, and in the larger tubes the thoracic movements possibly help to mix the two mechanically. But the interchange between the fresh tidal air and the impure aveolar air can only take place by diffusion. Diffusion is constantly occurring between the air of the small tubes and the terminal sacs, and it alone suffices to maintain the necessary standard of purity in the air of the aveoli. If the harmless gas, hydrogen, be inhaled during *one* inspiration, it requires 6 to 10 respirations to get rid of the impurity from the expired air. From this it has been inferred that this number of respiratory acts would be necessary to render the air in the alveoli quite pure, even if no fresh impurities were allowed to enter from the blood.

IV. Respiratory Sounds.

As the streams of air enter the air-passages and lungs they produce sounds which are of the greatest importance to the physician, owing to the manner in which they become altered by disease.

A sound called "bronchial breathing" is produced in the large bronchi and trachea, and is like the noise of blowing through a tube. This can normally be heard over the trachea, or at the back between the shoulder-blades, over the entrance of the large bronchi into the root of the lung.

Another sound called "vesicular" can be heard all over the chest, being most distinct where the lung is most superficial, and where other sounds are absent, as in the sub-axillary region. It is a gentle rustling sound caused by the air passing into the infundibuli. It varies much with the force of respiration and many other circumstances. In children up to ten or twelve years of age it is remarkably sharp and loud, and is called "puerile breathing."

V. Nervous Mechanism of Respiration.

The movements of respiration go on rhythmically without any voluntary effort, and even when we are quite awake they occur almost without our being conscious of them, and repeated variations take place in the rate, depth, and general type of our

respirations without our knowledge. Indeed, if this self-regulating arrangement did not exist we should have to devote much attention to adapting our respiratory movements to the ever-varying requirements of the gas-interchange of the blood.

Like all other groups of skeletal muscles, those which act on the thorax are regulated by nerves, and work together in harmony. The co-ordinated movements are so far under the control of the will that either of the two great groups of muscles, abdominal or thoracic, may be employed separately, or in conjunction.

But the respiratory differ from the other skeletal muscles, in that they undergo rhythmical co-ordinated contractions which are not directed by our will, and can be influenced only to a certain extent by it, for they cannot be made to cease altogether, or be made to work on one side only.

THE RESPIRATORY CENTRE.—The normal, rhythmical, co-ordinated movements of respiration are not only brought about, but are also regulated by, an involuntary nervous mechanism. Since we are unconscious of breathing, it certainly is not dependent on the voluntary centres. The upper parts of the brain cannot be needed for regular breathing, since (1) animals born with deficiently developed brains breathe rhythmically; and (2) removal of the brain of birds, &c., or loss of voluntary movement in man (hemiplegia), causes no interruption of the respiratory movements. Injury to the upper part of the spinal cord causes death by stopping respiration. The regulating *centre* must then be lower than the cerebral centres, and higher than the cervical part of the spinal marrow. The direct evidence of the seat of this centre was found by Flourens, who showed that a localised spot exists in the medulla oblongata, injury of which causes instant cessation of the respiratory movement.

This vital spot, *nœud vital*, is situated in the floor of the fourth ventricle, near the point of the *calamus scriptorius*, and is now commonly spoken of as the respiratory centre. It is convenient to suppose that there are two groups of cells, one presiding over the inspiratory, and the other over the expiratory, muscles.

From this centre the impulses which give rise to the all-important respiratory movements rhythmically pass down the spinal cord and nerves. So long as the nervous communica-

tion between the centre and the muscles is intact the movements go on with undisturbed regularity ; if it be cut off, or the centre be destroyed, respiration instantly stops.

Excitation of Respiratory Centre.—What keeps this centre active? All the conditions of the body which cause an increased tissue change, *i.e.* oxidation, are accompanied by greater activity of the respiratory movements. From this it would appear that there exists some relation between the activity of the respiratory centre and the condition of the blood. Deficiency of oxygen or excess of carbonic acid calls forth increased action. One has only to hold one's breath as long as possible, and note the series of rapid and deep respirations that follow, in order to see that respiration is influenced by a deficiency of oxygen.

The respiratory centre is especially sensitive to the products of muscle metabolism. Increased respiratory activity, which is not accompanied by any detectable reduction in the oxygen nor by any measurable increase in the carbonic acid in the blood, occurs when the leg muscles of an animal are tetanised.

Experimentally it can be shown that the centre is excited, in a great measure, at least, by the blood flowing through the medulla, and, probably, also by the action of the venous blood circulating through distant organs, and reflexly affecting the centre. It has also been shown that the temperature of the blood circulating through the medulla affects the activity of the centre, for, if the blood in the carotids be warmed, the respiratory movements become more rapid.

The respiratory centre is a good example of what is called an "automatic nerve centre," not depending for its ordinary excitation upon the arrival of nerve impulses from afar, nor merely reflecting the influences of other centres, but acquiring its rhythmic energy from its nutritive income, and the thermal condition of the warm blood which flows through it.

So long as the amount of O_2 and CO_2 flowing through the centre is kept up to a certain standard, the normal excitability of the centre continues, and we have natural quiet breathing, called *Eupnœa*. When the waste products increase and the oxygen falls below the normal standard, the respiratory centre becomes more excitable, more active movements are carried out and "difficulty of breathing" called *Dyspnœa* is produced.

It is probable that dyspnœa is produced by a deficiency in oxygen rather than by an excess of carbonic acid gas. This is

proved by the fact that it occurs when the carbon dioxide is removed from the blood by breathing air which is free from CO_2, and is only deficient in oxygen, and, secondly, because an excess of CO_2 gas in the air causes a drowsy condition rather than an active dyspnœa.

If the theory that a deficiency of oxygen acts as the normal stimulus of the respiratory centre be correct, a superabundant quantity should diminish the activity of the centre, and a condition the opposite of dyspnœa would be produced. This is difficult to show in natural breathing, though every one knows the efficiency of taking a few deep breaths before a dive into water or an attempt to hold the breath. With artificial breathing, if the movements be carried on very energetically for some time, and then be stopped, the animal will not at first attempt to breathe, but after a time, somewhat less than a minute, gentle and slow respiratory movements commence. This cessation of breathing, called *apnœa*, depends upon the exhaustion of certain reflex (vagus) mechanisms, to be described below, and partly upon the blood being so charged with oxygen that it acts as a lesser stimulus to the centre.

Regulation of Respiratory Rhythm.—Although the respiratory centre can act *automatically* and *rhythmically*, yet it is constantly affected by influences coming from other parts, which reflexly modify the respiratory movements, and its normal rhythm is always under the control of reflex impulses.

Mental *emotions* variously influence both the rate and the depth of breathing, sometimes causing more rapid and sometimes slower respiratory action. The application of a stimulus to almost any part of the *air-passages* completely changes the respiratory rhythm, as may be seen by irritating the nasal mucous membrane. The ordinary *sensory nerves* passing from the *skin* are also capable of exciting inspiratory movements. This is well shown by the gasping that follows the sudden application of cold to the body. It is along these sensory nerves that one tries to transmit impulses by applying mechanical, thermal, or other stimulus to the skin of a new-born infant, whose respiratory centre is slow to respond to exciting influence of venous blood.

Vagi.—Experiment proves that most afferent nerves can affect the respiratory centres, either by increasing or reducing their activity ; but the special nerves which must be regarded as the normal regulating nerves of respiration, are the *vagi*, which may be called the afferent pulmonary nerves.

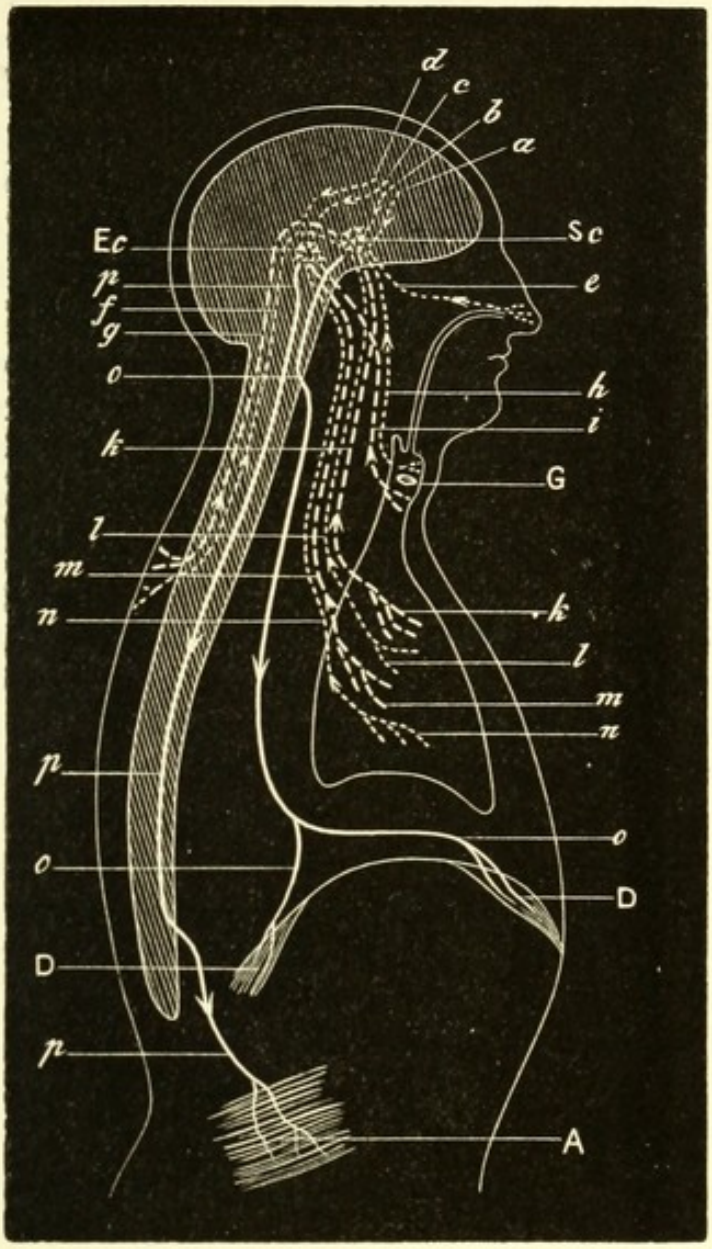


Fig. 140.—Diagram of the Nervous Mechanisms of Respiration. (After Fick.

Sc. Centre for inspiratory movements, from which pass efferent channels, represented by the continuous white line (*o*) to the inspiratory muscles represented by the diaphragm **D**.

Ec. Centre for expiratory movements, from which efferent channels (*p*) pass down the cord to the muscles of expiration, represented by the abdominal muscles **A**.

Impulses may come from the cerebral centres (*a*, *b*, *c*, *d*,) to check or excite the activity of these centres. These voluntary impulses may be called afferent as far as the respiratory centres are concerned. From the cutaneous surface (*f*, *g*) and the nose (*e*), impulses arrive, which modify the action of the inspiratory centre. From the larynx **G** come checking impulses (*h*) to the inspiratory, and exciting impulses (*i*) to the expiratory centre. And, finally, from the lungs come both exciting and inhibiting impulses (*k*, *l*, *m*. *n*) to both the expiratory and inspiratory centres. By these latter channels the rhythm of ordinary breathing is regulated.

Though section of *one* vagus has little or no effect on respiration, if the *two* vagi be cut a marked change takes place in the respiratory rhythm. The rate of the inspiration is reduced to less than half the normal, while each breath becomes deep and prolonged, so that the respiratory function of the lungs goes on for some time unimpaired, and the hæmoglobin of the blood receives the due amount of oxygen. Although the character of the breathing is completely changed, from the rapid gentle motion of natural respiration to a series of slow deep gasps, the air volumes and the chemical changes remain much the same per minute. If the central end of the cut vagus be now stimulated gently, the rate of the respiratory movements may again be quickened to the normal. If the stimulus be strong, inspiratory spasm can be produced. Weaker stimulations of the vagus may call forth increased expiratory efforts. And if the central end of the cut superior laryngeal branch of the vagus be stimulated, breathing becomes slow, and can be made to cease in the position of forced expiration, or a violent spasm of the laryngeal and expiratory muscles follows.

So that in the vagus nerve, fibres exist which convey impulses of two kinds to the respiratory centres ; the one hastens the discharge of inspiratory impulses, the other checks the inspiratory movement and excites expiration. The marked change just described as occurring when the two pneumogastrics are cut, proves that these afferent influences are *constantly* at work, quickening the respiratory rhythm. We may assume that the slow, deep respirations which follow section of the vagi are caused by the un-regulated automatic action of the inspiratory centre. No impulse is discharged until the venosity of the blood in the centre arrives at a certain point, and then the accumulated energy is sent to the respiratory muscles, and a deep gasping inspiration occurs, and thus each respiratory act is called forth by the blood becoming so venous as to act as a powerful stimulus.

So long as the centre is stimulated by the normal reflex regulating influence of the vagi this venous condition is not allowed to occur, the intense excitation of the centre is thereby prevented, and the necessary movements performed with a minimum of muscle energy.

The exact mode of stimulation of the pulmonary terminals of the afferent fibres of the pneumogastric is not quite certain. It has been suggested that distension or retraction of the lungs may act as a mechanical stimulus to the nerve fibres inhibiting

or exciting the inspiratory or expiratory centres respectively. Each expansion of the lungs thus calls forth reflexly the ensuing relaxation, and the relaxed state, in its turn, induces reflexly a new inspiration. Thus the state of the lungs themselves guides the thoracic movements by means of the vagi.

The expiratory part of the centre probably takes no part in ordinary breathing, but is called into play in dyspnœa, in vocal use of the expiratory blast of air, and in various modified respiratory movements.

CHAPTER XVII.

THE CHEMISTRY OF RESPIRATION.

The simplest way to investigate the study of the gas interchange that takes place in the lungs, between the air and the blood, is to compare the composition of the expired air with that of the atmosphere, and from the alteration found to have taken place during the tidal current we arrive at the changes which the air undergoes during its journey in and out of the air-passages, and we then examine the venous and arterial blood in order to ascertain the changes the blood undergoes in becoming arterial.

The atmosphere is made up of a mixture of nitrogen and oxygen with a variable amount of moisture and a minute proportion of carbonic acid.

The following table gives the *volume* * of the gases in dried air :—

Oxygen . .	20·96 per cent.,	or about	21 per cent.
Nitrogen . . .	79·02 „	„	79 „
Carbonic dioxide	0·02—0·06 „	„	4 parts in 10,000.

The amount of moisture contained in the air is very variable, and depends in a great measure upon the temperature and the direction of the wind. The dampness of the air depends upon the temperature, so that air containing the same absolute amount of moisture may be relatively dry or damp, according as the temperature rises or falls. As a general rule the air is relatively dry, that is to say, it does not contain so much moisture as it is capable of taking up in the form of aqueous vapour at its ordinary temperature. At certain times of the day the air may be saturated owing to a sudden fall of temperature.

* On account of the difference in the atomic weights, the atmospheric being only a *mechanical mixture* of the gases, the proportion by *weight* is slightly different, being about—Oxygen 23 per cent., Nitrogen 77 per cent.

The temperature of the air which we breathe varies considerably, according to the season of the year, &c., but almost always in this country it is lower than that of our bodies.

I. Changes the Air undergoes in the Air-passages.

The following are the notable characters in the tidal air on its leaving the air-passages :—

1. It is rich in CO_2, containing in quiet breathing on an average 4·38 per cent. instead of ·04 per cent.

2. It is poor in O_2, containing about 4·5 per cent. less than the atmosphere, *i.e.*, 16·46 per cent.

3. A slight increase in the amount of N has been observed.

4. The temperature of the air is approximated to that of the body, and it therefore commonly exceeds the temperature of the air inspired. The air on leaving the air-passages is about 36·5° C. This is not much influenced by the temperature of the atmosphere, as may be seen from Valentine's Table :—

Temperature of the Atmosphere and of Expired Air.

− 6·3° C.	=	+ 29·8° C.
+ 17·0° C.	=	+ 36·2° C.
+ 44·0° C.	=	+ 38·5° C.

It can be seen from the last statement that very hot air (+ 44° C.) if breathed is cooled in its transit through the air-passages.

5. In quiet breathing the expired air is saturated with moisture ; in rapid breathing this is not the case. It must be remembered that the air when warm is capable of holding a greater quantity of vapour than when it was inspired. The difference can be best appreciated in cold weather, when the vapour of the warm expired air is condensed on meeting the cold atmosphere. Great quantities of water and heat are given off in producing this saturation.

6. If the tidal air be dried and cooled and measured at a certain pressure before and after respiration, it is found that the expired air has lost about $\frac{1}{50}$ of its volume. But owing to the expansion from the increased temperature and the presence of the vapour, the volume of air when expired is greater than that inspired.

If the oxygen were all used to make CO_2, these volumes ought

to be the same, for the volume of CO_2 is equal to that of the O_2 it contains, if set free. The volume of CO_2 given off is, however, only about 4·38, to 4·5 volumes of O_2 taken in, so that part of the O_2 must be used in some other way, viz. in forming H_2O urea, &c.

7. The expired air is also said to contain traces of the following impurities :—(1) ammonia, (2) hydrogen, (3) carburetted hydrogen (CH_4), (4) organic matter. These, and probably other impurities, give the breath its peculiar odour and noxious properties, for an atmosphere rendered "stuffy" by expired air is much more injurious to health than an atmosphere in which a similar deficiency of O_2 or excess of CO_2 had been artificially produced by chemical means ; this fact ought to be remembered when calculating the ventilation required for hygienic purposes. The following Table may assist in comparing the atmosphere with the expired air :—

	Atmosphere.	Expired Air.	Difference.
CO_2	·04 per cent.	4·38 per cent.	+ 4·34
Oxygen	20·81 ,,	16·03 ,,	− 4·78
Nitrogen ...	79·15 ,,	79·55 ,,	+ ·40
Temperature	− 6° *C.*— + 25° *C.*	29·8° *C.*—38·5° *C.*	
Moisture ...	about 10 grms. to 1 cubic metre.	about 40 grms. to 1 cubic metre.	
Volume	.....	Apparently increased, absolutely reduced $\frac{1}{50}$th.	
Impurities...	.....	NH, H, CH_4, and poisonous organic matter.	

About $\frac{1}{7}$ of the O_2 which is used does not take part in the production of the CO_2, but this proportion may vary greatly. Thus the estimation of the CO_2 can give no sure guide to the amount of O_2 taken up ; and each gas has to be estimated separately if an accurate measurement be required.

The average amount per diem may be said to be :—

Carbon dioxide given off about . .	900	grammes.
Oxygen consumed ,, . . .	750	,,
Water given off ,, . . .	500	,,

The 900 grms. of CO_2 contain about 650 grms. of O_2, so that there is about 100 grms. of O_2 used in excess of that necessary to form CO_2. This leaves the body chiefly in combination with

H as water, and also to a very slight extent in combination with N as urea, uric acid, &c.

The amounts of O_2 taken up and of CO_2 given off, differ in different individuals and in the same individuals under varying circumstances, among which the following may be enumerated :—

1. Increase in the rapidity or the depth of respiratory movements, accompanied by an increase in the tidal stream, produces an increase of the total amount of CO_2 given off, while the percentage in the volume of expired air is diminished.

2. It varies with age. The amount increases with age up to 30 years, and then remains constant.

3. Sex ; is less in women than in men, but it increases in pregnancy.

4. With muscular activity it is notably increased.

5. Change of temperature of the air has a marked influence on the CO_2 output of cold-blooded animals, which is increased in direct proportion to the elevation of temperature. The effect on warm-blooded animals is the opposite, so long as they can regulate their temperature. The sustentation of the body temperature in cold weather is accompanied by a distinct increase in the output of carbon dioxide.

6. The time of day ; a maximum is arrived at about mid-day and a minimum about midnight.

7. An increase in the amount of carbon dioxide in the atmosphere diminishes the amount given off from the lungs.

The ratio,

$$\frac{\text{vol. of } CO_2 \text{ eliminated}}{\text{vol. of } O_2 \text{ absorbed}}$$

is called the "respiratory quotient," and this as we have seen is always less than 1. It is nearest 1 in the herbivora, in some of which it is as large as ·9 or even more, and is smallest in the case of carnivora, man having an intermediate number.

It further varies very considerably at different times even when experimenting with the same animal.

II. Changes the Blood undergoes in the Lungs.

In order to understand how the oxygen and the carbonic acid pass to and from the blood in the pulmonary capillaries, we must know the relationship of these gases to the blood in the arterial and venous sides of the circulation.

In the chapter on the blood (pp. 209, 214) it is stated that both the oxygen and the carbon dioxide can be removed from the blood by the mercurial air-pump, and that the greater part of these gases are chemically united with some of the constituents of the blood, and that a different quantity of each gas is found in arterial and venous blood. Now that we know the change from the venous to the arterial condition to take place during the passage of the blood through the pulmonary capillaries where it is exposed to the air, we may assume that the acquisition of oxygen and the loss of CO_2, form the essential difference between venous and arterial blood.

From either kind of blood about 60 volumes of gas may be extracted, with the mercurial gas-pump, from every 100 volumes of blood. The composition of this gas varies considerably in venous, but not very much in arterial blood. An average is given in the following Table :—

	O vols. %.	CO vols. %.	N vols. %.
Arterial . .	20	39	1—2
Venous (about) .	8—12	46—50	1—2

The sooner after bleeding the gases are removed, the greater is the proportion of O_2 that can be obtained, as delay allows some of it to combine with easily oxidised substances in the dying blood. The amount of oxygen varies in different parts of the venous system. In the blood of an animal dying of slow asphyxia only traces of oxygen can be found and these soon disappear after death.

The proofs that O_2 is in chemical combination with the hæmoglobin of the red blood corpuscles, and not merely absorbed, are numerous and satisfactory.

1. When arterial blood is submitted to gradual diminution of pressure in the mercurial air-pump the oxygen does not come off in accordance with the established law relating to gases held in solution, viz., in proportion to the diminution of the pressure (Henry-Dalton). At first only traces appear (probably the small amount really dissolved), and when the pressure has been reduced to a certain point, about $\frac{1}{25}$th of that of the atmosphere, nearly all the oxygen comes off suddenly. Hæmoglobin combines with O_2 in the same way, rapidly at first even when the pressure is low.

2. If simple absorption were the only state in which the oxygen existed in the circulation, the warm blood, while passing

through the pulmonary capillaries, could only take up about 0·4 volume per cent., which would be inadequate for life. We know that the quantity of O_2 going to the blood from the air in the alveoli amounts to 10 vol. p. c. This cannot be explained on physical grounds alone. Further, when an animal dies of asphyxia in a limited space, all the O_2 of the air in the chamber is absorbed, while some still exists in the hæmoglobin of the animal, the pressure cannot then make the O_2 pass into the blood.

3. Another proof that the O_2 combines with hæmoglobin chemically, is given by the spectroscopic examination of hæmoglobin solutions, both the reduced, and the oxyhæmoglobin showing characteristic spectra, as already pointed out in Chapter XII. (Frontispiece and p. 210).

4. The amount of O_2 taken up is not in proportion to the pressure of that gas, but rather to the amount of hæmoglobin in the blood; and we therefore find the adequacy of the respiratory function of the blood going hand in hand with its richness in hæmoglobin. The "shortness of breath" of anæmic and chlorotic individuals is thus explained.

5. The oxygen can be displaced by the chemical union of other gases with the hæmoglobin.

The great importance of the chemical nature of the union between the O_2 and hæmoglobin for external respiration becomes striking when the manner in which the entrance of the O_2 is effected is taken into account.

The further we trace the air down the passages, the less O_2 it contains, and, therefore, the less is the pressure exerted by that gas. This is shown by the fact that the air given out by the latter half of a single expiration has less O_2 and more CO_2 than that of the first half. The exact determination of the percentage of O_2 in the air of the alveoli has not been accomplished, but it must be low, for, since the tidal air only fills the larger tubes, the air in the small bronchi can contain only a small percentage of O_2, and the alveoli receive O_2 only by diffusion with this impure air of the small bronchi.

Our knowledge concerning the relation of the CO_2 to the constituents of the blood is less definite.

It does not all exist as a mere physical solution, for it comes off irregularly under the air-pump, and does not exactly obey the Henry-Dalton law of the absorption of gases. Part comes off easily and part with difficulty. It is not associated with the corpuscles, for more of this gas can be obtained from serum

than from a like quantity of blood. It is more easily removed from the blood than from the serum, a certain proportion (about 7 per cent. of the whole) remaining in the serum, in vacuo, until dissociated by the addition of an acid or a piece of clot containing corpuscles. If bicarbonate of soda be added to blood from which all the gas has been removed, still more CO_2 can be pumped out, from which it would appear that something exists in the blood capable of dissociating CO_2 from sodium bicarbonate.

It has been suggested that the CO_2 is in some way associated (possibly as sodium bicarbonate) with the plasma of the blood, and that the corpuscles have the power of acting like a weak acid, and of dissociating it from the soda, and thus raising its tension in the blood.

The difference of tension of the CO_2 in the alveolar air and in the blood, hardly explains the steady manner in which the CO_2 escapes, and it has, therefore, been suggested that this escape also depends in some way upon a chemical process, possibly connected with the union of O_2 to hæmoglobin, because the admission of O_2 to the blood seems to facilitate the exit of CO_2.

III. Internal Respiration.

The arterial blood, while flowing through the capillaries of the systemic circulation and supplying the tissues with nutriment, undergoes changes which are called internal, or tissue respiration, and which may be regarded as the converse of pulmonary or external respiration. In the external respiration the blood is changed from venous to arterial ; whereas in internal respiration the blood is again rendered venous.

There can now be no doubt that these chemical changes take place in the tissues themselves, and not, as was formerly supposed, in the blood as it flows through the vessels. The amount of oxidation that takes place in the blood itself is indeed very small. The tissues extract a certain part of the O from the blood, along with the other substances necessary for their nutrition. In the chemical changes which take place in the tissues, the oxygen rapidly disappears, the tension of that gas becoming low ; at the same time the character of the chemical changes is indicated by the appearance of CO_2. The disappearance of the O_2 and the manufacture of CO_2 do not exactly correspond in amount. As already mentioned, the ratio $\frac{CO_2 \text{ eliminated}}{O_2 \text{ absorbed}}$

gives the quotient which is sometimes called the coefficient of respiration. This varies in different parts and under different circumstances. Of the intermediate steps in the tissue chemistry we have in most instances but theoretical knowledge. We do not know the way in which the oxygen is induced by the tissues to leave the hæmoglobin ; we can only say that the tissues have a greater affinity for O_2 than the hæmoglobin has, and they at once convert the O_2 into more stable compounds than oxyhæmoglobin, and ultimately manufacture CO_2, which exists in the tissues and fluids of the body at a higher tension than even in the venous blood.

IV. Respiration of Abnormal Air, &c.

The oxygen income and carbonic acid output are the essential changes brought about by respiration, therefore the presence of oxygen in a certain proportion is absolutely necessary for life. The 21 per cent. of O_2 of the atmosphere more than suffices to saturate the hæmoglobin of the blood, and 14 per cent. of O_2, at ordinary atmospheric pressure, has been found to be capable of sustaining life without producing any marked change in respiration. Human beings live in perfect health at a height of 10,000 to 12,000 feet above the sea level.

Dyspnœa is produced by an atmosphere containing only 7·5 per cent. of O_2. This dyspnœa rapidly increases as the percentage of O_2 is further decreased, and when it gets as low as 3 per cent. suffocation speedily ensues.

The output of CO_2 can be accomplished if the lungs be ventilated by any harmless or indifferent gas, and since the manufacture of the CO_2 does not take place in the lungs, its elimination can go on independently of the quantity of O_2 in them. The 79 per cent. of N contained in the atmosphere has a passive duty to perform in diluting the O_2 and facilitating the escape of the CO_2 from the lungs.

Indifferent gases are those which produce no unpleasant effect of themselves, but which in the absence of O_2, are incapable of sustaining life, such as nitrogen, hydrogen, and CH_4.

Irrespirable gases are such as, owing to the irritating effect on the air passages, cannot be respired in quantity, as they cause instant closure of the glottis. In small quantities they irritate and produce cough, and if persisted in, inflammation of the air passages ; among these are chlorine, ammonia, ozone, nitrous, sulphurous, hydrochloric, and hydrofluoric acids.

Poisonous gases are those which can be breathed without much inconvenience, but when brought into union with the blood cause death. Of these there are many varieties. (1.) Those which permanently usurp the place of oxygen with the hæmoglobin, viz., carbon monoxide (CO), hydrocyanic acid (HCN).

(1.) Narcotic : (α) carbonic dioxide (CO_2), of which 10 per cent. is rapidly fatal, 1·0 per cent. is poisonous, and over 0·1 per cent. injurious. (β) nitrogen monoxide (N_2O). Each of these gases leads to a peculiar asphyxia without convulsions. (γ) chloroform, ether, &c.

(3.) Sulphuretted hydrogen (H_2S), which reduces the oxy-hæmoglobin, and produces sulphur and water.

(4.) Phosphuretted hydrogen (PH_2), arseniuretted hydrogen (AsH_2), and cyanogen gas (C_2N_2) also have special poisonous effects.

V. Ventilation.

In the open air the effects of respiration on the atmosphere cannot be appreciated, but in enclosed spaces, such as houses, rooms, &c., which are occupied by many persons, the air soon becomes appreciably changed by their breathing.

The most important changes are (1) removal of oxygen, (2) increase in carbonic acid, and (3) the appearance of some poisonous materials which, though highly injurious, cannot be determined. The deficiency in oxygen never causes any inconvenience, as it is never reduced below what is sufficient for the saturation of the hæmoglobin. The excess of CO_2 seldom gives any inconvenience, since the air becomes disagreeably fusty or stuffy long before the amount of CO_2 from breathing has reached 0·1 per cent., which amount of pure CO_2 can be inspired without any unpleasantness. It is, then, the exhalations coming from the lungs, and probably skin, some of which must have a poisonous character, that render the proper supply of fresh air imperative.

The difficulty of determining the presence of the poisonous organic materials, makes it convenient to use the amount of CO_2 present in the air as the means of measuring its general purity. For this we must suppose that the relation between the poisonous organic ingredients and the CO_2 is constant.

Air, which is rendered impure by breathing, becomes disagreeable to the sense of smell when the CO_2 has reached the low standard of ·06 or ·08 per cent., that is to say, scarcely twice as much CO_2 as is contained in the pure atmosphere. Supposing

that air is unwholesome when its impurities are appreciable by the senses, then, if the animal body be the source of the CO_2, ·06 per cent. of this gas makes the air unfit for use.

An adult disengages more than half a cubic foot of CO_2 in one hour (·6 Parkes), and consequently in that time he renders quite unfit for use more than 1,000 cubic feet of air, by raising the percentage of CO_2 to ·1 (·04 being the initial percentage, and ·06 the respiratory addition).

It is obvious that the smaller the space and the more confined, the more rapidly will the air become vitiated by respiration. It becomes necessary for health, therefore, to have not only a certain cubic space and a certain change of air for each individual, but the cubic space and the change of air should bear to each other a certain proportion in order that the air may remain sufficiently pure.

The space allowed in public institutions varies from 500 to 1,500 cubic feet per head in such apartments as are occupied by the individuals day and night. As a fair average 1,000 cubic feet may be fixed as the necessary space in a perfect hygienic arrangement. In order to keep this perfectly wholesome and free from a stuffy smell, and the CO_2 below ·06 per cent., it is necessary to supply some 2,000 cubic feet of air per head per hour.

To give the necessary supply of fresh air without introducing draughts or greatly reducing the temperature of the room is no easy matter, and forms the special study of the hygienic engineer.

VI. Asphyxia.

If an adequate supply of oxygen be withheld, and its percentage in the blood be reduced to a certain point, the death of the animal follows in 3 to 5 minutes, accompanied by a series of phenomena commonly included under the term asphyxia. This may be divided into four stages. 1. Dyspnœa. 2. Convulsion. 3. Exhaustion. 4. Inspiratory spasm. As asphyxia is a mode of death the symptoms of which the physician may be called upon to treat, he should be able to recognise its different phases.

If the air passages be closed completely the respirations become deep, laboured, and rapid. The respiratory efforts are more and more energetic, and the various supplementary muscles are called into play one after the other, until gradually the second stage is reached in about one minute.

As the struggles for air become more severe, the inspiratory muscles lose their power, and the expiratory efforts become more and more marked, until finally the entire body is thrown into a general convulsion in which the traces of a rhythm are hardly apparent. This stage of convulsion is short, the expiratory muscles becoming suddenly relaxed by exhaustion.

Then the longest stage arrives in which the animal lies almost motionless, making some quiet inspiratory attempts. These become gradually deeper and slower, until they are nothing more than deep gasps, separated by long irregular intervals.

The pupils of the eyes become widely dilated, the pulse can hardly be felt, and the animal lies apparently dead, when often after a surprisingly long interval one or more respiratory gasps follow, and with a gentle tremor the animal stretches itself in a kind of tonic inspiratory spasm, after which it is no longer capable of resuscitation. This last pulseless stage, to which the term asphyxia is more properly confined, is the most irregular in duration, but always the longest.

The blood of an animal which has died of asphyxia is nearly destitute of oxygen, the hæmoglobin being in a much more reduced condition than is found in venous blood.

The first and most obvious effect produced by the circulation of blood so deficient in oxygen, is excessive stimulation of the respiratory centre, which causes the extreme and varied actions just described. In the first stage of asphyxia, the venous blood reaching the systemic arterioles affects their muscular walls, and passing through the vaso-motor centre excites the vaso-constrictor mechanism, so as to cause a rapid and considerable rise in blood pressure and consequent distension of the left ventricle. The general constriction of the small arteries may be brought about by the venous blood acting as a stimulus to the cells of the medullary and spinal vaso-motor centres, or it may act as a direct stimulant to the muscle cells of the arterioles themselves. The centres in the medulla which govern the inhibitory fibres of the pneumogastric are also stimulated, and consequently the heart beats more slowly. The increase in arterial tension and the slow beat give rise to distension of the ventricle, which, when a certain point is reached, impedes the working of the heart, and its muscle begins to beat more and more feebly, so that in the third stage the pulse can hardly be felt. The arterioles then become relaxed by the action of the depressor nerve, the blood pressure

falls rapidly, and with the death of the animal it reaches the level of atmospheric pressure. The right side of the heart and the great veins are engorged with blood, in the last stage of asphyxia; the cardiac muscle being inhibited or exhausted from want of oxygen, is unable to overcome the resistance offered by the pulmonary arterioles and cannot therefore empty its cavities or pump the blood out of the veins.

Owing to the persistent contraction of the pulmonary vessels and the great capacity of the systemic veins, the left side of the heart is found comparatively empty after death, and at *post-mortem* examination the right side alone is found overfilled.

CHAPTER XVIII.

BLOOD ELABORATING GLANDS.

In the preceding chapters we have seen that the blood undergoes important changes as it courses through the different parts of its circuit. Where it comes in contact with the tissues it yields to them nutrient material for assimilation, and oxygen for their metabolism, and carries away from them some waste products. In the lungs it receives oxygen and gives off carbonic acid. While it flows through the minute vessels of the alimentary tract, many of the materials are absorbed by the blood. At the confluence of the great veins in the neck the stream of lymph and chyle is poured into the blood.

Thus there is a circulation of material, a constant income and output going on in the blood and in the different tissues of the body. The investigation of the changes taking place in the blood while passing through each organ is difficult, and in many cases impossible. It may be made out, in one instance, the lungs, by noting the substances given off or taken up by the blood. Here we can find out from the expired air that the blood has lost and gained certain materials. In secreting glands the secretion enables us to judge of some of the changes taking place in the organ. In other parts, such as the muscles or the ductless glands, we have no separate output which we can analyse, and we must therefore trust to the differences which may be found to exist in the blood flowing to, and that flowing from them. For this purpose one can either examine samples of the blood from the artery and vein of the organ, or, immediately after its removal, by causing an artificial stream of blood to flow through it ; then the changes in the blood during its passage through the organ should give the required information. But in many cases these experiments are disappointing, the amount of the substances being so small.

Blood Glands.

There is a certain set of organs which resemble one another in being larger in the embryo and rapidly growing young animals than in adults, and in the fact that they do not pour their products into ducts, but into the blood current, and are therefore commonly grouped together as *ductless* or *blood glands*.

It has been shown that a great part of the absorbed nutrient material passes through the lacteals or lymphatics, and in so doing has to traverse *lymphatic glands*, where it is modified by the addition of a number of lymph corpuscles which are subsequently poured into the large veins and become important constituents of the blood. Some of the blood glands are nearly akin to these lymphatic glands, already described (page 172), their duty being the further elaboration and perfection of the blood.

In this group are commonly placed the SUPRA-RENAL CAPSULES, the THYROID, the THYMUS, and the SPLEEN.

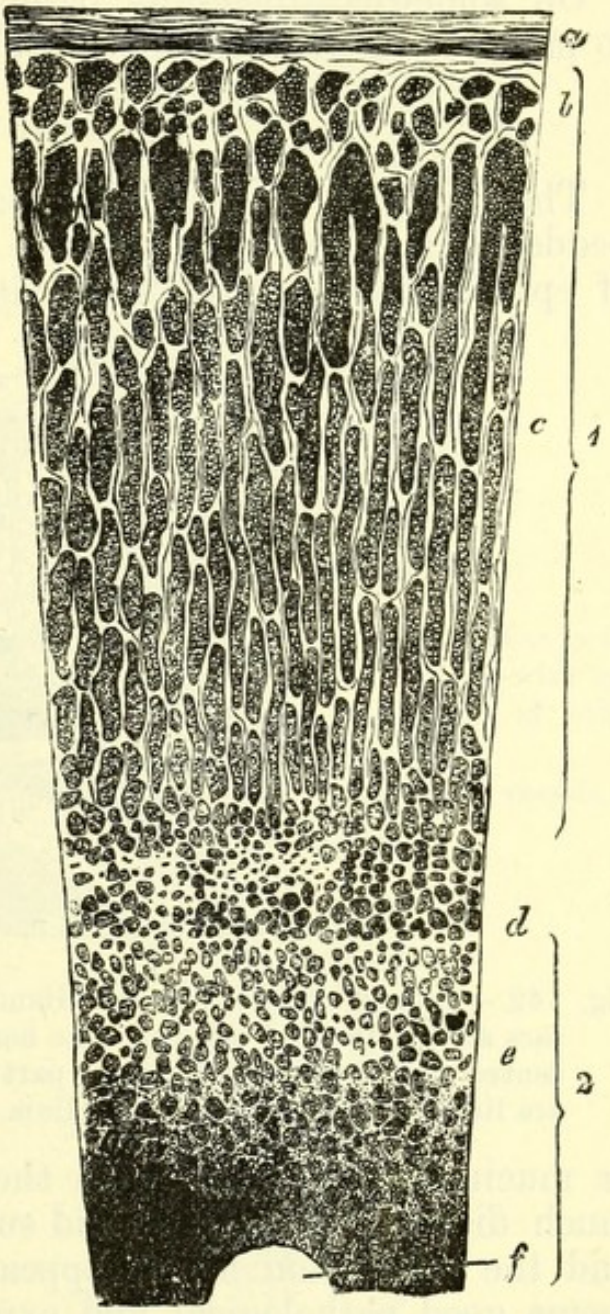


Fig. 141.—Vertical section of the Supra renal Capsule. (Eberth.)
1. Cortex. 2. Medulla.
a. Fibrous capsule.
b. External cell masses.
c. Columnal layer.
d. Internal cell masses.
e. Medullary substance, in which lies a large vein, partly seen in section *f*.

Supra-renal Capsule.

With regard to the function of the supra-renal capsule we may say that nothing definite is known. The cortical part is said to resemble the lymph follicles in struc-

ture, while the central part, on account of its numerous peculiar large cells, its great richness in nerves, and its close developmental relationship, has been thought to have some connection with the nervous system. Extirpation of the suprarenal bodies in rabbits and frogs leads to slowly progressive fatal paralysis.

On somewhat indefinite pathological data it has been said to preside over the destiny of the pigments of the body.

Thyroid Body.

The thyroid is made up of groups of minute closed sacs embedded in a stroma of connective tissue, lined with a single row of epithelium cells, and filled with a clear peculiar albuminoid

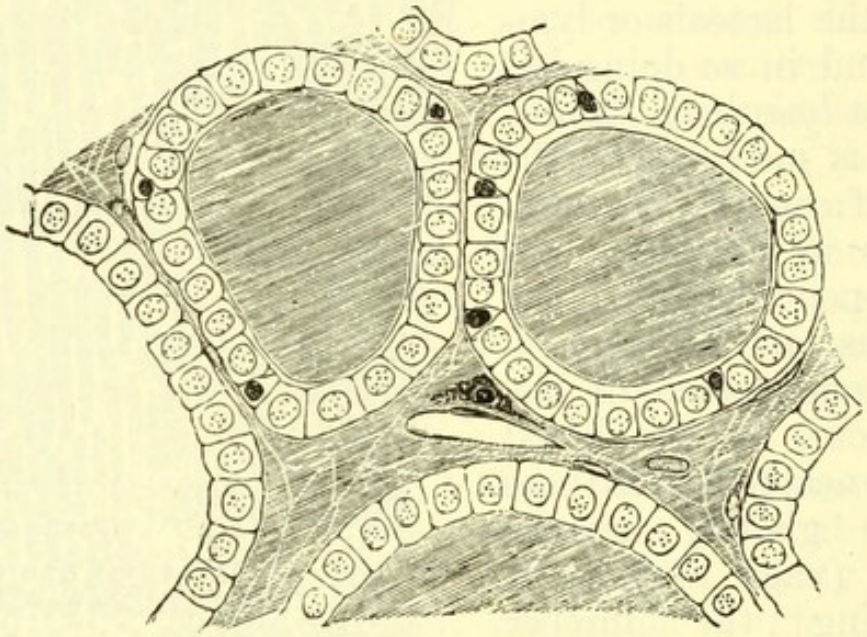


Fig. 142.—Section of the Thyroid Gland of a child, showing two complete sacs and portions of others. The homogeneous colloid substance is represented as occupying the central part of the cavity of the vesicles, which are lined by even cubical epithelium. (Schäfer.)

or mucin-like substance. In the adult the sacs are commonly much distended with a colloid substance and peculiar crystals, and the epithelium has disappeared from their walls. There seems good pathological and experimental evidence that this body has an obscure influence on (1) the elaboration of the plasma, and the blood corpuscles, on (2) nutrition in general, and (3) the development of the connective tissue in particular. Its removal frequently is followed by changes in the blood and excessive development of all the connective tissues. A fall of temperature, difficult respiration and convulsive attacks, usually fatal in a few weeks, have also been observed. These symptoms are said to be averted by injection of glycerine extract of the gland. (Schiff.)

THYMUS GLAND.

The functional activity of the thymus is restricted to that period of life when growth takes place most rapidly. It is well

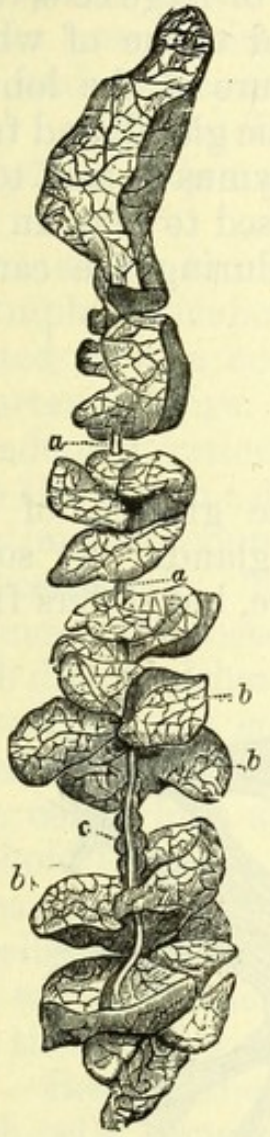


Fig. 143.—Portion of Thymus removed from its envelope and unravelled so as to show the lobules (*b*, *b*) attached to a central band of connective tissue (*a*).

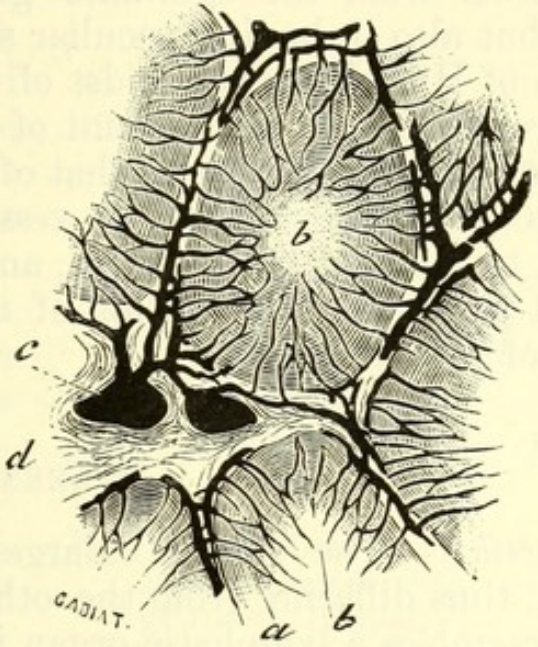


Fig. 144.—Magnified section of a portion of injected Thymus showing one complete lobule with soft central part (cavity) (*b*), and parts of other lobules. (Cadiat.)

(*a*) Lymphoid tissue. (*c*) Blood vessels.
(*d*) Fibrous tissue.

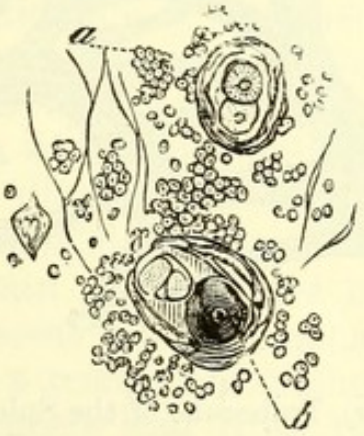


Fig. 145.—Elements of Thymus (high power). (Cadiat.)

(*a*) Lymph corpuscles.
(*b*) Epitheloid nests of Hassall.

developed in the fœtus, and increases in size for a couple of years after birth ; but it gradually diminishes in bulk during the later periods of childhood. It loses its original structure about puberty so as to become completely degenerated and

fatty in the adult. It is composed of numerous little follicles of lymphoid tissue collected into groups or lobules connected with a kind of central stalk. The lymphoid follicles of the young thymus have some likeness to those of the intestinal tract, but they differ from the agminate glands, not only in arrangement, but also in having peculiar small nests of large cells (corpuscles of Hassall) in the midst of the adenoid tissue of which they are made up. On account of the structure of the lobules being so nearly identical with that of a lymphatic gland, and from its great richness in lymphatic vessels, the thymus is said to be related to the lymphatic system, and is supposed to play an important part in the elaboration of the blood during the earlier stages of animal life.

Spleen.

Structure.—The spleen enlarges with the growth of the animal, thus differing from the other blood glands. It somewhat resembles a lymphatic organ in structure, but differs from

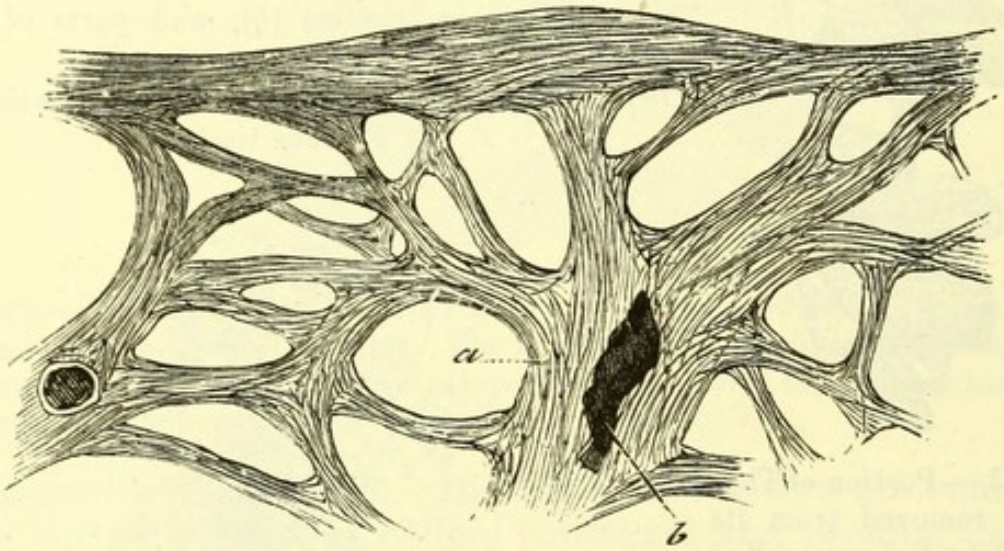


Fig. 146.—(*a*) Trabeculæ of the Spleen. (*b*) Artery cut obliquely. (Cadiat.)

it in the relation borne by the blood to the elements of the follicular tissue. It is incased in a strong *capsule* made of fibrous tissue and unstriated muscle cells. From this many branching prolongations pass into the substance of the organ, so as to traverse the soft red spleen pulp. In these *trabeculæ* or prolongations from the capsule are found the branches of the splenic artery, dividing into smaller twigs without anasto-

mosis. On leaving the trabeculæ the arteries break up suddenly into a brush-like series of small branches, ending in capillaries which are lost in lymphoid tissue.

Between the trabeculæ are found two distinct kinds of tissue—(1.) Rounded masses of *lymphoid tissue*, called *Malpighian corpuscles*, scattered here and there through the organ ; and (2.) the peculiar soft *splenic pulp* making up its bulk.

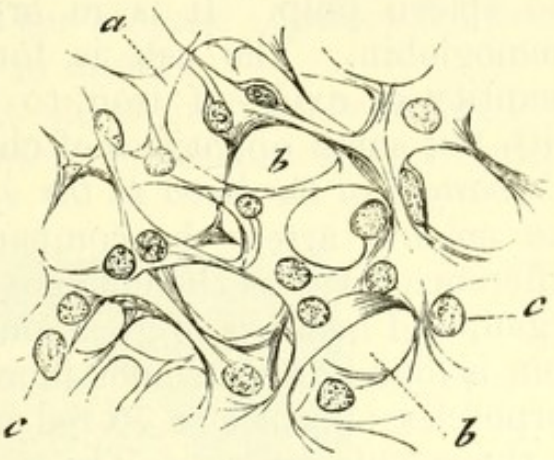


Fig. 147.—Reticulum of the Spleen Pulp injected with colourless gelatine. (Cadiat.)
(*a*) Meshes made of endothelium.
(*b*) Lacunar spaces, through which the blood flows.
(*c*) Nuclei of endothelium.

The small rounded masses of lymph follicular tissue are situated on the course of the fine arterial twigs. The delicate adenoid reticulum which holds the lymph cells together, is intimately connected with the vessel wall. The pale appearance of these follicles, which distinguishes them from the surrounding splenic pulp, depends on the number of the white cells which are packed in the meshes of this perivascular lymphoid tissue.

The splenic pulp consists of a reticulum of flattened branching cells, forming a system of communicating lacunar spaces lined with endothelium. Into these spaces the blood is poured from the arteries, and thus mingles with vast numbers of white cells. Besides the ordinary blood discs, white corpuscles and lymph cells, some peculiar large amœboid cells are found in the spleen pulp. Some of these contain little masses of hæmoglobin, or red corpuscles, whilst some small, misshapen, red corpuscles, are regarded as steps in a retrograde change in the discs. But few, if any, lymph channels lead from the spleen-pulp, and only a relatively small number pass out from the hilus, so that the splenic artery and vein must be regarded as taking the place of the afferent and efferent lymph channels.

Chemical composition of the spleen pulp.—Chemical examination shows the splenic pulp to have remarkable peculiarities. Although so full of blood, which is alkaline, the spleen is acid in *reaction*. It contains a great quantity of the oxidation products (so-called *extractives*) commonly found as the result of

active tissue change, viz., uric acid, leucine, xanthine, hypoxanthine, inosit, cholesterin, lecethin, &c. It also yields many fatty acids, viz. lactic, formic, succinic, acetic, and butyric acids. It also contains *pigments*, which probably result from hæmoglobin A peculiarly large amount of *iron* is present in the spleen pulp. It is in organic combination, probably in hæmoglobin. The ash is found to contain a considerable quantity of oxide of iron, to be rich in *phosphates* and *soda*, with but small quantities of chlorides and potassium.

Changes in the blood in the spleen.—If the blood flowing in the splenic artery be compared with that in the vein, the difference gives us the changes the blood has undergone in the organ, and hence is of great importance. In the blood of the vein is found an enormous increase in the number of the white corpuscles (1 white to 70 red in the vein, as against 1 to 2,000 in the splenic artery). The red corpuscles from the vein have been said to be smaller, brighter, less flattened than those of ordinary blood; they do not form *rouleaux*, and are more capable of resisting the injurious influence of water. The blood of the splenic vein is also said to have a greater proportion of water, and to contain an unusual quantity of uric acid and other products of tissue waste. The amount of blood in the spleen varies greatly at different times. Shortly after meals the organ becomes turgid, and remains enlarged during the later periods of digestion.

Pathological changes.—The size of the spleen, which may be taken as a measure of its blood contents, is also altered by many abnormal conditions of the blood. Thus, in all kinds of fever, particularly ague and typhoid, and in syphilis, the spleen becomes turgid, and in some of these diseases it remains swollen for some time. In a remarkable disease, leucocythæmia, in which the white blood cells are greatly increased in number, and the red ones are relatively diminished, the spleen, in company with the lymphatic glands, is often found to be much altered and, as a rule, immensely enlarged; but, on the other hand, advanced amyloid degeneration of the spleen may occur without any notable alteration taking place in the number or properties of the blood corpuscles.

Extirpation of the spleen.—The spleen may be removed from the body without any marked changes taking place in the blood or the economy generally. It is said that if an animal whose spleen is extirpated be allowed to live for some time the lymphatic glands increase in size, or become swollen.

In attempting to assign a definite function to the spleen all the foregoing facts must be carefully reviewed, and the peculiarity of its (1) *structure*, (2) *chemical composition*, (3) the *changes the blood* undergoes while flowing through it, (4) the *variations in blood supply* which follow normal and pathological changes in the economy, and (5) the absence of effect following its *extirpation*, must all be borne in mind.

Its *structure* teaches us that it is intimately related to lymphatic glands. The Malpighian bodies are simply lymph

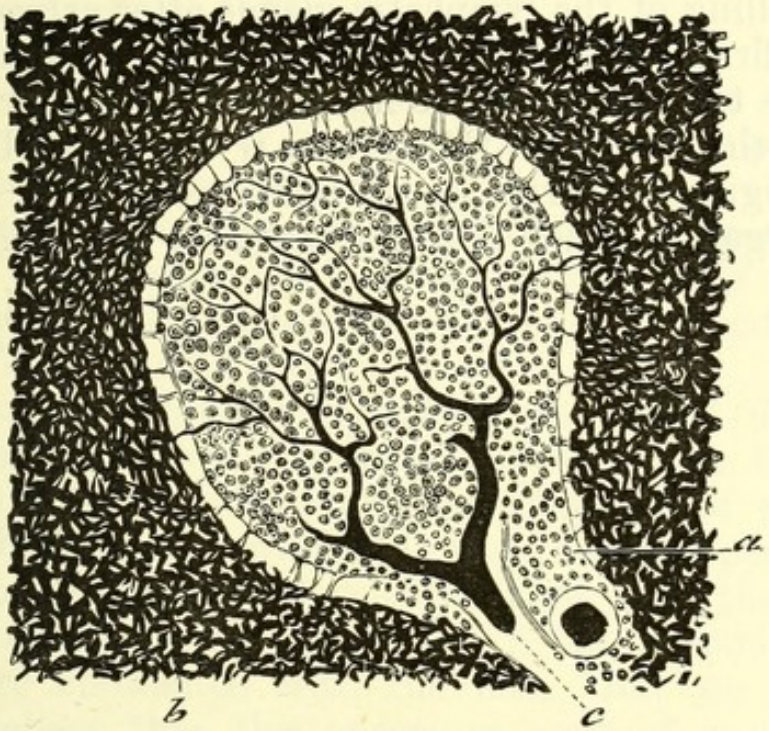


Fig. 148.—Section of Spleen through a lymph follicle (Malpighian body) (*a*) injected to show the vessel, (*c*) entering the follicle, the lymphoid tissue of which is pale in comparison with the pulp (*b*), the meshes of which are filled with injection. (Cadiat.)

follicles, and the pulp may be regarded as a sinus like that of a lymph-gland, with this difference, that it is traversed by blood instead of lymph. The cell elements found in it, indicate that not only white cells are rapidly generated, but also that some of these cells acquire a peculiar relationship to hæmoglobin, as they are often found to contain it. The varieties in size, form, and general appearance of the red corpuscles can be accounted for by either their destruction or their formation occurring in this organ.

Its *chemical composition* also shows it to be connected with active metabolic changes, and that possibly stages of the construction or destruction of hæmoglobin are here accomplished.

From the characters of the *blood* flowing from the spleen it has been argued that production of white corpuscles, and destruction of the red discs goes on, while some new discs are formed, probably by means of the white cells making hæmoglobin in their protoplasm, which, gradually disappearing, leaves only the red mass of hæmoglobin.

The increased activity and greater size of the spleen after *meals*, and in certain *abnormal states* of the blood, distinctly points out that some form of blood elaboration goes on in it, which is nearly related to, or associated with, nutrition.

The swelling of the lymphatic glands after *extirpation* of the spleen confirms its relation to these organs ; but the paucity of evidence as to changes in the number or character of the red discs after this operation proves that if the spleen be either the place of origin or destruction of the red corpuscles, it cannot be the only organ in which they are produced or destroyed.

CHAPTER XIX.

THE LIVER.

Introductory.

THE secretion of the liver was discussed in the chapter on digestion, and its relation to the processes taking place in the intestinal tract were enumerated.

As may be surmised from the smallness of the amount of the secretion in comparison with the enormous bulk of the gland, the production of the bile is not the only, or even the most important, function of the liver.

Placed on the highway by which the great majority of materials absorbed from the intestines reach the blood, it is obviously in a position to act as the guardian of the blood's purity and health. It certainly in some respects performs this duty, for many poisons when introduced into the digestive tract are stopped by the liver, and if their amount be not excessive, are eliminated with the bile. But we have good reason to believe that this enormous mass of protoplasm is placed in this peculiar position in the circulation to preside over much more important duties than that of mere gate-keeper. Many, if not all, of the absorbed materials are found to be altered during their visit to the liver. The liver protoplasm has the power of giving the finishing touch, as it were, to many of the stuffs on their way to assimilation, and of converting into the most suitable form many of the effete materials that are on their way to elimination. To do this greater powers than those commonly ascribed to the animal tissues are required. We have ample evidence that *building up*, as well as the more ordinary *breaking down*, processes take place in the liver. In fact we must regard it as the great chemical laboratory of the blood where not only many important *analyses* are made, but also many *syntheses* essential to life are accomplished, in a manner inimitable by the chemist with all his modern laboratory appliances.

Among the most striking peculiarities of the liver may be mentioned the following :—

1. In the adult it is as large as all the other glands of the body put together, relatively larger in the growing animal, and in the embryo it nearly equals in weight the rest of the fœtus.

2. It has an immense and double blood supply. It receives (1) all the blood of the portal vein coming from the digestive tract and spleen, or from the placenta in the fœtus, where it has been enriched by absorption. This supply of blood, which varies much in amount, after meals equals one-fourth of all the blood in the body. It has (2) a small supply of arterial blood from the hepatic artery, under ordinary arterial pressure, whereas the portal blood, though not venous, properly so-called, moves under exceptionally low pressure, its amount and rate depending on the circulation in the digestive organs.

3. The nerves entering the gland are insignificant, scarcely more than would be expected to supply the ramifications of the hepatic artery.

4. Although developed as an ordinary compound tubular gland, the cells are not found lining the lumen of ordinary duct-radicles, and, in the higher animals at least, it shows little resemblance to the tubular type of gland.

5. The bile is collected by minute channels (bile canaliculi) without intrinsic walls, which lie between the glandular cells and open into the ducts.

6. It is the only secretion poured into the intestine during intra-uterine life.

7. In no other organ are ducts found so rich in small saccular glands as the distinctly-walled ducts of the liver.

8. In most animals a diverticulum from the duct, the gall-bladder, forms a receptacle for the temporary reception of the bile.

9. It is more widely distributed in the animal kingdom than any other gland.

Structure of the Liver.

On the surface of the liver small rounded markings about the size of a pin's head are seen which give the organ a mottled appearance. This is much more striking in some animals (giraffe, bear, pig) than others, but is easily recognizable in the livers of all mammalia. These little areas are the surfaces of the *lobules* of the liver. They are surrounded by a dark red boundary, and their centre is marked by a dark spot ; between

these there is a paler yellowish zone. The dark parts correspond to the blood-vessels, which have a constant relation to the lobules.

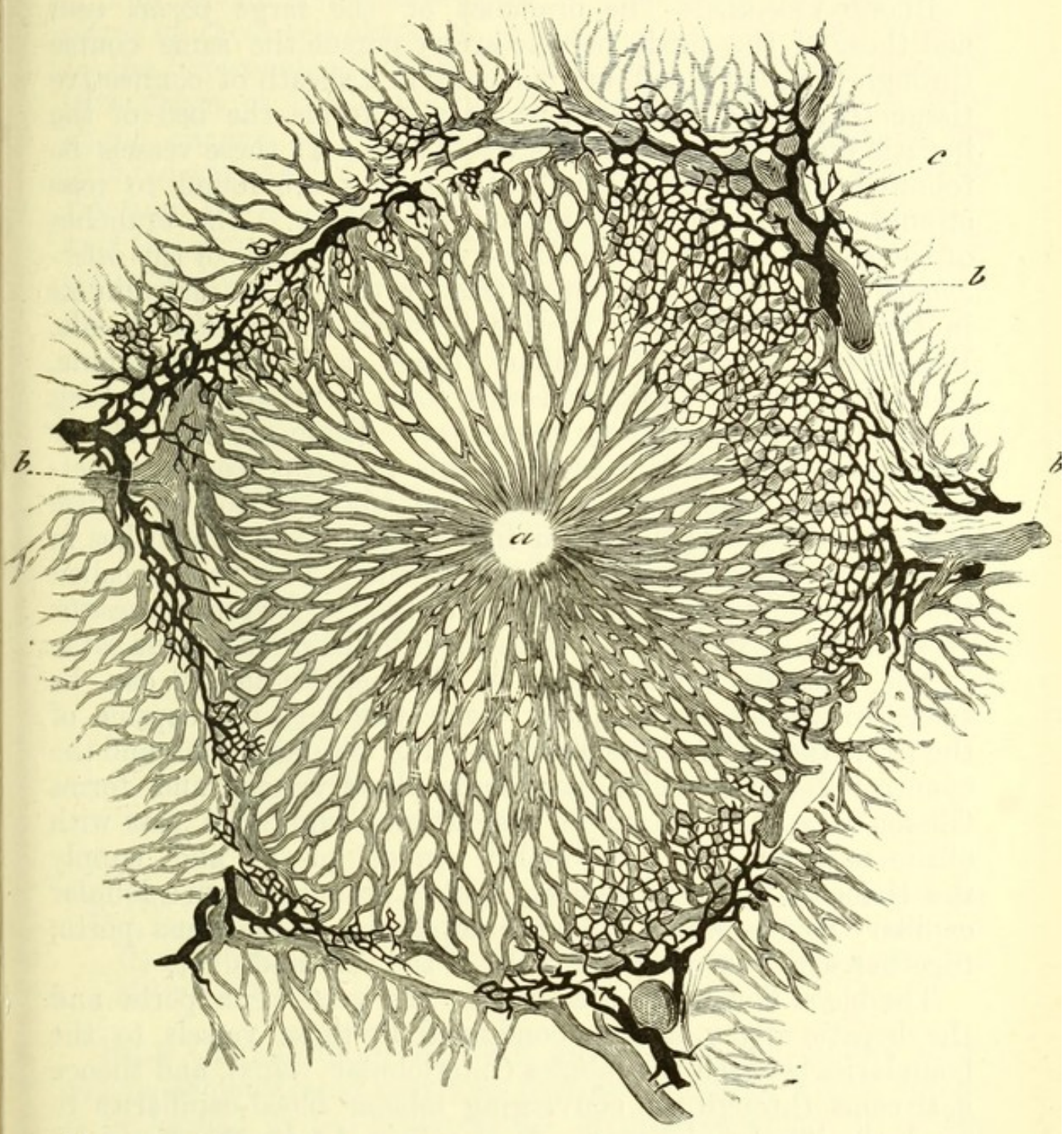


Fig. 149.—Section of Lobule of Liver of Rabbit in which the blood capillaries and bile canaliculi have been injected. (Cadiat.)

a. Intralobular vein. *b*. Interlobular veins.
c. Biliary canals beginning in fine capillaries.

The entire liver is made up of these little lobules, and each one of them has the same construction and blood supply, and therefore forms in itself a little liver, perfect in all its structural

arrangements, so that the description of one such unit will suffice to give an idea of the structure of the gland. For other details, anatomical works must be referred to.

Blood-Vessels.—The branches of the large *portal vein* and those of the small hepatic artery pursue the same course through the gland, and are enclosed in a sheath of connective tissue (capsule of Glisson), which also forms the bed of the hepatic duct and its numerous tributaries. If these vessels be followed to their final ramifications, they are found to pass around and between the neighbouring lobules. The branches of the portal vein in this situation receive the name of the *interlobular veins*. They anastomose freely with the terminal veinlets in the vicinity, so as to form a network round each lobule. From this a number of capillary vessels pass into the lobule, and, lying between the gland-cells, form a network with long meshes converging towards the centre. These are the *lobular blood-capillaries*. The vessels of this radiating capillary network become larger as they unite and converge to the centre of the lobule, where they open into a central vein which lies in immediate apposition with the gland-cells. This vein is called the *intralobular vein*, and is the radicle of the efferent or *hepatic veins*, which carry the blood of the liver to the inferior vena cava.

The ultimate ramifications of the hepatic artery can be traced to various destinations. Some pass into the capsule of the liver, the walls of the accompanying vein and duct, and the connective tissue which surrounds these vessels, and forms Glisson's capsule. Many of the arterial capillaries pass with offshoots from the interlobular venous plexus and supply the tissue between the lobules. Other branches form a lobular capillary plexus, which joins the capillaries of the vena porta, together with that from the walls of the vein and duct.

The blood flowing to the liver in the great vena porta and the hepatic artery, is thus conducted by those vessels to the boundaries between the lobules (interlobular veins), and thence it streams through the converging lobular blood-capillaries to reach the intralobular vein. It is collected from the latter by the sublobular tributaries of the hepatic vein, by which it is conducted back to the general circulation, and enters the heart by the inferior vena cava.

Liver Cells.—Between the meshes of the lobular capillaries the gland-cells are tightly packed. These are large, soft, polyhedral cells, with one, two, or even more nuclei, and no

trace of a limiting membrane. Owing to the shape of the capillary meshes the cells are placed in rows radiating from the centre of the lobule towards the periphery.

The blood-capillaries are said to pass along the angles and edges of these cell-blocks so as not to come into close relation to the bile canaliculi (Figs. 151 and 152). The finely granular protoplasm of the liver-cells is capable of undergoing some slight change in form while alive. In the protoplasm are situated varieties of granules, the commonest being bright refracting fat globules, which vary in amount with the food and the stages of digestion ; others of a yellow colour, seem connected with the colouring matter of the bile ; and a third variety, less refracting and colourless, is said to be glycogen.

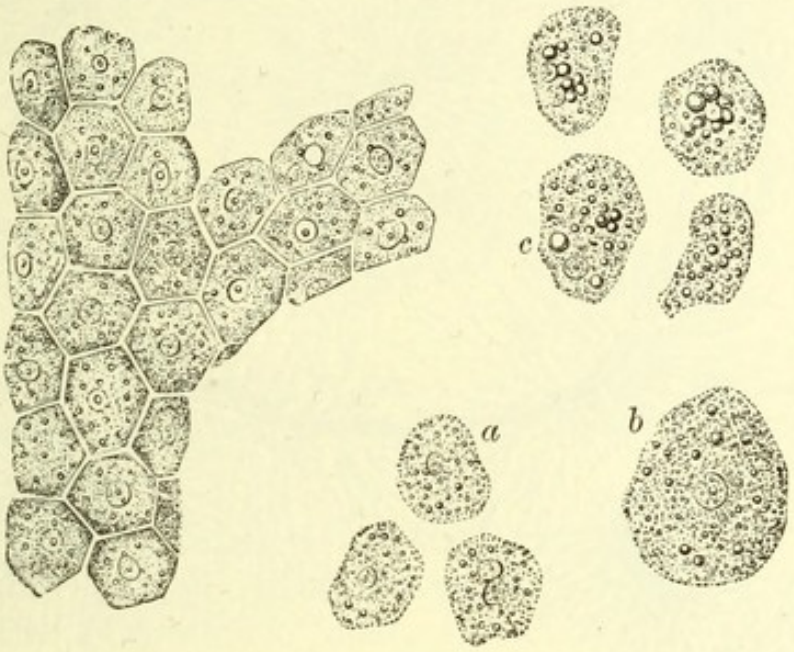


Fig. 150.—Cells of the Liver. One large mass shows the shape they assume by mutual pressure. (*a*) The same free, when they become spheroid. (*b*) More magnified. (*c*) During active digestion containing refracting globules like fat.

Bile Canaliculi.—Between the cells of the lobules there can be demonstrated very fine branching canals, which appear to be formed by the juxtaposition of grooves which lie in the middle of the flat surface of two neighbouring cells. Every liver-cell is related to at least one such canal, and consequently a very dense system of vessels with peculiarly regular diameters is present (Fig. 152) among the cells of the lobule, each mesh corresponding in size to one cell.

These fine intercellular channels are called *lobular bile canaliculi.* They are easily distinguished from *lobular blood-capil-*

laries, the diameter of which is about ten times as great as that of the former, and they have a definite boundary-wall, whilst the bile canaliculi have no other boundary than the

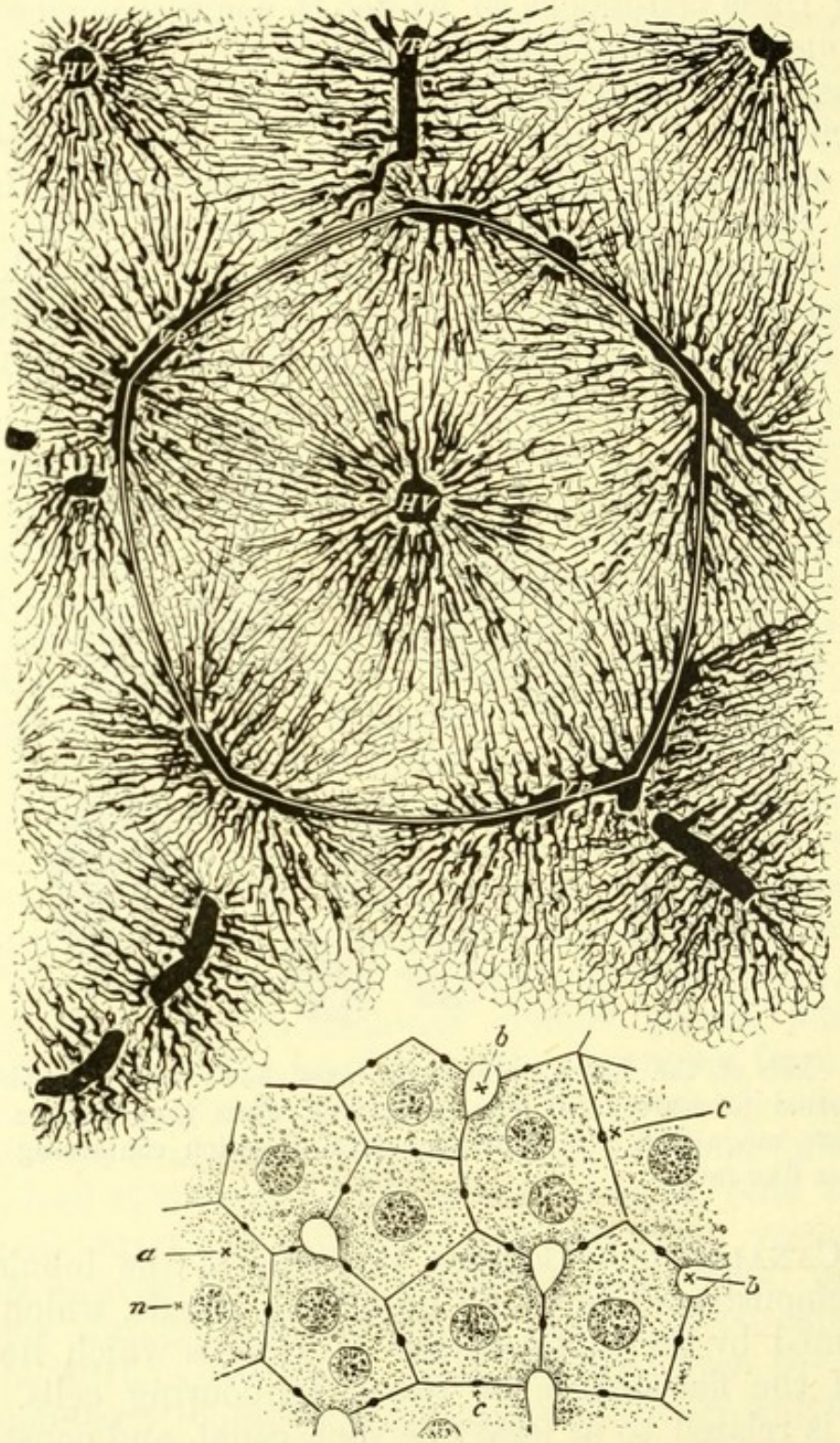


Fig. 151.—Section of injected liver, showing the position of the portal branches (*interlobular veins*, VP) and radicles of hepatic veins (*intralobular veins*, HV) connected by lobular capillaries.

Below is a portion of the same highly magnified. (*a*) Liver-cell with (*n*) nucleus; (*b*) Blood-capillaries cut across, passing along angles of cells; (*c*) Bile capillaries between flattened sides of cells cut across. (Huxley.)

substance of the liver-cells, between the juxtaposed flat surfaces of which they lie. They are said to communicate by direct openings into the protoplasm of the cells.

These fine intercellular bile-passages are described as communicating freely with the very minute interlobular ducts without undergoing any marked increase in the size. The interlobular ducts, which follow the course of the artery and portal vein, are composed of a delicate basement membrane

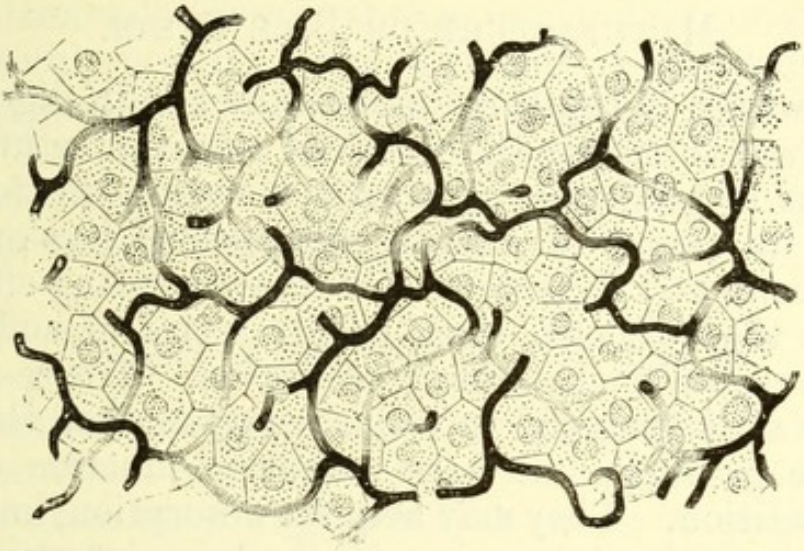


Fig. 152.—Section of the Liver of the Newt, in which the bile ducts have been injected. The canaliculi can be seen through the transparent liver-cells.

lined with a thin layer of epithelium, which in the larger vessels shows a cylindrical character. The larger bile-ducts have a firm fibro-elastic coat, lined by a definite mucous membrane with cylindrical epithelial cells, lying upon a vascular submucosa, in which are scattered numerous mucous glands of saccular form.

There is but a small amount of connective tissue in the liver of man and most domestic animals, but in the pig, bear, giraffe and others, it is present in considerable quantity, surrounding the vessels and sending processes between the lobules so as to render the individuals distinct.

The lymphatics are very plentiful, and in intimate relation to the blood-vessels.

Functions of the Liver.

As far as we are at present acquainted with the functions of the liver, we may group them under the following heads :—

1. Manufacture of bile salts and pigments.
2. Elimination of injurious constituents from the blood.
3. Formation of urea (nitrogenous synthesis).
4. Formation of glycogen (carbo-hydrate synthesis).

Manufacture of Bile Salts.

Our knowledge of the work done by the bile in digestion goes but a short way to explain the objects of its manufacture (p. 157). The help it gives the pancreatic secretion in forming an emulsion ; its power of altering the surface tension between the fat particles and the tissues ; or its stimulating effect on the activity of the epithelial cells, hardly seems of sufficient importance to require such a complex secretion. The re-absorption of the bile salts from the intestine, suggests that they are not mere waste products, but have a definite function capable of endless repetition. They may help fat absorption, but it is said that their absorption takes place in the large intestine, and not with the fat. Their re-absorption is certainly necessary for the adequate secretion of bile salts, which falls to a very low ebb if the bile be removed by a fistula, so that none can be re-absorbed from the intestine. The secretion of bile salts regains its normal standard if the bile taken from a fistula be subsequently allowed access to the intestinal canal. Can the bile salts have some connection with the synthetic processes in the liver, which might require their repeated circulation through that organ and the intestinal tract? Or, are the bile acids merely neutral travellers carrying soda from the liver to the duodenum to neutralise the gastric acid?

Origin of Bile Pigments. We may assert, as already mentioned, that the colouring matter of the bile represents the effete colouring matter of the blood. Animals with coloured blood have coloured bile. Hæmatin and bilirubin are sufficiently alike in composition to suggest some close relationship between them (Hæmatin $C_{32}H_{32}N_4O_4$ Fe, Bilirubin $C_{32}H_{36}N_4O_6$).

When blood escapes in mass from the vessels into the tissues, the hæmatin loses its iron, and after a time crystals of a substance called hæmatoidin appear. Hæmatoidin is isomeric, and probably identical, with bilirubin, which forms similar crystals.

If hæmoglobin freed from corpuscles be introduced into the portal vein, the amount of pigment in the bile is increased. When after the injection of chloroform, &c., into the blood-vessels, the hæmoglobin is discharged from the corpuscles, it is changed to bilirubin by the liver, and appears in the urine as urobilin.

In severe internal hæmorrhages or extravasations, urobilin—*i.e.*, the form which bilirubin assumes in the urine—also appears in the urine in unusual quantity.

Under certain conditions when the blood discs are rapidly destroyed, hæmoglobin may appear in the urine unchanged.

It is certainly possible for a substance (hæmatoidin) similar to a bile pigment, to arise from hæmoglobin independently of the liver. Yet there can be but little doubt that, under normal circumstances, the liver is the organ in which the change from hæmoglobin to bilirubin takes place.

Uremic Function of the Liver.

Urea practically represents all the nitrogenous metabolism of the body, so that every tissue, in which nitrogenous material is used up, must in some way contribute to the production of this end-product. It is said to be present in all the organs and tissues, but the amount found in most of them is so insignificant that it does not seem to correspond with the daily output by the kidneys. Although it is the most important solid ingredient of the urine, the urea is certainly not manufactured by the kidneys. This may be gathered from the following facts :—

1. It is known to accumulate in the body during any disease which lowers the efficacy of the kidneys.

2. After extirpation of these organs, the urea in the blood has been found to increase fourfold in about 24 hours.

3. If blood containing ammonium carbonate (which in the liver gives rise to urea) be made to stream through the kidney, no urea is formed. Though we know the kidney can make hippuric acid from glycocine and benzoic acid supplied in this manner.

In searching for a source of urea, physiologists naturally first turned to muscle, which makes up half of the body-weight of most animals. Here practically no urea was found, but in its stead a large quantity (about 90 grammes for an adult) of a nitrogenous body called kreatine. Neither this nor kreatinine appear in the urine in anything like an amount equivalent to the above, but it is significant that urea can be made from either of them.

Urea cannot be made artificially from proteid. Although this fact is not a conclusive argument against its being separated from proteid directly, as a neutral compound, in the body, where vital activity holds sway, it and other facts suggested the idea that the formation of urea was a change secondary to that occurring in the actual tissue metabolism. The belief that precursors of urea were formed in the tissues is supported by the fact that it can be made from certain substances found in the tissues, notably from kreatine, as has just been mentioned.

Physiologists have sought diligently for these precursors of urea, but so far with but indifferent success, and we must admit we are in complete ignorance of the early or intermediate stages of its formation.

The following substances have been given the credit of forming intermediate steps in the formation of urea :—

1. *Amido acids:* glycocine, aspartic acid, leucine, tyrosine, &c. Concerning tyrosine evidence is still wanting, but as regards the other substances it has been shown that when they are introduced into the intestine, or into the blood-vessels, the amount of urea is increased.

2. *Ammonium Carbonate:* is nearly related to urea chemically, and if given to dogs gives rise to an increased excretion of urea. Ammonium chloride is said to have had the same effect in rabbits.

3. *Uric acid.* From this substance (which quite replaces urea in the urine of birds, reptiles, &c.) urea can be artificially made, and in mammalia, under certain circumstances, uric acid seems to increase in proportion as urea decreases.

4. *Kreatine.* Urea can be made from this substance, which, in muscle alone, is produced in much larger quantities than it appears in the urine. How is it then eliminated if not as urea ?

5. *Cyanic acid* or *cyanates* have been suggested from their near chemical relationship to urea (see page 45).

The small proportion of urea found in the blood (2 grm.) compared with that excreted (30 grm. per diem) supports the view that the direct result of nitrogenous metabolism is not urea, but certain bodies capable of producing urea.

The question now arises, where is this production of urea accomplished ?

Many circumstances confirm the view that the changes occur in the liver, and we now believe that the liver is by far the most important source of urea in the body.

Its *position* in the course taken by the blood coming from the

intestine, would alone suggest that the liver builds up urea from these compounds, for this blood contains a quantity of the amido acids, which have been shown experimentally to give rise to urea. This appears all the more probable when we consider the close relationship between the quantity of proteid food eaten, and the urea excreted, and the fact that an increased excretion of urea accompanies any increased activity of the liver from any cause either biliary or glycogenic.

Pathology leads to the same conclusion. In all diseases in which the functional activity of the liver cells is impaired, the amount of urea excreted is reduced, and in its stead certain of its precursors appear in the urine.

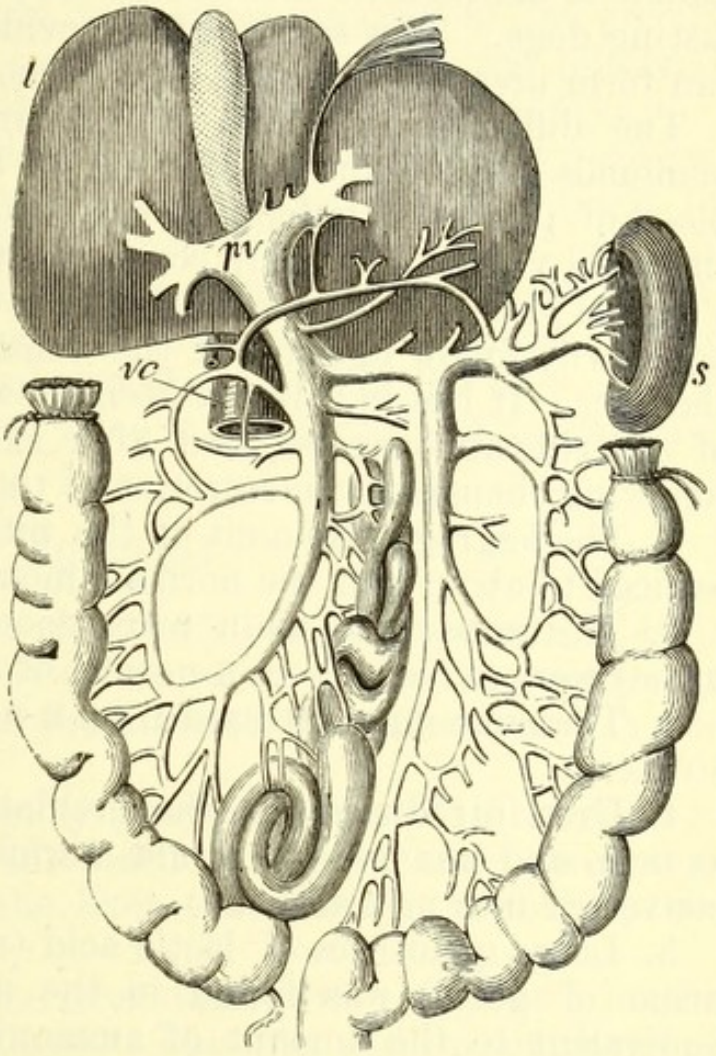


Fig. 153.—Diagram of the Portal Vein (*pv*) arising in the alimentary tract and spleen (*s*), and carrying the blood from these organs to the liver.

To gain additional evidence as to this function of the liver, one would naturally turn to its experimental excision. But in mammals this adds nothing to our knowledge, because the extirpation of the organ, or ligature of all its vessels, so soon results in death, that there is no time for the processes we wish to investigate to be carried out. Attempts to convey the portal blood directly to the vena cava have so far not given satisfactory results.

Experiments of a less radical nature have been made, and have yielded interesting facts. It has been mentioned that ammonia is supposed to be an antecedent of urea. Its administration, wrapped up in slices of meat, to dogs, caused an increase of urea

much greater than could be accounted for by the meat alone. It was shown more directly, in the case of the liver removed from a dog, that if a stream of fresh blood, containing carbonate of ammonia, be caused to circulate repeatedly through the organ, after a few hours the amount of urea in the blood was increased three-fold. In a control experiment, with the carbonate of ammonia omitted, no increase of urea occurred in the livers of fasting dogs. This seems strong evidence that the liver cells can form urea synthetically from carbonate of ammonia.

The difficulty met with in experimenting on the liver of mammals is not found in the case of birds. In the latter the blood of the portal tributaries can reach the vena cava through the renal vessels, which are connected with the portal system by a special vein. Thus the stasis in the intestinal tract does not necessarily follow ligature of the vena porta or extirpation of the liver. It has in this way been shown, by an extensive series of experiments on geese, that after extirpation of the liver the following changes in the secretion of the kidneys can be found:—

1. The aggregate amount of the nitrogenous substances was reduced to about half the normal amount.

2. The urates (the main nitrogenous end-product in birds' urine) were reduced from a normal of about 60 p.c. to 3 p.c.

3. The ammonia increased from a normal of about 9 p.c. to 50 p.c.

4. Urea introduced into the circulation appeared in the urine as urea, and was not—as would normally occur in the bird—converted into uric acid.

5. Large quantities of lactic acid (normally unknown in the urine of geese) was found in the urine. The amount was equivalent to the amount of ammonia. The appearance of a large amount of lactic acid is important in connection with the amount produced by muscle.

It was concluded : (*a*) that ammonia is a normal antecedent of uric acid, (*b*) that the latter is formed by synthesis from ammonia and, probably, lactic acid, (*c*) that this synthesis can only occur in the body when the liver is acting.

Though only referring to uric acid and not urea, these results are interesting in relation to the origin of the latter. Uric acid replaces urea in birds' urine, and is the chief nitrogenous end-product into which urea, amido-acids, ammonium carbonate and formate or hypoxanthine is invariably converted. The analogy is obvious, and points to the liver as the active organ in bringing about the syntheses.

Glycogenic Function of the Liver.

A remarkable function of the liver is the production of a material of great interest to physiologists, viz. "animal starch," which has been thought to represent in the animal kingdom the starch stored up in vegetable tissues. It is widely spread throughout the body, and seems essential to the growth and nutrition of all the tissues, as indicated by the relatively large amount in the rapidly-growing tissues of the embryo.

It was discovered by Claude Bernard, who called it *glycogen*, from the readiness with which it was converted into sugar by diastatic ferments. He found that this change took place in the liver after its removal from an animal, and in a lesser degree during life, when the sugar was removed by the blood. From this he concluded that glycogen was stored in the liver until it was required by the tissues, when it was served out by the liver in the form of sugar.

Glycogen.

In *chemical composition* it closely resembles starch. It is converted into dextrose by dilute acids, and into maltose by saliva, pancreatic juice, or the diastatic ferments found in the tissues.

This change occurs rapidly after the removal of the liver or the death of the animal, and hence it has been supposed that a ferment is present in the liver tissue, being formed by the dying cells.

The sugar formed by the liver during life and found in the blood, is dextrose, not maltose. This fact and the similarity of the *post mortem* hydrolysis to other fermentive processes, seem to throw a doubt on the theory that the formation of sugar, in the dying liver, is the result of the vital activity of the cells, and not due to the presence of a ferment.

After a time all the glycogen disappears from the liver and is replaced by maltose, the relative amounts of each being equivalent to each other, and in proportion to the time that has elapsed since the animal's death. If a piece of liver be examined immediately after death, there is only a trace of sugar in the tissue.

The *mode of preparation* of glycogen depends upon the foregoing facts. The perfectly-fresh liver taken from an animal killed during digestion, four hours after a meal rich in carbo-

hydrates, is rapidly subdivided and placed in boiling water acidulated with acetic acid. When the liver cells have been coagulated by heat, and the formation of the ferment stopped, the pieces of liver are rubbed to a pulp in a mortar, and then re-boiled in the same fluid and allowed to stand until fully extracted. The liquor is then filtered, and from the filtrate the remaining albuminous substances are precipitated with potassio-mercuric iodide and hydrochloric acid, and removed on a filter. From the filtrate the glycogen may be precipitated by excess of alcohol, caught on a filter, washed with ether to remove fat, and dried.

The *properties* of glycogen, thus prepared, are the following: It is a white amorphous powder without smell or taste, forming a remarkably opalescent solution in water, which becomes clear on the addition of caustic alkalis. It is insoluble in alcohol or ether. With a solution of iodine it gives a wine-red colour, and not blue, like starch, which it otherwise much resembles in chemical characters.

It is *widely distributed* throughout the tissues, being abundant in many other parts besides the liver, namely, in the muscles, all protoplasm, inflamed organs, and pus, and in all the tissues of the embryo; in short, where any very active tissue-change or growth is going on, some glycogen can be found.

The *origin* of glycogen is easily traced to the liver. Some light is thrown upon its antecedents by the fact that the amount of glycogen in the liver depends in a great measure on the kind and quantity of food used. It rapidly increases with a full, and decreases with a spare diet, though it never disappears even in prolonged starvation. The amount of glycogen depends much more on the quantity of carbo-hydrate than of proteid food, for it rapidly rises with increase in the quantity of sugar taken, and falls when pure proteid (fibrin) free from carbo-hydrate is used. Although the large supply of glycogen normally manufactured in the liver is probably derived from the sugar of the food, we must not conclude from this that the liver cells cannot make glycogen from other materials, for glycerine in the food increases the amount. Possibly anything that suffices for the nutrition of their own protoplasm, and gives an adequate supply of material for their function, enables the cells to produce glycogen. It is increased in the starving animal by pure proteid food. The slow rate at which glycogen disappears in starvation would seem, in this case, to point to its origin from proteid.

Fatty food has no power to augment the amount of hepatic glycogen.

The glycogen in the liver *diminishes* rapidly after active muscular exercise, in certain diseases, and after the administration of certain poisons, *e.g.*, strychnin, which causes muscular spasms, and curara which paralyzes the vaso-motor nerves.

The *destiny* and physiological application of glycogen have been for some time vexed questions. Whether it is converted into sugar, and as such carried off by the blood to the tissues, or whether it is simply distributed as glycogen, is disputed by different observers, while others say glycogen is a step in the formation of fats out of carbo-hydrates.

The want of clear evidence on the subject, together with the obvious chemical difficulties, force us to abandon the theory that fat can be an immediate outcome of liver glycogen, though we must admit that carbo-hydrates, or any form of nutriment, may indirectly aid in the ultimate formation of fat by the protoplasm of the animal tissue.

It seems probable that glycogen forms the general carbo-hydrate nutriment of the growing and active tissues, particularly muscle which uses up a great quantity in its active state.

The difficulty of accurately determining the exact amount of either sugar or glycogen present in the blood, which contains so small an amount of either (under ·1 p.c. of sugar and traces of glycogen) makes such estimates an unsatisfactory basis for physiological views. The weight of evidence seems to be in favour of sugar being more plentiful in hepatic than portal blood, therefore it should be the form assumed by the carbo-hydrate for travelling through the system. Carbo-hydrate appears to be required in the tissues in the form of glycogen.

Diabetes.

As the symptom called by pathologists *Diabetes* has no anatomical entity as a disease, it is allowable here to mention some of the questions that suggest themselves to physiologists on the subject of glycosuria. It consists in the appearance of an amount of sugar (4 p.c. to 12 p.c.) sufficient to raise the sp. gr. of the urine, which is correspondingly increased in bulk, from 1030 to 1050.

Normally there is no sugar in the urine. How does it come to be present in diabetes? Is the kidney at fault, or is there an excessive quantity of sugar in the blood?

Its presence in the urine does not seem to depend on any failure on the part of the kidney, for the following reasons :—

1. It is not a common symptom of disease of the kidney. No lesion of the kidneys is found in the early stage of even the most severe cases, and the gland performs all its other functions thoroughly.

2. If the kidney deprived the blood of its sugar there ought to be less in the circulating fluid, but there is always an excess, the sugar being increased from ·1 p.c. to ·4 p.c., in some cases.

3. Sugar occurs temporarily in the urine as a result of many great general disturbances of the circulation, which have less influence on the kidney than on other organs.

Of the *causes* of fatal diabetes we are quite ignorant. The transient glycosuria of some fevers, &c., probably depends on vaso-motor disturbances set up by them. We can enumerate certain causes of so called artificial glycosuria, viz. :—

(1.) A reducing substance relating to the carbo-hydrates—glycuronic acid, formerly thought to be sugar—is found in the urine after the use of chloroform, chloral, morphia, curara, and other drugs.

(2.) Puncture of the floor of the 4th ventricle causes severe glycosuria, which, however, passes off in a few days, if the animal survive the operation.

(3.) Complete extirpation of the pancreas gives rise to severe glycosuria, which is said to be permanent.

The next question is, why does this excess of sugar appear in the blood? Does the surplus depend upon (1) diminished demand for carbo-hydrate in the tissues which can no longer use it? or, (2) is there an increased output of sugar from the liver?

The view that the power of decomposing the sugar is lost by the tissues (muscle) is supported chiefly by chemical argument, but the evidence that the demand for sugar is lessened in muscle, to such a degree as to give rise to so large a surplus in the blood, is too slight to upset some broader considerations. In diabetes the muscles are able to do their work, and therefore a fair amount of sugar must be used to supply the energy. If want of demand by the muscles were the cause of the surplus sugar, we should expect to find glycosuria as a regular concomitant of muscular paralysis.

That the excess of sugar in the blood depends on increased income from the liver, is rendered probable by the following facts :—

(1.) The amount of surplus sugar in the blood (*i.e.*, found in the urine) has a definite relation to the amount of carbo-hydrate food. No such equivalence is found in the normal animal.

(2.) Temporary and "artificial" glycosuria is always connected with great disturbance of the general blood pressure, which has more influence on the liver than on any other organ, for the liver is uniquely helpless with regard to its blood-supply from the portal vein.

(3.) The first principle of the glycogenic function of the liver is to regulate the percentage of sugar in the blood.

We are therefore entitled to conclude that glycosuria depends on some disturbance of the glycogenic function of the liver, but of how the latter is brought about in chronic diabetes we are so far quite ignorant.

The fact above referred to concerning the pancreas may in time give us some light, but at present the demonstration that its total removal causes acute glycosuria, remains a mystery. The influence of the pancreas cannot be exerted through the medium of its secretion entering the intestine, for even a small scrap of the tail of the gland, quite cut off from its connection with the gut, if left in situ seems to suffice to prevent sugar appearing in the urine. For the same reason the glycosuria cannot be attributed to operative injury of the solar plexus, or the nerves of the liver, for these are as much injured when only the main part of the gland is removed as when it is extirpated in its entirety.

CHAPTER XX.

SURFACE GLANDS.

THE secretions which are poured into the alimentary tract have been already described in the chapter on Digestion. There are other glands which may now be conveniently considered. They are subservient to very different functions; some having merely local offices to perform, and others having duties allotted to them of the greatest general importance to the economy. This becomes obvious from a glance at the following enumeration of glandular organs.

I. *Secreting glands* (other than those forming special digestive juices) :—

Lachrymal.
Mucous.
Mammary.
Sebaceous.

II. *Excreting glands* :—

Sudorific.
Urinary.

LACHRYMAL GLANDS.

Most vertebrate animals, that live in air, have a gland in connection with the surface of their eyes, which secretes a thin fluid to moisten the conjunctiva. This fluid passes from the eye into the nasal cavity, and helps to supply the inspired air with moisture.

The lachrymal fluid is clear and colourless, with a distinctly salty taste and alkaline reaction. It contains only about 1 per cent. of solids, in which can be detected some albumin, mucus, and fat (1 per cent.), epithelium (1 per cent.), as well as sodium chloride and other salts (·8 per cent.).

The secretion is produced continuously in small amount, but is subject to such sudden increase, that it cannot all escape by the nasal duct, but overflows as tears. This excessive secretion may be induced by the application of stimuli to the conjunctiva, the lining membrane of the nose, or the skin of the face, or by strong stimulation of the retina, as when one looks at the sun. A similar increase of secretion follows certain emotional states consequent on grief or joy. These facts show that the secretion of the gland is under nervous control; the impulses exciting secretion, starting, either from some sensory organ at the periphery, or from the emotional centres in the brain and passing along the sensory branches of the fifth, or along the optic nerve, are reflected in the bulb and arrive at the gland in the fifth nerve. The amount of secretion can also be augmented by direct stimulation of the lachrymal nerves, which are the efferent channels for the secretory impulse.

Mucous Glands.

In connection with secretions of the mouth, stomach, &c. mention has been made of glands which are elongated saccules, lined with clear cells, with highly refracting contents (Fig. 165). They are distributed over all mucous membranes, and are the chief source of the tenacious, clear, alkaline, and tasteless secretion called mucus.

This material contains about 5 per cent. of solid matters, of which the chief is *mucin*, a widely distributed body which swells up in water and gives the peculiar tenacity to the fluid. It is precipitated by weak mineral and acetic acids. The precipitate with the latter does not redissolve in an excess of the acid, which test distinguishes it from its chemical allies. Mucin is not precipitated by boiling. It is regarded as a glucoside, made up of a proteid and animal gum, which may be hydrated to sugar. Mucus also contains traces of fat and albumin, and inorganic salts, viz., sodium chloride, phosphates and sulphates, and traces of iron.

The fluid is secreted either by special mucous glands, or by the epithelium of the mucous surfaces. The cells produce a material in their protoplasm, which may often be seen to swell them out to a considerable extent. This clear substance is then expelled, and the altered cells are repaired or replaced. Many form-elements, remains of epithelial cells, are found in the secretion; and also round nucleated masses of protoplasm

similar to white blood corpuscles after the imbibition of water. In the abnormal secretion of a mucous surface during inflammation these mucous corpuscles are greatly increased, so that the secretion may become opaque, and may appear to be purulent.

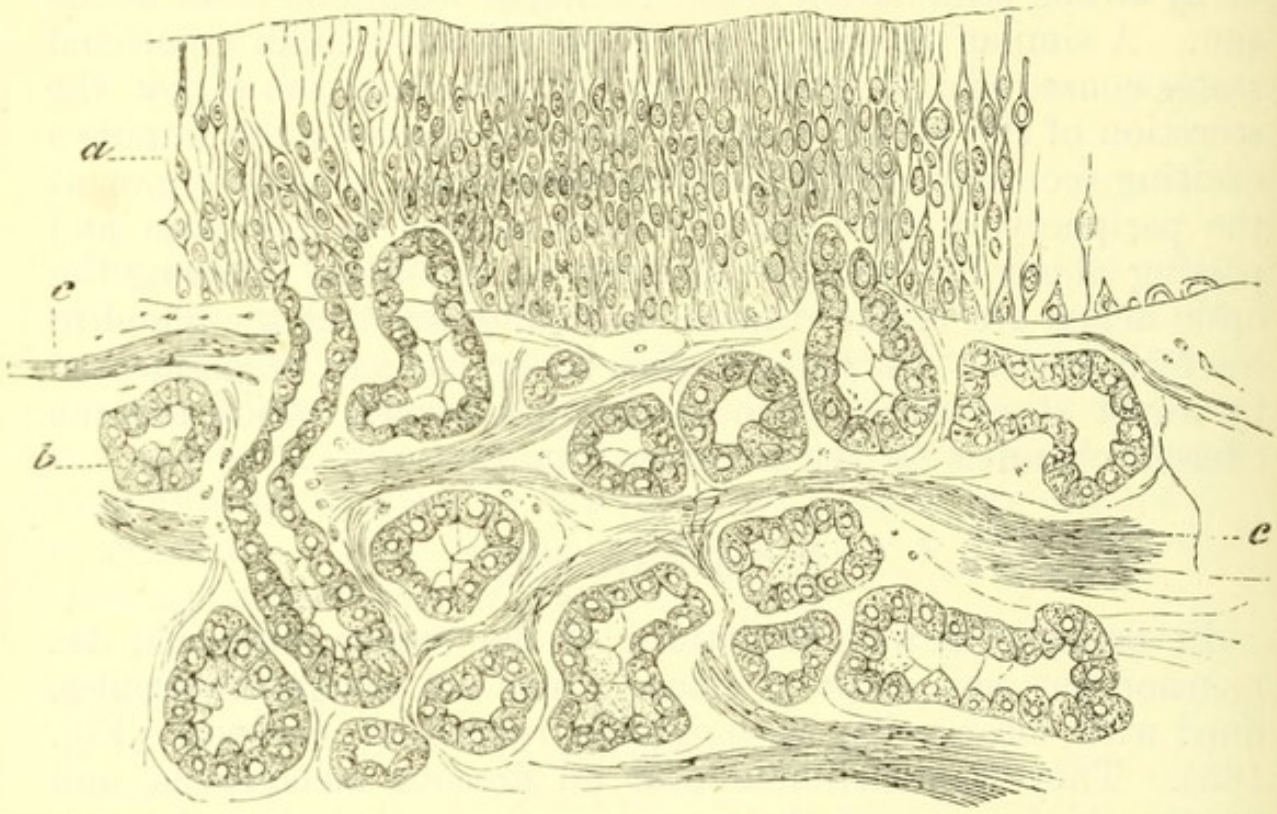


Fig. 154.—Section of the Mucous Membrane of the upper part of nasal cavity showing numerous Mucous Glands cut in various directions. *a*, Surface epithelium ; *b*, gland saccule lined with secreting cells ; *c*, connective tissue. (Cadiat.)

The chief object of the secretion seems to be to protect the mucous surfaces, which are rich in delicate nerves and vessels, and are subjected to many injurious influences of a chemical or mechanical nature.

Sebaceous Glands.

These belong to the outer skin, and open into the follicles of the hairs. They also appear on the free surface of the lips and prepuce, &c., where no hairs exist.

Their secretion cannot be collected in great quantity, but as far as can be made out, it is composed of neutral fat, soap, an albuminous body allied to casein, organic salts and water, about 60 per cent.

The secretion contains the remains of numerous epithelial

cells undergoing a peculiar kind of fatty change. These cells are gradually broken down during their sojourn in the alveoli. The secretion is finally pressed out by the band of smooth muscle which embraces the gland and squeezes it against the hair follicle.

The purpose of this secretion is to lubricate the surface with a fatty material. The Meibomian glands of the eyelids are

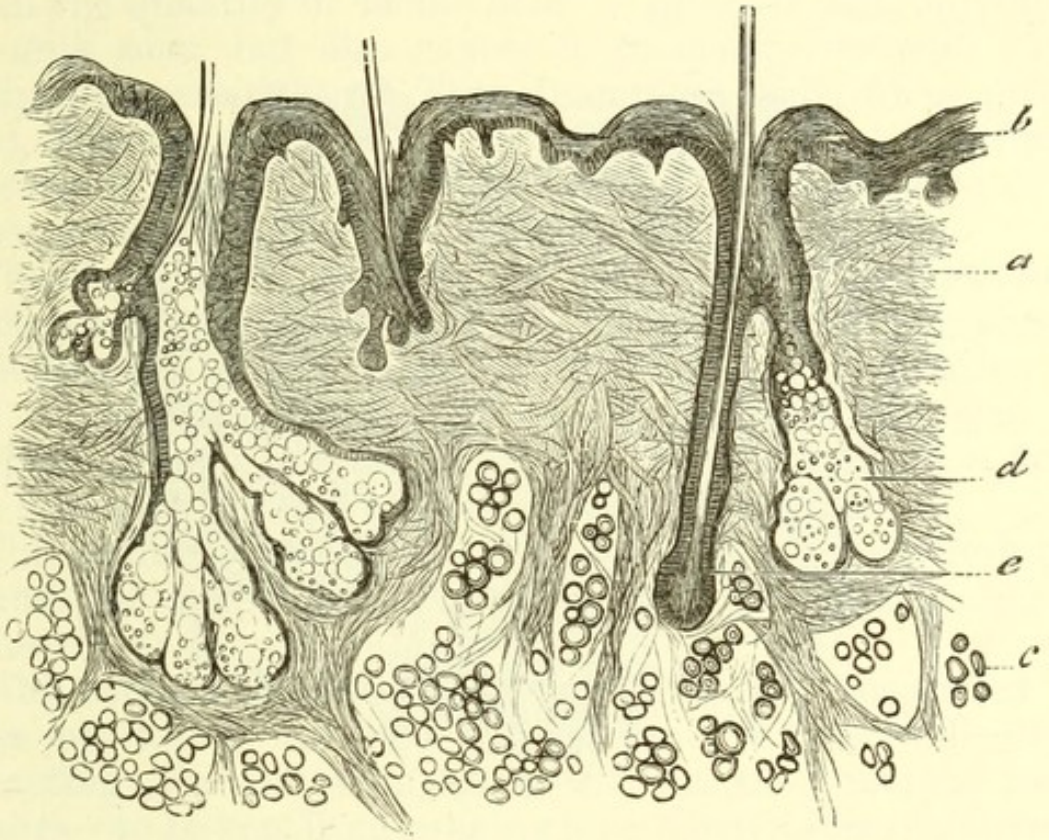


Fig. 155.—Section of Skin showing the roots of three hairs and two large sebaceous glands (*d*). (Cadiat.)

analogous structures, and are specially arranged for the lubrication of the ciliary margin. The glands about the prepuce and clitoris are also analogous to the sebaceous glands; in some animals (Castor) they secrete a peculiarly odoriferous material.

Mammary Glands.

These glands are characteristic of animals that bring forth their young alive (mammalia). The secretion of milk only takes place, under normal circumstances, after pregnancy, and continues for a limited period. The activity of the gland commences in the later stages of pregnancy, and then continues, if

the secretion be regularly withdrawn from the gland, for some 9 to 12 months.

During pregnancy the breasts undergo certain preparatory changes prior to the appearance of the milk. They increase in bulk owing to the greater blood supply and to certain changes in the cell elements of the compound saccular glands. Each breast contains a series of some ten to twelve glands with distinct ducts; upon these there are dilatations that act as reser-

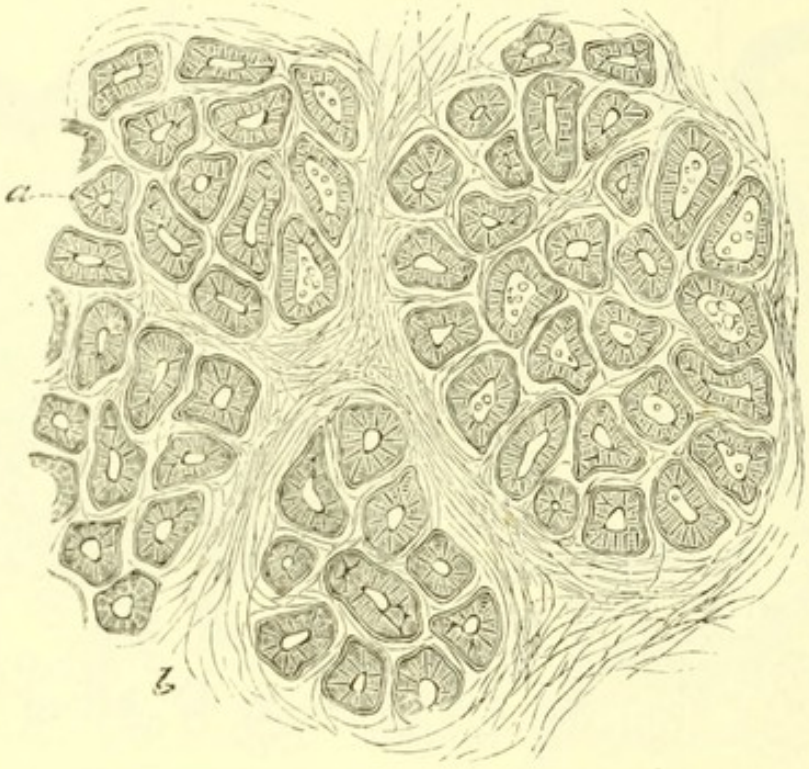


Fig. 156.—Section of Mammary Gland during active lactation (human).

(*a*) Saccules lined with regular epithelium.
(*b*) Connective tissue between the alveoli. (Cadiat.)

voirs in which, during active lactation, the secretion is stored until needed.

The alveoli are chiefly saccular in form, and are lined with a single layer of glandular epithelium. During active lactation they contain but little fat, though in the later stages of pregnancy, before the secretion is established, the cells contain quantities of large fat globules.

Milk.

Human milk is a yellowish white, perfectly opaque, sweetish fluid, with alkaline reaction and sp. gr. about 1030. The milk

of carnivora is acid. When exposed to the air in warm weather, the cow's milk, which is used for investigation, soon loses its alkalinity, first becoming neutral, and subsequently acid; the milk is then said to have "turned sour," but its appearance is not at first changed. This turning sour depends upon a change brought about in the milk sugar, by means of fermentation. The milk sugar, in the presence of a special bacillus, takes up water to form galactose, and then *lactic acid*. When the quantity of lactic acid is great, it not only makes the milk sour, but also causes it to crack, or *curdle; i.e.* it precipitates caseinogen. This albuminous body, when precipitated, entangles the fat of the milk, and we have thus formed the *curd* of cracked milk, whilst the fluid *whey* consists of the water, acid, salts, and remaining milk sugar.

The change brought about by the ferment known as *rennin*, which curdles milk in gastric digestion (see p. 141), must be distinguished from the above. The gastric fermentation is a true clotting or coagulation, *i.e.* change of caseinogen into casein. Human milk when curdled by rennet, gives a flocculent clot unlike the gelatinous curd of cow's milk.

The curdling of milk is never produced by boiling fresh milk, because the chief proteid is *caseinogen*, which does not coagulate by heat.

Milk consists of a fine emulsion of fat, the suspended particles of which are said—on account of the difficulty of extracting the fat with ether, without the previous use of alkalies—to be kept from running together by a superficial coating of dissolved caseinogen. When left at rest the light fatty particles float to the top, but do not run together. If kept clean and in a cool place, in some hours a thick yellow layer collects on the top of the milk. The thickness of this *cream* may be taken as a gauge of the richness of the milk.

When the mammary glands commence to secrete, the milk is called *colostrum*, and contains numerous peculiar structural elements which subsequently disappear from the secretion, but which are of considerable interest in relation to the physiological process. These are the *colostrum corpuscles*, which consist of large spherical masses of fine fat-globules held together by the remains of a gland cell, which encloses them, and in which at times a nucleus can be recognized.

Chemical Composition.

The most remarkable point about the chemical composition of milk is the large proportion of proteids and fat it contains. This fact renders it unique among the secretions.

Proteids: There are two distinct proteid bodies present, viz. (1) *Caseinogen*, which is like alkali albumin in not coagulating with heat and being precipitated by neutral salts ; but differs from it by not being readily soluble in weak acids and rapidly coagulating with rennet, which does not coagulate the alkali albumin. From globulin it may be distinguished by its not coagulating with heat. (2) *Lactalbumin*, which remains in solution after the caseinogen is precipitated by magnesium sulphate ; it coagulates slowly at the surface when heated to 70° C. It is partly precipitated by sodium sulphate. It differs from serum albumin in its power on the plane of polarised light, in its mode of coagulating by heat (p. 196), and in containing more sulphur.

Fats: The fats are present as globules of various sizes, being in the condition of a perfect emulsion as above stated. They consist of glycerides of palmitic, stearic, and oleic acids.

Carbohydrates : The milk sugar *lactose* like glucose reduces Fehling's solution, but not in so great proportion. It has the peculiarity of undergoing lactic fermentation, see p. 59.

Salts : Of the inorganic constituents of milk the most important are phosphates and carbonates of the alkalies, *i.e.* the salts required to form bone. It is a remarkable fact that the potash compounds, which are the most abundant in the red blood corpuscles, are present in greater quantity than those of soda. Iron is present in milk in very minute quantity—$\frac{1}{6}$ that found in the fœtal tissues, so the infant cannot depend on its food for its supply of iron, but has enough in its tissues when born for the new hæmoglobin formed while suckling.

A number of extractives exist in milk, but all in insignificant quantity.

The following table shows the composition of human milk, a comparison of which with that of some domestic animals will be found on p. 88 :—

Proteids . . .	39·24	
Fats	26·66	
Milk sugar . .	43·64	
Salts	1·38	
	——	110·92
Water		889·08

The relative quantity of the several ingredients of milk varies with the kind of diet used. A vegetable diet increases the percentage of sugar, but diminishes that of the other constituents, and also the general quantity of milk. A rich meat diet increases both the general quantity and the percentage of fats and proteids.

The quantity of milk secreted in the twenty-four hours is extremely variable in different individuals, and under different circumstances in the same individual ; the average in general being about two pints.

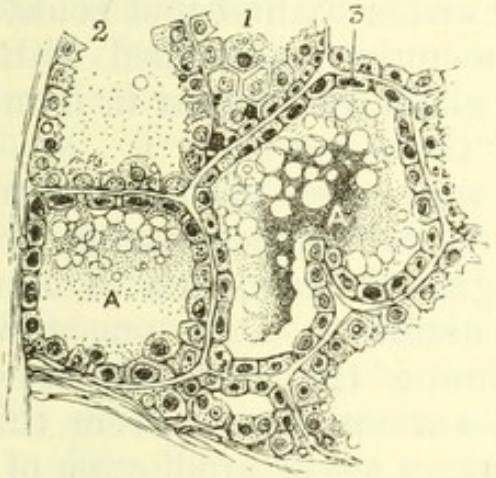


Fig. 157.—Section of the Mammary Gland of a Cat in the early stages of lactation.

(A) Cavity of alveoli filled with granules and globules of fat.

1, 2, 3. Epithelium in various stages of milk formation.

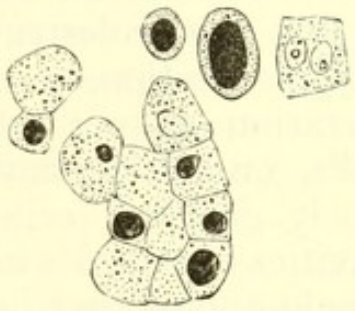


Fig. 158.—Cells of Mammary Gland during lactation, stained with osmic acid so as to show the various sized oil globules as black masses. (Cadiat.)

The amount of the different materials in milk varies under the following rules. The proportion of albumin increases as the milk sugar decreases, and the fat remains the same as the period of lactation advances. The portions of milk last drawn are much richer in fats than that which is first taken from the gland. In the evening the milk is richer in fat than in the morning. The general amount of solid constituents falls, up to the age of thirty years, then gains slightly until thirty-five, after which age the milk becomes decidedly thinner. These points should be borne in mind, as a knowledge of them may prove useful in the selection of a wet nurse.

Mode of secretion.—Although the blood contains albumins, fats, &c., very similar to those of the milk, we have good reason for thinking that the constituents of milk are not

merely extracted from the blood, but that the manufacture of this valuable secretion is due to the activity of the protoplasm of the gland cells, which construct the various ingredients as the result of their metabolism.

It has been suggested, as a simple explanation of the formation of milk, that the cells undergo fatty degeneration, and the secretion is then only the débris of the degenerated cells.

Some facts support this view. In the first place the ingredients one finds in milk are suggestive of, though not identical with, the chemical materials which can be obtained from protoplasm by chemical disintegration, rather than of any group of substances found in the blood. Further we find that colostrum corpuscles, which appear to be secreting cells filled with fat particles, are thrown off from the gland, and appear in numbers in the milk in the early period of the secretion.

But these colostrum corpuscles soon cease to be thrown off in the secretion, and the saccules of the glands during active lactation do not contain any signs of the débris of cast-off cells, or any gradations in degeneration. Only one row of finely granular cells is found lining the saccules, and the cavities are filled with globules of various sizes. From this it would appear that in the earlier stages of the production of the secretion, the mammary cells, after a long period of inactivity are so unaccustomed to the duty they are called upon to perform, that they succumb in the effort, and, being unable to produce the rich secretion and retain their vitality, they are cast off. Their successors acquire the necessary faculty of making within their protoplasm all the necessary ingredients of the milk, and discharge them into the lumen of the saccules without themselves undergoing any destructive change.

The composition of the milk teaches us that the cells of this gland can, from their own protoplasm, manufacture casein, fat, milk sugar, &c., which fact shows beyond doubt that these complex materials may be built up by animal cells just as they are by vegetable protoplasm.

The *influence of the nervous system* on the secretion of the mammary glands is distinctly shown by the wonderful sympathy between the action of these glands and the conditions of the generative apparatus. Even emotions have a marked effect not only on the quantity, but also on the quality of the secretion. Local stimulation also promotes the secretion, for the application of the child to the breast at once produces this effect, partly, it may be, through mental influences, but chiefly,

no doubt, by reflex excitation of the gland following the local stimulation.

For the details of the dietetic value of milk, see Chapter V. on Food, p. 88.

Excretions.

Sudoriferous Glands.

The term "excretion" is used to denote a gland-fluid the chief constituents of which are the result of katabolic changes in the tissues, and are of no use in the economy, but, on the contrary, require to be continually removed in order that their accumulation in the blood may not give rise to injurious consequences. These effete matters are collected by the blood and carried to the glands which preside over their elimination.

The next group of cutaneous glands is placed among the excretory organs, though its more important function, as will hereafter appear, is to supply the surface with moisture for the purpose of regulating the temperature.

The *sweat glands* are, in man, distributed all over the cutaneous surface, but in some parts, viz. the palms, soles, axillæ, and perineum, they are both more abundant and larger than elsewhere. They are absent in some animals (rats and rabbits), and localised in others (dog and cat), which only sweat on the pads of the feet. They are simple tubes extending in a more or less wavy manner through the skin, and ending some way beneath the corium in a rounded mass formed of several coils of the tube. The coil, which is the gland proper, is surrounded by a capillary plexus. The tube is lined with glandular epithelium, and its basement membrane is beset with longitudinally arranged smooth muscle fibres.

The *secretion of sweat* is always going on, though it does not constantly appear as moisture on the surface, because the amount produced in a given time is only just equal to the amount lost by evaporation. In this case it is spoken of as *insensible perspiration*. Under certain circumstances the sweat being produced more rapidly than it can be evaporated, collects on the surface and becomes obvious as liquid—*sensible perspiration*. The quantity of secretion necessary to become sensible varies with the dryness and temperature of the air, that is, with the rapidity with which evaporation takes place. It happens that the very circumstances which tend to assist evaporation also

promote the secretion of sweat. Great heat and dryness of the air increase the cutaneous secretion more rapidly than they increase the evaporation, therefore when the air is hot and dry and evaporation is going on very actively, the secretion of sweat is often only made just sensible to our feelings. When dampness is associated with warmth of the atmosphere the sweat collects in large quantities on the skin, for the heat aids the secretion, and the damp air impedes the evaporation.

The *quantity* of perspiration given off is considerable, but the wide limits within which the amount may vary render useless an attempt to express an average in numbers. The amount will depend on (1) the temperature of the air, (2) the quantity and quality of the fluids imbibed, (3) the amount of heat generated in the body, and it therefore varies directly with muscular exercise. The amount that becomes sensible depends on the rate of evaporation as well as on the amount of fluid produced.

The *chemical composition* of sweat varies with the amount secreted. When collected as a fluid by enclosing a part of the body in an impervious sac, it is found to have about 2 per cent. of solid matters, the greater quantity of which is made up of inorganic salts, sodium chloride being by far the most abundant. It also contains some epithelial débris, traces of neutral fats, and several volatile and fatty acids (butyric, propionic, caproic), to which it owes its peculiar smell. It sometimes contains urea. Since all the nitrogenous income is accounted for in the urea excreted by the kidneys, it is probable that the cutaneous elimination of urea is minimal, if not exclusively pathological. It affords a means of escape to many drugs and abnormal, or excessive, effete matters from the blood. In certain parts of the body, especially in some individuals, it contains a considerable amount of pigments, varying in colour from brick-red to bluish-black.

The *effect of nervous influence* on the secretion of sweat is so closely associated with the vaso-motor mechanisms of the skin that it is a difficult matter to separate the nervous influences acting on the vessels and on the glands. A dilated state of the vessels usually accompanies profuse sweating. But there can be no doubt that a special nervous mechanism controls the production of sweat. This is observed in some diseases, which variously affect the two sets of nerves. Thus, in some fevers, we observe a dry skin, red by an increased supply of blood, whilst in certain stages of acute rheumatism, the exact opposite

is seen, *i.e.*, a profuse sweat drips from the pale bloodless skin. Injury of the nervous centres gives rise to disordered sweating. It has been shown that in some animals (cats) the stimulation of the sciatic nerve, causing contraction of the blood-vessels, produces at the same time a copious secretion of sweat. This occurs even in the bloodless limb after amputation. A warm atmosphere is said to have no effect on the secretion of a limb the nerve of which has been cut, although the warmth be so great as to make other parts of the animal's body sweat profusely.

Besides the ordinary reflex activity excited from the skin sweating may be caused by stimulation of the mouth or gastric mucous membrane. This may be seen in a marked degree when the vaso-motor mechanism is disturbed locally, as by injury.

The *effect of drugs* upon the cutaneous secretion is well-known. There is a large group of medicines, especially pilocarpin, which produce an increased flow, while many others, notably atropin, have a contrary effect. They probably act on the centre directly.

Cutaneous Desquamation.

Together with cutaneous excretion should be mentioned the continuous and extensive loss from the superficial layers of the dried horny cells of all parts of the surface of the body.

The cells of the epidermis devote their nutritive activity to the production of a certain material—keratin, which forms an insoluble, impervious, tough coating, for the exterior of the body, which, though thin and elastic, is very strong and resisting.

The nearest analogy among the secretions to the keratin, is the production of mucin by the cells of the epithelial lining of the mucous membranes. Both substances perform a definite function, and they are produced by epiblastic and hypoblastic elements respectively.

The amount of nitrogenous substances thus excreted cannot well be reckoned, but having regard to the great extent of surface from which they are derived, it must be considerable.

CHAPTER XXI.

URINARY EXCRETION.

THE urine is the most important excretion, for by it nearly all the nitrogen of the used-up proteid leaves the body, in mammalia, in the form of *urea*. The construction of the urinary glands is peculiar, and requires special notice.

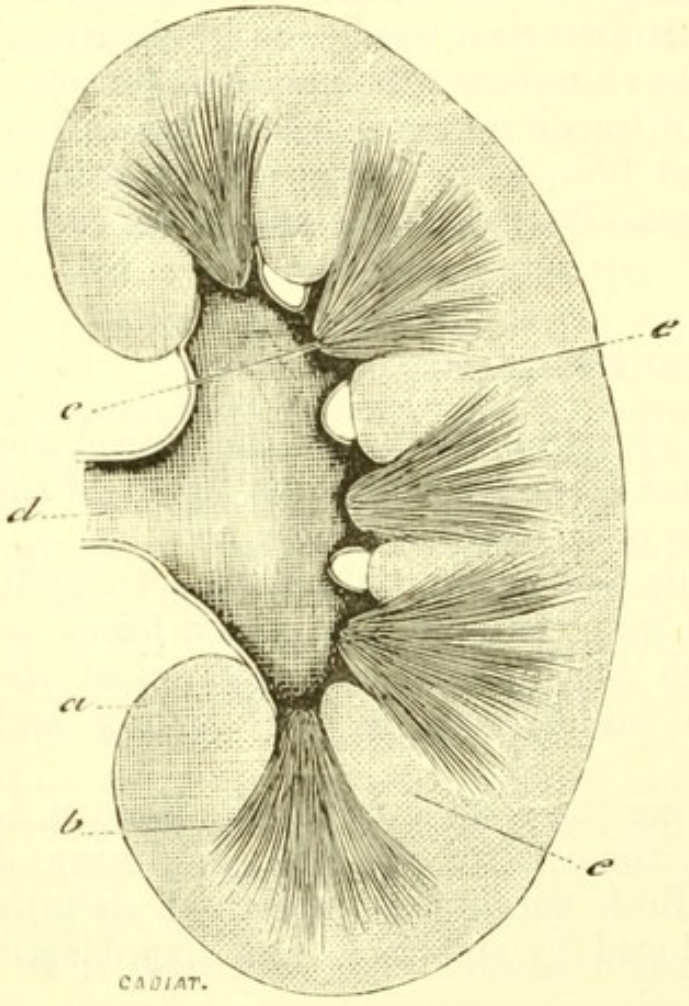


Fig. 159.—Section of Kidney of Man.

a. Cortical substance composed chiefly of convoluted tubules and Malpighian bodies.

b. Pyramids of medullary substance, composed of straight tubes and loops of Henle, radiating towards cortex.

c. Papillæ, where the tubes open into pelvis. —(Cadiat.)

d. Commencement of ureter, leading from central sac or pelvis.

STRUCTURE OF THE KIDNEYS.

The kidneys may be called complex tubular glands, the tubes of which they are composed being made up of a number of parts essentially differing from one another both in their structure and in their relation to the blood vessels.

The tubes begin in the cortex by a small rounded dilatation (*Malpighian body*) consisting of a bunch of capillary loops enclosed by *Bowman's capsule*, which is lined by thin flattened epithelium reflected over the capillaries. Opening from this capsule, Fig. 160 (*g*), is found a tor-

tuous tubule (*f*), lined by peculiar large rod-beset epithelial cells, which occupy the greater portion of its diameter. This

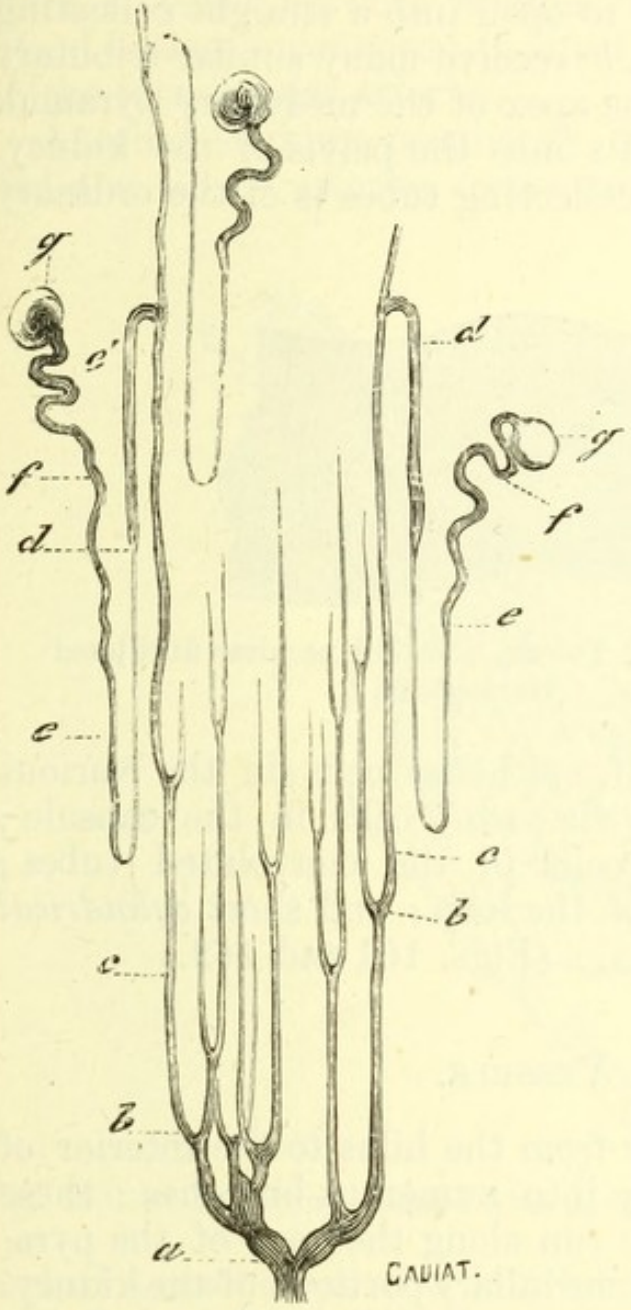


Fig. 160.—Diagram of the Tubules of the Kidney. (Cadiat.)

a. Large duct opening at papilla.
b and *c*. Straight collecting tubes.
d and *e*. Looped tubule of Henle.
f. Convoluted tubules of cortex.
g. Capsule from which the latter spring.

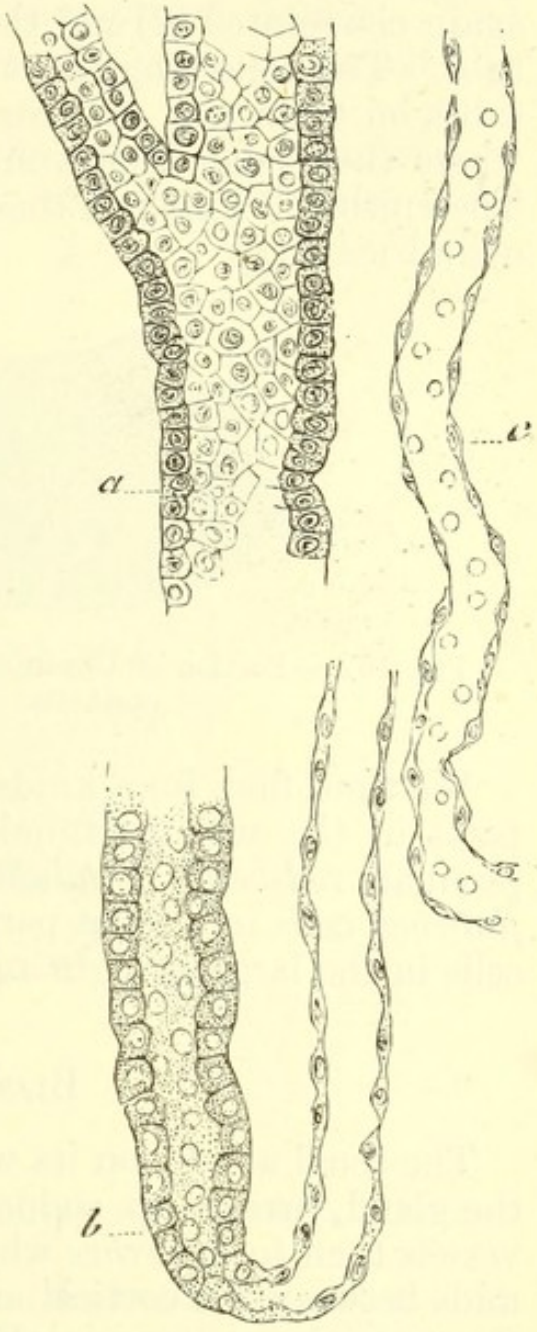


Fig. 161.—Portions of various Tubules highly magnified, showing the relation of the lining epithelium to the wall of the tube. (Cadiat.)

a. Large duct near the papilla.
b. Commencement of Henle's loop.
c. Thin part of Henle's loop.

convoluted tubule (*f*) leads into a tube (*e*) of much less external diameter, but about equal lumen, owing to the thinness of its lining epithelium, the cells of which are more flattened and

much thinner than those in the tortuous tubes. This thin tube forms a loop extending down to the medullary pyramid and returning to the cortex, where it can be seen to become again convoluted (*d*) and then to open into a straight collecting tube. The collecting tubes (*c*, *b*) receive many similar tributary tubes on their way towards the apex of the medullary pyramid, where they pour their contents into the pelvis of the kidney. The epithelial lining of these collecting tubes is of the ordinary cylindrical type.

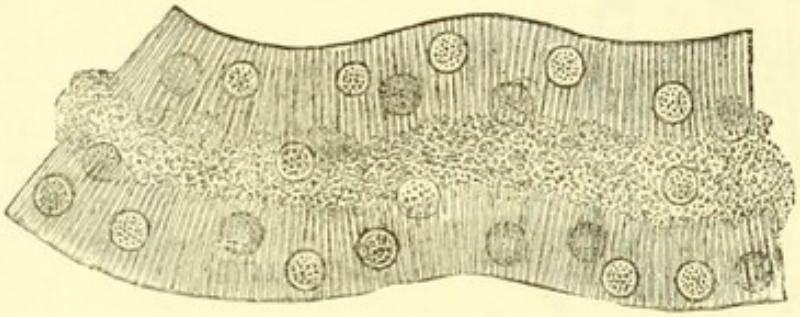


Fig. 162.—Portion of Convoluted Tubule, showing peculiar fibrillated epithelial cells. (Heidenhain.)

We thus find four kinds of epithelial cells in the various parts of the urinary tubules, viz., *scaly* cells in the capsule; peculiar *rod-beset glandular* cells in the convoluted tubes; *flattened* cells in a great part of the loop; and short *cylindrical* cells in the large straight tubes. (Figs. 161 and 162.)

Blood Vessels.

The renal artery, on its way from the hilus to the interior of the gland, breaks up suddenly into numerous branches; these vessels then form *arches* which run along the base of the pyramids between the cortical and medullary portions of the kidney. From the latter, tapering branches, called *interlobular arteries*, pass towards the surface, and give off numerous lateral branchlets (*vasa afferentia*) which enter the neighbouring Malpighian bodies. Within the capsules the afferent arteries at once break up into a bunch of capillary loops, forming a kind of tuft of fine vessels, the *glomerulus*, which nearly fills the cavity, and is only covered by thin, scaly epithelial cells reflected from those lining the capsule. The capillaries of the glomerulus are thus separated from the lumen of the tube, and are enclosed in a delicate sack. The capillary loops unite to form the *vas efferens*. It is a singular fact that the

efferent vessel is smaller than the afferent, and on leaving the glomerulus does not, like most veinlets, unite with others to form a larger vein ; but again breaks up into capillaries, which form a dense network around the convoluted tubules. The blood is thence conveyed to small straight veins corresponding to the intralobular arteries.

Another striking peculiarity of the renal vessels is that a distinct set of arteries (*vasa recta*), starting from the same

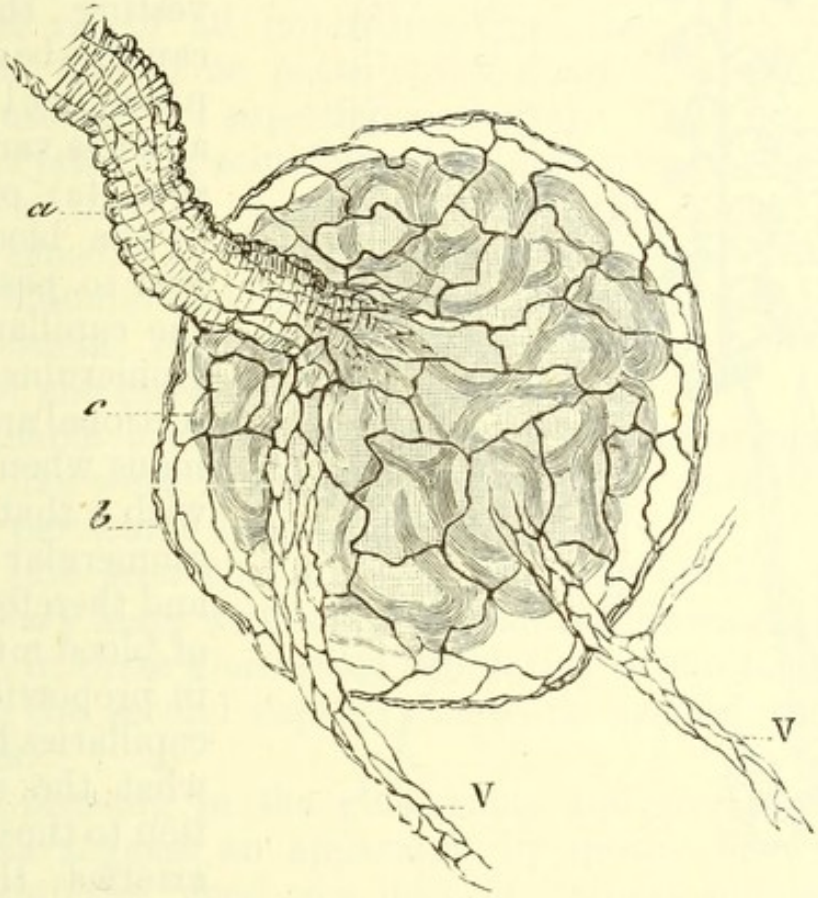


Fig. 163.—Glomerulus, treated with silver nitrate, showing the endothelium.

arched branches as the interlobular (between the cortex and medulla), pass towards the centre of the gland into the pyramids. They consist of bunches of straight arterioles, which lie between the straight and the looped tubules. Corresponding with these straight arteries are long meshed capillaries and minute straight veins, which carry the blood back to the vessels at the base of the pyramids.

In the kidney, then, we have three sets of capillary vessels, which differ in their position, the form of their meshes, and their relation to their patent artery. The pressure and the rapidity of flow of the blood in them differ also, as follows :—

1. The capillaries in the glomeruli are loops collected into a

tuft by their covering of delicate epithelium. On account of (1) the afferent artery ending abruptly in these capillaries, and of the efferent vessel (2) being smaller than the afferent, and (3) breaking up into a secondary plexus of capillaries, which offer additional resistance, the pressure and velocity within the glomerulus must be great.

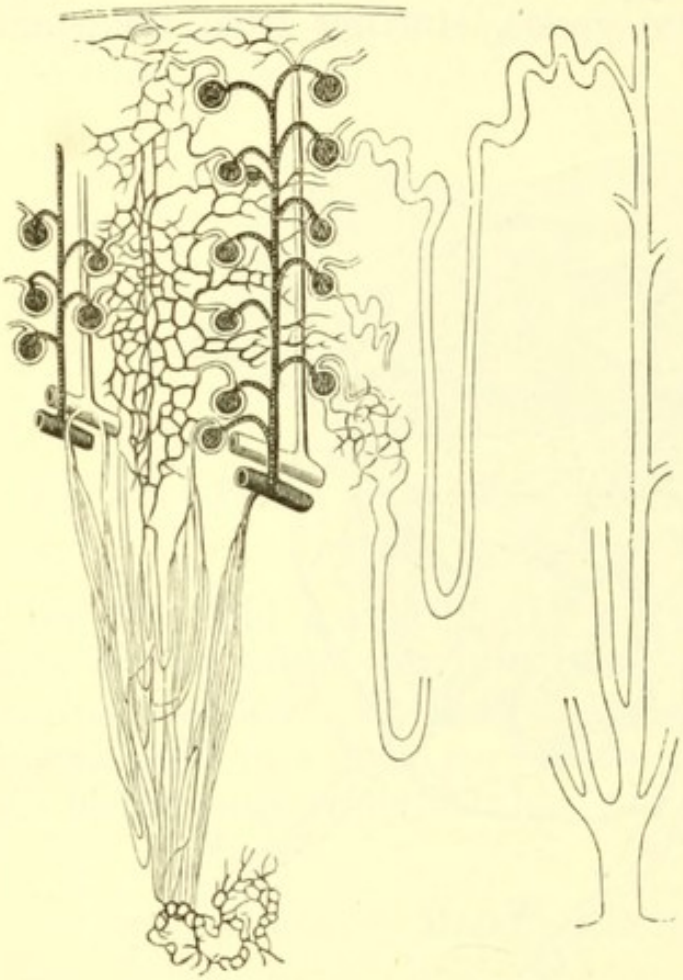


Fig. 164.—Diagram showing the relation borne by the blood vessels to the tubules of the kidney. The upper half corresponds to the cortical, the lower to the medullary part of the organ. The plain tubes are shown separately on the right, and the vessels on the left. The darkly shaded arteries send off straight branches to the pyramid and larger interlobular branches to the glomeruli, the efferent vessels of which form the plexus around the convoluted tubes.

2. The secondary capillary plexus investing the tubules can only be under comparatively trifling and less variable pressure, (*a*) on account of the blood having first to pass through the capillaries of the glomerulus. (*β*) Their sectional area is enormous when compared with that of the glomerular vessels, and therefore the flow of blood must be slow in proportion. These capillaries have somewhat the same relation to the glomerular arteries that exists between the portal capillaries and the intestinal arteries. The similarity is still greater in the lower vertebrates, in which this plexus is mainly derived from the veins of the lower extremities.

3. The straight vessels have long meshed capillaries, which lie between the looped and straight tubules. In these straight vessels the blood flows with greater velocity than in those around the convoluted tubes. The pressure of

their blood, though less than that in the glomeruli, is greater than that in the intertubular capillaries.

Secretion of the Urine.

We cannot be surprised at the complicated arrangement of vessels and tubes, and the variety of epithelial cells in the kidney if we consider the divers duties the organ has to perform. It has to get rid of all impurities from the blood. Whether the result of normal or pathological change, it eliminates all injurious, useless or superfluous matter. Whether they be colloid or crystalloid, soluble or insoluble, alkaline or acid, the kidney expels them if they tend to alter the normal constitution of the blood. It discriminates between the proteids, expelling egg-albumin and carefully retaining serum-albumin. It gauges the sugar, removing the least excess of dextrose. It presides over the reaction of the blood.

We are unable even to guess in what particular part of the gland such like work is done. Possibly each class of function has its own particular kind of cell or tube.

We have just seen that the *afferent* artery breaks up into a tuft of capillary loops within the capsule of Bowman, and that the pressure in these glomerular capillaries is habitually higher than that in the second capillary network around the convoluted tubules.

The high pressure in the glomerulus and the arrangement of its vessels suggest an apparatus by means of which the watery parts of the blood pass into the urinary tubules. This view seems supported by the fact that, within certain limits, the quantity of urine secreted bears a direct proportion to the blood-pressure in the minute renal vessels, whether the change in pressure depends on local vascular mechanisms, or on changes in the general blood-pressure. Comparative anatomy also supports this suggestion, for the more watery the urine the more complex the Malpighian body. In snakes which void solid urine the glomerulus is very small.

It was seen that in a great part of the tubules, both the epithelial and vascular supply give the idea of actively secreting gland tubes. Thus from the mere construction of the gland, it has been concluded that there are two distinct departments each of which play a different part in the production of the urine. (1) "The tuft of vessels to furnish the fluid portion of

the urine, while the solid matter is separated by the aid of the (2) glandular epithelium lining the convoluted portion of the tube."

Such was the simple view of Bowman, enunciated more than 50 years ago and since confirmed by much experimental evidence.

This view does not quite adequately explain the formation of urine, because the latter differs so materially from the fluid obtainable by filtering the blood. Urine contains no proteid, and it is incomparably richer in urea and salts than the blood plasma. This difference implies a distinct selection in the glomerulus, indicating a secretive process.

Further, this view assigns no special function to the loops of Henle and special set of vessels.

Ludwig, admitting that the watery part of the plasma, bearing with it the salts, &c., was separated at the glomerulus, suggested that as this fluid passes through the tortuous urinary tubules, a large portion of the water is re-absorbed into the capillary networks surrounding them. This re-absorption is assisted by the high specific gravity of the blood, under low pressure, in these capillaries, as compared with those of the glomeruli, where the filtration of the liquid occurs. The *rôle* of the epithelium is then not only selection from the blood of specific materials, but the re-absorption of much fluid and possibly the prevention of the return of the solids to the blood vessels.

Why simply water and salts, without albumin, should pass through the capillaries of the glomerulus and not through any other capillaries, is not sufficiently explained. No doubt there are many such selections which we can only explain as vital phenomena, but the difficulty gave rise to a view which is worthy of mention. From the fact that where vascular filtration—*i.e.*, the passage of liquid under pressure through the capillary wall—occurs elsewhere in the body, not only water and salts, but also plasma passes out of the vessels, we should assume that the fluid part of the blood, as such, and not merely its watery part, escapes at the glomerulus. That is to say, the plasma containing the solid ingredients of the urine in a diluted form, pass into the capsule. But on its way down the long and circuitous route through the tubules, the proteids with much water are re-absorbed by the capillaries of the convoluted and looped tubes. The first step in this case is a mechanical filtration ; the second is a vital process of re-absorption of a solution of serum-albumin carried on by the gland-cells in the

tubules. This view is said to be supported by pathological experience, as the removal of the epithelium from the tubes (the glomeruli remaining perfect) is followed by the appearance of albumin in the urine, and cysts formed by the destruction of the epithelium and occlusion of the tubules, contain a fluid somewhat like plasma.

Heidenhain confirmed Bowman's view by experiment. He introduced into the blood a blue colouring matter—pure sodium sulphindigotate—which he found to be eliminated by the kidneys, giving rise to blue urine. On examining the organ with the microscope at a suitable time after the injection of the colour into the blood, the entire tubules are found to be filled with the pigment, and in some cases the peculiar epithelium of the convoluted portion is stained with the blue substance, while the glomerulus and capsule are entirely free from the colour. If the stream of fluid from the glomerulus be stopped in any way—tying the ureter, section of the spinal cord, or local destruction of the glomeruli—the blue colour is only to be found in the convoluted tubes and their epithelium, and hence he concludes that its presence in the looped and collecting tubes of the kidneys and urinary bladder, depends upon its being washed out of the convoluted tubes by the stream of fluid poured out from the blood at the glomerulus.

Nussbaum showed in frogs and newts—which have an arterial supply to the glomeruli, and a venous one to the tubules—that sugars, &c., which freely escaped by the intact kidney, after being introduced into the blood, were no longer eliminated when the arteries to the glomeruli were tied. But urea injected into the blood was excreted whether the arteries were tied or not—the urea was accompanied by some water, but indigo-carmine merely passed into the epithelium, no water appearing to wash it into the tubes. The value of this evidence is impaired by the fact that some glomerular blood flows into the peritubular capillaries.

The following facts also support the view that the glandular epithelium takes the chief share in the removal of the more important solid constituents of the urine.

The amount of liquid passing out at the kidneys is in direct proportion to the blood pressure, whereas the excretion of the specific constituents of urine is independent of the pressure, but is related to the amount of each existing in the blood, and the condition of the epithelium. This is shown by the increased elimination of urea when that substance is artificially intro-

duced into the circulation, even after the flow of the fluid has been checked by section of the spinal cord.

The epithelium in the tubules of the kidney of birds is found impregnated with acid urates, which form the chief constituents of the solid urine of birds, but are not found in any other part of the kidney.

That the glandular epithelium takes an active part in the elimination of the urea is rendered certain by the researches of Heidenhain, &c., and the escape of watery solutions is confirmed by the experiments of Nussbaum. Yet there remain the loops of Henle, which are invariably found in the kidney, and have a special vascular mechanism, to which only the function of re-absorption has been assigned.

Reviewing these different explanations of the secretion of urine by the light of our present knowledge of other secretive processes, there seems to be but little doubt, that a distinctly selective power must be assigned, not only to the large epithelial cells lining the convoluted tubes, but also to their homologues, the thin cells covering the capillaries in the glomerular tuft, as well as both varieties in Henle's loop. Each of these cell groups probably has a specific secretion to make, the sum total of the work being urine. There is ample evidence that the term filtration is quite inapplicable to the process occurring in any region of the tubes or in the capsule.

The Urine.

When freshly voided the urine of man in health is a clear straw-coloured fluid, with a peculiar aromatic odour. The intensity of the colour normally varies with the amount of solids—the colour being a rough indication of the degree of concentration. On standing and cooling a slight cloud of mucus often appears floating in the fluid. This comes from the lining membrane of the bladder, and it usually entangles a few flattened epithelial cells, which are the only organised structural elements found in it in health.

The fresh urine of carnivorous and omnivorous animals has a distinctly acid reaction. This does not depend upon the presence of free acid but upon acid salts, particularly acid sodium phosphate, which it invariably contains. A strictly vegetable diet renders man's urine alkaline, and it becomes less acid after meals. In the herbivorous mammalia the urine is normally alkaline, but

when they are deprived of food for some time it becomes acid, showing that the alkalinity depends upon their diet.

The specific gravity of urine varies greatly, normally ranging between 1015—1025. After copious drinking, abstinence from proteid food, and in cool weather it may possibly fall as low as 1005, and, on the other hand, after prolonged abstinence from liquids, much animal food, and very active sweating, it may attain 1040 without pathological process.

The quantity of urine secreted is also very variable, broadly, being in proportion to the amount of blood flowing through the renal capillaries ; the amount produced by an adult is usually about 2 pints per diem (1000—1500 c.c.) The amount is increased by—(1) increase of rate of flow through glomerulus from elevation of the general or renal blood-pressure ; (2) contraction of the cutaneous vessels from cold ; (3) copious drinking ; (4) excess of nitrogenous diet ; (5) the presence of certain matters in the blood, such as sugar, salt, &c. ; (6) the presence of urea ; and (7), various medicaments, having a special action on the renal secretion.

Although the quantity of urine differs so much under different circumstances, the amount of solids excreted by the kidneys in the 24 hours remains pretty much the same, being on an average over 1½ oz. (50 grammes) for an average adult man.

From this it is obvious that the sp. gr. must vary inversely with the amount of fluid secreted, so that the more scanty the urine the higher we expect to find the per-centage of solids.

Source of the Urinary Constituents.

It may be regarded as established that the chief materials of the urine pre-exist in the blood and are therefore merely removed by the kidney. The synthesis of hippuric acid by the cells of the kidney may be named as an important exception. (See pp. 50 and 377.)

The following points may be recapitulated :—

1. The blood normally contains most of the urinary constituents.

2. The blood of the renal artery is said to contain more urea, uric acid, &c., than that of the renal vein.

3. If the renal arteries or the ureters be tied, accumulation of urinary products in the blood results.

4. Extirpation of the kidneys also gives rise to increase of the urea in the blood.

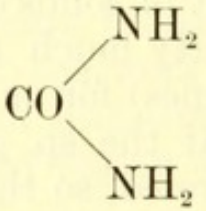
5. In diseases which suppress the secretion of the kidneys, an accumulation in the blood of injurious materials takes place, and gives rise to grave symptoms called uræmic poisoning, which closely coincide with those observed in experimental annihilation of the renal function.

Chemical Composition of Urine.

The per-centage of the solid and liquid materials in urine varies much, but on an average it may be said to contain about 4 per cent. of solids and 96 per cent. of water.

The following are the more important solid materials :—

Urea is the most essential, and at the same time most abundant solid constituent, forming on an average about 2 per cent. of the urine. It is regarded as the chief end-product of the oxidation of the nitrogenous matter in the body, so that its amount per diem gives us an estimate of the nitrogenous metabolism. It is readily soluble in alcohol and water, but insoluble in ether. It forms acicular crystals with a silky lustre. From a chemical point of view it may be regarded as carbamide, with the formula



It is isomeric with ammonium cyanate, from which it was first prepared artificially.

$$NH_4.CNO = CO.(NH_2)_2.$$

On exposure to the air bacteria develop in the urine, and, acting as a ferment, change the urea into ammonium carbonate, two molecules of water being at the same time taken up thus :

$$CO(NH_2)_2 + 2H_2O = CO(ONH_4)_2 \text{ or } (NH_4)_2CO_3.$$

This gives rise to a change in the reaction of the urine, which after a time becomes increasingly alkaline, and the change is spoken of as the alkaline fermentation of the urine. This change is extremely slow in solutions of pure urea, which do not support bacterial life.

With nitrous acid or sodium hypobromite it is decomposed with brisk effervescence of gases N and CO_2.

With nitric and oxalic acids, urea forms sparingly soluble salts—a fact made use of in its preparation from urine.

The *amount* of urea eliminated in the 24 hours is about 500 grains (35 grammes). Its production varies (1) with the character and quantity of the diet, the amount increasing in direct proportion to the quantity of proteid consumed. Fasting causes a rapid fall in the amount of urea; even in the later days of starvation it continues to fall, but very slowly. (2) It varies with the amount of urine secreted; an increase in the bulk of the water being accompanied by a slight increase in the urea eliminated. Some materials, such as common salt, increase the water, and thereby also increase the urea. (3) The amount differs with age, being relatively greater in childhood than in the adult (about half as much again in proportion to the body weight). (4) Many diseases have a marked influence on the amount of urea. In most febrile affections it increases with the intensity of the fever, while in disease of the liver it often notably decreases. In diabetes, if the consumption of food be very great, the daily excretion of urea may reach nearly 4 oz. (100 grammes) or three times as much as normal.

Preparation.—To obtain urea from human urine it is evaporated to one-sixth of its bulk, an excess of nitric acid is added, and it is left to stand in a cool place. Impure nitrate of urea separates from the fluid as a yellow crystallized precipitate. This sparingly soluble salt is caught on a filter, dried, dissolved in boiling water, mixed with animal charcoal to remove the colouring matter, and filtered while hot; when the filtrate cools, colourless crystals of nitrate of urea are deposited. The precipitate is dissolved in boiling water, and barium carbonate added as long as effervescence takes place, barium nitrate and urea being produced. This is evaporated to dryness, and the urea extracted with absolute alcohol, which on evaporation leaves crystals of pure urea.

Estimation.—Urea can be estimated volumetrically by the *method of Liebig*, which depends on the power of mercuric nitrate to give a precipitate with it. The sulphates and phosphates must be first removed by the addition of 20 c. c. of a mixture of 1 volume saturated barium nitrate and 2 volumes saturated solution of caustic baryta, to 40 c. c. of urine. This is filtered, and 15 c. c. of the filtrate, an amount corresponding to 10 c. c. urine, is taken. Into this known volume of urine a standard solution of mercuric nitrate (of which 1 c. c. precipitates ·01 gramme of urea) is dropped until a sample drop of the liquid, mingled on a watch-glass with a drop of concentrated sodium carbonate solution gives a yellow colour,

which indicates that some free mercuric nitrate is present. For every cubic centimetre of the standard mercuric solution used, there is one centigramme of urea in the sample of urine; a reduction of 2 c. c. should be made from the mercuric solution used in the experiment on account of the chlorides, which are present in tolerably constant amount.

A readier and more accurate method (*Hüfner's*) consists in adding a known quantity of urine to a solution of sodium hypobromite (NaBrO), containing an excess of caustic soda, in an apparatus by which the gas evolved may be collected and measured. The urea is decomposed in the presence of this salt; the CO_2 is absorbed by the free soda and free nitrogen evolved—

$$CO(NH_2)_2 + 3(NaBrO) + 2(NaOH) = 3NaBr + Na_2CO_3 + 3H_2O + N_2.$$

The quantity of urea may be determined by ascertaining the volume of nitrogen, which can be measured directly in a graduated tube. 35·4 c. c. of N represents 0·1 gramme of urea at ordinary temperature and pressure.

Uric acid, of which the formula is $C_5H_4N_4O_3$, is only present in extremely small quantities in the normal urine of mammalia, but in birds, reptiles, and insects its salts form the chief ingredient of the renal secretion. It is sparingly soluble in water, and insoluble in alcohol and ether. However, in solutions of the neutral phosphates and carbonates of the alkalies it combines with some of the base, so as to form acid salts, and at the same time converts the neutral into acid phosphates. Physiologically only quadri-urates are found in the body or urine; the soda salt, which alone is commonly found, has the formula

$$HNa.C_5H_2N_4O_3.\ H_2.C_5H_2N_4O_3.$$

Its salts are more soluble in warm than in cold water. Uric acid is readily converted into urea by oxidation out of the body. It may possibly be one of the steps in the formation of urea, occurring in the body.

The presence of uric acid may be recognized by the murexide test. The substance to be tested is gently heated and cautiously evaporated, in a flat capsule, with some nitric acid. A decomposition occurs, a yellow residue remaining. A drop of ammonia gives a striking purple colour, which on the addition of potash turns violet.

The amount of uric acid normally follows pretty closely the

variations in urea, but is, usually, only about 8 grains (·5 gramme) per diem. In certain diseases the quantity may be much increased. For the rough quantitative estimation, crystals of the acid may be thrown down by hydrochloric acid. After standing 24 hours these are caught on a weighed filter and estimated by weight. For other methods the student must consult the text books of physiological chemistry.

Kreatinine ($C_4H_7N_3O$) is always present in urine, probably being formed from kreatine by the loss of one molecule of water. About 15 grains (1 gramme) is excreted per diem.

Xanthine ($C_5H_4N_4O_2$) also occurs in urine, but in extremely small quantities.

Hippuric acid ($C_9H_9NO_3$) is a normal constituent of human urine, occurring, however, in very small quantities. On the other hand, it is one of the most important nitrogenous constituents of the urine of the herbivora, where it takes the place of uric acid. Its presence depends on the existence of certain ingredients in the food containing benzoic acid ; the latter is capable of combining with glycocine to form the acid, a molecule of water being formed at the same time, thus—

$$\underset{\text{Benzoic Acid.}}{C_6H_5.CO.OH} + \underset{\text{Glycocine.}}{CH_2.(NH_2)CO.OH} =$$

$$\underset{\text{Hippuric Acid.}}{CH_2.(NHC_6H_5CO)CO.OH} + \underset{\text{Water.}}{H_2O}.$$

The amount of hippuric acid increases with increased consumption of vegetable food. The union of glycocine and benzoic acid takes place in the kidney, the excised organ being capable of effecting this synthesis if blood containing these substances be passed through its vessels.

Oxalic acid ($C_2H_2O_4$) occurs often but not constantly in the urine. It is generally united with lime. It is said to appear in greater quantity, together with an excess of uric acid, after meals, and therefore to be related to the production of the latter in the body ; but it probably is chiefly derived from oxalates being contained in some materials taken with the food.

Indican or indoxyl-sulphate of potassium is present in the urine of man, and in greater quantity in that of herbivora. It is formed from indol consequent on the pancreatic digestion. Under certain conditions it can be converted by oxidation into indigo-blue.

Colouring Matter.

(1). *Urobilin* is the normal colouring matter of the urine. It is an outcome of the biliary pigments, and therefore a derivative of the colouring matter of the blood. It is probably the same as hydrobilirubin, some of which is absorbed from the intestinal tract and eliminated by the kidneys. There is reason to believe that other sources of urobilin exist.

(2). *Urochrom* is probably impure urobilin.

Inorganic Salts.

The urine is the great outlet for all inorganic salts. The most important of these are—

Common salt (NaCl) of which a very variable, but always considerable amount is found in the urine. The average quantity excreted per diem may be said to be about half an oz. (15 grammes). It depends greatly on the quantity taken with the food, and falls during starvation, but does not completely disappear. It is said that if absolutely no common salt be taken with the food the quantity of NaCl excreted diminishes greatly, and albumin appears in the urine about the third day. The amount of salt eliminated follows, with striking accuracy, the changes that take place in the quantity of urea excreted. This fact seems to indicate that there is some relationship between the secretion of the two substances, or that sodium chloride participates in the chemical changes of the nitrogenous tissues. In many diseases variations in the quantity of common salt in the urine occur which can hardly be explained by the change in food.

Phosphates.—About 60 grains (3 to 4 grammes) of phosphoric acid are excreted daily in the urine, being combined with alkalies to form salts, viz., sodium, potassium, calcium, and magnesium phosphates. These salts are increased after meals.

Sulphates.—Nearly 40 grains (2 to 3 grammes) of sulphuric acid, as sulphates of alkalies, are daily got rid of in the urine. The acid comes partly from the food, but chiefly from the oxidation of the sulphur contained in the proteids of the tissues.

A considerable quantity of *potassium*, *sodium*, *calcium*, and *magnesium*, combined as already mentioned, or with chlorine, is contained in the urine.

Small traces of *iron* are also always present in the urine.

Gases.—The urine also contains free CO_2, N, and some O. 100 volumes of gas pumped out of fresh urine have been found to consist of—

$CO_2 = 65{\cdot}40$ per cent.
N $= 31{\cdot}86$ „
O $= 2{\cdot}74$ „

CO_2 is present in the urine to the amount of about 10 vols. p. c.

Abnormal Constituents.

Different substances occur in urine under circumstances of physiological interest, and may be here enumerated, although their accurate study belongs rather to pathology. First amongst these to be named is,—

Albumin, which occurs from (1) any great increase in the blood-pressure in the renal vessels, particularly when caused by impeded outflow. (2) Excess of albumin in the blood, and, strange to say, some forms of albumin escape much more readily than others. Thus, egg albumin, globulin, or peptone, if introduced artificially into the blood, are soon found in the urine. (3) A watery condition of the blood, such as would give rise to œdema elsewhere. (4) Total abstinence from NaCl for some time. (5) Destruction of the epithelium of the urinary tubes.

Next in importance to albumin are the following :—

Grape sugar; of which normally only the merest trace occurs in the urine, although there is always a certain quantity in the blood. It is present in large quantities in (1) the disease known as diabetes, when a great quantity of pale urine with a very high specific gravity is passed. (2) After injury of a certain part of the floor of the 4th ventricle of the brain. (3) After total excision of the pancreas. (4) After poisoning by curara, carbonic oxide, and nitrate of amyl. In short any great disturbance of the circulation of the liver gives rise to an increase of sugar in the blood which normally only contains ·1 per cent. and when the amount reaches ·3 per cent. it appears in the urine.

Bile Acids and *Pigments* appear in the urine when, from occlusion of the bile ducts, they find their way into the blood.

Leucine and *Tyrosine* also occur in the urine, but only after interference with the function of the liver, such as follows phosphorus poisoning.

The urine undergoes important changes after being voided, the explanation of which is of much interest to the practitioner, and must be understood by the student of medicine. The urine often loses its transparency as soon as it gets cold, though perfectly clear when passed, or when again heated to the body-temperature. This "muddiness," which soon settles down as a more or less brightly coloured sediment, is chiefly caused by the precipitation of sodium quadri-urate, stained with a colouring matter derived from the urinary pigment; for the urates, though soluble in warm, are almost insoluble in cold water. When this occurs the urine will always be found to be distinctly acid, and if it be left standing for some time in a cool place, the acidity will be found to increase.

After a certain time (which is shorter when the urine is not very acid and is exposed to a warm atmosphere) the development of bacteria occurs in it, and causes the urea to unite with water, and to change in the manner already mentioned (p. 46) into ammonium carbonate. This gradually neutralises the acidity, and finally renders the urine alkaline. At the same time an amorphous precipitate of earthy phosphates appears, and crystals of ammonio-magnesium phosphate, and of ammonium urate are produced.

Urinary Calculi.

Various ingredients of the urine, which are difficult of solution, sometimes become massed together as concretions, particularly if there exist any small foreign body in the bladder, which, by acting as a nucleus, lays the foundation of a stone. Sometimes small concretions are formed in the tubes or pelvic recesses of the kidney, and, when these make their way into the bladder, they commonly grow larger and larger. The structure and composition of a calculus often give the history of its own transit from the kidney, and also of various changes in the metabolism of the individual, for successive layers of different substances are generally found in a stone that has attained any great size. The chief materials found in calculi are—uric acid, ammonium urate, calcium oxalate and carbonate, ammonio-magnesium phosphate, &c.

Nervous Mechanism of the Urinary Secretion.

With regard to the influence exerted by the nervous system on the renal secretion, we have not very satisfactory informa-

tion. There can be little doubt that here, as in other glands, the process is under the control of the nerves. Many of the conditions which cause increased secretion have no effect on the general blood pressure, so that, if the increased flow be brought about by the vaso-motor mechanisms, it must be by means of nervous channels altering the blood flow in the special arteries of the glands. Further, in some emotional conditions, such as hysteria, an unaccountably great quantity of urine of very low specific gravity is evacuated.

The renal vaso-motor nerves leave the spinal cord by the anterior roots of dorsal nerves, particularly the 11th, 12th and 13th.

With regard to the effects of the vaso-motor nerves, we know that section of all the nervous twigs going to the kidneys causes great congestion and an immense increase in the secretion, which commonly contains albumin. This no doubt depends on the sudden rise in pressure in the glomeruli, owing to the dilatation of the arterioles. If the splanchnics, in which the renal vaso-motor nerves run, be cut, a great quantity of urine is produced from the same cause—vaso-motor paralysis—but, on account of the large area of vessels injured, the general blood pressure falls, and therefore the effect is not so much marked. If the peripheral end of the cut nerves be stimulated, the secretion is diminished, owing to spasm of the renal arterioles. Section of the spinal cord at the 7th cervical vertebra stops the flow, because it reduces the general blood pressure below that necessary for the secretion of the urine.

The introduction of various substances into the blood causes a marked change in the blood supply of the kidney and the amount of urine secreted. These facts can be demonstrated by Roy's *oncometer*, an instrument consisting of a bivalve metal case in which the kidney can be placed and surrounded with a cushion of warm oil contained in a thin membrane. The oil-space is connected with the *oncograph*, which records the variations in size, *i.e.*, blood contents of the kidney. These changes do not invariably correspond with the changes in general blood pressure occurring during the experiments.

Passage of the Urine to the Bladder.

The pressure exerted by the blood is quite sufficient to make the urine flow into the bladder, because when the ureters are tied they become distended above the ligature by the urine

flowing from the pelvis, where a pressure may be produced of some forty millimetres of Hg, *i.e.* far exceeding the maximum pressure that can be supposed to occur in the capillary vessels of the kidney. At this pressure the secretion stops and becomes somewhat changed in chemical composition.

Normally, however, the passage of the urine along the ureters is accomplished by the peristaltic motion of the ducts, which goes on alternately in the two ureters, so that the urine flows into the bladder at different periods from the right and left kidney.

The ureters have a strong middle coat of encircling fibres of smooth muscle along which a wave of contraction, lasting about one-third of a second, passes rhythmically from the pelvis of the kidney to the bladder.

Having reached the bladder, the urine cannot return into the ureters on account of the oblique way in which these ducts pass through the walls of the bladder. When the pressure in the bladder increases, the opening of the ducts becomes closed and acts as a kind of valve.

Retention of Urine in the Bladder.

The urine, which is continuously secreted and rhythmically conveyed to the bladder, can be voided at convenient times; therefore special arrangements exist for its retention and expulsion.

The *retention* of urine in the bladder depends up to a certain point on the elasticity of the parts concerned, the dense elastic tissues around its outlet being able to resist the elastic force exerted by the walls of the bladder. Thus where no muscular force can possibly come into play, as in the case of the dead subject, or in complete paralysis following destruction of the spinal cord, a considerable amount of urine is retained. But when a certain pressure is arrived at within the bladder, the elasticity of the sphincter and the other tissues around the outlet is overcome by the elasticity of the bladder wall, &c., and the urine slowly dribbles away.

In the normal condition, however, the urine is retained by a muscle excited reflexly by nerves over which we have acquired considerable voluntary control.

This is the *sphincter* muscle, which surrounds the neck of the bladder and by contracting can retain the urine. The accumulation of the urine gradually gives the sensation known as a

fulness of the bladder, but this feeling is not accompanied by any irresistible call to make water, though it gives rise to the desire. The stimulus given to the afferent nerves of the bladder, causes, reflexly, a contraction of the sphincter muscle, so that, in proportion as the pressure within the bladder increases, the resistance to its outflow is also augmented. This does not imply an automatic action of the sphincter, but merely a constant reflex excitation of that muscle, which secures the retention of a considerable amount of urine without the intervention of attention or voluntary effort.

Evacuation of the Bladder.

Micturition, or the expulsion of the urine, in the adult does not normally depend on elastic forces alone, as in paralytic incontinence, but is accomplished by the *detrusor urinæ* muscle situated in the wall of the bladder.

Under ordinary circumstances there is a correlation between the expelling and retaining powers, in which the retaining power of the sphincter is just able to resist the elastic pressure. If the amount of urine reach a certain point, the reflex stimulation of the sphincter no longer suffices, and voluntary effort has to be used. If a drop of urine happen now to make its way into the sensitive urethra, matters are altered. Even voluntary effort cannot retain it, and an irresistible call to make water follows. This is accomplished by relaxation of the sphincter and

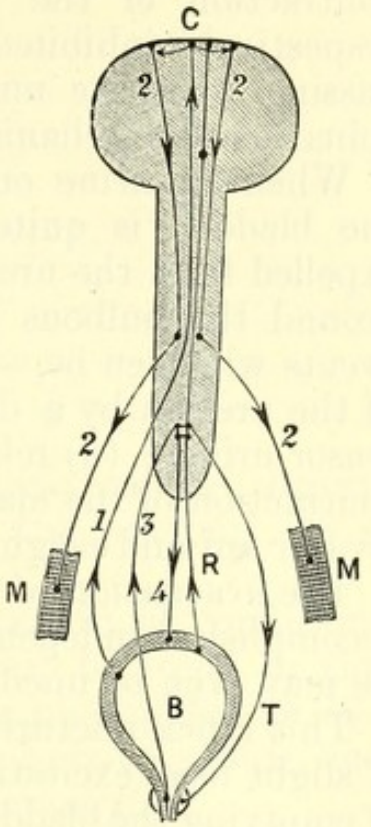


Fig. 165.—Plan of the Nervous Mechanism of Micturition.

B. Bladder.
M. Abdominal muscles.
C. Cerebral centres.
R. Represents impulses which pass from the bladder to the centre in the spinal cord, whence tonic impulses are reflected and pass along T to sphincter, which retains the urine.

When the bladder is distended, impulses pass to the brain by 1, and when we *will*, the tonus of the spinal centre stimulating the sphincter is checked, and the abdominal muscles are made by 2 to force some urine into neck of bladder, whence impulses pass by 3 to inhibit the sphincter centre and excite the detrusor through 4.

contraction of the muscular coat of the bladder, which are respectively inhibited and excited, reflexly, by the stimulus passing from the mucous membrane lining the urethra to the spinal nerve mechanisms.

When the urine once commences to flow it continues until the bladder is quite empty, the last drops of urine being expelled from the urethra by rhythmical spasms of the muscles around the bulbous portion of that canal. The sequence of events will then be,—(1) stimulation of the mucous membrane of the urethra by a drop of urine ; (2) contraction of the detrusor urinæ ; (3) relaxation of the sphincter ; (4) rhythmical contraction of the ejaculator urinæ, and, finally, a twitch of the levator ani and neighbouring muscles.

The evacuation of the bladder is under these circumstances accomplished independently of the will by a reflex act, of which we may even be unconscious.

This reflex micturition may occur during sleep, as the result of slight local excitations. In infants this is the normal mode of emptying the bladder, and the gradual education of the centres controlling the retention mechanisms is watched with interest in young children.

At an early age we begin to learn to control these spinal centres by our will. We feel a desire to empty the bladder before the reflex contraction of the sphincter is overcome. Almost at any time we can call forth the reflex act by increasing the pressure on the bladder by voluntary contraction of the abdominal muscles ; the diaphragm being depressed and fixed, the muscles of expiration are put into action so as to press upon the pelvic viscera. At the same time the contraction of the sphincter is probably checked by the will, and thus the reflex evacuation is started.

CHAPTER XXII.

NUTRITION.

We are now in a position to see what light can be thrown upon the actual changes taking place in the economy, by a comparison of income and output.

In order that the body may be kept in its normal condition, it is necessary that the income should at least be equal to the output, and, except where growth is going on rapidly, an income equal to the expenditure ought not only to suffice, but ought to be the most satisfactory for the economy.

We know that animals can live for a considerable time without food, in which case a certain expenditure of material derived from the body itself is made to sustain life, and therefore some output continues. We ought thus to be able in a simple manner to arrive at the minimal expenditure necessary for the sustentation of the body. We shall find, however, that (1) an income equal to this minimal expenditure (that of starvation) does not at all suffice to keep up the body-weight, and that (2) a considerable margin over and above this minimum is necessary in order to establish a nutritive equilibrium; (3) further, that the proportion of material eliminated and stored up in the body, respectively, varies as the income is increased; (4) and finally, that the quality of the food—*i.e.*, the proportion of each group of food-stuff present in the diet—has an important influence on the quantity required to establish the equilibrium, and that best suited to cause increase of weight or to fatten.

It will be convenient to consider the following different cases in succession.

1. No income, except oxygen and water, *i.e.*, starvation.
2. An income only equal to the expenditure found during starvation.
3. Establishment of perfect nutritive equilibrium.
4. Excessive consumption.

Tissue Changes in Starvation.

As is well known, deprivation of oxygen—by cessation of the respiratory function—almost immediately puts an end to life, so that the oxygen-income cannot be interfered with or the experiment comes to an end. It has also been found that a small supply of water makes the investigation more reliable, by facilitating tissue-changes and prolonging life. We therefore speak of a total abstinence from solids as starvation.

When an animal is deprived of food, those tissues, upon the activity of which life immediately depends, must feed upon materials stored up in other tissues of less vital importance. The first questions to discuss are how much the body loses daily in weight during the time that it is thus feeding on itself, and how far the different individual tissues contribute to this loss.

The general loss of weight is directly estimated by weighing the animal, and the loss of the individual tissues is calculated by a careful analysis of the various excreta, by which the exact amount of nitrogen, carbonic acid, &c., is ascertained : the nitrogen corresponds to the loss of muscle ; and the carbon (after excluding that portion which is the outcome of muscle change, which may be calculated from the nitrogen) corresponds to the fats oxidised.

Loss of weight.—It has been found that a starving animal loses weight rapidly at first, and subsequently more slowly. The cause of this difference is that the food last eaten continues to excite metabolism for the first three or four days, and the materials eliminated are proportionately large in quantity. When the influence of the food taken prior to starvation has ceased, the daily amount of materials eliminated is much reduced and remains nearly constant, decreasing very slightly, the decrease being in proportion to the loss of body-weight, which diminishes gradually until the animal's death.

Adult animals generally live until they have lost about half of their normal body-weight. Young animals die when they have lost about 20 per cent. of their weight.

Relative loss in various tissues.—Roughly speaking, we may take the body of a man to be made up of the following proportions of the more important textures :—

Muscles	50 per cent.
Skin and fat . . .	25 „
Viscera	12 „
Skeleton	13 „

When we consider that the muscles make up such a large proportion to the body-weight, we cannot be surprised that in starvation the greatest *absolute loss* occurs in this tissue—except in the case of excessively fat animals. Next comes adipose tissue, which almost entirely disappears, so that its *relative loss* is greatest, but its absolute loss varies in proportion to the fatness of the animal at the beginning of the investigation. The spleen and liver lose more than half their weight, and the amount of blood is greatly reduced. The smallness of the loss that occurs in the great nervous centres is very striking. They seem to feed on the other tissues.

The following table gives the approximate *per-centage* of loss which takes place in each individual tissue during starvation :—

Fat	97·0 per cent.
Muscle	30·2 „
Heart	0· „
Liver	56·6 „
Spleen	63·1 „
Blood	17·6 „
Nerve-centres . .	0· „

With regard to the *place of exit* of the waste product, it has been found that practically all the nitrogen passes off with the urine, and about nine-tenths of the carbon escapes by the lungs as CO_2, the remaining one-tenth passing off by the intestine and kidneys. Three-fourths of the water is found in the urine, and one-fourth goes off from the skin and lungs.

The following table shows the items of the general loss, and the amount per cent. which passes out by the chief channels of exit :—

	Total Elimination.	Viâ Kidneys.	Lungs and Skin.	Excrement.
Water . .	995·34 grm.	70·2 %	26·1 %	3·7 %
Carbon . .	205·96 „	6·4 %	92·6 %	1·9 %
Nitrogen .	30·81 „	100·0 %	—	—
Salts . .	10·03 „	97·0 %	—	2·4 %

The loss of weight of an animal's body during starvation is at first rapid and then very gradual. The amount of material eliminated is also found to diminish much more slowly after

the first few days. This is well seen from the nitrogenous elimination. For the first four days the amount of urea falls very rapidly, it then decreases slowly as long as some fat remains, after which it increases, remaining almost constant until death. The amount varies with the slow decrease in weight of the animal. This has led to the conclusion that the nitrogenous material eliminated during a full diet comes partly from used-up nitrogenous tissues, and partly from nitrogenous materials which have never been really assimilated, but are the result of decomposition of the surplus nitrogenous food. Proteids have been supposed to exist in the body in two states, viz., (1) that forming part of the tissues, and (2) that "circulating," ready for the nutritive demands of the tissues.

An Income Equal to the output of Starvation.

In the second case, namely, where the amount of food supplied is just equal to the expenditure found to take place during starvation, one might suppose that the diet, though minimal, would yet suffice to preserve the normal body-weight. Experiment shows this to be far from being the case.

An animal fed on diet equal in quantity to the output during starvation, loses weight, and the quantity of nitrogen eliminated (urea) is in excess of the low standard found during complete abstinence from food. From this it would appear that even when supplied with an amount of nitrogenous material equal to that used by the tissues during starvation, an animal takes a further supply from its own textures, and eliminates some of the nitrogenous nutriment before its assimilation. The scanty allowance of nutriment borrowed from the tissues during starvation, is only adequate so long as there is absolutely no income ; when food is supplied an increased expenditure is set up, the income is exceeded, and a deficit occurs in the nitrogen balance. Probably some of the nitrogenous nutriment is rendered useless by the processes it undergoes in the intestine, even when the quantity is not sufficient to support the equilibrium (compare pp. 149, 344).

It follows, then, that feeding an animal on an amount of food-stuffs exactly corresponding to the quantity of nutriment abstracted from its own textures during total abstinence is only a slower form of starvation.

With regard to nitrogenous substances, it has been proved that nearly three times the amount eliminated during starva-

tion is required in the food to establish an equilibrium between the income and expenditure of those special substances, and that less than this leads to a distinct nitrogenous deficit. It has been proved that ·02 per cent. of the body-weight is the minimal daily allowance of proteid required to prevent loss of weight.

Nutritive Equilibrium.

The third case mentioned, viz., that in which the nutritive equilibrium is exactly maintained, so that the body-weight remains unaltered, is the most important one for us to determine, since its final settlement would enable us to fix the most beneficial standard of diet. Unfortunately, this case is also the most difficult upon which to come to a satisfactory conclusion, for the following reasons :

1. The elaborate nature of the conditions imposed during the experiment makes it difficult to carry on the investigation with scientific accuracy.

2. Even when the amounts of gain and loss exactly correspond we cannot say that we have the best dietary ; because some of the income may be quite useless, and pass through the economy without performing any function, and yet appear in the output so as to give an accurate balance.

3. We have just seen that the relative amounts of outgoings and of material laid by as store are altered and regulated by the *quantity* of income. And we find that the *quality* of the income, *i.e.*, the relative proportions of the various food-stuffs, has a material influence on the quantities of material laid by and eliminated, respectively. We must, therefore, consider the efficacy of each of the groups of the food-stuffs when employed alone and mixed in different proportions.

4. Different animals seem to have different powers of assimilation ; and under various circumstances the requirements and assimilative power of the same animal may vary.

Nitrogenous diet.—An animal fed upon a purely meat diet requires a great amount of it to sustain its body-weight. It has been found that from $\frac{1}{20}$ to $\frac{1}{25}$ of the body-weight in lean meat must be eaten daily to keep an animal from losing weight, If more than this amount be supplied the animal increases in weight, and as its weight increases a greater amount of meat is required to keep it up to the new standard. So that to produce a progressive increase of weight, with a purely meat diet,

it is necessary to keep on increasing the quantity of meat given. The reason of this is found in the fact that albuminous diet causes an increase in nitrogenous metabolism.

If an animal be given an *ad libitum* supply of lean meat, by far the larger proportion of the nitrogen is given off in the urine, and a comparatively small proportion is stored up. If this large supply of meat be continued for some time, less and less of the nitrogen is stored, and more and more is eliminated as urea, until finally the nitrogen excreted just corresponds with that of the albuminous materials in the ingesta. This balance of nitrogenous income and expenditure is spoken of as *nitrogenous equilibrium*. For each new body-weight there is a new nitrogenous equilibrium, which is only attained after the disturbed relation between the nitrogenous ingesta and excreta has been re-adjusted.

Gelatine, which forms an important item in many kinds of food, contains a large proportion of nitrogen. It is remarkable that, in spite of its chemical likeness to albumin, it can sustain the body-weight no better than fats or carbohydrates. Even when mixed with the latter and given in abundance, the animal dies of nitrogen starvation. But if used together with albumin, it prevents excessive nitrogenous metabolism and spares the proteid. Thus a dog was found to lose weight on a diet of 500 grms. of meat, but when 200 grms. of gelatin were substituted for 200 grms. of the meat, the animal gained weight. Though useless by itself as a source of nitrogen, it seems more efficacious in establishing an equilibrium, than proteid, when mixed with the latter.

The increase of weight which follows a liberal meat diet depends in a great measure on fat being stored up in the body. Much more of this material is made than could come from the fat taken with the meat; hence, we conclude that it is made from the proteid.

Non-nitrogenous diet.—The effect of a diet without any albuminous food is that the animal dies of starvation nearly as soon as if deprived of all forms of food, with the exception that the weight of the body is much less reduced at the time of death.

Both fats and carbohydrates when given with proteid diminish the nitrogenous waste and reduce the amount of meat necessary to sustain the equilibrium. They, like gelatine, are "proteid-sparers," *i.e.* supply some essential material that would, in their absence, require much proteid to yield.

It has been estimated that the nitrogenous metabolism is reduced 7 per cent. by the addition of fat, and 10 per cent. by the addition of carbohydrate food to the meat diet ; therefore a mixed diet is the best. Fats and sugars supply to the body readily oxidisable materials, and thus shield the albuminous tissues from oxidation, as well as reducing absolutely the nitrogenous metabolism.

It would appear from the experience gained from the stall-feeding of animals that a good supply of carbohydrates, together with a limited quantity of nitrogenous food, is admirably adapted to produce fat. Since much more fat is produced than could be accounted for by the fatty constituents of their diet, we must suppose that fat can be manufactured from their carbohydrate food.

A sound knowledge of the production of fats in the body can only be gained by bearing in mind the properties of the protoplasm. There can be no doubt that protoplasm, if properly nourished, can manufacture fat. As examples, we may take the cells of the mammary gland and connective tissue. This fat production may be regarded as a *secretion* of fat, though only in one of the examples given does it appear externally as a definite secretion—milk. We cannot scrutinise the chemical methods by which this change is brought about in protoplasm, any more than those which give rise to the special constituents of other secretions. We know that protoplasm requires for its nutrition, albumin, fat, and carbohydrate, and the proportion most nutritious for the body generally, is also the proportion in which protoplasm requires these substances for its perfect nutrition. In the case of fat-formation a supply of fat or carbohydrate ought to suffice if accompanied by a small amount of albuminous substance. If these non-nitrogenous substances be withheld, the protoplasm can obtain the quantity of carbon, hydrogen, and oxygen requisite to manufacture fat from albumin, but this would be an extravagant method, wasting both proteid nutriment and protoplasmic energy.

Fat cannot be produced by the tissue cells without nitrogen in the diet, because the fat-manufacturing protoplasm cannot live without nitrogen, which is absolutely necessary for its own assimilative re-integration. A good supply of nitrogenous food aids in fattening, since it gives vigour to all the protoplasmic metabolism, and among them fat-formation.

Excessive Consumption.

The last case we have to consider is that in which the supply of food material is in excess of the requirements of the economy. This is certainly the commonest case in man.

Much surplus food never really enters the system but is conveyed away with the fæces.

In speaking of pancreatic digestion, reference has been made to the possible destiny of excess of nitrogenous food. In the intestine, some of it is decomposed into leucine and tyrosine, which are absorbed by the intestinal blood-vessels. In the body these substances undergo further changes, which probably take place in the liver. As a result of the absorption of leucine, a larger quantity of urea appears in the urine, and hence the leucine formed in the intestine by prolonged pancreatic digestion, is an important source of urea. This view is supported by the almost immediate increase in the quantity of urea eliminated when albuminous food is taken in large quantity.

From the fact that a considerable amount of fat may be stored up by an animal supplied with a liberal diet of lean meat, we must conclude that part at least of the surplus albumin goes to form fat. It has been suggested that after sufficient albumin has been absorbed for the nitrogenous tissues, the rest is split up into two parts, one of which is immediately prepared by the liver for elimination as urea, and the other undergoes changes, probably in the same organ, preparatory to its being converted into fat.

From the foregoing it will be gathered that we cannot say what are the exact destinies of the various food-stuffs in the body. Proteids are not exclusively utilised in the re-integration of proteid tissues, as an excess gives rise to a deposit of fat. Carbohydrates are not employed simply to replace the carbohydrates constituting part of the tissues, but as will be shown when speaking of muscle metabolism, they are intimately related to the chemical changes which take place during the activity of that tissue. If fats are chiefly devoted to the restitution of the fat of the body, they certainly are not the only kind of food from which fat can be made.

We may say that all food-stuffs are destined to feed the living protoplasm, whether it be in the form of gland cells, the cells of the connective tissues, or muscle-plasma, so that all the food-stuffs that are really assimilated contribute to the maintenance of protoplasm and subserve to its various functions.

Besides nourishing itself and keeping itself up to a certain standard composition, protoplasm can make the various chemical materials we find in the body. Some produce fat, some animal starch (glycogen), and others manufacture the various substances we find in the secretions; while yet another group is devoted to setting free and utilising the energy of the various chemical associations.

Dietaries.

The question of the quantity and quality of food required to form the most economic and wholesome dietary is one of great importance, and involves many questions which cannot receive adequate attention in this manual. As a rule men, like other animals, partake of food largely in excess of their physiological requirements, when they can get it. This may be seen by contrasting one's own daily food with the amount which has been found to be adequate in the case of individuals who have not the opportunity of regulating their supplies of comestibles.

All the proximate constituents, mixed in varying proportion, are contained in many kinds of foods. From the following list combinations may be selected to form dietaries suitable for special cases.

100 parts of the following foods contain :—

	Proteids.	Fats.	Carbohydrates.	Salts.
Cow's milk	5·4	4·3	4	0·5
Cheese	36	25	—	4
Pea-meal	23	2	57	2
Maize-flour	11	8	65	1·7
Oat-meal	12·6	5·6	64	3
Barley-meal	6·3	2·4	74	2
Rye-meal	8	2	73	1·8
Wheaten flour	12	1·7	70	2
Rice	6·3	0·9	79	0·5
Eggs (yolk and white)	15	16	0·5	0·8
Beef (fat)	13	33	0·2	2·5
Beef (lean)	20	2	·3	3·6
Fish (white)	18	2·9	—	1
Cabbage	2·1	0·3	4·5	1
Potatoes	2	0·1	22	0·7
Carrots	1·3	0·2	14·5	1
Turnips	1·2	—	7·2	·6
Butter	0·6	83	—	2

Ranke concluded from experiments on himself that an adult man should be supplied with the following amounts of the proximate principles of food daily :—

Proteid foods . .	100 grms.	or about	3·5 ozs.
Fats . . .	100 „	„	3·5 „
Carbohydrates .	250 „	„	8·75 „
Salts . . .	30 „	„	1·0 „
Water . .	2000 c.c.	„	3·5 pints.

Many persons have to work on a less liberal diet than this, and working natives of India thrive on a far less quantity of proteid than that given in this table, but this amount is said to be necessary for an English workman.

Individual taste, as a rule, selects a diet with excess of proteid, *i.e.* too much meat. Economy dictates the cheaper carbohydrates in excess—maize and oatmeal being especially valuable from the amount of fats they contain. Necessity has been said to enforce in some parts of Ireland, a diet, consisting of potatoes only. It was found difficult to understand how a human being could eat enough potatoes to obtain an adequate supply of proteid or of fat, requiring 25 lbs. per diem. The mystery is solved by the fact that there are no instances in which this, so called, potato diet, is not supplemented by copious draughts of butter-milk, and perhaps an egg, or an occasional rabbit.

The following diets may be compared with the standard given above. The most liberal of these is, as a rule, exceeded by well-to-do people.

	Prison Fare— Short term without labour.	Prison Fare— Hard labour.	Naval-allowance.
Proteid . . .	2·44 ozs. . .	4 ozs. . .	5 ozs.
Fat	·6 „ . .	1·5 „ . .	2·37 „
Carbohydrates	14·7 „ . .	18 „ . .	20 „

As a sample of a very liberal domestic diet, without luxury, the following proportions of ordinary comestibles may be given :

Bread . . .	8 ozs.	Potatoes, &c. .	4 ozs.
Butter . . .	2 „	Milk . . .	½ pt.
Sugar . . .	1 „	Cheese . . .	1 oz.
Meat (free from bone)	8 „	Rice, &c. pudding	2 „
Fish . . .	4 „		

This would cost about 1*s.* 6*d.* per diem and would yield in round numbers—

Proteid . .	132 grms.	=	4·6 ozs.
Fat . . .	78 „	=	2·6 „
Carbohydrate .	315 „	=	10·5 „

An adequate diet, constructed with a view to economy alone, would require the expensive proteids and fats to be reduced, and the deficiency made up by a greater quantity of the cheaper carbohydrates. Thus—

Oat-meal	10 ozs.
Pea-meal	3 „
Potatoes	16 „
Cheese	1 „
Suet, &c.	½ „

Which would cost about 3*d.* per diem, and would yield about—

Proteid . .	80 grms.	=	2·75 ozs.
Fat . . .	37 „	=	1·25 „
Carbohydrate .	350 „	=	11·75 „

The estimates of cost are irrespective of cooking.

CHAPTER XXIII.

ANIMAL HEAT.

THE bodies of most animals are considerably warmer than their surroundings. Part of the energy set free in the animal tissues appears as heat. *Warm-blooded* animals are those which habitually preserve an *even temperature* independent of the changes which take place in that of the medium in which they live ; and, as the term warm-blooded implies, their temperature is, as a rule, higher than the surrounding air or water. *Cold-blooded* animals, on the other hand, are those with a *varying temperature*, which is considerably affected by that of the medium surrounding them.

The blood of all mammalia has about the same temperature as that of man, about 37·5° C. But birds have a temperature about 4° or 6° C. higher than that of mammals.

The blood of animals with varying temperature is generally from 1° to 5° C. higher than the medium in which they live. They produce some, though little, heat, and since they have no special plan for its regulation, it does not remain at a fixed standard. In every part where active oxidation takes place, heat is produced ; so even in invertebrate animals an elevation of temperature occurs ; this can be ascertained where they exist in masses, as in bee-hives, an active hive sometimes reaching a temperature of 35° C.

Instead of the term "warm-blooded" and "cold-blooded," respectively, it is more accurate to apply to animals with even temperature, the term "*Homœothermic*" (of constant temperature), and to animals with varying temperatures, "*Poikilothermic*" (of changing temperature.)

On account of the slight amount of variation that occurs in the temperature of man, all the changes can be measured with a thermometer having a short scale of 20 degrees, each degree of which occupies considerable length on the instrument, so that very slight variations may be easily appreciated. Such thermometers have a detached fragment of mercury which

remains to register the maximum height attained, and are in daily use for *clinical* observation, for the temperature of the body is now a most important aid to diagnosis and prognosis in febrile diseases.

As heat is constantly being lost at the surface of the body. the skin is colder than the deeper parts. In order to avoid variations caused by this surface loss—which depends on the temperature of the air—special care is necessary. The instrument may be brought into close proximity to the deeper parts by being introduced into one of the mucous passages, where it is closely surrounded by vascular tissue. In animals the rectum is the most convenient part for the application of the thermometer, but in clinical practice it is usually placed under the tongue, or in the armpit, the bulb being held so that on all sides it is in contact with the skin and protected from the cool air.

The variations at different parts of the body are but slight, and the average normal surface temperature in man is found to be about 37° C.

Normal Variations in Temperature.

I. The temperature of *the whole body* normally undergoes certain variations.

a. It is highest between 4 and 5 P.M. and lowest between 2 and 4 A.M., the transition being gradual. This diurnal variation, which normally does not exceed 1° C., is much exaggerated in certain fevers.

b. The temperature rises after a hearty meal and falls during fasting. During starvation the temperature sinks gradually until the death of the individual.

c. The temperature is highest at birth, and falls about 1° C. between that and the age of 50 years,—in extreme old age it is said that it again rises.

d. Muscular exertion, which gives the individual the sensation of great warmth, only changes the temperature of the blood about ·5° C. The very high temperature which accompanies the disease tetanus, where all the muscles are thrown into a state of spasm, probably depends more on pathological changes than on muscular action.

e. Mental exertion is also said to cause a rise of temperature.

f. Slight differences in the heat of the blood may be

brought about by variations in the surrounding temperature. The abnormally high temperature of fever is much more easily affected by changes in the rate of removal of the heat from the body, than is the normal temperature, and hence the therapeutic value of cold applications in this class of disease.

II. In *different parts of the body* the temperature varies to a slight extent, and depends upon the following circumstances :— 1. The amount of blood flowing through the part, 2. The amount of heat produced in it, *i.e.*, the activity of its tissue change. 3. The amount of heat lost, which depends on its proximity to the surface.

From this it is obvious that the deeper parts of the body, where active chemical change takes place, and which are protected from exposure, must be warmer than the exterior, which is constantly giving out its heat. The blood which flows through the surface vessels is cooled, and that which flows through the deeper vascular viscera is warmed. Thus the skin is usually about 37° C., while the mouth beneath the tongue is about 37·5° C., and the rectum about 38° C. The temperature of the blood therefore varies within narrow limits according to the part of the body though which it has recently passed. The mean temperature of the blood is higher than that of the tissues. The blood in the hepatic capillaries is the warmest in the body. This reaches 40·73° in the dog, or nearly two degrees higher than that in the aorta of that animal. The cool blood from the extremities and head mingling in the right side of the heart with the unusually warm blood from the liver keeps the blood going to the lungs at the standard temperature. The blood in the left side of the heart is a little cooler than that in the right, probably because the latter lies on the warm liver, as is proved by the substitution of a cold object for this organ, when the blood on the right side becomes colder than the left. It is not because the blood is cooled going through the lungs, for the heat used in warming the respired air is given off chiefly by the nose and other air-passages, and not by the alveoli of the lungs.

III. The temperature *of an organ* varies with the state of its activity. During the active state the glands, &c. receive more blood and undergo more active chemical change, so that they become warmer.

Mode of Production of Animal Heat.

It has already been stated that the general tendency of tissue change may be compared to combustion of certain substances obtained from the vegetable kingdom, viz., proteid, fat, carbo-hydrate. The combustible substances are capable of being burned in the open air, or made to unite with oxygen so as to produce a certain amount of heat, being thus converted into CO_2 and H_2O. In the body the oxidation goes on in a gradual or modified way, and the end products of the process can be recognised as CO_2 eliminated from the lungs, and as water and urea got rid of by the kidneys. The general tendency of the chemical changes in the tissues is such as will set free energy in the form of heat.

The amount of heat that any substance is capable of giving off corresponds to the amount of energy required for the formation from CO_2 and H_2O, &c. of the compounds contained in it, and this correspondence remains whether the oxidation take place rapidly or slowly. The substances we make use of as food have thus a certain heat value which depends upon their chemical composition.

The high temperature which homœothermic animals can keep up in spite of the cold of the atmosphere in which they live is readily accounted for by the chemical change which is constantly occurring in the tissue of their bodies.

The amount of heat produced in any part depends upon the activity of the tissue change, for we find that it varies with the elimination of CO_2, and urea, which gives a fair estimate of the normal chemical changes of the tissues.

1. The diurnal changes in temperature are accompanied by an afternoon increase and a morning decrease of CO_2 and urea.
2. The tissue change giving rise to CO_2 decreases in a fasting animal, as does also the production of heat.
3. More CO_2 is eliminated after meals, when the temperature also rises.
4. The activity of various organs, such as the muscles and glands, is associated with a local increase of temperature.

Income and Expenditure of Heat.

Income.—Food is the fuel of the animal body, and the peculiarity of the combustion is that the tissues first assimilate

the fuel, and then themselves undergo oxidation by means of which they perform their several functions, and produce heat.

As already mentioned, heat is produced most abundantly in those tissues which undergo most active chemical changes, hence the protoplasmic cells of glands and the contractile substance of muscle must be looked upon as the chief agents in setting heat free.

The physical heat-value of a body, determined by its combustion, is always the same; but the physiological heat-value of food varies, and is generally less than the physical heat-value, because many substances in the food are not completely burned in the body. Proteid, for instance, is only oxidised to urea, which can still yield heat. As each gramme of proteid corresponds to $\frac{1}{3}$ grm. urea, the heat-value of this amount of urea must be taken from that of each grm. of proteid. Fat alone appears to yield as much heat when burned in the body as when burned outside.

From this it is clear that the possible heat-income depends on the quality and quantity of nutrient matter assimilated. As each kind of food has a certain heat-value, *i.e.*, the number of heat-units its combustion will produce, we ought to be able to estimate the amount of heat produced by ascertaining this value, and subtracting the calorific value of the various excreta, and the energy used in producing the muscular movements of the body. Interesting balance-sheets, setting forth the income of energy from the various foods and the calculated expenditure, as heat, have been drawn out, but the data on which they are based are so arbitrary that they seem to be of little practical value. Attempts to make the calculated heat-income correspond with the expenditure have not been productive of satisfactory results, the calorific-value of an "adequate diet" being hardly sufficient to account for the heat calculated to be given off, and the work done by the muscles in movement, &c.

Since the activity of muscle and gland tissue is constantly varying, the amount of heat produced must also vary. We know that the heat set free by any organ, such as a gland or a muscle, increases in proportion to the increase of its functional activity, but we cannot say that the calorific activity can vary independently of other circumstances. Without such a special calorific function of some tissues, such as muscle, the actual net heat-income must vary with circumstances which are accidental, and therefore irregular.

Since we know that the nervous system controls those tissue activities which are accompanied by the setting free of heat, we can understand how the nerve-centres can materially influence the production of heat in the body. That the nervous system can cause a chemical change, giving rise to a greater production of heat, without any other display of functional activity, we do not know, but many facts seem to point to such a possibility.

Stimulation of certain regions of the nerve-centres causes a rise of temperature, and would seem to indicate a special thermal nervous mechanism.

But for the present, we are not in a position to speak with decision of special heat metabolism, or of nerves with a purely thermic action.

The *Expenditure* of the heat may be classed under the following headings :

1. In warming ingesta. As a rule the food and drink we use as well as the oxygen we breathe are colder than the body, and before they pass out they are raised to the body temperature.

2. Radiation and Conduction. From the surface of the skin a quantity of heat is expended in warming the surrounding medium, which is habitually colder than our bodies. The colder the medium, the greater its absorption of heat. The better conductor of heat the surrounding medium happens to be, the more quickly it robs us of warmth ; thus water, or damp air, takes up more heat from our surface than dry air of the same temperature. The quantity of heat lost is still further increased if the medium be in motion, so that the relatively colder fluid is constantly renewed. Hence wind of the same temperature as still air feels much colder.

3. Evaporation. (a.) From the larger air-passages : a quantity of water passes into the vaporous state and saturates the tidal air, and this change of condition from liquid to that of vapour absorbs much heat ; (b.) From the skin : surface evaporation is always going on, even when no moisture is perceptible on the skin, and much fluid of which we are not sensible is lost in this way. The quantity of heat lost by evaporation from the skin, will depend on the temperature and the dryness of the air.

Balance.—As has been said, the exact income of heat is uncertain and variable because the data upon which the absolute amount can be calculated are not scientifically free from error.

According to the most careful estimates an adult weighing 82 kilo. produces 2,700,000 units of heat in the twenty-four hours, which are expended in the following way :—

In warming ingesta . .	70,157	units of heat.
In warming tidal air . .	140,064	„ „
By the evaporation of 656 grm. of water from the air passages . . .	397,536	„ „
By surface loss . . .	2,092,243	„ „

From this it appears that more than three-quarters of our heat is lost by the skin (77·5 per cent.) ; by pulmonary evaporation, 14·7 per cent. ; in heating the air breathed, 5·2 per cent. ; in heating ingesta, 2·6 per cent.

Maintenance of Uniform Temperature.

In order that the vital processes of homœothermic animals should go on in a normal manner, it is necessary that their temperature remain nearly constant, and we have seen that under ordinary circumstances it varies only about one degree below or above the standard 37° C. Thus we can live in cold or warm climates, and our body temperature remains unaltered.

There is a limit however to this power of maintaining a uniform standard temperature. If a mammal be kept for some time in a moist medium, where evaporation cannot take place, at a temperature but little higher than its body, say over 45° C., its temperature soon begins to rise and it dies with the signs of dyspnœa and convulsions (probably from the nervous centres being affected) when its temperature arrives at 43°—45°. If placed in water at freezing point an animal loses its heat quickly, and when its body temperature has fallen to about 20° C. it dies in a condition resembling somnolence, the circulation and respiration gradually falling.

Since a variation of more than one or two degrees in the temperature of our bodies interferes with the vital activities of the controlling tissues in the nervous centres, it is of course of the utmost importance that adequate means for the regulation of the mean temperature of our bodies should exist.

The temperature of an animal's body depends on the relations existing between the amount of heat generated in the body and the amount allowed to escape at the surface. Both

these factors are found to vary as the result of quite independent conditions. Every increase in the activity of the muscles, liver, &c. causes a greater production of heat, while a fall in external temperature causes a greater escape of heat from the surface.

The maintenance of uniform temperature may be accomplished by (1) variations in the heat income, so arranged as to make up for the irregularities of expenditure, or (2) variations in the loss to compensate for the differences of heat generated.

Since the temperature and moisture of our surroundings are constantly varying between tolerably wide limits, the amount of heat given off by our bodies must vary considerably. In cold damp weather a great quantity of heat is lost in comparison with that which escapes from the body when the air is warm. If the heat generated had to make up for the changes in the heat lost, we should find a correspondingly great difference in the amount of heat generated at different times of the year. No doubt some evidence of this exists in the keener appetite, *i.e.* use of more fuel, during cold weather, but the difference is not sufficiently marked to prove that a greater amount of combustion takes place in winter than in summer. Further, if the preservation of a uniform body temperature depended solely upon the variations in the amount of income keeping pace with the variation in the expenditure, we should find it inconvenient to set our muscular or glandular tissues in action, except when the external temperature was such as would enable us easily to get rid of the increased heat following their activity. It no doubt appears that the general tissue combustion, as measured by the amount of CO_2 given off, increases when we are placed in colder surroundings—such as a cold bath ; still, it is probable that the variations in heat-income have but secondary influence in regulating the temperature. If the heat-income have any regulating influence, we are ignorant of the manner in which such influence is exerted. Its variations must occur more slowly than those in the output, and they cannot follow extrinsic changes of temperature so closely, as do the variations in expenditure.

On the other hand, we know that the heat-expenditure may be varied by mechanisms which are almost self-regulating. It has already been stated that the great majority of the heat is lost by the parts in contact with the air, namely, the skin and air passages. In these places the warm blood is exposed to the

cool air, and loses much of its heat by radiation, conduction, and evaporation. It is obvious that the greater the quantity of blood thus exposed for cooling the greater will be the amount of heat lost in a given time by the body as a whole.

If we review the circumstances which tend to destroy the uniformity of the temperature of the body, we shall see that each one is accompanied by certain physiological actions which tend to compensate for the disturbing influences.

Compensation for internal variations.—An increase in the heat-income may be induced by increased chemical activity in the tissues, notably the action of the muscles and large glands. When this increased heat is communicated to the blood, the latter flowing through certain nerve centres, brings about the following results :—(*a.*) An acceleration of respiratory movement, increasing the amount of cold air to be warmed and saturated with moisture in the air passages. (*b.*) Relaxation of the cutaneous arterioles, exposing a greater quantity of blood to the cooling influence of the air. (*c.*) An increase in the amount of sweat secreted affording opportunity for greater surface evaporation. All these changes concur in causing escape of the surplus caloric.

As an example, may be mentioned active muscular exercise, which daily experience shows us is always accompanied by quick breathing, and a warm moist skin.

The increased production of heat in fever depends upon a pathological increase of metabolism. It gives rise to the same results, with the exception of the secretion of the sweat, which is checked probably owing to the toxic inhibition of the special nerve mechanisms controlling the glands. This deficiency in the heat-regulating arrangements has much to do with the abnormally high temperature of febrile disease.

When on the other hand a lesser quantity of heat is produced, owing to inactivity of the heat-producing tissues, the reverse takes place, namely, the respiration is slow, the skin is pale and dry, so that little heat can escape.

Compensation for External Variations of Temperature.—When the temperature of the air rises much above the average, the escape of heat from our body is hindered. But before the blood can become warmer, the hot air, by stimulating the skin, brings about reflex changes, independent of the body temperature, which satisfactorily check the tendency to an abnormal rise. This can be shown by the local application of external heat, by means of which (*a*) a rush of blood to the

skin, and (*b*) copious sweat secretion may be induced *in a part*. This is brought about by impulses, sent directly from the skin, to the centres regulating the local vasomotor and secretory mechanisms, which cause vascular dilatation and secretive activity in the excited part. If a part only be warmed, a local effort is made to cool that part ; this cannot be induced by variations in the general body temperature.

When, however, the atmosphere becomes very warm, all the cutaneous vessels dilate simultaneously, and the escape of heat is greatly increased ; while, at the same time, so much blood being occupied in circulating through the skin, the deeper—heat-producing—tissues are supplied with less blood, and therefore generate a lesser quantity of heat. Thus any rise in the external temperature, which at first sight would seem to impede the escape of heat from the body, really facilitates it, by causing, through the vascular and glandular nerve mechanisms of the skin, a greater exposure of blood to the air, and a greater quantity of evaporation from the warm skin. When the temperature of the air reaches that of the body, the only way of disposing of the heat generated in the body is by evaporation, for the removal of heat by radiation and conduction stop. In animals like man, whose cutaneous moisture is great, external heat seldom causes marked change in the rate of breathing, but in animals whose cutaneous secretion is limited, external heat distinctly affects their respiratory movements, as may be seen by the panting of a dog on a very warm day, even when the animal is at rest.

The arrangements for preventing the loss of heat when the surroundings are unusually cold, are as important as those for facilitating its escape in very warm weather. In this case the cold acting as a stimulus to the vaso-constrictor nerve agencies of the skin causes the blood to retire from the surface and fill the deeper organs, where more heat is produced. This bloodless skin and the underlying fat then act as a non-conducting boundary protecting the warm blood from exposure. At the same time the secretion of sweat is controlled by a special nerve mechanism, which lessens the secretion and checks evaporation, thereby enabling the body to remain at the normal standard temperature.

It would, then, appear that the chief factors regulating the body temperature belong to the expenditure department, viz. —(*a*) variation in the quantity of moisture evaporated from the skin and the air passages, and (*b*) variations in the quantity

of blood exposed to be cooled, or driven from the surface to the deep-seated heat-producing organs.

These methods of regulation have to compensate not only for differences of external temperature, but also for fluctuations in the amount of heat produced in the tissues.

The regulating power of the skin and respiratory tract, appears to be adequate for the perfect maintenance of uniform temperature only within certain limits. These limits vary much in different animals; many have special coverings protecting them from external influences, and retain their warmth in an atmosphere seldom above 0° C. In man the limits vary according to many circumstances, *e.g.*, both extremes of age are very sensitive to changes of temperature. It would appear that for about 10° C. above and below the body temperature our skin-regulating mechanisms are adequate, but beyond these limits external changes affect our general temperature, and if continued become injurious. Of course, by imitating with clothing the natural protection with which some animals are endowed, we can aid the normal regulating factors, and bear much greater extremes of temperature with safety, or even comfort.

The sensation of cold.—It is somewhat surprising to learn that our bodies are always at the same temperature, no matter how hot, or how cold, we *feel*. Our sensations of being hot or cold are explained as follows. We feel hot when our cutaneous vessels are full of warm blood, and this communicates to the cutaneous nerve terminals—the sensory nerves—the sensation of general warmth. On the other hand, when the cutaneous vessels are empty, the sensory nerves are directly affected by the cold of the external air. Since the full or empty state of the vessels of the skin frequently depends on the heat or cold of the air, we use the expressions "it is hot or cold" and "we are hot or cold," as synonymous, because both ideas arise from the same state of the skin. But we can make ourselves feel warm by violent exercise even on a frosty day, because we generate so much heat, by muscular action, that the cutaneous vessels have to be dilated in order to get rid of the surplus, and our skin feels warm. Our feelings, when we say we are warm or cold, simply depend upon our cutaneous vessels being full or empty of warm blood.

The local appreciation of differences of temperature will be discussed in the chapter dealing with the sense of Touch.

CHAPTER XXIV.

CONTRACTILE TISSUES.

In the lower forms of organisms the motions executed by protoplasm suffice for all their requirements. Thus the amœba manages to pass through its lifetime with no other kind of motion at its disposal than the flowing circulation and the budding out of its soft protoplasm. A vast number of minute organisms depend wholly upon the protoplasmic stream, and the twitching of cilia for their digestive and progressive movements. Before we leave the class of animals which never pass beyond the unicellular stage, we find, however, examples in which a portion of their protoplasm is specially adapted to the performance of sudden and rapid motions. The protoplasm so modified in function deserves the name of contractile material. Thus, though the protoplasm which lies within the stalk of the bell animalcule is morphologically undifferentiated, it can contract with such rapidity that the eye cannot follow the motion.

As we ascend in the scale of animal life, the necessity for motions of varied rapidity and duration becomes more urgent, and so we find not only one, but several kinds of tissue specially adapted for carrying out motions of different rates and durations.

As a general rule the more rapid the contraction it performs, the more the tissue differs from the original type of protoplasm; and the slower and more persistent the contraction, the more the tissue elements resemble protoplasmic cells. In the minute blood-vessels, a very prolonged contraction, for example, is the rule, and the contractile elements differ but little from ordinary protoplasmic cells. The intestinal movements are rapid compared with those of the arterial muscles, and in them we find a thin, elongated form of muscle cell. In the heart a forcible and quick contraction takes place, which, however, is slow when compared with a sudden jerk of a single spasm of a skeletal

muscle, and its texture is different, being a form intermediate between the slow-contracting smooth muscle and the quick-contracting striated skeletal muscle.

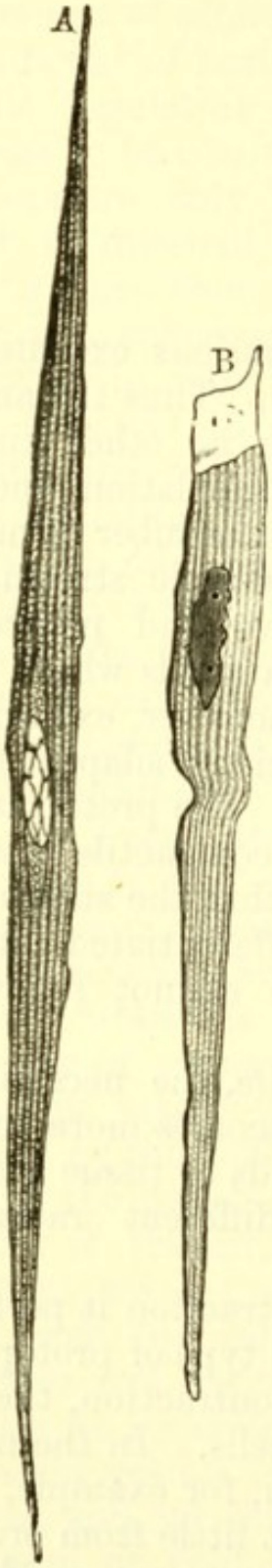


Fig. 166.— Muscle cells, showing different conditions of the protoplasm of the cell and nucleus.

By borrowing examples from the lower animals, this parallelism of structural differentiation and increase of functional energy can be more perfectly demonstrated, and we can make out a gradual scale of increasingly rapid motion corresponding with greater complexity of structure.

Histology of Muscle.

The term muscle includes the textures in which the protoplasm is specially differentiated for purposes of contraction.

The muscle tissues of the higher animals may be divided into two classes ; 1. non-striated or smooth, and 2. striated, in which again there are some slight variations.

The *non-striated muscle tissue* is that in which the elements have so far retained the typical form as to be easily recognisable as cells when separated one from the other. These cells are more or less elongated, flattened elements with a single, long, rod-shaped nucleus and no cell wall. They are tightly cemented together by a tough elastic substance, so that their tapering extremities fit closely together and form commonly a dense mass or sheet. Sometimes they branch more or less regularly, and then are arranged in net-works.

These cells vary greatly in size as well as in the relation of their length to their width, in some places deserving the name fibres, or fibre-cells, and in others being only elongated cells.

The *striated muscle tissue* is that of which the skeletal muscles and the heart are composed. It therefore forms the larger proportion of the animal, known as the flesh. The flesh can by judicious dissection easily be divided into single parts called muscles, each of which contains many other tissues and is attached so as to carry on certain movements, and may, therefore, be regarded as an organ.

Such a muscle is enclosed in a sheath of connective tissue, from which sheet-like partitions, or septa, pass into the mass of the muscle and divide it into bundles of fibres. These septa also act as the bed in which the vessels and nerves lie.

The tissue of the heart differs from other striated muscle in being made up of truncated oblong branching cells with a central nucleus and no sarcolemma (see page 234).

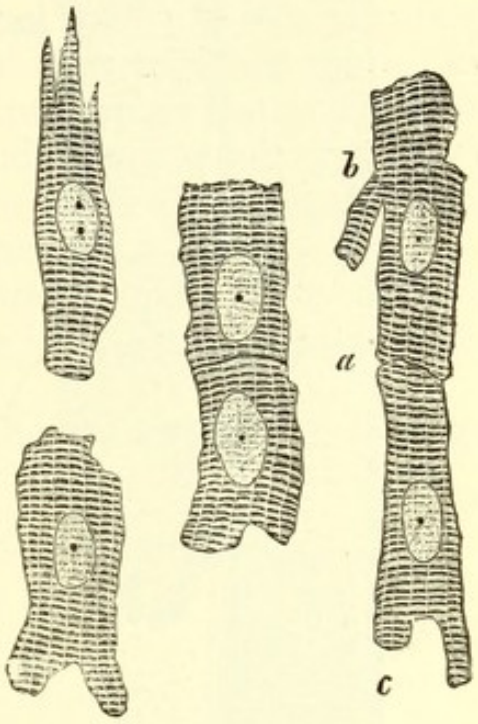


Fig. 167.—Short striated cells of the *heart-muscle*, separated one showing the truncated (*a*), or divided (*c*), ends and branches (*b*).

The bundles of fibres of *skeletal muscle* vary much in size, giving a coarse or fine grain in different muscles; they are composed of a greater or less number of fibres, which lying side by side run parallel one to the other. The single fibres of striated muscle vary in length, sometimes reaching 4—5 cm. (2 inches), but being on an average much shorter, they only extend the entire length of a muscle in the case of very short muscles. In long muscles their tapering points are made to correspond with those of other fibres to which they are firmly attached. The soft fibres are pressed by juxtaposition into prismatic forms, so that in a fresh condition they appear polygonal in transverse section. When freed from all pressure or traction they become cylindrical, and the transverse striation of the contractile substance appears regular, and is easily recognised.

Each fibre consists of a delicate case of thin, elastic, homogeneous membrane, forming a sheath called *sarcolemma*, within which the essential contractile substance is enclosed. The soft contractile substance completely fills and distends the

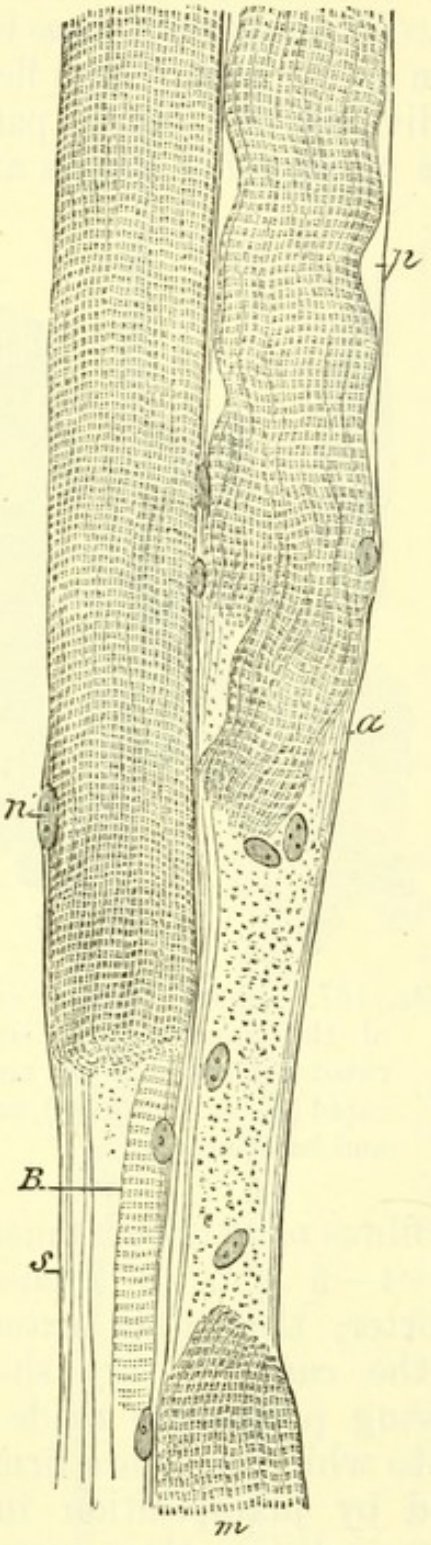


Fig. 168.—Two fibres of striated muscle, in which the contractile substance (*m*) has been ruptured and separated from the sarcolemma (*a*) and (*s*); (B) shows a thin strip of torn contractile substance in which the transverse markings are clearer; (*n*) nuclei, (*p*) space under sarcolemma. (Ranvier.)

elastic sarcolemma, so that when the latter is broken its contents bulge out or escape.

After death, particularly if preserved in weak acid (HCl), the striation becomes more marked, and the dead, and now rigid, contractile substance can be broken up into transverse plates or discs.

Besides the transverse striation, a longitudinal marking, well defined after steeping in alcohol, can be seen in the muscle fibre. This indicates the subdivision of the contractile substance into thin threads called *primitive fibrillæ*. Each primitive fibril shows a transverse marking, corresponding with the transverse striation, which divides the fibrils into short blocks called *sarcous elements* (Bowman). The differentiation is most marked in the highly developed muscles of insects. For details works on histology must be consulted.

In the muscle fibre are found long granular masses like protoplasm; these are the nuclei of the contractile substance. They must not be confounded with the oval nuclei of the sarcolemma, which are much more numerous along the edge of the fibre, or with the other short nuclei seen in such numbers between the fibres, which indicate the position of the capillary vessels.

It is stated that each striated muscle fibre has a nerve fibre passing directly into it, but the exact details of the mode

of union in mammalia are not yet satisfactorily made out.

Properties of Muscle in the Passive State.

Consistence.—The contractile substance of muscle is so soft as to deserve rather the name fluid than solid ; it will not drop as a liquid, but its separated parts will flow together again like half-melted jelly. In this respect it resembles the protoplasm of some elementary organisms, the buds from which are so soft that they can unite around foreign bodies, and yet have sufficient consistence to distinguish them from fluid.

Chemical composition.—The chemical constitution of the contractile substance of muscle in the living state is not accurately known.

On analysis human muscle gives the following per centage composition :—

Water	73·5
Proteids	18·02
Gelatin	1·99
Fat	3·27
Extractives	0·22
Inorganic Salts	3·12

Muscle Plasma.—The death of muscle is accompanied by changes of a chemical nature which give rise to coagulation, resulting in the formation of *muscle clot*, or *myosin*, and *muscle serum*. The rigidity of muscles after death, *rigor mortis*, is the result of this coagulation. Some thirty years ago it was shown by Kühne that coagulation could be postponed in frog's muscles by freezing. A pale yellow, opalescent, alkaline juice was pressed out of the muscle at 0° C. and separated by a cold filter. It changed to a jelly above the freezing point and coagulated at ordinary temperatures.

Mammalian muscle plasma also may be prevented from clotting by cold, or by the action of neutral salts, as in the case of blood-plasma. When diluted, the salt-plasma coagulates quickly between 30° and 40°, giving rise to a clot, myosin, and muscle-serum. Sarco-lactic acid is at the same time formed.

Myosin may be extracted from muscle after *rigor* by a solution of ammonium chloride and precipitated by removing the salt by dialysis. It is soluble in 5% sodium chloride and other-

wise behaves towards neutral salts like a globulin. It is gelatinous in consistence, never forming threads like fibrin, which in some other respects it resembles.

It is produced by a fermentive process from *myosinogen* as fibrin from fibrinogen. But it differs from fibrin in the following particulars. (1) Its ready solution in saline solutions. (2) On solution it behaves like myosinogen. (3) Its appearance is associated with the formation of sarco-lactic acid.

The following proteids may be obtained from muscle clot :—

1. *Para-myosinogen*, which coagulates at 47° C. It differs from myosinogen, (*a*) in requiring less concentrated solutions of magnesium sulphate, or sodium chloride, to throw down the characteristic flocculent precipitate, (*β*) in not being precipitated by acetic acid, and (*γ*) in not being capable of forming myosin.

2. *Myosinogen*, which coagulates at 56° C., can, with the suitable ferment, be made to coagulate and form myosin. Like the last body it is a globulin, being precipitated by saturation with NaCl, or $MgS.O_4$.

Muscle-Serum.—In the salted serum three other proteids are present, viz. :

1. *Myoglobulin* is coagulable at 53° C. (the coagulating point of serum-globulin being 75° C.) It requires complete saturation with NaCl or $MgSO_4$ for its precipitation.

2. *Myo-albumin* is coagulable at 73° C. and is not precipitated by saturation with NaCl or $MgSO_4$.

3. *Myo-proteose* is not coagulated by heat and not precipitated by saturation with NaCl or $MgSO_4$. It is a deutero-proteose probably identical with myosin-ferment.

Muscle-Pigments.—Muscle-plasma contains (1) *Hæmoglobin*, and (2) *Myohæmatin* (McMunn) which is widely spread in the animal kingdom, and has respiratory affinity for oxygen like hæmoglobin. It was discovered by its spectroscopic appearances, which resemble those of hæmochromogen.

Extractives.—In muscle-plasma are found kreatine, kreatinine, xanthine, hypoxanthine and traces of carnin, urea, uric acid, also fats, glycogen, inosite, sugar and lactic acids, which give the serum an acid reaction.

Inorganic Salts in which preponderate potassium as a base, and phosphoric acid among the acids.

Gases.—A certain quantity of CO_2 can be removed from muscle. It exists partly free and partly fixed. It increases in

quantity—particularly the fixed—by rigor or contraction. Muscle does not yield any oxygen.

Metabolism of resting Muscle.—In the state of rest a certain amount of oxygen is taken from the hæmoglobin of the blocd and carbonic acid is given off. These changes seem connected with the nutrition, and active powers of the tissue.

A muscle cannot be said ever to be at rest. It is always slightly, tonically, contracted. Section of its nerve causes elongation, by paralysing the *tonus*, and is followed by changes in its nutrition. On this account the chemical changes of nutrition and contraction cannot well be separated.

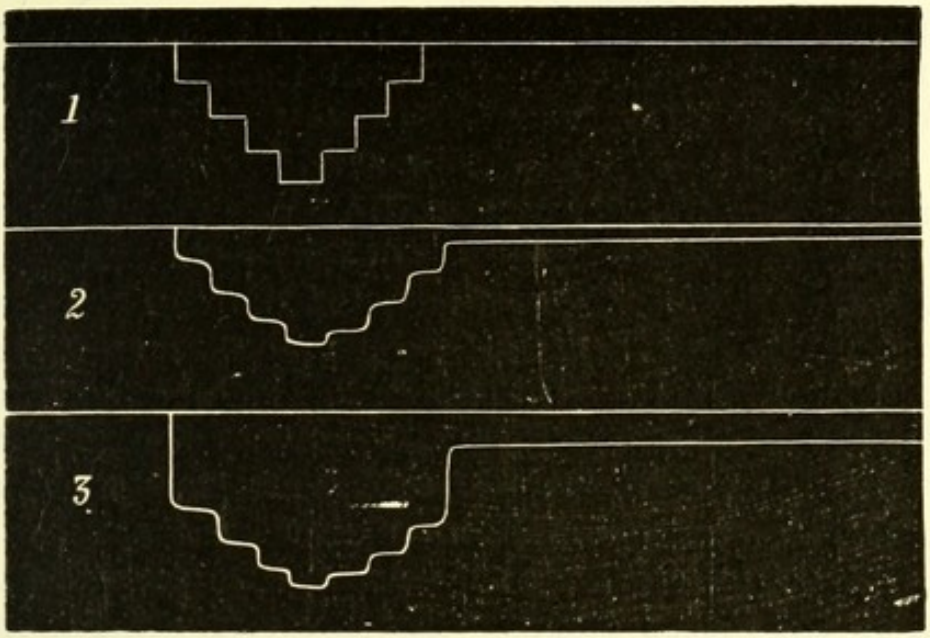


Fig. 169.—1. Shows graphically the amount of extension caused by equal weight increments applied to a steel spring.
2. Shows the amount of extension caused by equal weight increments applied to an india-rubber band.
3. The same applied to a frog's muscle. Showing the decreasing increments of extension ; the gradual continuing stretching and the failure to return to the abscissa when the weight is removed.

Elasticity.—Striated muscle is easily stretched, and, if the extension be not carried too far, recovers very completely its original length. That is to say, the elasticity of muscle is small or weak, but very perfect. When a muscle is stretched to a given extent by a weight—say of 1 gramme—if another gramme be then added, it will not stretch the muscle so much as the first did ; and so on if repeated gramme weights be added one after the other, each succeeding gramme will cause less extension of the muscle than the previous one ; so that the more a muscle is stretched the more force is required to

stretch it to the given extent, or, in other words, the elastic force of muscle increases with its extension.

If a tracing be drawn showing the extending effect of a series of equal weights attached to a fresh muscle, it will be found that a great difference exists between it and a similar record drawn by inorganic bodies or an elastic band of rubber. (Fig. 169.)

When a weight is applied to a muscle, it does not immediately stretch to the full extent the weight is capable of effecting, but a certain time, which varies with circumstances, is required for its complete extension. The rate of extension is at first rapid, then slower, until it ceases. As a muscle loses its powers of contraction from fatigue, it becomes less easily extended. Dead muscle has a greater but less perfect elasticity than living, *i.e.*, it requires greater force to stretch it, but does not return so perfectly to its former shape.

The importance of the elastic property of muscle in the movements of the body is noteworthy. The muscles are always on the stretch, partly by their elasticity and partly by tonic contraction, to be considered later. This can be seen in a fractured patella, the fragments of which remain far apart, causing the surgeon much anxiety. When one muscle—for example, the biceps—contracts, it finds an elastic antagonist already tense, and has to lengthen this antagonist as it contracts itself. The triceps in this case opposes the biceps, as a weak spring, and gently returns to its natural length when the contraction of the biceps ceases. The muscles being kept tense by their elasticity, there can be no jarring or jerking, as might take place if the attachments of the inactive muscles were allowed to become slack.

Electric Phenomena.—In a living muscle electric currents may be detected, having a definite direction, and certain relations to the vitality of the tissue. As they seem to be invariably present in a passive muscle they have been called *natural muscle currents.*

They are generally studied in the muscles of cold-blooded animals after removal from the body. The muscle is spoken of as if it were a cylinder with longitudinal and transverse surfaces corresponding to its natural surface and its cut extremities. In such a block of frog's muscle the measurement of the electric currents requires special precautions, because a sensitive galvanometer must be used, which can easily be disturbed by such currents as are brought about by the contact of metal electrodes with the moist saline tissues. Specially

constructed electrodes are used to avoid the occurrence of these currents by polarisation. These *non-polarisable electrodes* may be made on the following plan :—Small glass tubes are drawn to a point ; the smaller opening is plugged with china clay moistened in saline solution (·65 per cent.) and placed in contact with the muscles. The tubes are filled with saturated solution of zinc sulphate, in which is placed the amalgamated zinc terminals from the galvanometer. Thus the muscle is not injured, and the zinc solution prevents the metal terminals from producing adventitious currents.

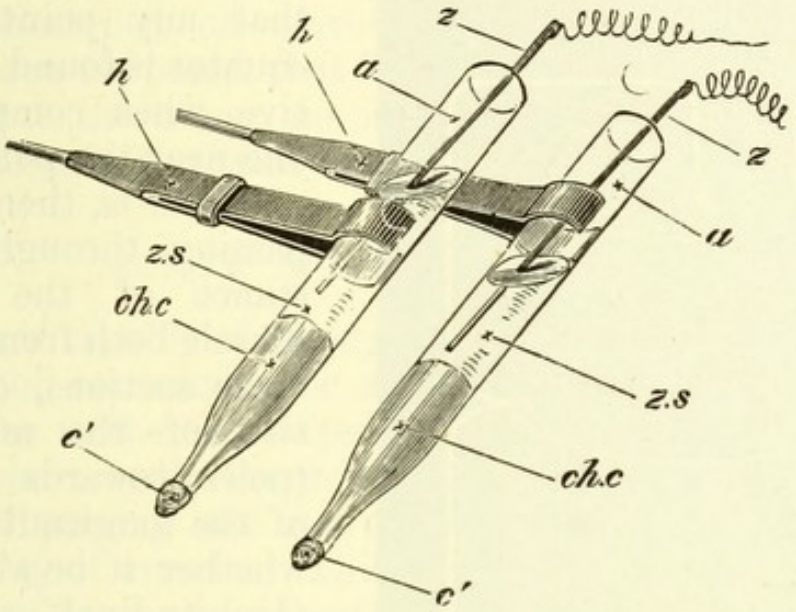


Fig. 170.—Non-polarisable Electrodes. The glass tubes (*a a*) contain sulphate of zinc solution (*z.s*), into which well amalgamated zinc rods dip. The lower extremity is plugged with china clay (*ch.c*), which protrudes at (*c'*) the point. The tubes can be moved in the holders (*h h*), so as to be brought accurately into contact with the muscle. (Foster.)

If a pair of such electrodes be applied to the middle of the longitudinal surface at (*e*) (Fig. 171), and of the transverse surface at (*p*) respectively, and then be brought into connection with a delicate galvanometer, it is found that a current passes through the galvanometer from the longitudinal to the transverse surface. A current in this direction can be detected in any piece of muscle, no matter how much it be divided longitudinally, and probably would be found in a single fibre had we the means of examining it. The nearer to the centre of the longitudinal and transverse sections the electrodes are placed, the stronger will be the current received by them. If both the electrodes be placed on the longitudinal or on the transverse surfaces a current will pass through the galvanometer

from that electrode nearer the middle of the longitudinal section (called the equator of the muscle cylinder) to the electrode nearer the centre of the transverse section (pole of muscle cylinder). If the electrodes be placed equidistant from the poles or from the equator no current can be detected.

The central part of the longitudinal surface of a piece of muscle is, then, positive, compared with the central part of the extremities or transverse sections. And between these parts, the *equator* and *poles* of the muscle cylinder, where the difference is most marked, are various gradations, so that any point near the equator is found to be positive when compared with one near the poles.

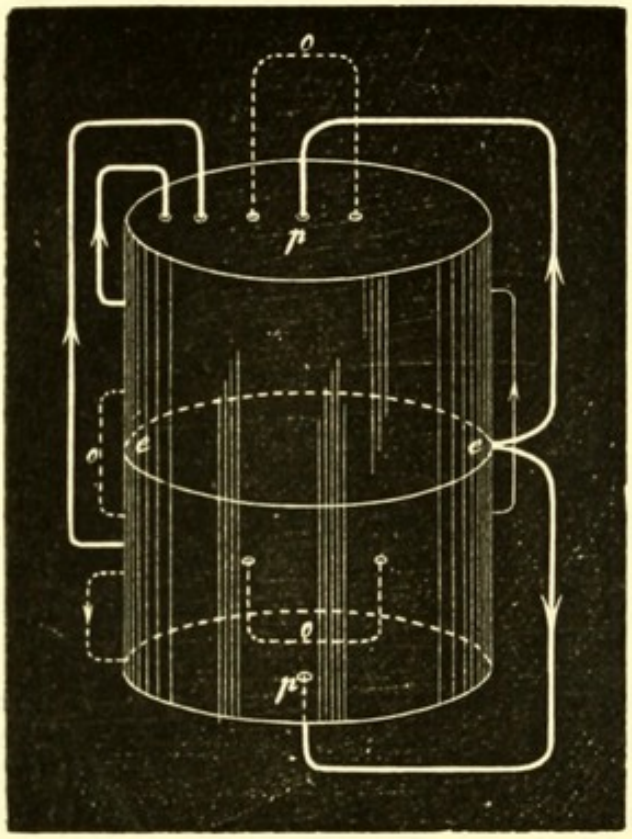


Fig. 171.—Diagram to illustrate the currents in muscle.

(*e*) Equator, corresponds to the centre of the muscle cylinder.

(*p*) Polar regions of cylinder representing the extremities of the muscle.

The arrow heads show the direction of the surface currents, and the thickness of lines indicates the strength of the currents. (After Fick.)

There is, then, a current passing through the substance of the piece of muscle both from the transverse sections, or extremities, of the muscle-block (poles) towards the middle of the longitudinal surface, whether it be a cut surface (longitudinal section) or the natural surface of the muscle (equator). This is called the *muscle current*, or sometimes natural muscle current.

If the cylinder in the accompanying figure be taken to represent a block of muscle, *e* would correspond to the equator, and *p* to the poles, and the arrowheads show the direction of the currents passing through the galvanometer, the thickness of the lines indicating their force. The dotted lines *o* are connected with points where the electro-motive force is equal, and therefore no current exists.

The electro-motive force of the muscle-current in a frog's gracilis has been estimated to be about ·05—·08 of a Daniell

cell. It gradually diminishes as the muscle loses its vital properties, and is also reduced by fatigue. The electro-motive force rises with the temperature from 5° C. until a maximum is reached at about the body temperature of mammals.

These muscle-currents are very weak if the uninjured muscle be examined *in situ*, the tendon being used as the transverse section ; they soon become more marked after the exposure of the muscle, and if the tendon be injured they appear at once in almost full force. In animals quite inactive from cold the muscles naturally are but slowly altered by exposure, &c., and the muscle-currents do not appear for a considerable time, which is shortened on elevating the temperature. It has, therefore, been supposed that in the *perfectly normal* state of a living animal there are no muscle currents so long as the muscle remains in the passive state.

Active State of Muscle.

A muscle is capable of changing from the passive condition, into a state of contraction or activity. Besides the change in form, obvious in the contracted state of the muscle, its chemical elastic, electric, and thermic conditions are altered. The capability of passing into this active condition is spoken of as the *irritability* of muscle. This is directly dependent upon its chemical condition, and therefore related to its nutrition and to the amount of activity recently exerted, which, as will hereafter appear, changes its chemical state.

Under ordinary circumstances, during life, the muscles change from the passive state into that of contraction in response to impulses communicated to them by nerves. The influence of the will can excite most skeletal muscles to action. Nearly all muscular actions in the living body are called forth by nervous impulses or *stimuli*. But many other influences can bring about the same change.

As a rule, in experiment we utilise the nerve belonging to a muscle in order to throw it into the contracted state. This is called *indirect stimulation*. Various stimuli can bring about the change when applied to the muscle directly (*direct stimulation*). Since the nerves branch in the substance of the muscle, it might be the stimulation of the terminal nerve ramifications that brings about the contraction, even when the stimulus is applied to the muscle directly.

That this is not so and that muscles can be stimulated

without the intervention of nerves is satisfactorily proved by the following facts :—

1. Some parts of muscles, such as the lower end of the sartorius, and many muscular structures which have no nerve terminals in them, respond energetically to all kinds of muscle-stimuli.

2. There are some substances which act as stimuli when applied directly to muscle, but have no such effect upon nerves, viz., ammonia.

3. For some time after the nerve has ceased to react, because of its dying, the muscle will be found quite irritable if directly stimulated.

4. *Curara*, arrow-poison, has the extraordinary effect of paralysing the nerve terminals, so that the strongest stimulation of the nerve calls forth no muscle contraction. If the muscles in an animal under the influence of this poison be stimulated directly, they respond with a contraction.

Muscle-Stimuli

May be enumerated thus :—

1. *Mechanical Stimulation.*—Any sudden blow, pinch, &c., of a living muscle causes a momentary contraction, which rapidly passes off when the irritation is removed.

2. *Thermic Stimulation.*—If a frog's muscle be warmed to over 30° C. it will begin to contract, and before it reaches 40° C. it will pass into a condition known as heat rigor, which will be mentioned presently. If the temperature of a muscle be reduced below 0° C. it shortens before it becomes frozen.

3. *Chemical Stimulation.*—A number of chemical compounds act as stimuli when they are applied to the transverse section of a divided muscle. Among these may be named—(1) the mineral acids (HCl, ·1 per cent.) and many organic acids ; (2) salts of iron, zinc, silver, copper, and lead ; (3) the neutral salts of the alkalies of a certain strength ; (4) weak glycerine and weak lactic acid ; these substances excite nerves only when concentrated ; (5) bile is also said to stimulate muscle in much weaker solutions than it will nerve fibres.

4. *Electric Stimulation.*—Electricity is the most convenient form of stimulation, because we can accurately regulate its force. The closing or opening, of an electric circuit of which a muscle forms part, causes it to contract. The sudden increase or decrease in the strength of a current passing through

a muscle acts as a stimulus, but a current of exactly even intensity may pass through a muscle without further exciting it, after the initial contraction has ceased.

The direct current from a battery (*continuous current*) may be used to stimulate a muscle in certain cases, but a current induced in a secondary coil by the entrance or cessation of a current

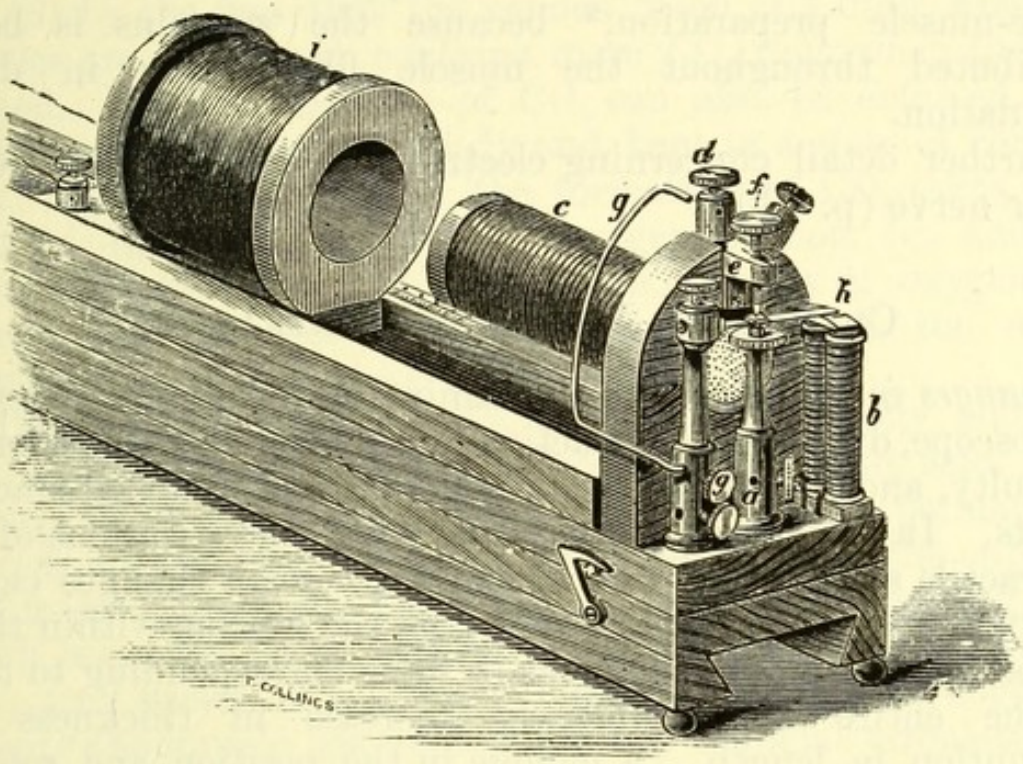


Fig. 172.—Du Bois-Reymond's Inductorium with Magnetic Interrupter.

c. Primary coil through which the primary, *inducing*, current passes, on its way to the electro-magnet (*b*).

i. Secondary coil, which can be moved nearer to or further from the primary coil (*c*), thereby allowing a stronger or weaker current to be induced in it. This *induced* current is the stimulus.

b. Electro-magnet, which on receiving the current breaks the contact in the circuit of the primary coil by pulling down the iron hammer (*h*), and separating the spring from the screw of *e*. When using Helmholtz's modification (*g*), (*e*) is screwed up and the current brings the spring in contact with the point of the pillar (*a*), and so demagnetises (*b*) by "short-circuiting" the battery.

When tetanus is to be produced, the wires from the battery are to be connected with *g* and *a*.

When a single contraction is required, the magnetic interrupter is cut out by shifting the wire from *a* to the binding screw to the right of *f*.

in a primary coil of wire (*induced shock*) is more commonly employed on account of the greater efficacy of its action, and short duration. The instrument used for this purpose in physiological laboratories is Du Bois-Reymond's inductorium, in

which the strength of the stimulus can be reduced by removal of the secondary coil from the primary. It is supplied with a magnetic interrupter by means of which repeated stimuli may be given by rapidly making and breaking the primary current (*interrupted current*) (Fig. 172.)

In experimenting on the contraction of muscle, as already stated, the electrodes are as a rule applied to the nerve of a nerve-muscle preparation,* because the stimulus is better distributed throughout the muscle fibres than in direct stimulation.

Further detail concerning electric stimulation is to be found under nerve (p. 460).

Changes in Muscle on Contraction.

Changes in Structure.—The examination of muscle under the microscope, during its contraction, is attended with considerable difficulty, and in the higher animals has not led to satisfactory results. In the muscles of insects, where the striations of the contractile substance are more marked, certain changes can be observed in it. The fibres, and even the fibrillæ within them, can be seen to undergo changes in form corresponding to those of the entire muscle, namely, increase in thickness and diminution in length. A change in the position and relative size of the light and dark portions of the muscle element has been described, and some authors state that the latter increases at the expense of the former after an intermediate period in which the two substances seem fused together.

Chemical Changes.—During the contraction condition the chemical changes which go on in passive muscle are intensified, and possibly new chemical decompositions arise of which not much is known.

Active muscle takes up more oxygen than muscle at rest, as is shown by the facts that, during active muscular exercise, more oxygen enters the body by respiration, and the blood leaving active muscles is poorer in oxygen than when the same muscles are passive in a proportion of 12 to 9. This absorption of oxygen may be detected in a muscle cut out of the body, but a supply of oxygen is not necessary for its contraction, since an

* By a nerve-muscle preparation is meant a muscle of a frog (commonly the gastrocnemius and the half of the femur to which it is attached) and its nerve which have been carefully separated from other parts and removed from the body.

excised frog's muscle will contract in vacuo or in an atmosphere containing no oxygen. From this it would appear that a certain ready store of oxygen must exist as a chemical constituent of the muscle substance.

The amount of CO_2 given off by a muscle increases in its state of activity. This may be seen (α) by the greater elimination from the lungs during active muscular exercise, and (β) by the fact that the venous blood of a limb, when the muscles are contracted, contains more CO_2 than when they are relaxed. (γ) The increase of CO_2 can also be detected in a muscle removed from the body and kept in a state of contraction. (δ) This increase in the formation of CO_2 takes place whether there is a supply of oxygen or not, (ϵ) and the quantity of CO_2 given off exceeds the quantity of oxygen that is used up. So that it is not exclusively from the newly-supplied oxygen that the CO_2 is produced.

Muscle tissue, when passive, is neutral or faintly alkaline; during contraction, however, it becomes distinctly acid. The litmus which it changes from blue to red is permanently altered, and the conclusion follows that CO_2 is not the only acid that makes its appearance. The other acid is *sarcolactic acid*, which is constantly present in muscle after prolonged contraction, and varies in amount in proportion to the degree of activity the muscle has undergone. If artificial circulation be kept up in the hind quarters of an animal while the muscles are contracting the quantity of sarcolactic found in the blood is very great. It varies directly with the CO_2, which would seem to suggest a relationship between the origin of the two products.

The amount of glycogen diminishes in muscle during its activity.

Active muscle contains more of those substances that can be extracted by alcohol and less that are soluble in water than passive muscle.

In the chemical changes which take place during muscle contraction the result of a decomposition of some carbohydrates alone appears; the albuminous substances therefore, do not take any part *that requires their own destruction.* This seems supported by the facts, that (1) the increased gas exchange in muscle during active exercise can be recognised in a corresponding alteration in the gas exchange in pulmonary respiration: (2) but no relation exists between muscular work and nitrogenous waste, as estimated by the urea.

The chemical changes taking place in muscle during its *contraction* are :—

1. The contractile substance, which is normally neutral or faintly alkaline, becomes distinctly acid in reaction owing to the formation of sarcolactic acid.

2. More oxygen is taken up from the blood than when the muscle is at rest. This using up of oxygen occurs also in the isolated muscle.

3. The extractives soluble in water decrease, those soluble in alcohol increase.

4. A greater amount of CO_2 is given off, both in the isolated muscle and in the muscles in the body, and the change in the quantity of CO_2 has no exact relation to that of the oxygen taken from the blood.

5. A diminution occurs in the glycogen, and prolonged rest causes an increase in the amount of glycogen.

6. A peculiar muscle-sugar makes its appearance.

I. *Change in Elasticity.*—The elasticity of a muscle during its state of contraction is less than in the passive state ; that is to say, a given weight will extend a muscle more, if attached to it while in tetanus than when it is at rest. The contracted muscle is then more extensible. If a muscle be stimulated when loaded with a weight just over the maximum load the muscle can lift, it becomes extended, because the change to the active state lessens its elastic power, while it cannot contract, being over-weighted.

II. *Electrical Changes.*—If a muscle, in connection with a galvanometer so as to show the natural current, be stimulated through its *natural* nerves, a marked change occurs in the *current.* The galvanometric needle swings towards zero, showing that the current is weakened or destroyed. This is called the *negative variation* of the muscle current which initiates the change to the active condition. When the muscle receives but a momentary stimulus sufficient to give a single contraction, this negative variation takes place in the current, but, owing to its extremely short duration, the galvanometric needle is prevented by its inertia from following the change. Only the most sensitive and well-regulated instruments show the electric change of a single contraction, but when the muscle is kept contracted by a series of rapidly repeated stimulations the inertia of the needle is overcome.

Rheoscopic Frog.—The negative variation of a single contraction can be easily shown on sensitive muscle. For this purpose

the sciatic nerve of a frog's leg is placed along the surface of the gastrocnemius of another leg, so as to pass over the middle and the extremity of the muscle, *i.e.* the points of greatest difference of electro-motive force. When the limb A (Fig. 173) (*stimulating muscle*) is made, by means of its nerve N, to contract, its negative variation acts as stimulus to the other nerve N′, lying along it, and the (*stimulated muscle*) B contracts. We shall see that artificial continued contraction is brought about by a rapidly repeated series of stimulations, so

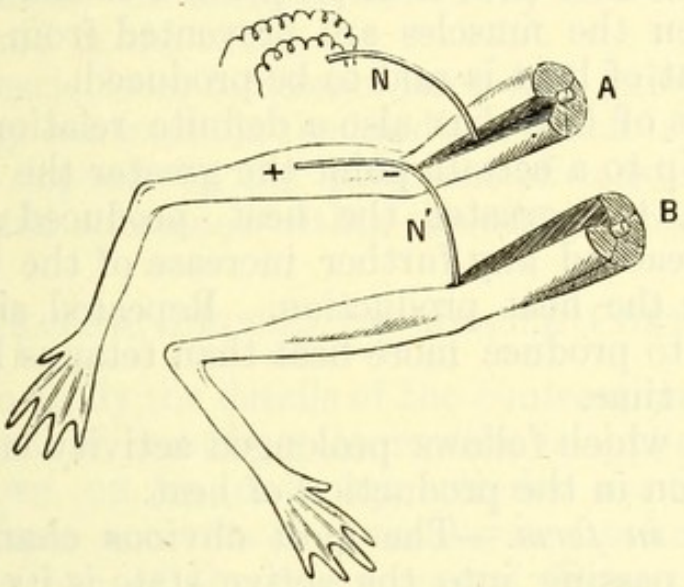


Fig. 173.—Diagram illustrating the arrangement in the Rheoscopic Frog.

A = *stimulating* limb. B = *stimulated* limb. The current from the electrodes passes into nerve (N) of stimulating limb (A), causing its gastrocnemius to contract. Whereupon the negative variation of the natural current between + and − stimulates the nerve (N′), and excites the muscles of B to action.

that the electric condition of the stimulating muscle undergoes a series of variations. The rheoscopic frog not only shows the negative variation of a single contraction, but it also demonstrates that the continued contraction, when produced by *interrupted electric stimulation*, is associated with repeated negative variations. The contraction of the *stimulated* muscle, whose nerve lies on the *stimulating* muscle, responds to the electric variations of the stimulator, and contracts synchronously with it.

If a muscle be stimulated at one end, a wave of negative variation passes along the muscle at the rate of 3 metres per second, lasting at any one point only ·003 of a second, so that the negative variation is over before the mechanical effect becomes obvious, for the muscle requires a certain time, called the latent period, before its contraction can be appreciated.

The origin of the electric currents of muscle will be discussed with nerve-currents, to which the reader is referred (p. 463).

III. *Temperature change.*—Long since it was observed in the human subject that the temperature of muscles rose during their activity. In frogs' muscle a contraction lasting 3 minutes caused an elevation of 18° C. A single contraction is said to produce a rise varying from ·001° to ·005° C., according to circumstances.

The production of heat is in proportion to the tension of the muscle. When the muscles are prevented from shortening, a greater amount of heat is said to be produced.

The amount of heat has also a definite relation to the work performed. Up to a certain point the greater the load a muscle has to move, the greater the heat produced; when this maximum is reached any further increase of the weight causes a falling off in the heat production. Repeated single contractions are said to produce more heat than tetanus kept up for a corresponding time.

The fatigue which follows prolonged activity is accompanied by a diminution in the production of heat.

IV. *Change in form.*—The most obvious change a muscle undergoes in passing into the active state is its alteration in shape. It becomes shorter and thicker. The actual amount of shortening varies according to circumstances. (*a*) A muscle on the stretch when stimulated will shorten more in proportion than one whose elasticity is not called into play before contraction, so that a slightly weighted muscle shortens more than an unweighted one with the same stimulus. (*b*) The fresher and more irritable a muscle is, the shorter it will become in response to a given stimulus; and, conversely, a muscle which has been some time removed from the body, or is fatigued by prolonged activity, will contract proportionately less. (*c*) With a certain limit, the stronger the stimulus applied the shorter a muscle will become. (*d*) A warm temperature augments the amount of shortening, the amount of contraction of frogs' muscles increasing up to 33° C. A perfectly active frog's muscle shortens to about half its normal length. If much stretched and stimulated with a strong current it may contract nearly to one fourth of its length when extended. Muscles are seldom made up of perfectly parallel fibres, the direction and arrangement varying much in different muscles. The more parallel to the long axis of the muscle the

fibres run, the more will the given muscle be able to shorten in proportion to its length.

The thickness of a muscle increases in proportion to its shortening during contraction, so that there is but little change in bulk. It is said, however, to diminish slightly in volume, becoming less than $\frac{1}{1000}$th smaller. This can be shown by making a muscle contract in a bottle filled with weak salt solution so as to exclude all air and to communicate with the atmosphere only by a capillary tube into which the salt solution rises. The slightest decrease in bulk is shown by the fall of the thin column of fluid in the tube.

Since a muscle loses in elastic force and gains but little in density during contraction, the hardness which is communicated to the touch depends on the difference of tension of the semi-fluid contractile substance within the muscle sheath.

The Graphic Record of Muscle Contraction.

In order to study the details of the contraction of muscle, the graphic method of recording the motion is applied. The curve may be drawn on an ordinary cylinder moving sufficiently rapidly. Where accurate time measurements are required it is better to use one of the many special forms of instruments, called *myographs*, made for the purpose. The principle of all these instruments is the same; namely, an electric current, which passes through the nerve of a frog's muscle connected with the marking lever, is broken by some mechanism while the recording surface is in motion; the exact point at which the contact is broken can be previously marked on the recording surface, by the lever. The rate of motion is registered by a tracing drawn by a tuning fork, of known rate of vibration, writing immediately under the lever.

In order that the muscle-nerve preparation may not be injured by the tissues becoming too dry, it is placed in a small glass box, the air of which is kept moist by a damp sponge. This *moist chamber* is used when any living tissue is to be protected from drying.

The first myograph used was a complicated instrument devised by Helmholtz; in which a small glass cylinder is made to rotate rapidly by a heavy weight, and when a certain velocity of rotation is attained, a tooth is thrown out by centrifugal force, which breaks the circuit of the current passing through the nerve of the muscle. The tendon is attached to a balanced

lever, at one end of which hangs a rigid style pressed by its own weight against the glass cylinder. When the circuit is broken the muscle contracts, raises the lever, and makes the style draw on the smoked glass cylinder.

Fick introduced a flat recording surface moving by the swing of a pendulum, by which the abscissa is made a segment of a circle, and not a straight line, and the rate varies, so that the different parts of the curve have varying time-values. The curves given in the following wood-cuts are drawn with the *Pendulum Myograph.*

Du Bois-Reymond draws muscle curves on the smoked surface of a small glass plate contained in a frame, which is shot by the force of a spiral spring along tense wires, and on its way breaks the contact. The trigger used for releasing the spring sets a tuning fork at the same time vibrating (*Spring Myograph*).

Single Contraction.

In response to an instantaneous stimulus, such as occurs in the secondary coil on breaking the primary current, a muscle gives a momentary twitch or spasm, commonly spoken of as a *single contraction*, which is of so short duration, that without the graphic method of recording the motion we could not appreciate the phases, described by Helmholtz, as occurring in it.

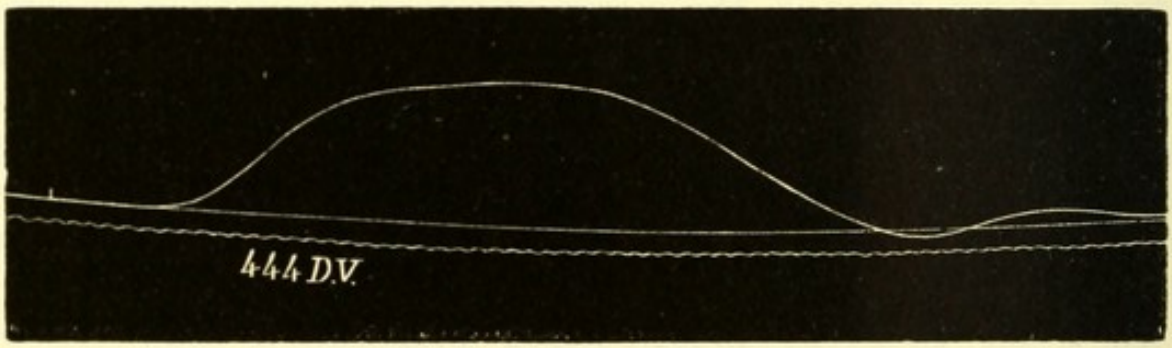


Fig. 174.—Curve drawn by a frog's gastrocnemius on the Pendulum Myograph; below is seen the tuning-fork record of the time occupied by the contraction. Parallel to the latter is the abscissa. The little vertical mark at the left shows the moment of stimulation, and the distance from this to the beginning of the rise of the curve gives the latent period, which is followed by the ascent and descent of the lever.

The curve drawn on the recording surface of a pendulum myograph, by such a single contraction, is represented in Figure 174. The short vertical stroke on the left of the abscissa, or base line, is drawn by touching the lever when the

muscle is in the uncontracted state, and indicates the time of stimulation. The upper curved line is drawn by the lever during the contraction of the muscle.

In such a curve the following stages are to be distinguished :—

1. The *latent period* is the short space between the point of stimulation and that at which the lever begins to rise, during which the lever does not move. In the skeletal muscles of the frog this delay seems to last nearly ·01 sec.

2. A period during which the lever rises, at first slowly, then more quickly, then again slowly, until it ceases to rise. This stage has been called the period of *rising energy*. It lasts about ·04 sec.

3. When the highest point is attained the lever commences to fall, at first slowly, then more quickly, and at last slowly. There is then no pause at the height of contraction. The stage of relaxing has been called the period of *falling energy*. It occupies when quite fresh about the same time as the second period, viz., about ·04 sec.

Thus a stimulus occupying an almost immeasurably short time sets up a change in the molecular condition, which taking nearly $\frac{1}{10}$ sec. to run its course, and requiring $\frac{1}{100}$ sec. before it exhibits any change of form, then in $\frac{4}{100}$ sec. attains the maximum height of contraction, and without waiting in the contracted condition, spends $\frac{4}{100}$ sec. in relaxing.

Wave of Contraction.—If one extremity of a long muscle be stimulated without the aid of the nerve (it is best to employ a muscle from a curarised animal), the contraction passes along the muscle from the point of stimulation in a wave which travels at a definite rate of 3—4 metres per sec. in a frog, and 4—5 metres per sec. in a mammal. Reduction of temperature and fading of vital activity cause the velocity of the wave to be lessened, until finally the tissue ceases to conduct; then only a local contraction occurs, severe stimulus causing simply an elevation at the point of contact. This seems analogous to the idio-muscular contraction, which marks the seat of severe mechanical stimulation after the general contraction has ended.

Variations in the Phases of a single Contraction.

The *latent period* which appears in a *single contraction curve* drawn by a muscle stimulated in the usual way, through the medium of a nerve, is not entirely occupied by *preparatory changes* going on in the substance of the muscle, but a certain

part of the time recorded as latent period corresponds to the time required for the *transmission* of the impulse along the nerve. This may be shown by stimulating first the far end of the nerve and then the muscle itself. In this case two curves will be drawn having different latent periods, that obtained by direct stimulation of the muscle being shorter, and representing the real latent period, while the longer one includes the time taken by the impulse to travel along the nerve to the muscle. The latent period in direct stimulation of muscle only lasts ·005 sec. or less. It has been ascribed, by some, to instrumental delay, the mechanical effect being said to be synchronous with the electric change. This view hardly seems applicable to non-striated muscle, heart muscle, or the skeletal muscle of the tortoise, all of which have a latency much too long to be accounted for as instrumental defect.

The latent period varies much in different kinds of muscle, in the same kind of muscle of different animals, and in the same individual muscle under different conditions. As a rule the slow-contracting muscles have a longer latent period. Thus the non-striated slow-contracting muscles found in the hollow viscera have a latent period of some seconds. The striated muscles of cold-blooded animals have a longer latency than the same kind of muscle in birds and mammalia. The latent period in insects' muscle is very short. Red muscle of rabbits has a longer latency than the pale variety.

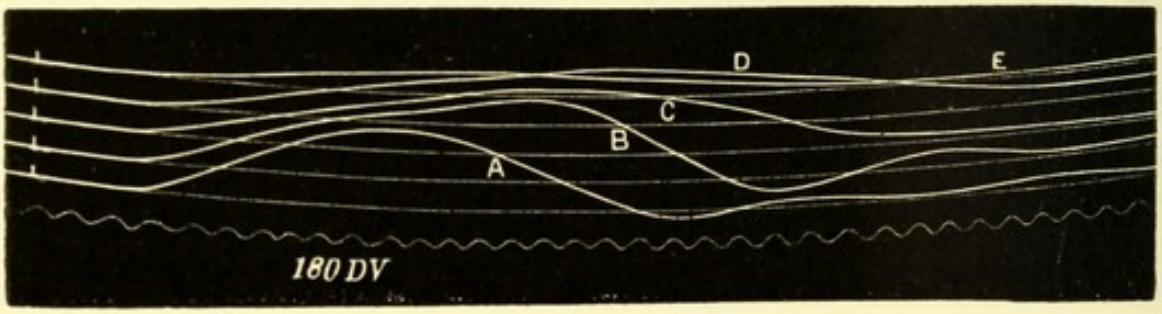


Fig. 175.—Curves drawn by the same muscle in different stages of fatigue—A, when fresh; B, C, D, E, each immediately after the muscle had contracted 200 times. Showing that fatigue causes a low, long contraction.

The latent period of the same gastrocnemius of a frog is considerably lengthened by fatigue, too weak stimulation or cold. If the weight be so applied that it does not extend the muscle before contraction, the duration of the latent period increases with heavy weights.

The *duration* of the single contraction of striated muscle as

a whole follows nearly the same rules, and varies in different cases and under varying circumstances.

Variety of Animal.—The greatest difference is observed in the muscles found in different kinds of animals. The contraction of some kinds of muscle tissue (non-striated muscle of mollusca, for example) occupies several minutes, and reminds one of the slow movement of protoplasm ; while the rapid action of the muscle of the wing of a horsefly occurs 330 times a second. Various gradations between these extremes in the rapidity of muscle contraction may be found in the contractile tissues of different animals. The following table gives the rate of contraction of some insects' muscles, which may help to show the extent of these variations.

Horsefly . . .	330	contractions per second.
Bee	190	,, ,,
Wasp . . .	110	,, ,,
Dragon-fly . . .	28	,, ,,
Butterfly . . .	9	,, ,,

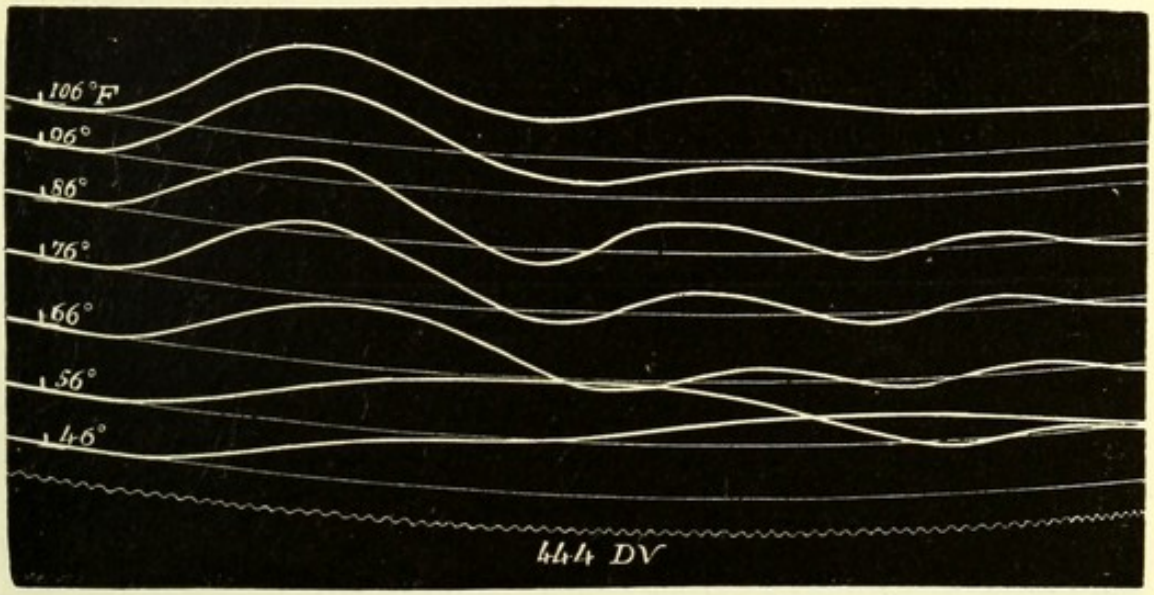


Fig. 176.—Curves drawn by the same muscle at different temperatures. Showing that with elevation of temperature the latency and the contraction becomes shorter. (The muscle had been previously cooled.)

Among the vertebrata the duration of the contraction of the skeletal muscles varies considerably according to the habits of the animal. The limb muscles of the tortoise and toad take a very long time to finish their contraction ; other muscles of the same animals act more quickly, but do not attain the rapidity of contraction of the skeletal muscles of warm-blooded animals.

Variety of Muscle.—Unstriated muscle has a variable, but in

all cases a long period of contraction. Of striated muscle, the heart is very slow, next come the red muscles of the rabbit's leg, and then the other skeletal muscles.

In the same muscle the duration of a single contraction is capable of considerable variation from changes in the following conditions.

Fatigue.—It seems to be lengthened by anything that leads to an accumulation of the chemical products which arise from muscle activity. Hence fatigue causes a slow contraction (Fig. 175).

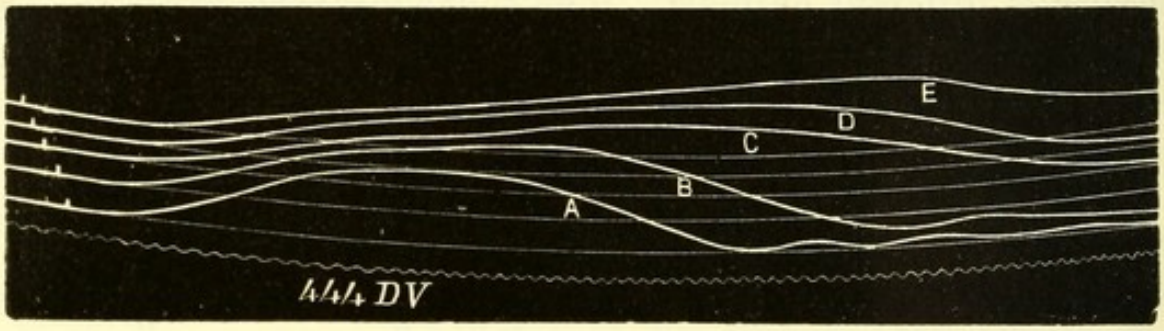


Fig. 177.—Curves drawn by the same muscle while being cooled. Showing that the latency and the contraction become longer as the temperature is reduced.

Temperatures.—Moderate increase of temperature greatly shortens the time occupied by the single contraction of any given muscle. Excessive heat causes a state of continued contraction.

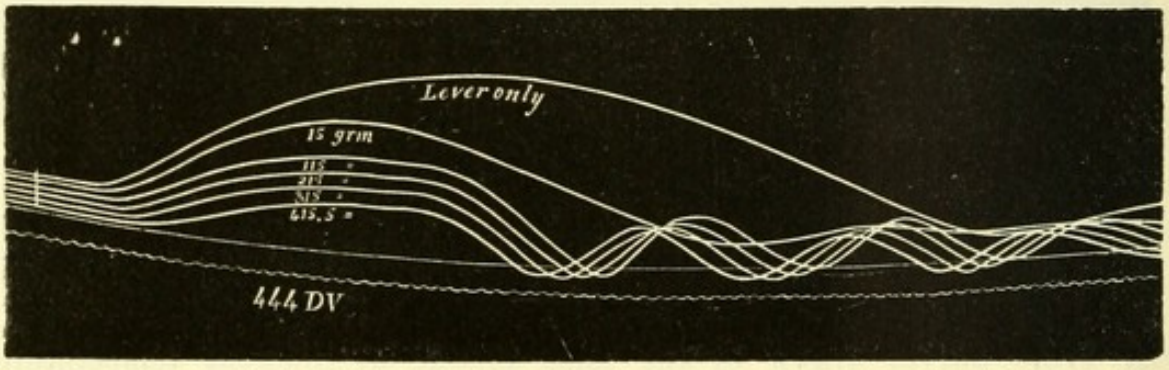


Fig. 178.—Six curves drawn by the same muscle when stretched by different weights. Showing that as the weight is increased the latency becomes longer and the contraction less in height and duration.

The reduction of temperature causes a muscle to contract more slowly, and, when extreme, the muscle remains contracted long after the stimulus is removed.

Load.—An increase of the weight attached to a muscle shortens the duration of its contraction.

Strength of stimulus.—The duration and extent of a contrac-

tion, depends only, up to a certain point, upon the force of the stimulus. A fresh muscle at the ordinary temperature with a medium load, will contract more and more as the intensity of the current is increased from the minimal stimulus. A limit to this increase is soon reached. With comparatively weak stimulation an effect is produced which cannot be surpassed by the same muscle with any increment of stimulus. The height of the contraction is the same for all medium stimuli while the muscle is fresh. This is called the *maximal contraction*, being the greatest shortening which can be produced by a single stimulus.

The *altitude* of the curve which represents the extent of the contraction varies in the same way as the latent period and the duration.

Summation.—Each time a muscle receives an induction shock of medium strength it responds with a "maximal contraction," but this is not the maximum amount the muscle can contract with *repeated stimulation*. If a second stimulus be given while the muscle is contracting, a second maximum con-

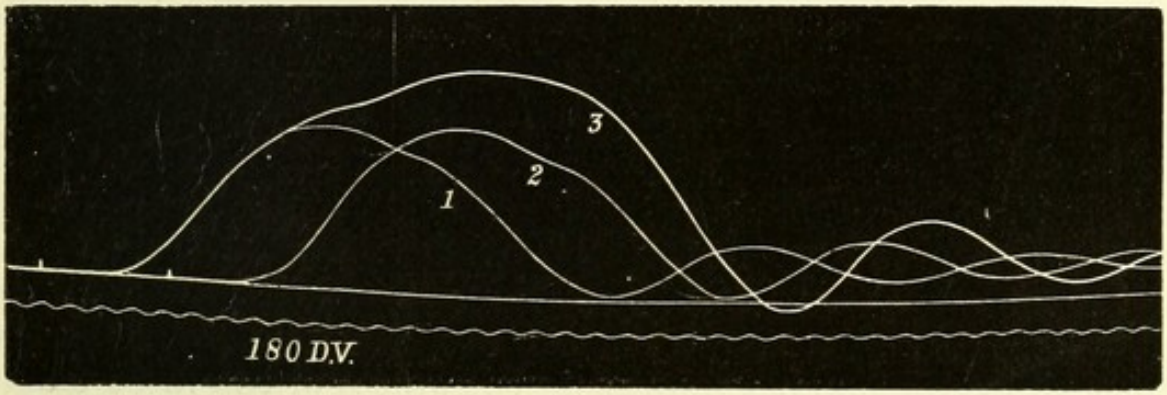


Fig. 179.—Pendulum Myograph tracings showing summation.

1. Curve of maximum contraction drawn by first stimulus, the exact time of application of which is shown by the small up-stroke of the left hand of the base line.
2. Maximum contraction resulting from second simple stimulation given at the moment indicated by the other small up-stroke.
3. Curve drawn as the result of double stimulation sent in at an interval indicated by the distance between the up-strokes, showing summation of stimulus and consequent increase in contraction over the "maximum contraction."

traction is *added* to the extent of contraction already arrived at at the moment of the second stimulation. If stimulated when the lever is at the apex of the curve the sum of the effect produced will be equal to two maximal contractions. If applied

in the middle of the period of the ascent or descent of the lever a second stimulation gives rise to $1\frac{1}{2}$ maximal contractions, and so on, in various parts of the curve, a new maximum curve is produced, arising from the point at which the lever is when the second stimulus is applied (Fig. 179).

A second stimulation given during the latent period produces the same effect, but the summation only begins at the end of the latent period of the second contraction. It is therefore difficult to demonstrate the summation when the stimuli are very close, but if the second stimulus come after an interval of more than $\frac{1}{600}$ sec., summation can easily be appreciated. This summation is more obvious when the stimulus is not sufficient to produce a maximum single contraction.

The following tracings (Figs. 180—182) show the effects of repeated stimulations applied at the various periods indicated by the numbers on the abscissa line. They are drawn on a comparatively slowly moving surface.

If a series of stimuli be applied in succession, at intervals less than the duration of a single contraction, a summation of contractions occurs, which results in the accumulation of effect until the muscle has shortened nearly twice as much as in a single contraction ; it then remains contracted to the same extent for some time, and does not shorten further though the stimulus be increased in rate or strength. As long as the stimuli are continued at a rapid rate, the various single contractions caused by the individual shocks are fused together (Fig. 180) ; but if the intervals between the stimuli be nearly as long as the time occupied by a single contraction, the line drawn by the lever will show notches indicating the apices of the fused single contractions (Figs. 181 and 182).

This condition of summation of contractions is called *tetanus*, and is said, by some, to be identical with the muscular motion produced by the action of the nerves in obedience to the will.

With from fifteen induced shocks to upwards of many hundreds a second, tetanus is produced in a frog's muscle. The lowest rate of electric stimulation at which human muscle passes into complete tetanus is about 25 per sec. The number of stimuli required varies with the rate of contraction of the muscle employed, the quick contracting bird's muscle requiring 70 per second, while the exceptionally slow-moving tortoise muscle only requires 3 per second. According to some, there is a limit to the number of stimuli which will cause tetanus, 360 per second is named as the maximum for a certain strength

of stimulus; with stronger stimuli, even when more frequent, tetanus occurs. It has been shown that many thousand stimuli per second can cause tetanus even with very weak currents. If tetanus be kept up for some seconds, and the stimulation be then suddenly stopped, the lever falls rapidly for a certain dis-

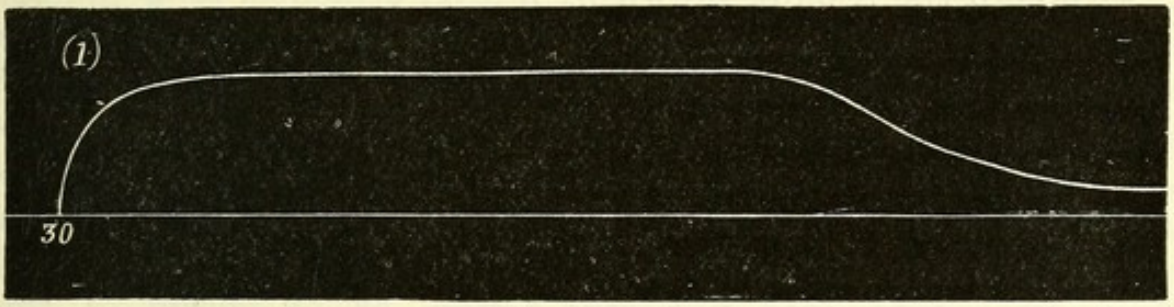


Fig. 180.—Curve of tetanus resulting from 30 stimulations per second, drawn by a frog's muscle on a drum, the surface of which moves 1·5 centimeter per second. The stimulation commences at "30," and ceases just before the lever begins to fall. No trace of the individual contractions of which the tetanus is composed can be recognised.

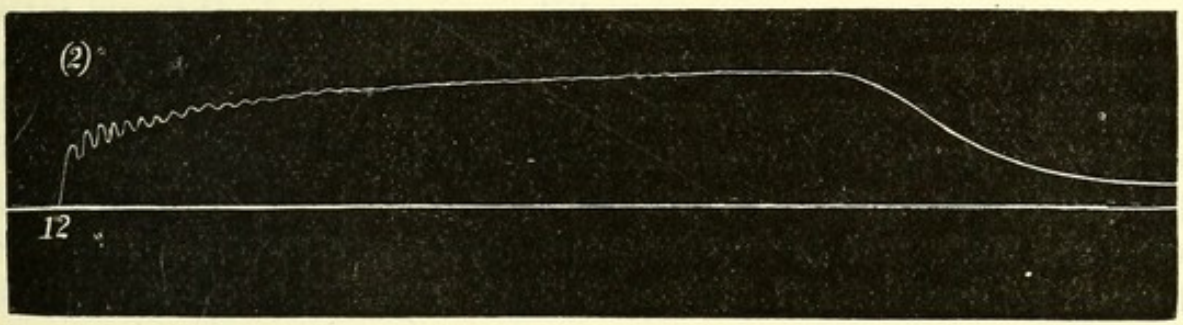


Fig. 181.—Curve of tetanus composed of imperfectly fused contractions resulting from 12 stimulations per second. The serrations on the left of the curve indicate the individual contractions.

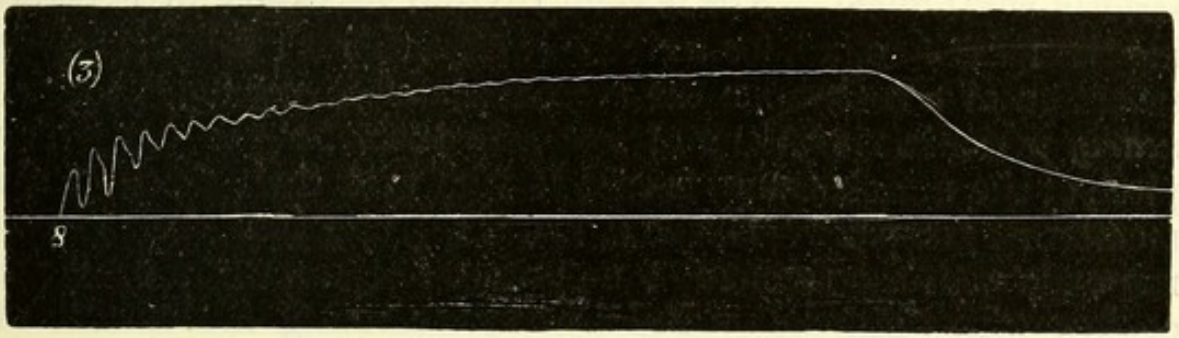


Fig. 182.—Tetanus produced by 8 stimulations per second. The more perfect fusion of the single contractions shown towards the end of the curve depends on the altered condition of the muscle.

tance, but the muscle does not quite return to its normal length for some few seconds. This residual contraction is easily overcome by any substantial load. If kept in a state of tetanus by weak stimulation, after some time the muscle commences to relax from fatigue, at first rapidly, then more slowly. This

falling off of the tetanic contraction may be prevented by increasing the stimulus.

Muscle Sound.

Although the tracing drawn by a lever attached to a muscle in tetanus is straight, and does not show any variation in the tension of the tetanised muscle, some variations in tension must occur, since a low humming sound is produced during contraction. This is called the *muscle-sound*. It can be heard by applying the ear firmly over any large muscle (biceps) while in tetanus, by throwing the muscles attached to the orbit and Eustachian tube into powerful action, or by spasm of the muscles in mastication.

The number of vibrations which has been estimated to occur in the voluntary contraction of human skeletal muscles does not produce an audible note ; hence it has been supposed that the note we hear is an overtone. When a muscle is thrown into tetanus by an induced current the primary of which is interrupted by a tuning fork, a tone is produced which corresponds with that of the fork. If, on the other hand, a contraction of the muscle be brought about by stimulating the spinal cord, with the same rate of breaking the current, the normal muscle-tone is produced, as if the contraction were the result of a nerve impulse.

There is no satisfactory proof, however, that the variation in tension of the continuous contraction of voluntary muscle is strictly rhythmical. Nor is such rhythm necessary in explaining the muscle-sound, for a single contraction is audible, and the sensation of a sound like the muscle-sound is produced by any *nearly* periodic vibrations of less rate than 25 per sec. The pitch of the muscle-sound is said to vary with the tension of the membrana tympani. Hence it has been suggested that it corresponds with the resonant tone proper to the membrane of the drum ; which may be evoked by any trembling movements of the muscle fibres due to slight variations in the force or distribution of the impulses transmitted by the motor nerves.

Irritability and Fatigue.

The activity of the muscle of mammalia is closely dependent upon its nutrition. If its blood current be completely cut off, in a short time, it loses its power of contracting. While the

muscle remains in the body, and is kept warm and moist by the juices in the tissues, it will live for many hours without any blood flowing through it, and it at once regains its contractility when the blood stream is again established. This is seen when the circulation of a limb is brought to a standstill by means of a tourniquet or a tightly applied bandage. A mammalian muscle soon ceases to be irritable and dies when removed from the body, but its functional activity may be renewed by passing an artificial stream of arterial blood through its vessels, and an isolated muscle may thus be made to contract repeatedly for a considerable time.

The muscle of a cold-blooded animal, on the other hand, will remain alive for a long time if kept cool and moist. When its functional activity is about to fade, it may be revived by means of an artificial stream of blood caused to flow through its vessels, just as in the case of the mammalian muscle.

Common experience teaches us that even when well supplied with blood our muscles become fatigued after very prolonged exertion, and are incapable of further action. This occurs all the more rapidly when anything interferes with the flow of blood through them, such as using our arms in an elevated position : the simple operation of driving in a screw overhead is soon followed by painful fatigue in the muscles of the fore-arm, though the same amount of force could be exerted for a long time when the arms are in a lower posture without the least feeling of fatigue.

The difficulties of experimenting with the muscles of mammals make the frog-muscle the common material for investigation, and from it we learn the following facts :—

1. When removed from the body and deprived of its blood supply, a muscle placed under favourable circumstances, and allowed perfect rest, may contract after twenty-four hours. If it be frequently excited to action, on the other hand, it loses its irritability, being worn out by *fatigue*.

2. From a muscle removed from a recently killed animal, we learn, that even without a supply of blood the muscle-tissue is capable of recovering from very well-marked fatigue, if it be allowed to rest for a little time, so that the muscle has in itself the material requisite for its recuperation.

The first question then is, what causes the loss of irritability which we call fatigue ? And the second is, by what means is the muscle enabled to return to a state of functional activity ? We know that the mere life of a tissue must be accompanied by

certain chemical changes which require (*a*) a supply of fresh material, and (*b*) the removal of certain substances which are the outcome of the tissue-change. When the muscle contracts, much more active changes go on, more new material being required, and more effete matter being produced. It is probable that the accumulation of these effete matters is the more important cause of the loss of irritability in a muscle, for a frog's muscle when quite fatigued may be rendered active again by washing out its blood vessels with a stream of salt solution (·65 per cent. NaCl), and removing the "fatigue-stuffs," which first act upon the end-plates of the nerves in the muscle. It is found that a very minute quantity of lactic acid injected into the vessels of a muscle destroys its irritability, and brings it to a state resembling intense fatigue. Of the new materials required for the sustentation of muscle irritability, oxygen is amongst the most important, though its supply is not absolutely necessary for the temporary recuperation of a partially exhausted, isolated frog's muscle.

The slow recovery of a bloodless muscle from fatigue may be explained by supposing time to be necessary for the reconstruction of new contractile chemical combination, and probably also for a secondary change to take place in the effete materials by which they become less injurious.

As already explained in speaking of the vasomotor influences, a muscle receives a greater supply of blood when actively contracting than when in the passive state. This is required to ward off exhaustion.

The irritability of a muscle may be said to depend upon :—

1. The adequacy of its blood supply : *i.e.* the better the supply of new material and the more quickly the injurious effete materials are removed.

2. Temperature has a marked effect on the irritability of muscles as well as upon the form of the contraction. Low temperatures—approaching 5° C.—diminish the irritability of a muscle, but do not seem to tend towards more rapid exhaustion. High temperatures—approaching 30° C.—increase the irritability, and at the same time rapidly bring about fatigue.

3. Functional activity is advantageous for their growth and power. Thus when the nerves supplying the voluntary muscles are injured, there is considerable danger of atrophy and degeneration of the muscles ; the contractile substance becomes replaced by fat granules. This degeneration also occurs in the

stump when a limb is amputated; the distal attachments of the muscles having been cut they cannot act, and in time they become completely atrophied.

The ordinary sensation of fatigue depends upon the nerve-centres being affected by the fatigue-stuff of muscle.

Death Rigor.

The death of muscle tissue is associated with a set of changes which, in some respects, resemble those observed in its active state. The most obvious phenomenon is an unyielding contraction, which causes the stiffening of the body after death. Hence it is called *rigor mortis*. The muscles harden; lose their elasticity, and the tissue is *torn* if forcibly stretched. When isolated, the muscle is seen to be opaque, and its reaction is found to be distinctly acid. A considerable quantity of heat is developed during the progress of the rigor. The electric currents alter in direction and finally disappear.

The period at which rigor comes on and its duration depend on (*a*) the state of the muscles at the time of death, and (*b*) the circumstances under which they are then placed. All influences which tend to fatigue induce early rigor of short duration, viz., (1.) Prolonged activity—as may be shown in a muscle artificially tetanised, or seen in an animal whose death was preceded by intense muscular exertion—causes rigor to appear almost immediately, and to terminate rapidly. (2.) Inactivity of the muscles delays rigor. If one sciatic nerve be cut, some little time before death, the muscles of that leg pass into rigor later than those of the leg still connected with the spinal cord. This occurs in a perfectly resting animal, and even if made immediately *after death* the section of the nerve delays rigor on the side operated upon. (3.) High temperature facilitates the production of rigor in dying muscles. This form of contraction, which is called *heat-rigor*, is brought about in mammalian muscles by a temperature of about 50° C., and in frog's muscles below 40° C. If, however, the temperature of a muscle be suddenly raised to the boiling point, it is killed, and the chief phenomena of rigor are prevented from occurring. (4.) Freezing postpones the changes in the muscles upon which rigor depends. (5.) Stretching, or any mechanical excitation which tends to injure the tissue, causes it to pass more rapidly into rigor. (6.) The application of water and of a number of chemical substances cause muscles quickly to pass

into a state of rigor similar to that which ordinarily follows the death of the tissue. (7.) Any stoppage in the blood-current makes it pass after some time into a state of rigidity like rigor mortis, but this may be removed by allowing the blood to flow freely again through the muscle.

It is generally admitted that rigor mortis depends on the tendency of the muscle plasma to coagulate. This is in most respects comparable with the coagulation of the blood, and may also depend upon the action of some ferment, of which there is no lack in dead muscle tissue. Compare the paragraph on chemistry, p. 412.

Most of the phenomena of the process of muscle-rigor remind us of the changes already described as occurring in muscle, when it passes from the passive to the active state. Thus the shortening of the fibres, the evolution of heat, and the chemical changes may be said to be identical in contraction and rigor mortis. The electrical changes are, however, very transitory, and the rigor is accompanied by complete loss of elasticity and irritability. Opacity of the tissue marks its later stages.

Thus, while dying, the muscle tissue may be said to go through a series of events analogous to those which would occur in a prolonged contraction. The idea naturally suggested itself (Hermann) that the active state of muscle depends upon chemical changes which are the initial steps in the coagulation of the contractile substance, when the muscle is dying. The muscle tissue is supposed to contain a special proteid, *inogen*, of extremely intricate and unstable chemical constitution. This, during activity, is constantly undergoing molecular change, and if not re-integrated by constant assimilation would pass into coagulation with the formation of carbonic anhydride, sarco-lactic acid and myosin. Under the influence of stimuli a comparatively sudden and intense molecular disturbance is brought about. Before the stage of coagulation appears a chemical re-arrangement takes place, the result of which is the re-construction of the unstable complex proteid. If nutriment be withheld, or if the stimulation be too powerful, the recovery cannot take place, and we find the muscle passing from a state of physiological contraction to one of intense exhaustion, and then to coagulation and death.

UNSTRIATED MUSCLE.

So far reference has only been made to the skeletal muscles, the fibres of which are marked by transverse striations, and whose single contraction is extremely rapid and short. The contractile tissues which carry on the movements in most organs of the body are not striated fibres, but consist of elongated flattened cells with rod-shaped nuclei. They occur generally in the form of sheets or layers, forming coats for the organs in which they lie. Their contraction is slow and prolonged, and is generally transmitted from one muscle-cell to another as a kind of sluggish wave. They are not capable of passing into a tetanic state of contraction like striated muscles.

The slowest contraction seems to be that of the muscle-cells in the walls of the blood-vessels. These remain in a state of partial contraction, which undergoes a brief and temporary rhythmical relaxation. The most forcible aggregate of unstriated muscle elements is met with in the uterus. This organ, which has very exceptional motor powers to perform, contracts in somewhat the same way as the muscles of the blood-vessels, but more quickly, and with longer rhythmical intervals of partial relaxation. The muscular wall of the intestine and the iris are among the most rapidly contracting smooth muscles.

The chemical properties of the smooth muscles are similar to those of striated skeletal muscles, and while dying, they pass into a state of rigor, which seems to depend on the same causes as the rigor mortis already described.

CHAPTER XXV.

THE APPLICATION OF SKELETAL MUSCLES.

The muscles are so attached that they are always slightly on the stretch. This elastic tension is augmented by the *tonic contraction* of the muscles kept up by the spinal cord. This *spinal tonus* can be seen to disappear when the nerves leading to a limb are cut. Thus when the muscles begin to contract they are in an advantageous position to bring their action to bear on the bones which they move. When the contraction ceases the bones are drawn back to their former position without any sudden jerk or jar.

As a very general, but by no means universal rule, a muscle has one attachment which is fixed, commonly spoken of as its *origin*, and a second, called its *insertion*, upon which it acts by approximating it to the origin. Muscles usually pass in a straight line between their two attachments, but sometimes they act round an angle by sliding over a pulley, or by means of a small bone in the tendon, like the patella.

The muscles act upon the bones as levers by working upon the short arm of the lever, so that more direct force is required on the part of a muscle than the weight of the body moved : but from this arrangement considerable advantages are gained, viz., that a small contraction of the muscle causes an extensive excursion of the part moved, and much greater rapidity of motion is attained.

All the three orders of levers are met with in the movements of the different bones of the skeleton ; often, indeed, all three varieties are found in the same joint, as the elbow, where the simple extension and flexion motions of the biceps and triceps muscles give us good examples (Fig. 183).

The *first* order of lever is used when the triceps is the power and draws upon the olecranon, thus moving the hand and forearm around the trochlea which acts as the fulcrum. This is shown in the upper diagram, in which the hand is striking a blow with a dagger.

The *second* order comes into play when the hand, resting on a point of support, acts as the fulcrum, and the triceps pulling on the olecranon is the power which raises the humerus upon which is fixed the body or weight (middle diagram).

The *third* order may be exemplified by the action of the biceps in ordinary flexion of the elbow. Here the muscle, which is the power, is placed between the fulcrum—represented by the lower end of the humerus—and the weight which is carried by the hand (lower diagram).

The various groups of muscles which are so arranged as to assist each other when acting together, and called *synergetic*, and those which when contracting at the same time oppose each other, are called *antagonistic*. The same muscles may, in different positions of a joint or in combination with other muscles, have totally different actions, at one time being synergetic and at another antagonistic. Thus, the sterno-mastoid muscle may, in different positions of the head, either bend the cranium backwards or forwards, and so co-operate with two sets of muscles which are definitely antagonistic to one another.

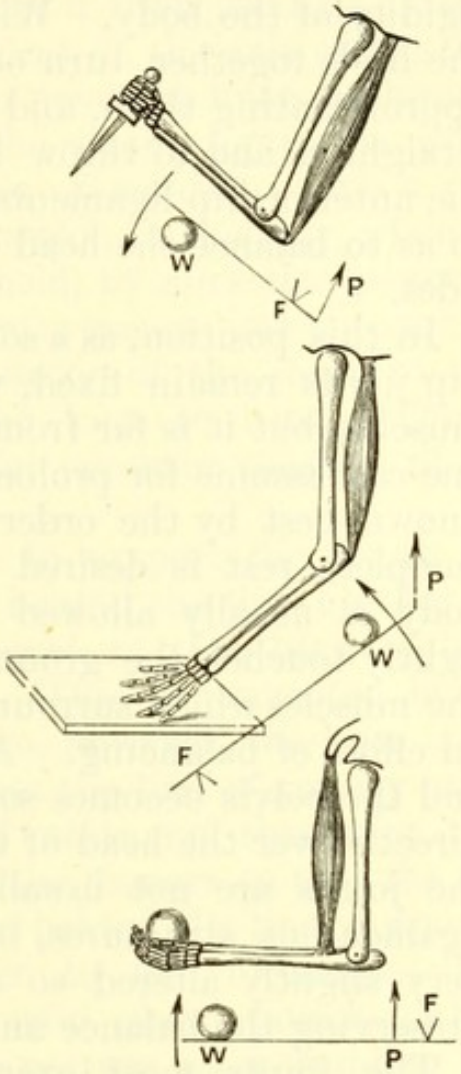


Fig. 183.—Diagrams showing the mode of action of the three orders of levers (numbered from above downwards) illustrated by the action of the elbow joint.

STANDING.

In order that an elongated rigid body may stand upright it is only necessary that a line drawn vertically through its centre of gravity should pass within its basis of support, and if the latter be sufficiently wide the object will remain permanently in that position. The human body, in the first place, is not rigid, and in the second place the basis of support is too small to ensure a satisfactory degree of steadiness. The act of standing must, therefore, be accomplished by the action of certain

muscles, which are employed in preventing the different joints from bending, and in so balancing the various parts of the body as to keep the whole frame from toppling over.

In order to economise muscular energy while standing, we may lock the more important joints, and thus depend rather on the passive ligaments than upon muscular action for the rigidity of the body. With this object we are taught to place the heels together, turn out the toes, bring the legs parallel by approximating them, and extending the knees to the utmost, to straighten and to throw back the trunk so as to render tense the anterior hip ligaments, to direct the face straight forwards so as to balance the head evenly, and to let the arms fall by the sides.

In this position, as a soldier stands at attention, the knee and hip joints remain fixed, without any effort on the part of the muscles, but it is far from being the most comfortable attitude one can assume for prolonged standing, and hence the position known best by the order "stand at ease" is adopted if more complete rest is desired. In this position the weight of the body is usually allowed to rest on one leg while the other lightly touches the ground to form a kind of stay and relieve the muscles which surround the supporting ankle from too great an effort of balancing. At the same time the knee is extended and the pelvis becomes somewhat oblique so as to bring it more directly over the head of the femur. In ordinary easy standing, the joints are not usually kept locked by the tension of the ligamentous structures, but their position is constantly being very slightly altered so as to vary the muscles employed in preserving the balance and thus prevent fatigue.

The joints most exercised in the erect posture are the following :—

1. The *ankle* has to support the weight of the entire body, while the joint is neither flexed nor extended to its utmost, and cannot be fixed in this position by ligamentous arrangements. The foot being placed on the ground, resting on the heel and the balls of the great and little toes, is supported in an arch-like form by strong though elastic ligaments, which allow but little motion in the numerous joints. The bones of the leg can move in the freest way, backwards or forwards, over the articular surface of the astragalus, which forms the roller of the hinge, lateral motion being prevented by the malleoli. The line passing through the centre of gravity of the body generally falls slightly in front of the axis of rotation of the ankle-joint,

so that the entire body tends to fall forwards at the ankles. This tendency is checked by the powerful calf muscles, which, attached to the calcaneum by means of the strong tendo Achillis, keep the parts in such a position that an exact balance is almost constantly kept up.

2. The *knee-joint*, when completely extended in standing, requires no muscular action to prevent it from bending, because the line of gravity then passes in front of the axis of rotation, and the weight of the body tends to press the knee backwards. This is impossible on account of the strong ligaments which exert their traction behind the axis of rotation. As a rule, these ligaments are not put on the stretch in this way, when the feet are together, but the joint is held, by muscular power, in such a position that the line of gravity passes just through, or very slightly behind, the axis of rotation of the joint, so that there is a slight tendency for the knee to bend. This is completely checked by the powerful extensor muscles of the thigh.

3. In the *hip-joints*, which have to support the trunk and head, the line of gravity falls just behind the line uniting the joints when the person is perfectly erect, so that here the body has a tendency to fall backwards. This is prevented by the strong ilio-femoral ligament. When, however, the knee is not straightened to the full extent, so that the line of gravity passes through or a little behind the axis of rotation of that joint, then the pelvis is very slightly flexed on the femora so that the axis of the joints lies exactly in or a little behind the line of gravity, and thus the body inclines rather to fall forwards. This tendency is prevented by the powerful glutei muscles, which also enable us to regain the erect posture after bending the trunk forwards.

The motions between the *pelvis* and the base of the *vertebral column* are too slight to deserve attention here. The vertebral column, wedged in as it is between the two innominate bones, may be taken, together with the pelvis, as forming a very yielding and elastic, but practically jointless, pillar, the upper part of which can alone be bent to such an extent as to require mention in discussing the mechanism of station.

The individual joints between *the cervical vertebræ* permit but a slight amount of movement when taken separately, but by their aggregate motion they enable considerable extension and flexion of the neck to take place. These motions follow so

closely, and are so inseparably associated with those of the head on the upper vertebra, that there is no need to consider them separately from the latter.

The *atlanto-occipital joints* admit of some little lateral movement, but that in the antero-posterior direction is much the more important, but even this would be insignificant were it not associated with the movements between the other cervical vertebræ.

The cranium has then to be balanced on the top of a flexible column, and rests immediately in a kind of socket, which can move as a double hinge around two axes at right angles one to the other. The vertical line from the centre of gravity of the cranium must vary with every forward, backward, or lateral movement of the head or neck, but in the erect posture it passes a little in front of the axis of rotation of the atlanto-occipital joint and somewhat behind the curve of the cervical vertebræ, so that the head may be said to be poised on the apex of the vertebral column, with some tendency to fall forwards. There are no ligamentous structures which can lock the joints so as to keep the head in the erect position ; therefore without the aid of muscular force the head will fall forwards or backwards according to the position it may be in when the muscles suddenly relax, as happens in falling asleep in the upright posture.

From the foregoing facts it will be seen that there exists a kind of co-ordinated antagonism at work in ordinary easy standing which keeps the elastic pliable body upright, without the rigidity adopted when standing "at attention." The muscular action is more exercised when we are not on steady ground and varied co-ordination becomes necessary : for instance, when we go on board ship for the first time. Standing then takes some little time to become easy, and requires new associations of movement. The gastrocnemius and soleus relax the ankle in a degree just proportionate to the amount of flexion of the knee permitted by the quadriceps extensor cruris, while simultaneously the great gluteal muscle allows the body to incline forwards so as to keep its centre of gravity in the proper relation to the basis of support.

Walking and Running.

Walking is accomplished by poising the weight on one foot and then tilting the body forwards with the other, which is then swung in front and placed on the ground to prevent

falling. These acts are performed alternately by each leg, so that the "swinging limb" becomes the "supporting limb" of the next step. The swinging leg is described as having two phases (1) active while pushing off from the ground, and (2) passive, while swinging forwards like a pendulum. In starting, one foot is placed behind the other, so that the line of gravity lies between the two, the hindmost limb having the ankle and knee a little bent. By suddenly straightening these joints it gives a "push off" with the toes and propels the body forward, so as to move it around the axis of motion of the fixed, or supporting ankle-joint. At the end of the swing, the pendulous leg comes to the ground and leaves the other limb in the attitude ready for the push-off. Thus on level ground walking is carried on with but small muscular exercise; but in ascending an incline or going upstairs, the supporting limb has to elevate the body at each step by extending the knee and ankle joints by the thigh extensors and the calf muscles.

Running is distinguished from walking by the fact that, while in the latter both feet rest on the ground for the greater part of each pace, in the former the time that either foot rests on the ground is reduced to a minimum, and the body can never be said to be balanced on either leg, so that in fact there is no longer a "supporting-limb." The legs are kept in a semi-flexed position ready for the push-off or spring, which is so forcibly carried out that the body is propelled through the air without any support between each step, and has a constant tendency to fall forwards. Thus an interval, of greater or less duration according to the pace, exists during which both the feet are off the ground, because the moment either foot comes to the ground it at once executes a new spring without waiting for the swing of the other.

CHAPTER XXVI.

VOICE AND SPEECH.

THE human voice is produced by an expiratory blast of air being forced through the narrow opening at the top of the windpipe called the glottis. The glottis, which lies in the lower part of the larynx, is bounded on each side by the edges of thin, elastic, membranous folds that project into the air-passages. These membranous folds, called the vocal cords, are set vibrating by the current of air from below, and communicate their vibrations to the air in the air-passages situated above them.

The vocal apparatus produces sound in the same manner as a musical instrument of the reed-pipe variety. If we compare it with the pipe of an organ, we find all the parts of the latter represented. The lungs within the moving thorax act as the bellows. The bronchi and trachea are the supply pipes and air box. The vocal cords are the vibrating tongues; while the larynx, pharynx, mouth, and nose, act as the accessory or resonating pipes. The blast of air is produced and regulated by the respiratory muscles; and special intrinsic muscles of the larynx change the conditions of the vocal cords so as to alter the pitch of the notes produced. Other sets of muscles, by altering the conditions of the resonating pipes, give rise to many modifications in the vocal tones, and thus produce what is called *speech*.

ANATOMICAL SKETCH.

The *larynx*, which may be regarded as the special organ of voice, is made up of four cartilages, viz., the cricoid, thyroid, and two arytenoids, jointed together so as to allow of considerable motion. Of these the inferior, the *cricoid*, is attached to the trachea, which it joins to the others. It forms a ring, which is thin in front, but deep and thick behind, owing to a peculiar projection upward of its posterior part. The *thyroid* consists of two side wings so bent as to form the greater part of

the anterior and lateral boundaries of the voice box, and can be felt easily in the front of the throat. It is articulated to the sides of the cricoid by its two inferior and posterior extremities, so that the upper part of the cricoid cartilage can move backwards and forwards. The *arytenoid* cartilages are little three-sided pyramidal masses placed on the upper surface of the posterior part of the cricoid, to which they are attached by a loose joint. They are so placed that one surface looks inwards, a second backwards, and the third forwards and outwards, while the inferior surface rides on the cricoid. One point looks forwards, and to it is attached the vocal cord on each side, hence it has been called the vocal process. The apex, which looks outwards and backwards, gives attachment to some of the intrinsic muscles, and hence has been called the muscular process.

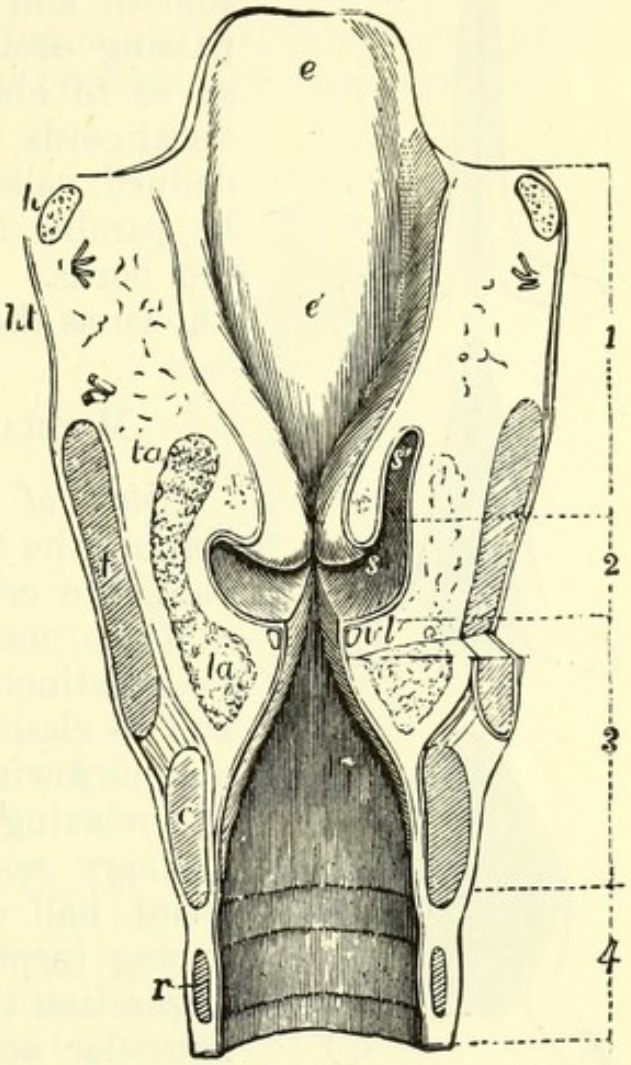


Fig. 184.—Anterior half of a transverse vertical section through the larynx near its middle, seen from behind. More is cut away on the upper part of the right side. 1. Upper division of the laryngeal cavity ; 2. Central portion ; 3. Lower portion continued into 4, trachea ; *e*, epiglottis ; *e'*, its cushion; *t*, thyroid cartilage seen in section. *vl*, true vocal cord at the rima glottidis ; *s*, ventricle of larynx ; *s'*, saccule. (A. Thomson.)

The thyroid cartilage is connected with the cricoid below, and with the hyoid bone above by ligaments and tough membranes, which hold the parts together, fill in the intervals, and complete the framework of the larynx.

The vocal cords are composed of small strands of elastic tissue, which are stretched between the anterior processes of the arytenoid cartilages and the inferior part of the thyroid, where they are attached side by side to the posterior surface of the angle formed by

the junction of the two lateral parts or alæ of the thyroid. The mucous membrane which lines the larynx is thin, and closely adherent over the vocal cords. The surface of the laryngeal cavity is smooth and even, the lining membrane passing over the cartilages and muscles so as to obliterate all ridges, except the vocal cords and two others, less sharply defined, called the false vocal cords, which lie parallel to and above the true vibrating cords. Between these is the cavity known as the ventricle of the larynx.

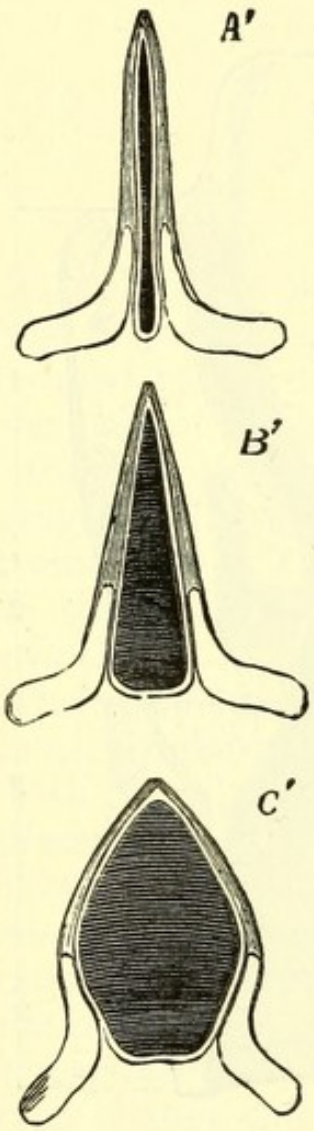


Fig. 185. — Diagrams taken from the laryngoscopic view of the larynx, showing in transverse section the position in which the vocal cords and the arytenoid cartilages are supposed to be during different actions of the larynx.

A'. Vocal chink as in singing.

B'. In easy quiet inhalation of air.

C'. In forced inspiration.

Mechanism of Vocalisation.

Shape of the opening of the glottis.— Taking the thyroid cartilage as the fixed base, the cricoid and arytenoid cartilages undergo movements which bring about two distinct sets of changes in the glottis and its elastic edges, namely, (1) widening and narrowing the opening ; (2) stretching and relaxing of the vocal cords. During ordinary respiration the glottis remains about half open, being slightly widened during inspiration (B'). During forced inspiration the glottis is widely dilated by muscular action (C'). If an irritating gas be inspired, the glottis is tightly closed by a spasmodic action of certain muscles, so that the true vocal cords act as a kind of valve.

During vocalisation the glottis is formed into a narrow chink with parallel sides (A'), while the cords are made more or less tense, according to the pitch of the note to be produced ; both these changes are brought about by muscular action.

The *opening* of the chink of the glottis is accomplished chiefly by a muscle called the posterior crico-arytenoid, which passes from the posterior surface of the cricoid cartilage to the outer and posterior angle

of the arytenoids. By pulling the latter point downwards and backwards it separates the arytenoid cartilages, particularly at their anterior extremity, where the cords are attached. In this action it is aided by a small muscle, the posterior arytenoid, connecting the posterior surfaces of the arytenoid cartilages, and tending, when the two arytenoid cartilages are held apart, to rotate them so that the vocal processes are separated.

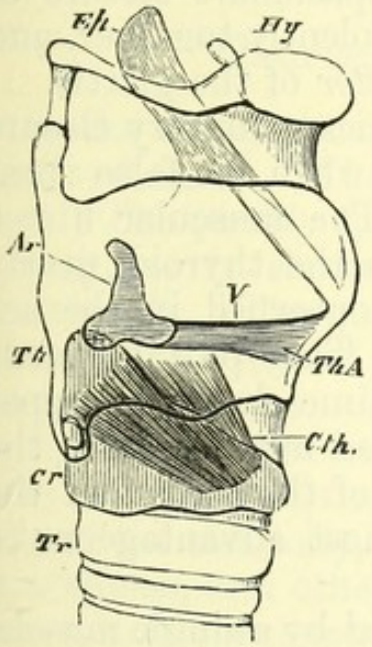


Fig. 186.—Diagram of the side view of the larynx showing the position of the vocal cords (v). (Huxley.)

Ar. Arytenoid cartilage.
Hy. Hyoid bone.
Th. Thyroid cartilage.
Cr. Cricoid cartilage.
Tr. Trachea.
C.th. Crico-thyroid muscle.
Th.A. Thyro-arytenoid muscle.
Ep. Epiglottis.

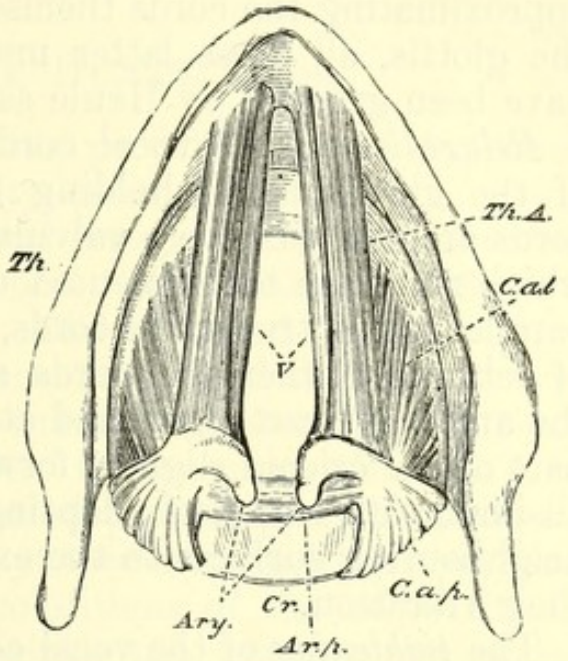


Fig. 187.—Diagram of the opening of the larynx from above. (Huxley.)

Th. Thyroid cartilage.
Cr. Cricoid cartilage.
Ary. Superior extremities of the arytenoid cartilages.
V. Vocal cords.
Th.A. Thyro-arytenoid muscles.
C.a.l. Lateral crico-arytenoid muscle.
C.a.p. Posterior crico-arytenoid muscle.
A.r.p. Posterior arytenoid muscle.

The *narrowing* of the glottis is executed by the lateral crico-arytenoids which run upwards and backwards from the antero-lateral aspect of the cricoid to the muscular processes of the arytenoid cartilages. They pull the muscular processes forwards, and thus rotate the arytenoid cartilages so as to approximate the vocal processes to one another, while any tendency towards pulling apart the bodies of the cartilages, owing to the downward direction of the muscle, is overcome by the posterior

arytenoid muscle and those muscular bands which pass from the posterior surface of the arytenoid cartilages to the epiglottis and the upper part of the thyroid cartilage, the external thyro-arytenoid, and the thyro-ary-epiglottic muscles (Henle). The other fibres, which pass directly from the arytenoid to the thyroid cartilages—internal and external thyro-arytenoid muscles—in the same direction as the vocal cords, complete the closure by helping to press together the vocal processes and by approximating the cords themselves. In spasmodic closure of the glottis, all these latter muscles act violently together, and have been grouped by Henle as the *constrictor* of the glottis.

Relaxation of the vocal cords accompanies voluntary closure of the glottis, as in holding the breath, when the false vocal cords are said to have a valvular action. The muscular fibres, which run from the arytenoid cartilages to the thyroid, nearly parallel to the true vocal cords, are those concerned in the act of relaxation when the cords are active. They pull forwards the arytenoid cartilages, and at the same time draw the upper part of the cricoid slightly forwards. These muscles have the all-important action of adapting the edges of the cords and the neighbouring surfaces to the exact shape most advantageous to their vibration.

The *tightening* of the vocal cords is caused by a single muscle, the crico-thyroid, which, on the outer side of the larynx, passes downwards and forwards from the lower part of the thyroid to the anterior part of the cricoid cartilage. It pulls the anterior part of the cricoid cartilage upwards, causing it to rotate round an axis passing through its thyroid joints. The upper part of the cricoid, which carries the arytenoids, is moved backwards, the attachments of the vocal cords are separated, and these membranes are thus put on the stretch.

The requirements necessary for the production of voice are the following :—

1. *Elasticity* of the vocal cords and smoothness of their edges : freedom from all surface irregularity, such as would be caused by thick mucus adhering to them, by ulceration or by any abnormality.

2. The cords must be very accurately adjusted, and closely approximated together, so that they almost touch evenly throughout their entire length.

3. The cords must be held in a *certain degree of tension*, or their vibration cannot produce any vocal tone, but only a raucous noise.

4. The air must be propelled through the glottis by a *forced expiration*. The normal expiratory current is too gentle to give the necessary vibration. After the operation of tracheotomy, the air escapes through the abnormal opening, and sufficient pressure cannot be brought to bear on the cords, so no vocal sound can be produced, and the person speaks in a whisper, unless the exit of air through the tracheotomy tube is prevented by placing the finger temporarily upon the opening.

Properties of the Human Voice.

In the voice we can recognise the properties noted in other kinds of sound. These are quality, pitch, and intensity.

(1.) The *quality* (p. 555) of vocal sounds is almost endless in variety, as is shown by the vocal capabilities of different individuals. The quality of any musical sound depends upon the relative power of the fundamental tone, and of the overtones that accompany it. The less the fundamental tone is disturbed by overtones, the clearer and better is the voice. This difference in quality of the human voice depends upon the perfectness of the elasticity, the relation of thickness to length, surface smoothness, and other physical conditions of the cords themselves, and the exactitude with which the muscles can adapt the surfaces. For singing well, much more is necessary than good quality of tone, which is common enough. The muscles of the larynx, thorax, and mouth must be all educated to an extraordinarily high degree.

(2.) The *pitch* of the notes produced in the larynx depends upon—first, the absolute length of the vocal cords. This varies with age, particularly in males, whose vocal organs undergo rapid growth at puberty, when vocalisation is uncertain from the rapid changes going on in the part ; hence the voice is said to *crack*. The vocal cords of women have been found by measurement to be about one-third shorter than those of men, and people with tenor voices have shorter cords than basses or baritones. Secondly, on the tension of the cords : the tighter the vocal cords are drawn by the crico-thyroid muscles, the higher the notes produced ; and the well-known singer Garcia believed he observed with the laryngoscope the vocal processes so tightly pressed together as to impede the vibration of the posterior part of the cords, and by this means they could be voluntarily shortened. A certain degree of force of blast is required for the higher notes.

(3.) *Intensity* or loudness of the voice depends on the strength of the current of air. The more powerful the air-blast the greater the amplitude of the vibrations, and hence the greater the sound produced. The narrower the chink of the glottis, and the tighter the parallel cords are stretched, the less is the amount of air required to set them vibrating ; and *vice versâ*, the looser the cords and the wider apart they are, the greater the volume and the force of the air current necessary for their complete vibration. Hence it is that an intense vibration or loud note can be produced much more easily with notes of a high pitch than with very low notes.

The human voice, including every kind, extends over about three and a half octaves. Of this wide range a single individual can seldom sing more than two octaves ; the soprano, alto, tenor, and bass forming a descending series, the range of each one of which considerably overlaps the next in the scale.

During the ordinary vocal sounds, the air, both in the resonating tubes above the larynx and in the windpipe coming from below, is set vibrating, so that the trachea and bronchi act as resonators as well as the pharynx, mouth, &c. This may be recognised by placing the hand on the thorax, when a distinct vibration is communicated from the chest wall. Such tones are, therefore, spoken of as chest notes. Besides the chest tones of the ordinary voice, we can produce notes of a higher pitch and a different quality, which are called head notes, since their production is not accompanied by any vibration of the chest wall. The physical contrivance by means of which this *falsetto* voice is brought about is not very clearly made out. The following are the more probable views :—(1) It has been suggested that in falsetto only the thin edges of the cords vibrate, the internal thyro-arytenoid muscles keeping the base of the cord fixed ; while with chest tones a greater surface of the cord is brought into play. (2) The cords are said to be wider apart in falsetto than in chest notes, and hence the trachea, &c., ceases to act as a resonator. (3) Or the cords may be arranged so that only one part of them, the anterior, can vibrate, and thus they act as shortened cords, a "stop" being placed on the point where the vibrations cease, by the internal thyro-arytenoid muscles.

The production of a falsetto voice is distinctly voluntary, and is probably dependent upon some muscular action in immediate relation to the cords, for it is always associated with a sensation of muscular exertion in the larynx as well as with changes that

take place in the conformation of the mouth and other resonating tubes.

Nervous Mechanism of Voice.

The nervous mechanism by means of which vocal sounds are produced is among the most complexly co-ordinated actions that regulate muscular movements.

Like respiration, vocalisation at first seems a simple voluntary act, sounds of various kinds being produced at will by the individual. No doubt the respiratory muscles, which work the bellows of the voice organ, are under the control of the will so long as the respiration is not interfered with. The mouth and throat muscles which shape the resonating tube are also voluntary. But the intrinsic muscles of the larynx are only voluntary in a certain sense, while in another they are distinctly involuntary, as may be seen in spasm of the larynx, which is purely reflex. The vocal movements are, in part at least, reflex. Thus pitch is controlled by impulses which arise at the organ of hearing and pass to a co-ordinating centre, which arranges the finer muscular movements necessary to produce a certain note. When we sing a note struck on a musical instrument, we voluntarily set the expiratory, mouth, and special vocalising muscles in readiness, for the proper application of the air-blast; but the exact tuning of the vocal cords is accomplished, in some measure at least, reflexly by impulses arriving from the ear at a special co-ordinating nervous centre, which is in ordinary persons in advance of the education of the voluntary centres. In persons specially educated in singing this co-ordinating centre may come under the control of the will. But persons who can promptly sing a given note without any mental effort, would find it difficult to overcome the accuracy of the reflex mechanism so as to sing sharp or flat. Or as musicians say, an untrained person with a naturally "good ear" finds it difficult, intentionally, to sing out of tune.

Though we feel that we have command over the pitch of vocal tones, we owe our accuracy to our sound-appreciating organs which first enabled us to have a conception of the qualities of sound, and thus led to their vocal reproduction.

Speech.

The variations in vocal sounds which give rise to speech are not produced in the larynx, but in the throat, mouth, and

nose. When unaccompanied by any vocal sound, speech only gives rise to a *whisper;* but when a vocal tone is at the same time produced, we have the ordinary loud speaking. Since vocal tones can only be produced by expiration, so we can only speak aloud by means of an expiratory current of air; but an inspiratory current may be made to give rise to a kind of whisper.

Speech is composed of two kinds of sounds, in one of which the sounds must be accompanied by a vocal tone, and are hence called "vowels;" in the other no vocal tone is necessary, but changes in shape take place in the resonating chambers, so as to give rise to noises called consonants. As the pronunciation of the consonants is always accompanied by some vowel sound, and as the difference between the vowels is brought about by changes in the shape of the mouth, the distinction between the two sets of sounds is rather artificial than real.

The production of the different vowel sounds depends upon such a change being brought about in the shape of the mouth cavity and aperture, that a resonator with a different individual note is formed for each particular vowel.

The sounds called consonants are caused by some check or impediment being placed in the course of the blast of air issuing from the air-passages. They may be classified, according to the part at which the obstructions occurs, as follows :—

1. *Labials*, when the narrowing takes place at the lips, as in pronouncing *b*, *p*, *f*, *v*.

2. *Dentals*, when the tongue causes the obstruction by being pushed against the hard palate or the teeth, as in *t*, *d*, *s*, *l*.

3. *Gutturals*, when the posterior part of the tongue moves towards the soft palate or pharynx, as in saying *k*, *g*, *gh*, *ch*, *r*.

Consonants may also be divided into different groups, according to the kind of movements which give rise to them.

1. *Explosives*, are produced by the sudden removal of the obstruction, as with *p*, *d*, *k*.

2. *Aspirates* are continuous sounds caused by the passage of a current of air through a narrow opening, which may be at the lips, as in *f*, at the teeth as with *s*, or at the throat as in *h*.

3. *Resonants* are the sounds requiring some resonance of the vocal cords, and the air current is suddenly checked by closure of the lips, as in *m*, or the dental aperture as in *n* or *ng*.

4. *Vibratory*, of which *r* is the example, requires a peculiar vibration of the vocal cords, while either the dental or the guttural aperture is partially closed.

CHAPTER XXVII.

GENERAL PHYSIOLOGY OF THE NERVOUS SYSTEM.

Anatomical Sketch.

The nervous system includes the various mechanisms by which the distant parts of the body are kept in communication one with another. By the nerves the condition of the various parts of the body and their surroundings are made known to a central department, which in turn regulates the activities of the various organs.

It is made up of two varieties of tissue, both of which possess special vital properties. The one, *nerve-fibres*, composed of thread-like strands of protoplasm, connects the elements of the other, *nerve-corpuscles*, which form the peripheral or central terminus of the fibres. Nerve-fibres are simply special conducting agents, having at one extremity a special terminal, or nerve-cell, for sending impulses, and at the other end a nerve cell for receiving the impulses. These terminal organs, between which the nerve fibres pass, are the agents which determine the direction in which the impulse is to travel along the nerve. The sending organ may be at the peripheral end of the nerve, and the receiver in the nerve centres, as in the case of an ordinary cutaneous nerve, which carries impulses from the skin to the brain; or the sending organ may be at the centre, and the receiving organ at the periphery, as in the case of the nerves conveying impulses from the brain to the muscles.

The former kind of nerves is called *afferent* carrying *centripetal* impulses, and the latter *efferent* carrying *centrifugal* impulses. Nerves are capable of carrying impulses in either direction, as has been proved by cutting the afferent lingual and the efferent hypoglossal nerves, and causing the proximal end of the former to unite with the distal end of the latter, which is distributed to the muscles of the tongue. When the

union has taken place, a stimulus applied to the upper part which was normally afferent, or sensory, carries motor impulses to the muscles, *i.e.*, acts as an efferent nerve.

Protoplasm though not formed into fibres can conduct impulses, as is seen in the transmission of an impulse in textures and animals which seem to have no special conducting elements or nerve fibres. Thus in the hydra all the cells act as nerves, and in the higher animals an impulse, producing a wave of

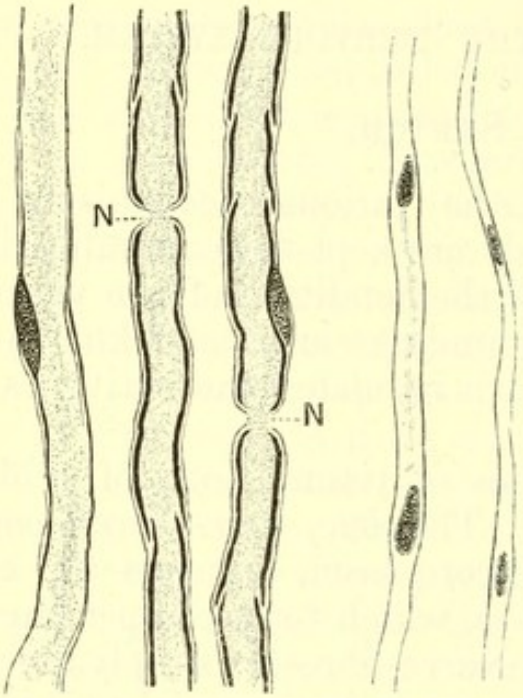


Fig. 188.—Highly magnified view of three medullated and two non-medullated nerve fibres of frog, stained with osmic acid, which makes the medullary sheath black.
N.—Nodes of Ranvier—where the axis cylinder can be seen to pass the gap in the medullary sheath.

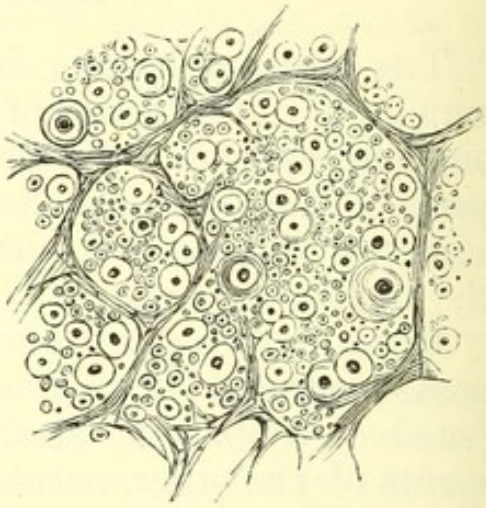


Fig. 189.—Transverse section of nerve fibres, showing the axis cylinders cut across, and looking like dots surrounded by a clear zone, which is the medullary sheath. Neuroglia separates the fibres into bundles.

contraction, can pass from one muscle-cell to the other directly, as is easily seen in the ureter, or in the heart of cold-blooded animals.

The only essential part of a nervous conductor is a delicate protoplasmic fibril. Such thread-like fibrils are found in the nerve centres, and peripherally, forming terminal networks, as seen in the cornea. In the peripheral nerves the fibrils are clustered together in large bundles, so as to make one nerve fibre, and this bundle of protoplasmic fibrils is called the *axis-cylinder* of the nerve-fibre. In some nerve-fibres there is but one very thin transparent covering, termed the *primitive sheath*,

while in others there is a thick layer of doubly-refracting fluid (*myelin*) inside the primitive sheath, in contact with the fibrils of the axis-cylinder. This is called the *medullary sheath*, or white substance of Schwann, because its peculiar refractive properties make the nerve look white, when viewed by a direct light. Nerves having this medullary sheath, are termed "white," those without it "grey." The former make up the greater part of the ordinary nerves.

Nerve-fibres repeatedly divide by branching, and the axis-cylinders increase in number and size on the way to their distribution. As an extreme example of this may be mentioned the branching nerves of the electric organ of the malapterurus, where the axis-cylinders increase by sub-division, until their aggregate cross-section, in the terminal branches, is 32,000 times as great as that of the single axis-cylinder process leading from the one nerve-cell that excites the organ.

Functional Classification.

Nerve-fibres may be classified according to their function, in the following way :—

I. Afferent Nerves which bear impulses from the surface to the nervous centres. These may be further divided into :

(*a.*) *Sensory nerves*, when the impulse they convey gives rise to a "perception." The perceptions may be the special sensations which are transmitted from the organs of *special sense*, or those of *general sensation*, giving rise to pleasure or pain.

(*β.*) *Excito-reflex nerves* communicate impulses to central nerve elements, and give rise to some action, without exciting mental perception. Such nerves regulate the viscera. According to the result of the excitation arising from their impulse they are termed—excito-motor, excito-secretory, excito-inhibitory, &c.

(*γ.*) *Mixed nerves* act as sensory and reflex nerves ; these are the most numerous, the sensory or reflex action depending upon the condition of the nerve centres.

II. Efferent Nerves, which carry impulses from the centres to the various organs throughout the body. According to the effect produced by their excitation they are termed :

(*a*) *Motor*, conveying impulses to muscles and exciting them to contract.

(β) *Secretory*, the stimulation of which calls forth the activity of a gland.

(γ) *Inhibitory*, when they diminish or prevent some activity by the impulses which they carry.

(δ) *Vaso-motor nerves*, which regulate the contraction of the muscular coat of the blood-vessels.

(ϵ) *Trophic*, *thermic*, *electric* nerves are also so named; the existence of the former two is doubtful, and the latter are only found in the electric fishes, *torpedo*, *gymnotus* and *malapterurus*, which are capable of emitting electric discharges.

III. Inter-central Nerves act as bonds of union between the several ganglion cells of the nervous centres, which are connected, in a most elaborate manner, one with the other. The terminals of these fibres are possibly both receiving and directing agents, and the delicate strands of protoplasm communicating between them probably convey impulses in different directions, but of this we can have no definite knowledge, although such a supposition would aid us in forming a mental picture of the manner in which the wonderfully complete intercentral communications are accomplished.

Mode of Investigation.

In order to understand the functions of the different nerves a knowledge of their central connections and their peripheral distribution is necessary. But anatomical research unaided by experimental enquiry does not suffice to determine their function.

The procedure adopted in testing the function of a nerve is the following. The nerve is exposed and cut, and it is observed whether there be any loss of sensation or muscular paralysis in the part to which it passes. The end connected with the centres is spoken of as the central or *proximal* end, and that leading to the distribution of the nerve, is called the peripheral or *distal* end. Each of these cut ends is then stimulated, and the results are observed. If the nerve be purely motor, stimulation of the proximal end will yield no result, but when the distal end is irritated, movements follow. If, on the other hand, it be a sensory nerve, stimulation of the distal end gives no result, and that of the proximal end produces signs of pain.

Chemistry of Nerve Fibres.

The axis cylinder of nerves is probably composed, as already mentioned, of protoplasm ; further than that nothing is known of its chemical properties. The medullary sheath yields certain substances which are related to the fats, and can be extracted with ether and chloroform. Among these is the peculiar compound nitrogenous fat, lecithin containing phosphorus, also cholesterin, &c.

The Active State of Nerve-Fibres.

Nerves pass into a state of activity in response to a variety of stimuli, but their active condition cannot be readily recognized, because the only change we can detect in the nerve is that which takes place in its electric state. If it be connected with its terminals, we know when a nerve is carrying an impulse from the results occurring in them on stimulation. In the case of an afferent nerve, we get evidence of a sensation, and when the nerve is efferent, for example, bearing impulses from the centres to the muscles, we judge of the state of activity of the nerve by the muscle contraction. For experimental purposes we use the nerve and the muscle of a frog. This *nerve-muscle preparation* is made from the leg of a frog : the sciatic nerve is carefully prepared from the thigh and abdominal cavity without being dragged or squeezed, and the gastrocnemius is separated from all its attachments except that to the femur, about two thirds of which bone is left so that the preparation may be fixed in the clamp. In fact, the method used for the *indirect* stimulation of muscle is also employed for the study of the excitability of nerve-fibres.

Nerve Stimuli.

Besides the normal physiological impulse which comes from the cells in connection with the nerve fibres, a variety of stimuli may excite their active state. These nerve stimuli differ little from those which are found to affect muscle, when applied directly to that tissue. They may be enumerated as follows :—

1. *Mechanical stimulation.* Almost any mechanical impulse applied to any part of a nerve, causes its excitation. The stimulus must have a certain degree of intensity, and a certain,

though short, duration. If mechanical stimuli be frequently applied to a nerve in the same place, the irritability of the part is soon destroyed; but if fresh parts of the nerves be stimulated at each application the nerve passes into a state of tetanus, as shown by the contraction of the muscle to which it is supplied.

2. *Chemical stimulation.* Loss of water by the tissue of the nerve, whether this be caused by ordinary evaporation, or facilitated with blotting paper, exposure over sulphuric acid, or the addition of the solutions of high density, such as syrup, glycerine, or strong salt solution. The application of strong metallic salts or acids; or alcohol and ether, also a solution of bile irritates nerves; weak alkalis, except ammonia, which has no effect on nerve, although it acts on muscle when applied directly to that tissue.

3. *Thermic stimulation* occurs when sudden changes are brought about approaching either of the extreme temperatures at which the nerve can act; *i.e.*, near 5° or 50° C.

4. *Electric stimulation* is by far the most important for physiologists, being the most easily applied and regulated, and the least injurious to the nerve tissue. As was mentioned with respect to muscle, a sufficiently rapid change of intensity in an electric current passing through a nerve causes excitation. The less the absolute intensity of the current, the greater the effect caused by any given change in intensity. The muscle of a nerve-muscle preparation contracts, when a weak *constant current*, say from a singly small Daniell cell, is suddenly allowed to pass through the nerve. This is done by placing a part of the nerve in the circuit, which is made complete, by closing a key, when the stimulation is to be applied. This form of stimulation is called a *making shock.* While the current is allowed to pass through the nerve little or no effect is produced if the battery be quite constant. On breaking the circuit by opening the key the current suddenly ceases, and another contraction occurs; this is called the *breaking shock.* At each making and breaking of the constant current, the nerve is excited. A weaker current suffices to bring about a contraction when applied to the nerve, than when applied directly to the muscle.

If a strong constant current be allowed to pass through a considerable length of a nerve for some little time, and the circuit be then suddenly broken, instead of a single contraction tetanus of the muscle results. This *breaking tetanus* (Ritter's

tetanus) is easily produced when the positive pole or anode is next the muscle. Sometimes in particular conditions of the nerve, and with certain strengths of stimulation, a *making tetanus* also occurs, but more rarely and only when the negative pole is next the muscle.

If a long piece of nerve lie between the electrode, it is not excited throughout its entire length, but one single point is stimulated whence the impulse spreads. This point may be at either of the poles in contact with the nerve ; according as the circuit is made or broken. With a *making shock* the stimulation takes place at the negative pole or *cathode*, and with a *breaking shock* at the positive pole or *anode*. That is to say, the point where the current leaves the nerve is affected at the *make*, and the point where the current enters the nerve is affected at the *break* of the current.

It has been found that, other things being equal, with a continuous current the making shock is a more powerful stimulus than the breaking shock ; *i.e.*, a weak current will sooner cause a contraction when the circuit is made, than when it is broken.

This fact, that the impulse starts from the *anode* in a breaking shock, is proved by means of the *breaking tetanus* just alluded to. It has been found that when the *anode* is next to the muscle the breaking tetanus is more marked and lasts longer than when the *anode* is further from the muscle than the *cathode*. When the *cathode* is nearer to the muscle than the *anode*, section of the nerve between these points during stimulation, stops the contraction at once, and no breaking tetanus occurs, because the point from which the stimulus comes is cut off from the muscle. Section of the intrapolar region has no effect if the anode be next the muscle, and the tetanus proceeds in a normal way, because the active pole remains in continuity with the muscle. That the stimulus occurs at the *cathode* in *making* a current may be demonstrated by the fact that it takes a certain measurable time for the impulse to travel along the nerve. If the cathode be placed as far as possible from the muscle and the anode quite near it, the contraction after a *breaking shock*, when the stimulus starts from the *anode*, will occur sooner than that which follows the *making shock*, when the stimulus starts from the *cathode*, because the impulse has a less distance of nerve to traverse in the former case. These time differences are found in the latest period of the recorded contraction.

In some experiments on nerve, a constant current, *i.e.*, one coming directly from a battery, is not used, because there is no ready means of regulating or varying the strength of the stimulation. The instantaneous current *induced* in one coil of wire—the *secondary coil*—by the making or breaking of a current passing through another coil—the *primary coil*—is more effective and suitable as an ordinary stimulus. It must be remembered that the induced current usually consists of a rapidly diminishing series of oscillations—makes and breaks—but the duration of the series is so short (*circa*, ·0004″) that it only acts as a single stimulus. As there is no current in the secondary coil, while a constant current is kept passing through the primary, of course the induced current cannot be used for experiments relating to the making and breaking shocks. The strength of the induced current being (in some positions of the coils) approximately in inverse proportion to the square of the distance between the two coils—moving the secondary away from the primary coil gives a ready means of varying and regulating the strength of the stimulus, without any special care being devoted to the exact strength of the element used.

Du Bois-Reymond's Inductorium is the instrument commonly used in physiological laboratories. A drawing and further description of the instrument will be found at p. 419.

Velocity of Nerve-Force.

Nerve impulses travel at a rate of about 30 metres per second.

When we reflect that the passage of an impulse along a nerve is brought about by a molecular change in the axis cylinder, we are struck with the rapidity with which impressions are transmitted from one part of the body to another. This velocity is only relatively great. When we compare it with the velocity of the electric current or of light, we see how incomparably slower the nerve-impulse moves. It may be compared with rates of motion commonly under our observation. To take every-day examples :—*viz.*, nine metres per second is about the rate at which a quick runner can accomplish his 100 yards ; race-horses can gallop about 15 metres a second for a mile or so ; a mail train at full speed travels at about 30 metres a second, and the velocity of nerve force has been estimated to be in cold-blooded animals 27 metres per second ;

and in man about 33 metres per second. So that the intercommunications between man's brain and the various parts of his body only travel about the same rate as an express train, and about twice as fast as the quickest horse can gallop.

Different methods may be employed for the measurement of the rate of transmission of nerve force. The simplest is the graphic method, with a myograph as described p. 425, to make a muscle draw two curves one over the other, in one of which the stimulation is applied to the nerve close to the muscle, and in the other, as far as possible away from it. The difference in duration of the latent period in the two curves, shown by the tuning-fork tracing, corresponds to the time taken by the impulse to travel along the part of the nerves between the two points of stimulation, the length of which can be directly measured; and hence the velocity of the impulse estimated.

Utilising the fact that the extent of deflexion of the needle of a galvanometer is in proportion to the *duration* of a current of known strength passing through it for a short time, an accurate measurement of the difference in time of remote and near stimulation of a nerve may be made. By a special mechanism the time-measuring current is sent through the galvanometer at the same moment that the stimulating current goes through the nerve, and the instant the muscle begins to contract, it breaks the current passing through the galvanometer, so that this time-measuring current lasts only from the moment when the nerve is stimulated until the muscle begins to contract.

Electric Properties of Nerves.

Like muscles, nerves may be regarded as having a state of rest and a state of activity, but the two states are not obvious in the same striking way as they are in muscle, nor do we know much of the physical properties of nerve. While at rest, however, it shows electric phenomena similar to those which have already been described as belonging to muscle tissue. These electrical currents are contemporaneous with the life of the nerve, and they undergo the same variation as occurs in muscle when the nerve passes into the active state; that is, when it transmits an impulse.

The so-called *natural current* of nerve is practically the same as that of muscle, passing in the nerve to the central part from the cut extremities of the fibre; that is to say, the

current passes through the galvanometer from the electrode leading from the middle of the nerve, to that applied to the extremity. The electro-motive force of a small nerve is much less than that of a muscle. In a frog's sciatic it has been estimated to be 0·02 of a Daniell cell. The natural current of the frog's nerve is said to increase in intensity in proportion to the increase in temperature up to about 20° C., after which it decreases.

Experiments on nerve currents must be carried on with all the precautions mentioned in speaking of muscle currents, and with the non-polarisable electrodes there figured (page 415).

Negative Variation.—The natural current of a nerve, like that of muscle, undergoes a diminution at the moment the nerve is stimulated ; this is termed the *negative variation.* It occurs with any form of stimulation, so it cannot be dependent on an escape of the stimulating current. In the case of a single stimulation, the negative variation is so rapidly over—lasting only ·0005 sec., that the inertia of the needle of most galvanometers prevents the change in the current being indicated. In tetanus, however, it makes a decided impression on the galvanometric needle.

The electric change occurring in a nerve, can be demonstrated without a galvanometer by a simple experiment known as the 'paradoxical contraction' of the frog's gastrocnemius muscle. If the division of the sciatic nerve that does not supply the gastrocnemius be separated from its peripheral attachments (care being taken not to injure its union to the parent trunk) and a single induction shock be passed through it, near its distal end, a variation in its electric condition passes up the nerve and acts as a stimulus to the trunk exciting the gastrocnemius to contract, through the medium of the other branch of the nerve.

The strength of the negative variation depends on the condition of the nerve and the strength of the stimulus ; being stronger when the nerve is fresh and irritable and has a good natural current, and when a strong stimulus is applied.

The negative variation of the natural currents passes along the nerve from the point of stimulation in both directions, just as the nerve impulse ; and with a galvanometer the electric change may be traced from the nerve to the muscle. It has also been shown that the negative variation travels along the nerve at the same velocity as the impulse ; namely, about 27

metres per second. The velocity is influenced by certain conditions (to be presently described) which alter the rate of the impulse. These points seem to lead to the belief that the nerve impulse and the negative variation are closely related. Both the electric change and the impulse pass along the nerve as a wave, the *speed* of which is 27 metres per sec., and its *duration* ·0005 of a sec. respectively ; the length of the wave is therefore about 18 millimetres.

The velocity of nerve impulse is increased by a rise of temperature and decreased by a fall. Cold thus distinctly lessens the conductivity of nerve.

Electrotonus.

If one of the wires leading to a galvanometer be applied to the centre, and the other to the end of a nerve, so as to show the effect of the natural current, and at the same time another

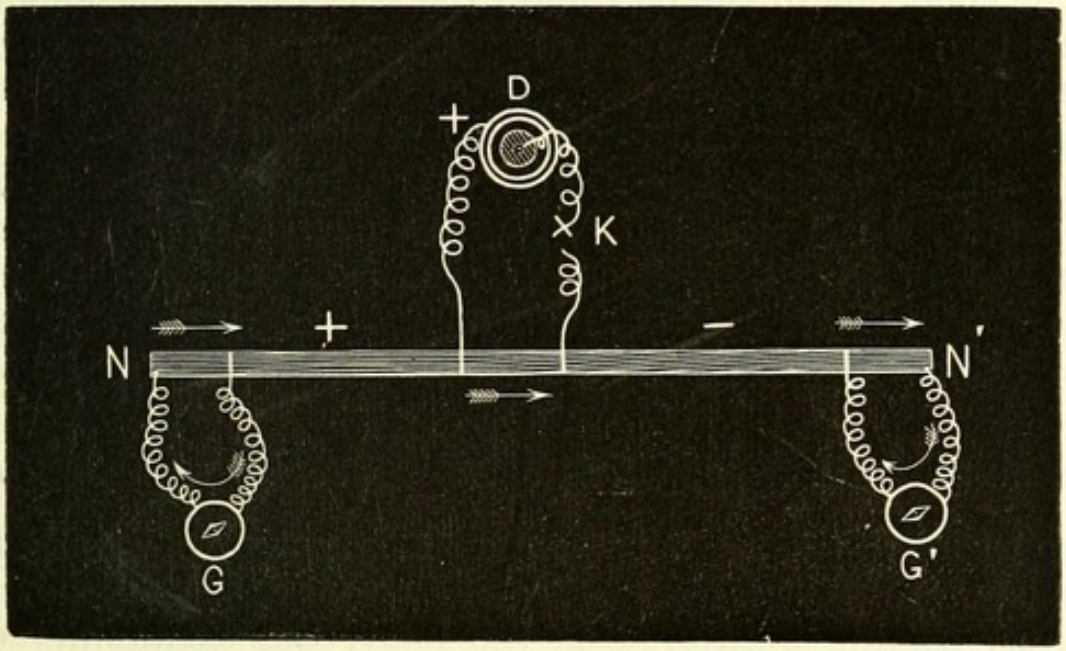


Fig. 190.—Diagram to illustrate Electrotonus.

N. N'. Portion of Nerve. G. G'. Galvanometers. D. Battery from which polarising current can be sent into nerve by closing key K. The direction of the polarising and electrotonic currents is indicated by the arrows, and is seen to be the same.

part of the nerve be placed in the circuit of a constant current from a battery, when the circuit of the constant (now called *polarising*) current is completed, a change is found to take place in the natural current. This is called *electrotonus*. Instead of the natural currents from the centre to the end of

the nerve, a current is found to pass through the entire length of the nerve in the same direction as the polarising current from the battery. This electrotonic current is not proportional to the strength of the natural currents, and is to be recognised when the latter are no longer to be found. It is stronger with a strong polarising current, and is most marked in the immediate neighbourhood of the poles, fading gradually away as one passes to the remoter parts of the nerve. The electrotonic state is not to be attributed to an escape of the constant polarising current, because it decreases gradually with the waning of the physiological activity of the nerve, and ceases at the death of the nerve, while the tissue retains its power of conducting electric currents. It has been shown that a ligature applied to the nerve so as to destroy its physiological continuity, but not its power of carrying electric currents, prevents the passage of the electrotonic current to the part of the nerve which is thus separated.

The condition of the portion of the nerve near the anode is found to differ somewhat from that near the cathode, and hence if is found convenient to speak of the region of the anode being in the *anelectrotonic*, and that of the cathode being in the *catelectrotonic* condition. A certain time appears to be required for the production of electrotonus ; with a current of less duration than ·0015 of a second we are unable to detect the electrotonic state. The negative variation must, therefore, have passed away before the electrotonus has commenced.

Excitability and Conductivity of Nerve Fibres.

The excitability of nerves, and their power of conducting impulses, varies according to certain conditions and circumstances. While uninjured in the body, the excitability of a nerve depends upon—

1. A supply of *blood* sufficient to provide nutriment, and to carry off any injurious effete matters that may be produced by its molecular changes.

2. A suitable amount of *rest.* Prolonged activity causes fatigue and loss of excitability.

3. Uninjured *connection* with the nerve centres. When a nerve is cut, the part connected with the periphery rapidly undergoes degenerative changes, which seem to depend upon faulty nutrition, since they are accompanied by structural changes—fatty degeneration. This appears to commence in a

very short time after the section—often in about three to five days. The part of the nerve remaining in direct connection with the cord, retains its excitability for a very much longer time.

In the artificial stimulation, by means of electric shocks applied to the nerve of a cold-blooded animal, there are many minor conditions which have considerable influence on the excitability, as evidenced by the response given by the attached muscle to weak stimuli. The more important of these are :—

1. *Temperature* changes. In the case of a frog's nerve, a rise of temperature to 32° C. causes an increase in its excitability. Probably this increased excitability is only to be taken as a sign of approaching death. A fall of temperature tends to make the nerve more easily excited. A nerve kept for some time at about 3° C. becomes highly irritable.

The variations in excitability following changes in temperature seem to depend on a change in the power of conducting the currents, as shown by the different results in short and long electric stimulation.

2. The *part* of the nerve stimulated, is also said to have some effect on the result of a given strength of stimulus. The further from the muscle, other things being equal, the more powerful the contraction produced. So that the impulse is supposed to gather force as it goes, as in the case of a falling body, and hence has been spoken of as the *avalanche* action of nerve impulse.

3. A *new section* of a nerve is said to increase its excitability, as indeed, any slightly injurious influence, such as drying, chemical or mechanical meddling, &c. This increase in excitability depends upon injurious changes going on in the nerve, as these influences are followed by complete loss of excitability which takes the same course down the nerve (Ritter-Valli law). The increase of excitability spreads from the point of section down the nerve.

4. The *electrotonic state.*—The most remarkable changes in the excitability of a nerve, are those brought about by the action of a constant current passing through the nerve, so as to set up the conditions just described as *anelectrotonus* and *catelectrotonus.*

The excitability of the nerve is increased in the region near the cathode, and is diminished in the neighbourhood of the anode.

The increase of excitability is in proportion to the intensity

of the catelectrotonic, and the decrease in proportion to the intensity of the anelectrotonic state. Thus the increase is most marked in the immediate neighbourhood of the cathode, and fades with the distance from the negative pole ; and similarly, the decrease is strongest at the anode, and becomes less and less as it passes away from the positive pole. In the same way, in the part of the nerve between the two poles—the intrapolar region—the decrease and increase of excitability become less marked towards the middle point between the cathode and the anode, so that here we find an unaffected part, which has been called the *indifferent point.*

It is a remarkable fact that this indifferent point is not

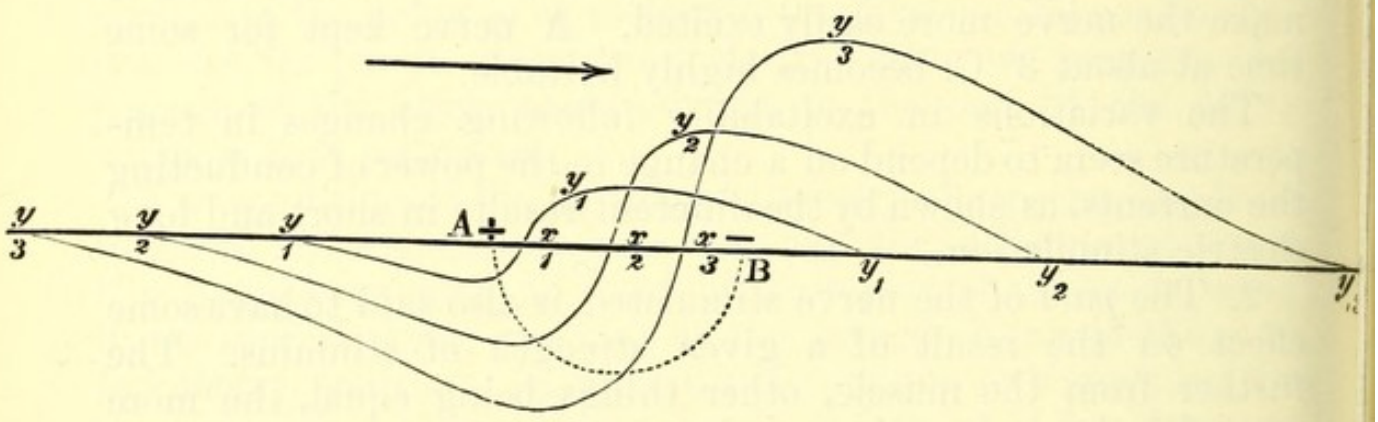


Fig. 191.—Diagram illustrating the variations of irritability of different parts of a nerve during the passage of polarising currents of varying strength through a portion of it.

A = Anode ; B = Cathode ; AB = Intrapolar district ; y^1 = Effect of weak current. y^2 = Effect of medium current. y^3 = Effect of strong current.

The degree of change effected in the irritability of the part is estimated by the distance of the curves from the straight line. The part of curve below the line corresponds to *decrease*, that above to *increase* of irritability. Where the curves cross the line is called the indifferent point. With strong currents this approaches the cathode. (From Foster after Pflüger.)

always midway between the two poles, but decreases its distance from the cathode in proportion as the polarising current is made stronger. That is to say, with strong polarising currents the indifferent point is near the cathode (B) ; with weak currents it lies near the anode (A) (Fig. 191).

Besides becoming less irritable in proportion as the polarising current becomes more powerful, the anelectrotonic region of the nerve loses its ability to conduct impulses, and may finally, with a very strong current, even when applied for a short time, become quite incapable of conducting an impulse.

If the polarising current be now opened, so as to stop its passage through the nerve, and remove the anelectrotonic and the catelectrotonic, states, a kind of rebound occurs in the condition of both the altered regions, and the part which has just ceased to be catelectrotonic, and was, therefore, over-irritable, becomes, by a kind of negative modification, very much lowered in its excitability; while on the other hand, the anelectrotonic part, by a positive rebound, becomes more excitable than in its normal state. The rebound over the line of normal excitability lasts a very short time; but as we shall see presently, it is of greater duration than the passage of the negative variation along the nerve.

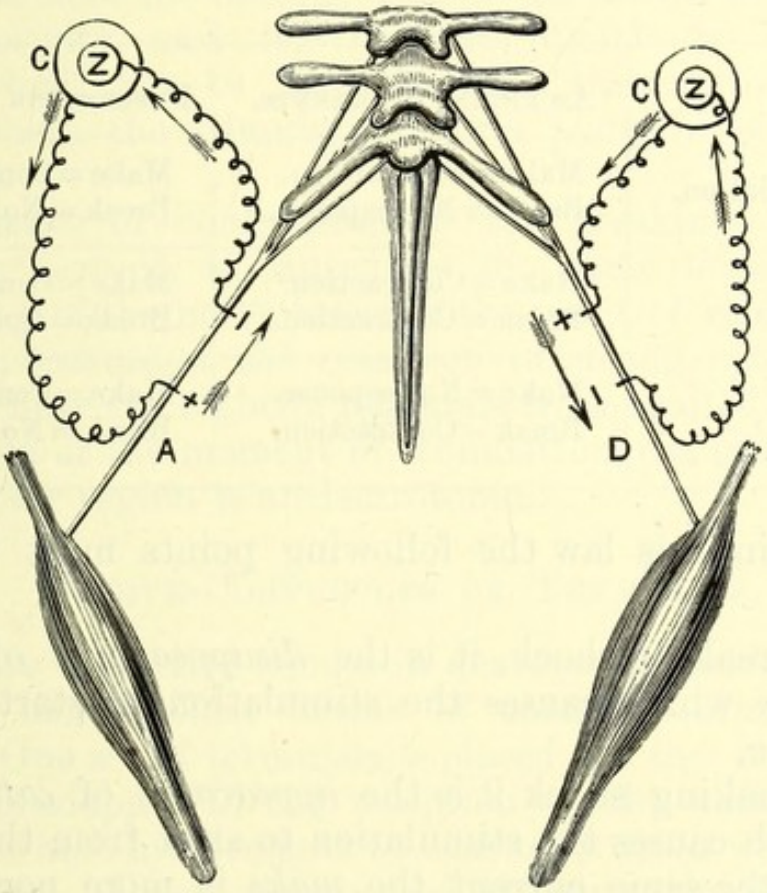


Fig. 192.—Diagram to show the meaning of the terms *ascending* and *descending* currents, used in speaking of the law of contraction. The end of the vertebral column, sciatic nerves and calf muscles of a frog are shown.

The arrows indicate the direction of the *ascending current* A, *on the left*, and the *descending current* D, *on the right*, according as the positive pole of the battery C, is below or above.

The Law of Contraction.

Upon the foregoing facts, and others already mentioned—*viz.*, that on *breaking* the current the stimulation occurs at the

anode, on *making* at the cathode—depends the law of contraction, which would be difficult to understand without bearing in mind all these interesting points.

It was found that, with the same strength of stimulation, not only were different degrees of contraction produced with making and breaking shocks, but also that, other things being similar, a different result followed when the current was sent through the nerve in an upward direction (*i.e.*, from the muscle), and when it was sent in a downward direction (*i.e.*, towards the muscle). The stimulating current is spoken of, in the former case, as an *ascending current*, and in the latter as a *descending current*. (Fig. 192.)

The following is a tabular view of the law of contraction :—

	Ascending Currents.	Descending Currents.
Weak Stimulation.	Make = Contraction. Break = No response.	Make = Contraction. Break = No response.
Medium ,,	Make = Contraction. Break = Contraction.	Make = Contraction. Break = Contraction.
Strong ,,	Make = No response. Break = Contraction.	Make = Contraction. Break = No response.

To explain this law the following points must be kept in view :—

1. In a breaking shock, it is the *disappearance* of *anelectrotonus* which causes the stimulation to start from the anode.
2. In a making shock it is the *appearance* of *catelectrotonus* which causes the stimulation to start from the cathode.
3. With the same current the *make* is more powerful than the *break*.
4. Anelectrotonus causes *reduction* of irritability and of conductivity of the nerve.
5. Catelectrotonus causes *increase* of irritability and of conductivity of the nerve.
6. With *ascending currents* the part of the nerve next the muscle is in a state of reduced functional activity (anelectrotonus).
7. With *descending currents* the part of the nerve next the muscle is in a state of exalted activity (catelectrtoonus).

8. The reduction or exaltation of activity is much greater with strong currents.

That only making shocks cause contraction with very weak currents, simply depends on the greater efficacy of the entrance of catelectrotonus into the nerve, which causes the making stimulation.

That contraction follows in all four cases (make and break, ascending and descending), with medium stimulation, is explained by assuming that the depression of the functional activity of the nerve is not sufficient to affect its conductivity.

The want of response to a making shock, in the case of the strong ascending current, depends upon the fact that the part of the nerve near the muscle, around the anode, is in a state of lowered activity, and is, therefore, unable to conduct the impulse which has to pass through this region from the cathode, where the stimulation takes place, in order to reach the muscle.

The absence of contraction at the breaking of a strong descending current, is caused by the same lowering of the conductivity of the nerve between the point of stimulation and the muscle, because at the cessation of strong catelectrotonus, the region near the cathode rebounds from exalted to depressed activity, and at the moment of stimulation the greater part of the intrapolar region is anelectrotonic.

Nerve-Corpuscles or Terminals.

These are the active agents in nervous operations, while the fibres are merely their means of communicating with one another. One set of terminals is placed on the surface of the body and is adapted to the reception of the various external influences which are brought to bear on it from without by its surroundings. These receivers of extrinsic stimuli are necessarily much varied so as to be capable of appreciating all the different kinds of stimulation presented to them. They are either distributed over the entire surface so as to meet with general mechanical and thermic changes, or they are further specialised for the reception of luminous, sonorous, odorous or gustatory impulses. In the latter cases the special terminals are collected into one part, and form complex organs, which will be described presently in the chapters on the special senses.

Another set of terminals is placed in the deeper textures,

where they act as local distributing agents ; such as the nerve plates on skeletal muscles, and the ganglionic networks in the wall of the intestine. In many instances, however, the exact mode of connection between the nerve and the protoplasm of the tissue elements, to which it bears impulses, has not been satisfactorily made out. In the remaining class of nerve terminals the cells are grouped together so as to form larger and smaller colonies, and more definitely deserve the name of nerve or ganglion cells. These are the central terminals, and are placed either in the cerebro-spinal axis, or in swellings of the nerves called sporadic ganglia.

Of these nerve-cells there are many varieties, all of which have the following characteristics. The cells are of considerable size and have processes branching off from them, by means of which they communicate with the nerve-fibres. These processes may be single or many, hence they are spoken of as uni-, bi-, or multi-polar cells, &c. The nucleus is commonly very distinct, and contains a well-marked nucleolus. The abundant protoplasm, which is usually contained in a delicate cell-wall, is in direct connection with the axis cylinder of the nerve fibres, with which it communicates by means of thin strands of protoplasm that pass out from the cell by the processes. A delicate striation of the protoplasm may sometimes be recognised, indicating the course of the nerve fibrils as they run into the cells from the processes.

The Functions of Nerve Cells.

Any mass of living protoplasm, such as an amœba, can receive extrinsic stimuli, which affect directly its conditions, and though the impression may be very localised in its application, yet all the parts of the cell participate in the sensation, and probably take part in the resulting movement.

Besides those acts of which we can recognise the cause, many others occur in amœbæ which we are not able to trace to any definite cause other than the energies derived from its special powers of assimilation. We say that not only can an amœba feel local stimulation, transmit the impulse to remoter parts of its body, and respond by movement to the stimulus, but it can also *initiate* impulses which appear as motions, &c., as the result of intrinsic processes of a chemical nature. We may conclude from this fact alone that automatic action is one of

the properties of protoplasm derived from its proper chemical activities.

In the nerve centres of all the more complex animals, we find that each of these kinds of action is distributed to different varieties of cells, and thus an important division of labour takes place. The first act is performed by a wonderfully elaborate set of special organs adapted to the reception of the various intrinsic impulses or sensations from without. The excitation is then sent by nerve fibres to another group of central nerve-cells, which are apparently employed solely in receiving the stimuli from the peripheral organs, and then distributing the impulses to their neighbours, which can direct, modify, analyse, classify, re-distribute, or check the impulses, so that the higher nerve-cells may have less work, and at the same time lose none of the advantage that is to be gained from the income derived from stimulus coming from without. Connected with the last group is another, the nerve-cells which lie out of the reach of the ordinary peripheral impulses, but are capable of developing within themselves energies, and can initiate impulses with no other aid than that of their nutrition and the chemical changes resulting from their assimilation.

These impulses are distributed to the peripheral active tissues, muscles, glands, &c., probably through the medium of other sets of cells analogous to the last group situated in the nerve centres as well as to the local distributors which act as unions between the other textures and the nerve fibres.

The functions of nerve-cells which form centres of action may be classified thus :—

1. Reflexion. Many cells are capable of reflecting impulses received from an afferent nerve ; that is to say, they send it by an efferent nerve to some active tissue, such as a muscle or gland. This kind of direction is spoken of as a simple *reflex action*. For instance, if a grain of red pepper be placed on the tongue, an impulse soon travels from the peripheral receiving terminal, along an afferent nerve to its central terminal, which reflects the impulse to the efferent nerve, going to the salivary gland, and the result is an increased secretion of saliva.

2. Co-ordination. There are but few reflex acts that do not require the co-operation of several cells, and these work together in an orderly manner, the resulting activity being well arranged and usually adapted to some purpose. The first act of the receiving cells of a reflex centre must be to distribute

and direct the impulse into those channels which lead to groups of cells capable of sending impulses in an orderly and definite direction. This directing and arranging power is spoken of as *co-ordination*, and probably is an attribute common to all nerve-cells.

3. AUGMENTATION. The force of the reflected efferent impulse bears a direct relation to the afferent impulse as determined by the strength of the stimulus. Thus if the amount of pepper on the tongue be much increased, not only is the flow of saliva greater, but the excitation spreads from one central cell to another until the neighbouring centres are affected. Thus we often find the lachrymal and sweat glands are influenced by very strong stimulation of the tongue, and pour out their secretion, as is said, "in sympathy" with the mouth glands. But the amount of the afferent impulse is not the only factor in determining the energy of response to be reflected along the efferent channels. Some nerve-cells have a distinct power of increasing the amount of response to a given stimulus. When an irritant falls near the mucous membrane in the neighbourhood of the laryngeal opening, a very different result is produced. The greater response to an equal stimulus in such cases probably depends rather on a peculiar *augmenting* power of some central cells than upon any special local mechanisms.

4. INHIBITION. Under certain conditions, which will be more fully explained presently, nerve-cells appear to have the power of restraining the activity of other cells or tissues, of checking their receptive or executive power, or lessening the impulse reflected so as to produce less effect, this is called *inhibition.*

5. AUTOMATISM. Nerve-cells are supposed to have the power of originating activity, *i.e.*, discharging impulses without receiving any exciting impulses from other nervous agencies that we can find out. *Automatic actions* are sometimes classified as those acting continuously and those that undergo rhythmical changes. If carefully examined, most of the so-called constant automatic actions will be found to show traces of rhythmic relaxation, and many of them will be found explicable as reflex acts. The centre governing respiratory movement is the best example of an automatic group of cells. Impulses are rhythmically discharged from it even when the connections with all the afferent nerves which influence it normally are cut off, and it has no other excitant than the warm blood supplying it with

nutriment. Respirations are, however, normally regulated by a reflex mechanism, the channels of which reside in the vagus nerve.

In the nerve-cells we must also seek *mental activity*, under which term may be considered perception, volition, thought, and memory. It is very difficult to allocate the due proportions of reflexion, co-ordination, augmentation, inhibition, automatism, &c., requisite for the development of mental faculties. In all probability what we call mental operations are related to activities called forth as the resultant of a long series of external and internal excitations, modified by intrinsic nutritive influences, acting upon innumerable groups and complex associations of nerve-cells, the general outline of whose function and tendency of action, *character*, has been rough-hewn by hereditary transmission.

CHAPTER XXVIII.

PHYSIOLOGY OF SPECIAL NERVES.

THE thirty-one pairs of nerves, which leave the vertebral canal by the opening between the vertebræ, are called spinal nerves, in contradistinction to the cranial nerves, which pass through the base of the skull. They are attached to the spinal marrow by two bands, the *anterior* and *posterior roots*, which unite together in the intervertebral canal to form the trunk of the nerve. Just before the junction of the two roots the posterior one is enlarged by the *ganglion* of the posterior root.

The spinal nerves are all "mixed nerves," that is to say, they contain both efferent and afferent fibres; but these two sets of fibres are separate in the roots of each nerve, the posterior root containing only *afferent*, and the anterior only *efferent* fibres. The spinal nerves are thus joined to the spinal marrow by two nervous cords, each one of which is functionally distinct. Nearly eighty years ago Charles Bell discovered that the anterior roots were motor, and the posterior sensory channels. Hence, the anterior are commonly spoken of as the *motor roots*, and the posterior as the *sensory roots* of the spinal nerves.

Anterior or Efferent Roots.

If the roots entering the nerves supplying the hind leg of an animal be divided, the muscles are paralysed, and the leg hangs limp.

The following facts further determine the motor function of these roots :—

1. Stimulation of the root near the cut end attached to the cord excites no obvious response.

2. Stimulation of the cut end leading to the limb throws its muscles into violent action.

3. If the animal be allowed to survive the operation, the

part of the nerve cut from its central connection is found after some time to degenerate, but the end connected with the cord continues healthy.

4. In the early embryo the development of these roots may be seen to start from the cord, and extend towards their peripheral distribution.

Besides the fibres carrying efferent impulses to the skeletal muscles, there are three other sets of efferent fibres already known, in the anterior roots, viz.—

1. To the muscles of the blood-vessels.
2. To the muscles of the viscera.
3. To the secreting glands.

The existence of the vaso-motor fibres may be proved as follows :—

If the two webs of a frog, with the anterior roots of the lower four nerves divided on one side, be compared, the blood-vessels in the transparent part of the web, on the injured side, will soon be found to be fuller than those in the web of the other limb, but if the distal ends of the cut motor roots be stimulated, the dilated blood-vessels contract to an extreme degree.

With regard to the viscero-motor fibres the proof is not so easily demonstrated, as we have not so ready a gauge of the activity, but from similar experiments there can be but little doubt that motor impulses travel by the anterior roots to the viscera.

Posterior or afferent Roots.

The functions of the posterior roots have been determined by the following methods.

Section of the posterior roots entering the plexus of a limb produces no paralysis of voluntary movement, but we find that :—

(*a.*) On excitation of the limb no reflex response can be elicited. On the other hand after section of the anterior roots *alone* reflex movements of other parts of the body, can readily be excited. Therefore afferent impulses exciting reflex action reach the cord through the posterior roots only.

(*b.*) On stimulation of the cut end connected with the limb, no response is called forth.

(*c.*) On stimulating the cut end attached to the cord, motions indicative of pain are produced.

(*d.*) If the animal be kept alive, the nerve degenerates according to the position of the section with regard to the ganglion of the root. Thus if the nerve be cut between the ganglion and the cord, the part of the root attached to the cord degenerates; but if it be cut between the ganglion and the periphery, the peripheral portion degenerates.

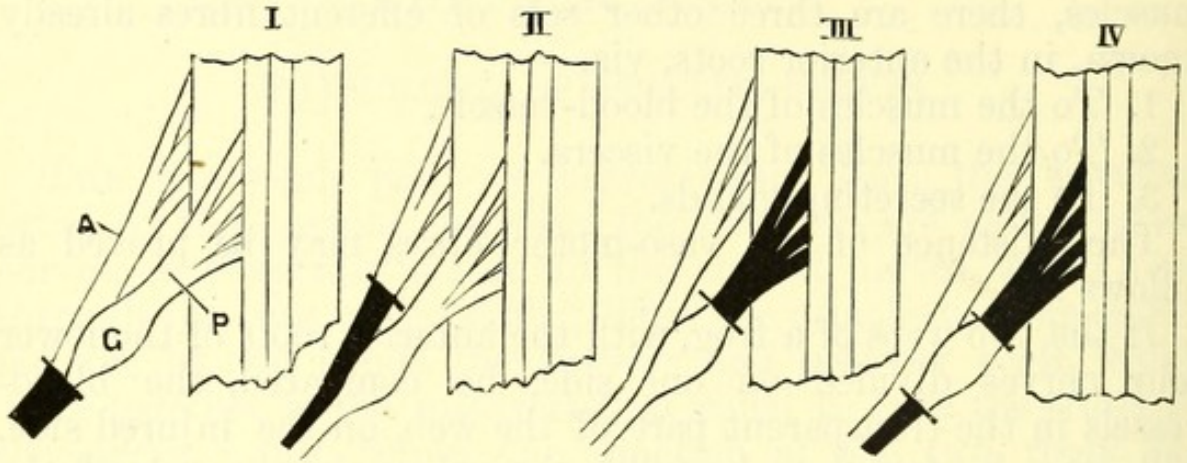


Fig. 193.—Diagram showing the degeneration (black) following section of spinal nerves and roots at different points. A, anterior; P, posterior root; G, ganglion.

(*e.*) If, in a frog previously decapitated, the lower four posterior roots on one side be divided, it will be found that the limb of that side will hang more limply than the other, because the afferent, excito-reflex impulses from the skin, which established muscular *tonus*, cannot reach the cord.

(*f.*) Pathological and other evidence leads us to believe that afferent impulses which serve to bring about muscular co-ordination also travel through the posterior roots. These include impulses starting both from skin and muscles.

In the early embryo the fibres of these roots are seen to start from isolated masses of cells, formed from that part of the sensory layer of the epiblast lying dorsally in respect to the medullary canal. From these cells processes grow, in either direction, peripherally towards the skin, &c., centrally into the sensory layer of the medullary canal.

It has been found that stimulation of the anterior roots causes pain, as shown by the motion of other parts besides those to which the roots are distributed. But it has been found that if the corresponding posterior roots be cut these signs of pain when the anterior roots are stimulated are absent.

These fibres are named the "recurrent sensory fibres," and they are nothing more than sensory fibres which pass from the nerve

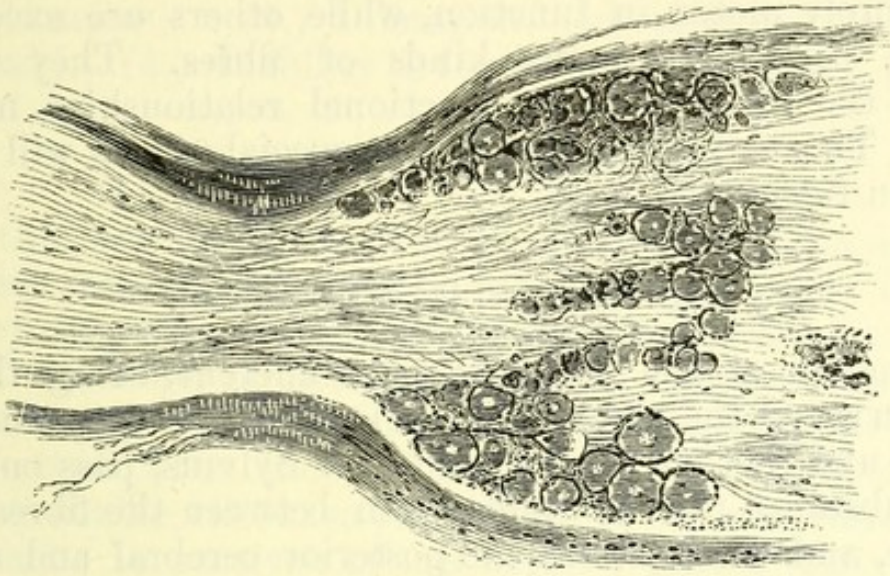


Fig. 194.—Section through spinal ganglion of a cat, showing ganglion-cells interspersed between the fibres. (Low power.)

trunk a little way up the motor root, and then turn back and descend to the junction of the roots, whence they pass along the posterior root to the cord.

In the ganglion of the posterior root (Fig. 194) numerous large nerve-cells are grouped together into masses between the nerve-fibres with which they are laterally connected. The cells are nearly spherical in outline, and are enclosed in a capsule made of flattened cells, from which the protoplasm commonly shrinks, spoiling the outline of the cell. Each nerve-fibre, with but rare exceptions, is known to be attached to a single cell, and the cells have never been found to have more than one fibre connected with them. The only known function of these cells is that of presiding over the nutrition of the nerve fibre to which they are attached.

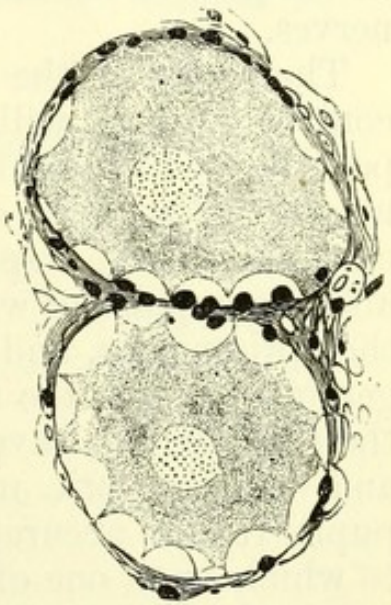


Fig. 195.—Two cells from the former seen under a high power, showing the fine protoplasm here and there retracted from the cell-wall.

The nerves which pass off through the foramina in the base of the skull are considered separately, on account

of their anatomical relationship differing from those of the spinal nerves and because the function of each shows some peculiarity. Some are exclusively nerves of special sense, some are simple, being purely motor in function, while others are exceedingly complex, containing many kinds of fibres. They may be taken in the order of their functional relationships, motor or mixed. Those which relate to the special senses will be considered in future chapters.

The Motor Oculi Nerve.

The nerves of the third pair are efferent, being the chief motor nerves of the eyes. They arise from the grey matter on the floor and roof of the aqueduct of Sylvius, pass out of the brain substance near the pons, from between the fibres of the peduncle, and run between the posterior cerebral and superior cerebellar arteries. They pass into the orbits in two branches, and are distributed to the following orbital muscles :—(1) elevator of the eyelid ; (2) the superior, (3) inferior, and (4) internal recti, and (5) the inferior oblique. They also contain fibres which carry efferent impulses to (1) the circular muscle of the iris, and to (2) the ciliary muscle. The latter branches reach the eye by a short twig from the inferior oblique branch, which goes to the ciliary ganglion, and thence enters the ciliary nerves.

The action of the orbital muscles is, in the main, under the control of the will, though they afford good examples of peculiar co-ordination and involuntary association of movements. The reflex contraction of the pupil by the action of circular muscle (sphincter pupillæ) is a bilateral act, the afferent impulse of which originates in the retina, passes along the optic nerves, and is transmitted, from the corpora quadrigemina, to both the third nerves. The central extremities of the third nerves have an intimate connection with each other and with the optic nerves, for the diminution in size of both pupils follows accurately the increase in intensity of the light to which even one of the retinæ is exposed. In retinal blindness and after section of the optic nerve the pupil becomes dilated from loss of the retinal excitation. The action of the ciliary muscle may be said to be voluntary, since we can at will focus our eyes for near or far objects. Contraction of the sphincter pupillæ and of the internal rectus is associated with the contraction of the ciliary muscle in accommodation.

Section of the third nerve within the cranium gives rise to the following group of phenomena :—(1.) Drooping of the upper lid (Ptosis). (2.) Fixedness of the eye in the outer angle (Luscitas). (3.) Dilatation and immobility of pupil (Mydriasis). (4.) Inability to focus the eye for short distances.

The Trochlear Nerve.

This thin nervous filament arises under the Sylvian aqueduct, and passes into the superior oblique muscle, to which it carries voluntary impulses, which are involuntarily associated with those of the other muscles moving the eyeball. Paralysis of this muscle causes no very obvious impairment in the motions of the eyeball when the head is held straight, but it is accompanied by double vision, so there must be some displacement of the eyeball. In paralysis of this nerve a double image is seen only when looking downwards, and the image on the affected side is oblique and below that seen by the sound eye.

The Abductor Nerve of the Eye.

This arises in the floor of the fourth ventricle, and appears just below the pons Varolii. It is the motor nerve of the external rectus muscle of the eye. Paralysis or section of it causes internal squint.

Motor Nerve of the Face (Portio Dura).

This nerve arises from a grey nucleus in the floor of the fourth ventricle. It passes with the auditory nerve (portio mollis) into the internal auditory meatus of the temporal bone. It first passes out towards the hiatus, then turns at a right angle to form a knee-like swelling (geniculate ganglion), and then runs backwards along the top of the inner wall of the drum, and passing downwards through a special canal in the bone, comes out at the stylo-mastoid foramen, and finally spreads out on the side of the face. It is essentially an efferent nerve, being partly motor and partly secretory, though its connections have caused afferent functions to be ascribed to it. Its distribution may be thus briefly summarised:—

i. *Motor fibres.*—(1.) To the muscles of the forehead, eyelids, nose, cheek, mouth, chin, outer ear, and the platysma, which may be grouped together as the *muscles of expression.* (2.) To

some muscles of *mastication*, viz., buccinator, posterior belly of digastric, and the stylohyoid—all the foregoing being supplied by external branches—while in the temporal bone it gives a branch to (3) the *stapedius* muscle, and also (4) a branch from the geniculate ganglion named the great superficial petrosal nerve, which after a circuitous course is supplied to the azygos muscle of the palate and uvula.

ii. *Secretory fibres.*—(1.) To the parotid gland by the small superficial petrosal nerve, which sends a branch to the otic ganglion, whence the fibres pass to the auriculo-temporal nerve, and then on to the gland. (2.) To the sub-maxillary gland by the chorda tympani, which having traversed the tympanum leaves the ear by a fissure at its anterior extremity, then joins the lingual branch of the fifth to separate from it and pass into the sub-maxillary ganglion which lies in close relation to the gland (compare figs. 64 and 65).

iii. *Vaso-motor*, or vaso-inhibitory influences, are chiefly connected with the motor and secretory functions, since dilatation of the vessels of muscles and glands accompanies the motion and secretion that follows stimulation of the nerves going to them.

iv. *Afferent impulses.*—(1.) Special taste-sensations, which are chiefly located in the chorda tympani branch, may be conveyed by the fibres of communication which pass from the trunk and petrous ganglion of the glosso-pharyngeal to the portio dura at its exit from the foramen, or by the connection, in the drum of the ear, between the tympanic branch of the glosso-pharyngeal and the geniculate ganglion of the portio dura, through the lesser superficial petrosal nerve. (2.) Ordinary sensations, which are also located in the chorda tympani, are said to traverse this nerve until it comes near the otic ganglion, when the sensory fibres leave the chorda and pass to the inferior division of the fifth nerve through the otic ganglion.

Injury of the facial nerve in any of the deeper parts of its course gives rise to the striking group of symptoms known as facial paralysis. When it is remembered that muscles aiding in expression, mastication, deglutition, hearing, smelling, and speaking, are paralysed, and that taste, salivary secretion, and possibly ordinary sensation are impaired, one can form some idea of the complex pathological picture such a case presents.

N. Trigeminus, or Tri-facial nerve.

This nerve transmits both efferent and afferent impulses. The motor part, which arises from a grey nucleus in the floor of the fourth ventricle, is much the smaller of the two, and has been compared to the anterior root of a spinal nerve. The large sensory division springs from a very extensive tract, which can be traced from the pons Varolii through the medulla to the lower limit of the olivary body, and on to the posterior cornua of the spinal marrow. This set of fibres has been compared to the posterior root of a spinal nerve, being somewhat analogous to it in origin, function, and the fact that there is a large ganglion on it within the cranium.

The distribution and peripheral connections of this nerve are somewhat complicated, and should be carefully studied when the manifold functions of its branches are being considered. The various impulses conveyed by the tri-facial nerves may be thus enumerated :—

I.—*Efferent Fibres.*

1. *Motor.*—To the muscles of (1) mastication, viz., temporal masseters, both pterygoids, mylohyoid, and the anterior part of the digastrics ; (2) to the tensor muscle of the soft palate ; and (3) to the tensor tympani. (4) In some animals (rabbit) nerve filaments are said to pass to the iris, reaching the eyeball by the ciliary ganglion.

2. *Secretory.*—The efferent impulses which stimulate the cells of the lachrymal gland to increased action, pass along the branches of the ophthalmic division of this nerve.

3. *Vaso-motor.*—The nerves governing the muscles of the blood vessels of the eye, of the lower jaw, and of the mucous membrane of the cheeks and gums.

4. *Trophic.*—On account of the impairment of nutrition of the eye and mucous membrane of the mouth, which occurs after injury of the fifth nerve, it is said to carry fibres which preside over the trophic arrangements of these parts.

II.—*Afferent Fibres.*

1. *Sensory.*—All the divisions of the tri-facial nerve may be said to be connected with cutaneous nerves, by which the ordinary sensory impulses are carried from—(1) the entire skin of the face, and the anterior surface of the external ear ; (2)

from the external auditory meatus ; (3) from the teeth and periosteum of the jaws, &c. ; (4) from the mucous membrane lining the cheeks, floor of the mouth, and anterior part of the tongue ; (5) from the lining membrane of the nasal cavity ; (6) from the conjunctiva, ball of the eye, and orbit generally ; (7) and from the dura mater including the tentorium.

2. *Excito-motor.*—Some of the fibres which have just been enumerated as carrying ordinary sensory impressions, have special powers of exciting co-ordinated reflex motions. Thus the sensory fibres from the conjunctiva and its neighbourhood are the afferent channels in the common reflex acts of winking and closing the eyelids ; and the fibres from the nasal mucous membrane excite the involuntary act of sneezing.

3. *Excito-secretory.*—As in the case of reflex movements, secretion may be excited reflexly. Fibres carry afferent impulses to the medulla from the anterior part of the tongue, and excite activity of the salivary glands. Stimulation of the mucous membrane of the nose or eye causes impulses to pass to the secretory centre of the lachrymal glands, which are frequently thus reflexly excited.

Intense stimulation of almost any of the afferent nerves may excite these reflex phenomena. Thus the most stoic person will experience active secretions of saliva and lachrymal fluid, as well as spasmodic closure of the lids during the extraction of a tooth. Even the bold use of a blunt razor will cause tears to flow down the cheeks, by sending excito-secretory impulses along the branches of the inferior and superior maxillary division of this nerve.

4. *Tactile impulses* are appreciated by the anterior part of the tongue with remarkable delicacy, and are conveyed by the lingual branch of the fifth nerve ; most of the cutaneous fibres are also capable of receiving tactile stimulation.

5. *Taste.*—The tastes appreciated by the anterior part and the edges of the tongue are carried by fibres which lie in the peripheral branches of this nerve. These belong chiefly, if not altogether, to the chorda tympani, and leave this lingual branch of the fifth to join the seventh nerve on their way to the trunk of the glosso-pharyngeal.

There are four ganglia in close relation to the branches of the fifth nerve which have certain points of similarity, and may, therefore, be considered together, although their positions show that they are engaged in the performance of very different functions.

We have not yet been able to ascertain the value of these little points of junction of motor, sensory, vaso-motor, and secretory fibres, because, so far, we are unable to attribute to the cells of the ganglia, either reflecting or controlling action, or any automatic power.

They all have efferent (motor and secretory) and afferent (sensory) connections with the nervous centres, and also connections with the main channels of the sympathetic nerves. These are spoken of as the roots of the ganglia. Their little branches are generally mixed nerves.

The Ciliary or Ophthalmic Ganglion.

This ganglion lies in the orbit. It has three roots, which come from—(1) the inferior oblique branch of the third nerve, by a short slip, which forms the motor root; (2) from the nasal branch of the ophthalmic division of the fifth, and (3) from the carotid plexus of the sympathetic. The branches go mostly to the ball of the eye, and may be divided into afferent and efferent. The afferent are sensory branches, connecting the cornea and its neighbouring conjunctiva with the centres. The efferent fibres go to the iris and cause dilatation of the pupil (coming mostly from the sympathetic), and the vaso-motor fibres going to the choroid coat, iris, and retina.

The Sphenopalatine or Nasal Ganglion.

This lies on the second division of the fifth nerve, from which it gets its sensory root. Its motor root comes from the seventh by the great superficial petrosal nerve, and its sympathetic root from the carotid plexus by the branch joining this nerve. These enter the ganglion together, and are spoken of as the vidian nerve. Afferent (sensory) impulses, from the greater part of the nasal cavity, pass through this ganglion. Its efferent branches are—(1) motor to the elevator of the soft palate and azygos uvulæ; (2) vaso-motor, which come from the sympathetic; and (3) secretory, which supply the glands of the cheek, &c.

Otic or Ear Ganglion.

The otic ganglion lies under the foramen ovale, where the interior division of the fifth comes from the cranium. Its

roots are—(1) motor ; (2) sensory, from the inferior division of the fifth ; and (3) sympathetic, made up of a couple of fine filaments from the plexus, around the meningeal artery. By its branches it communicates with the seventh, chorda tympani, and sends filaments to the parotid gland.

The Submaxillary Ganglion.

This is on the hyoglossus muscle in close relation to the lingual branch of the fifth, from which it gets a sensory root. The chorda tympani passes to the ganglion, carrying efferent impulses through it to the gland. Its sympathetic branches come from the plexus around the facial artery.

The Glosso-pharyngeal Nerve.

This nerve springs from the floor of the fourth ventricle above the nucleus of the vagus. It is a mixed nerve, the functions of which may be thus classified.

Afferent fibres, which are of various kinds, viz. :—

(1.) *Sensory fibres*, carrying impulses from the anterior surface of the epiglottis, the base of the tongue, the soft palate, the tonsils, the Eustachian tube and tympanum.

(2.) *Excito-motor*. This nerve excites important reflex movements in swallowing and vomiting, when a stimulus is applied to the glosso-palatine arch.

(3.) *Excito-secretory*, the stimulation of the back of the tongue gives rise to a copious flow of saliva by means of reflex action.

(4.) *Taste* sensations are, for the most part, carried by this nerve ; they are conveyed from special nerve-endings in the back of the tongue (see Taste).

The *efferent fibres* are not so varied, being simply *motor* to the middle constrictor of the pharynx, stylo-pharyngeus, elevator of the soft palate, and the azygos uvulæ.

The Vagus Nerve.

The vagus arises from the lower part of the floor of the fourth ventricle, and is connected with many of the important groups of nerve-cells in this neighbourhood. It receives a large branch from the spinal accessory, which branch contains

all the efferent fibres found in the vagal trunk in the neck. Its root is purely afferent.

The functions of its widely distributed fibres may be thus briefly stated :—

A. The EFFERENT FIBRES (from spinal accessory root) may be divided into—

1. *Motor-nerve* channels, going to a great portion of the alimentary tract and air-passage ; the following muscles getting their motor supply from the branches of the vagus—the pharyngeal constrictors, some muscles of the palate, œsophagus, stomach, and greater part of the small intestine. Motor impulses also pass along the trunk of the vagus—though leaving the cord by the roots of the accessory nerve—to the intrinsic muscles of the larynx ; these fibres lie in the inferior or recurrent laryngeal nerve except that to the crico-thyroid, which lies in the superior laryngeal branch. The tracheal muscle and the smooth muscle of the bronchial walls are also under the control of the pulmonary branches of the vagus.

2. *Inhibitory impulses* of great importance for the regulation of the forces of the circulation pass along the vagus to the ganglia of the heart. As already explained in detail (see p. 250), these fibres are always acting, as shown by the fact that section of the vagi causes a considerable quickening of the heart-beat. On the other hand, if the distal end of the cut vagus be stimulated, the heart beats more slowly, and in some animals may come to a standstill in a condition of relaxation.

3. *Vaso-inhibitory fibres* are said to be supplied to the stomach and small intestine.

B. The AFFERENT FIBRES still more widely spread, are important for the functions of the various viscera. They are :—

1. *Sensory fibres* carrying impulses from the pharynx, œsophagus, stomach, and intestine, and from the larynx, trachea, bronchi, and lungs generally. The pneumonia which follows section of the vagi depends on—(1) the removal of sensibility, and the ease with which foreign matters can enter the air-passages ; or (2) the violent breathing necessary when the motor nerves of the larynx are cut ; or (3) the injury of trophic or vaso-motor fibres.

2. *Excito-motor nerves.* There is no nerve that can be compared with the vagus in the variety of reflex phenomena in which it participates. Afferent fibres in this nerve cause spasm of the muscles of the glottis and thorax and govern the

respiratory rhythm, preside over inhalation of air, and excite the expiratory muscles. Thus irritation of the mucous membrane at the root of the tongue, the folds of the epiglottis, larynx, trachea, or bronchi, causes spasmodic fits of coughing. Irritation of the pharyngeal or the gastric fibres gives rise, by reflex stimulation, to the act of vomiting.

Stimulation of the proximal cut end of the trunk of the vagus causes inspiratory effort and cessation of breathing movements in the position of inspiration. Stimulation of the central cut end of the superior laryngeal branch, causes reflex spasm of the muscles of the larynx and a fixation of the expiratory muscles in the position of expiration. The fibres which regulate the respiratory rhythm consist of two sets, probably passing from the lungs to the inspiratory and expiratory centres, and causing each to act before its automatism would excite any discharge of impulse to the muscles.

3. *Excito-inhibitory* fibres pass from the heart to the vaso-motor centre. Stimulation of these fibres, which take somewhat different courses in different animals, checks the tonic action of the vaso-motor centre, and greatly reduces the blood pressure. Hence these fibres form the *depressor nerve.* Its terminals in the heart are stimulated by distension of that organ ; and the vaso-motor centre is thereby inhibited, the arteries dilate and the blood pressure falls so that the over-filled heart can empty itself.

4. *Excito-secretory fibres.* Stimulation of the gastric endings of the vagus causes not only gastric, but also salivary secretion, which occurs as a precursor of vomiting.

Section of both vagi in the neck causes the death of the animal within a day or two after the operation, and the following changes may be observed while it lives :—1. The heart-beat is much quicker as shown by the increased pulse-frequency. 2. The rate of breathing is very much slower. 3. Deglutition is difficult, the food easily passing into the air-passages through the insensitive larynx.

Section of the superior laryngeal nerves is followed by slight slowness of breathing, loss of sensibility in the larynx, entrance of food into the air-passages, chronic broncho-pneumonia, and death.

Section of the inferior laryngeal nerves gives rise to the same final result, because the muscles of the larynx are paralysed, and closure of the glottis is impossible. Loss of voice follows the section or injury of even one inferior laryngeal, as may

often be seen in man from the effect of the pressure of an aneurism.

The Spinal Accessory Nerve.

This nerve arises from the medulla oblongata and spinal cord, as low down as the seventh cervical vertebra. The lower fibres leave the lateral columns at their posterior aspect, and then run up between the denticulate ligament and the posterior roots of the spinal nerves to enter the cranial cavity. On their way out of the cranium they divide into two parts, one of which becomes amalgamated with the vagus, and the other passes down the side of the neck, as the motor nerve of the sterno-mastoid and trapezius muscles. Physiologically, it may be compared with the anterior root of a spinal nerve, and the part accessory to the vagus supplies that nerve with all its efferent branches. With this nerve an important set of vaso- and viscero-inhibitory fibres leaves the cord to join the sympathetic system in the neck.

Hypoglossal Nerve.

This nerve appears in the furrow between the olivary body and the anterior pyramid, on a line with the anterior roots of the spinal nerves. It corresponds with the anterior roots in function, being a purely motor nerve. It bears impulses to the muscles of the tongue, and others attached to the hyoid bone.

Some sensory fibres lie in its descending branch, but these are probably derived from the vagus or tri-facial nerves, with which its branches inosculate.

It is also said to contain the vaso-motor fibres of the tongue.

Section of the nerves causes paralysis of the muscles of the tongue; when this is unilateral, the tongue inclines to the injured side, while being protruded from the mouth; but while being drawn in, it passes to the sound side. This is easily understood when it is borne in mind that the two acts depend upon the intrinsic muscles of the tongue, bringing about an elongation or shortening of the organ respectively.

The Sympathetic System.

The ganglionic chain of nerves lying in the body cavity on each side of the vertebral column commonly called the sympathetic system, may be regarded as a complicated plexus of

nerve-fibres arising from the spinal cord and forming the main nervous supply of the vessels and viscera.

The old view, that it formed a system homologous to the chains of ganglia of the invertebrates, and that it was independent of the cerebro-spinal axis, is now definitively abandoned upon the following evidence :—

1. It is developed as an outgrowth from the medullary axis.
2. The vaso-motor nerves, which are experimentally proved to obey the centres in the spinal cord and bulb, are among the most important and best known of the sympathetic fibres.
3. The fibres from a special centre, known to exist in the cord, pass along the cervical sympathetic chain to the iris.
4. Characteristic small medullated fibres can be traced from the cord through the roots into the sympathetic ganglia.
5. The sympathetic ganglia do not give a reflex response to any stimulus, and can be proved to belong only to fibres of one function.
6. The spinal cord itself with its metameric roots and segment is the real homologue of the nervous chain of the invertebrates.

Among the peculiarities of the sympathetic the following points may be enumerated :—

I. Its *numerous ganglia*.—These may be divided into three classes—

a. Lateral ganglia, which lie on the sides of the vertebral column and form the main sympathetic chain (vaso-motor ganglia).

β. Collateral ganglia, which form a more or less distinct group, in close proximity to the viscera ; *e.g.* the semilunar, mesenteric, &c.

γ. Terminal ganglia, which are found on the course of the fibres before their final division and distribution ; *e.g.* cardiac and intestinal ganglia.

II. In *diameter* the medullated fibres of the sympathetic are very small, sometimes under 2μ, numbers not being more than 3μ and none exceeding 9μ, while those of the ordinary motor fibres of a spinal nerve may reach 18μ. The fibres of distribution are as a rule non-medullated grey fibres, and correspondingly small.

III. The *distribution* of the sympathetic fibres, so far as they have been traced up to the present, is exclusively to the blood vessels, heart and other viscera.

It must be borne in mind throughout the following brief description, that it is chiefly founded on researches made on the dog.

The central connections of the sympathetic with the grey matter of the spinal cord are confined to the white communicating branches, to which the characteristic small medullated fibres may—by consecutive sections—be traced from the cord through both the roots of the spinal nerves. The grey connections of the sympathetic ganglia are simply branches of distribution, on their way chiefly to the blood vessels.

The relatively larger fibres have been said to be sensory and no doubt many afferent fibres pass from the lateral ganglia to the cord, by the posterior roots of the spinal nerves.

The branches of communication only exist in certain parts of the spine ; viz. dorsal, sacral and upper cervical. Hence they have been divided into three groups distinguished from each other by the position of their outflow and their mode of distribution—

1. *Dorsal Group.*—The main outflow of sympathetic fibres from the cord, takes place through the roots of the spinal nerves from the *2nd dorsal* to the *2nd lumbar*, inclusive.

They are more abundant in the upper dorsal region (2nd to 5th dorsal nerves), where the white rami communicantes are seen by the naked eye to be large. Most of these fibres may be traced upwards to the cervical region ; many of them pass directly through the lateral ganglion to reach the great upper ganglion in the neck.

In the lower part of the back (6th dorsal to the 2nd lumbar nerve roots) the fibres are fewer in number, the white communicating branches are smaller and join the dorsal ganglia, to form the dorsal chain. Branches from the several dorsal ganglia converge to form the splanchnic nerves which pass into the abdominal cavity.

2. *Sacral Group.*—The next group begin considerably below the last. They pass out by the roots of the 2nd and 3rd sacral nerves. The fibres of this sacral outflow have no connection with the lateral ganglia, but run straight to the collateral hypogastric plexus as the so-called *nervi erigentes.*

3. *Cervico-cranial Group.*—These arise mainly from the roots of the spinal accessory, and pass from that nerve to the ganglion of the trunk of the vagus. Small fibres are also found in the roots of the vagus and glossopharyngeal nerves. The fibres of this group are distributed to the viscera by the branches of the vagus.

Functions.

Our knowledge of the functions of the sympathetic roots is limited almost exclusively to those of the efferent fibres. They may be divided into three classes which are supplied—

1. To the muscles of the blood-vascular system.
2. To the muscles of the hollow viscera.
3. To the secreting glands.

The vaso-motor system—with which we may group the innervation of the heart—may be divided into two antagonistic sets—

1. Vaso-constrictor and cardio-accelerator.
2. Vaso-dilator and cardio-inhibitory.

The constrictor and accelerator fibres all leave the cord in the dorsal region by the anterior roots of the spinal nerves from the 2nd dorsal to the 2nd lumbar, and join the lateral chain of ganglia (vaso-motor ganglia, Gaskell). When the fine medullated fibres of which they are formed join the cells in the ganglia, they lose their medullary sheath, increase in number and proceed to their distribution as fine non-medullated filaments. Those destined for the head and upper limbs stream upward ; those for the abdominal viscera pass along the dorsal chain and thence into the splanchnics ; and those for the lower limbs run along the lumbar chain to reach the lumbo-sacral plexus and the large blood-vessels.

The cardio-accelerator fibres join the upper part of the dorsal sympathetic chain and run up to the stellate ganglion, where they enter the cells and lose their medullary sheath, thence passing as fine non-medullated fibres to the heart.

Inhibitory fibres (vaso-dilator nerves) are no doubt supplied to the blood-vessels in all parts of the body, but their course is only known in a few cases, viz. the nervi erigentes, the chorda tympani, and the small petrosal nerve. With these may be enumerated the cardio-inhibitory fibres, which come from the spinal accessory root and join the vagus. It is seen from this that none are known to leave the spinal cord with the dorsal outflow of sympathetic fibres, but that they are restricted to the upper cervical and the sacral regions.

These inhibitory fibres do not join the cells of the lateral ganglia, but pass on as medullated fibres to the more distant collateral ganglia. Thus the cardio-inhibitory pass through the

ganglion trunci vagi along the vagus to Bidder's ganglion in the heart, where they lose their medullary sheath. The chorda tympani, at the submaxillary ganglion, consists mainly of fine medullated fibres. The nervi erigentes also carry their medullary sheath nearly to their termination through the hypogastric plexus.

The visceral fibres may also be divided into motor and inhibitory sets.

The *viscero-motor* nerves seem to leave the spinal cord in all of the three outflows. Those for the upper part of the alimentary canal come by the vagus, those for some abdominal and all the pelvic viscera, from the dorsal and sacral regions. Their arrangement and course must be said to be undetermined, being still under examination.

The *viscero-inhibitory* are also supposed to pass by all three outflows from the cord. They lose their medullary sheath at the distal ganglia. Our knowledge concerning them is very imperfect.

Glandular nerves doubtless are supplied to each secreting organ, but our knowledge on the subject is restricted to those of the salivary glands, particularly those of the sub-maxillary and the parotid glands, which have already been discussed (pp. 121 *et seq.*). In these cases the exciting nerve of secretion and the inhibitory nerve for the blood-vessels come from the cervico-cranial outflow and reach the gland by the chorda tympani. The fibres which cause constriction of the blood-vessels of the gland are accompanied by fibres from the dorsal cord passing along the cervical sympathetic, which inhibit the gland cells.

The *Ganglia* are said to have three functions—

a. To stop the medullary sheath of the fibres, and change them to non-medullated fibres.

β. To divide the fibres, on losing their medulla, into a great number of filaments.

γ. To exert a nutritive influence on the distal part of the nerve, and through it on the tissue to which it is distributed.

Central connections.

With regard to the central connections of these three outflows of sympathetic fibres from the cord, it may here be mentioned that each corresponds with a definite set of nerve cells in the grey matter.

The elongated spindle-shaped collection of cells, called *Clarke's vesicular column*, extends from the second dorsal to the second lumbar segments of the spinal cord—the region from which the great vaso-constrictor and viscero-motor outflow takes place. (See under Spinal Cord.)

A series of cells known as *Stilling's sacral nucleus* occupies a position in the cord corresponding with the second and third sacral segment, whence springs the lower sympathetic outflow.

Similarly a cell-tract can be traced from the second segment of the cervical cord upwards to be lost in the *vagal nucleus*.

The above and other facts have suggested that these nerve groups are the centres from which at least some functional sets of sympathetic fibres take their origin.

CHAPTER XXIX.

SPECIAL SENSES.

It has been pointed out that sensory nerves, receiving impressions at the surface of the body, carry impulses to nerve cells in the brain where they give rise to *sensation*. The afferent nerves are the channels by which the mind becomes acquainted with occurrences in the outer world, and by which impulses pass to the reflex nerve centres.

The ordinary sensory nerves are affected at the surface by slight mechanical and thermal stimuli. But we can appreciate many other impressions besides those excited by the ordinary sensory nerves. We feel the character of a surface by touch, and we distinguish between degrees of *heat* and *cold*, when the difference is far too slight to act as a direct nerve stimulus. We can appreciate *light*, of which no degree of intensity is capable of exciting a nerve fibre to its active state. We recognise the delicate air-vibrations called *sound*, which have no effect on an ordinary nerve ending. We can also distinguish several *tastes*, which we can only recognise by the tongue. And we perceive odours when the amount of substance is too small to be recognised even by the delicate test of spectrum analysis. Special mechanisms must exist by means of which heat, light, sound, taste, and odour are enabled to act as nerve stimuli. These nerve terminals are known as the special sense organs, the physiology of which is at the same time the most difficult and most interesting branch of study in Biological Science.

The nerve-fibres connected with special sense organs do not differ from other nervous cords. But they connect the special peripheral end organs with nerve-cells in the brain, the sole duty of which is to receive special impulses, and distribute them, so that they may cause a special sensation. By whatever means a nerve-trunk from a special sense organ be stimulated, its impulse excites the sensation usually arising from stimulation of the organ to which it belongs. Thus electric stimulation of nerves in the tongue causes a certain taste ; mechani-

cal or other stimulation of the optic nerve-trunk gives rise to the sensation of flashes of light, and the sensation of an odour may be caused by the presence of a bony growth, pressing upon the olfactory nerve.

The power of a nerve-centre connected with a nerve of special sense to give rise to a specific sensation, is called its *specific energy*. And the influence, light, sound, &c., which the given terminal alone can convert into a nerve stimulus, is called its *specific* or *adequate stimulus*.

Although we habitually think of the sensation as if coming from without, it really arises only in the centres in the brain. Thus we say we feel with our skin, hear with our ears, and see with our eyes, &c., whereas these are only the parts from which the nerve impulses, giving rise to the specific energy, pass to the feeling, hearing, or seeing regions of our cerebral cortex. The peripheral localisation of cutaneous sensations is accomplished in the mind, just as by a mental act of a different character, the impressions communicated by the eye are projected into the space about us, in our thoughts, instead of being referred to the retina, or thought of as being in the eye itself. This power of the sensorium to localise impressions to certain points of the skin, and to project into space the stimulation caused by the light reflected from distant objects, so as to get a distinct and accurate idea of their position, is the result of experience and habit, which teach each individual that when a certain sensation is produced, it means the stimulation of a certain point of the skin, and that the objects we see are not *in* our eyes, but at a distance from us. We learn this from a long series of unconscious experiments carried on in our early youth by movements of the eyes with co-operation of the hands. Even the sensations which arise in the various centres of the sensorium, as the result of internal or central excitations, are from habit attributed to external influences, and thus we have various hallucinations and delusions, such as seeing objects or hearing sounds which may only depend on the excitation of certain groups of cells in the cortex of the brain.

The sensations produced in our nerve centres, as the result of impulses coming from our special sense organs, give rise to a *perception*. Each perception helps to make up our knowledge of the outer world and of ourselves. Without this power of perception we could have no notion of our own existence and no ideas of our surroundings ; in fact we should be cut off from

all sources of knowledge, and be idiots by deprivation of all intelligence from without.

A complete special sense apparatus may be said to be made up of the following parts :—

1. A special nerve-ending only capable of being excited by a special *adequate stimulus*.

2. An afferent nerve to conduct the impulses from the special end-organ to the nerve centre.

3. Central nerve-cells, capable by *specific energy* of translating the nerve-impulse into a *sensation*, which is commonly referred to some local point of the periphery.

4. Associated nerve-centres, capable of *perceiving* the sensations, forming *notions* thereon, and drawing conclusions, from the present and past perceptions, as to the intensity, position, quality, &c. of the external influence.

Skin Sensations.

The sensations arising from the skin may be resolved into a number of different *qualities* of sensation. These are :—(1) Sensation of *pain*, not usually included under the special sense of touch ; (2) *Tactile Sensation* proper, by means of which we judge of the surface and form of bodies ; (3) sense of *locality*, by which the position of the stimulus is determined ; (4) the sense of *pressure* by which the force used is appreciated ; and (5) the sense of *temperature*.

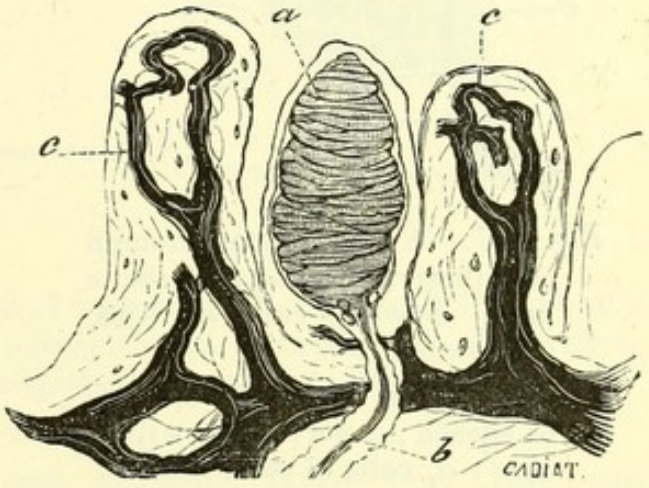


Fig. 196.—Drawing from a section of injected skin, showing three papillæ, the central one containing a tactile corpuscle (*a*), which is connected with a medullated nerve, and those at each side are occupied by vessels. (Cadiat.)

The variety of perceptions derived from the cutaneous surface, and the large extent of surface capable of receiving impressions, make the skin the most indispensable of the special sense organs, though we value this source of our knowledge but little. If we could not place our hands as feelers on near objects to investigate their

surfaces, &c., we should lose an important source of information that has contributed largely to our visual judgment. For we know by the look of a thing only what we originally learned by feeling it. If our conjunctiva did not feel, we should miss its prompt warning, and our voluntary movements could not protect our eyes from many unseen injuries that normally never trouble us. If the skin were senseless it would require constant mental effort to hold a pen, and our power of standing and walking would be most seriously impaired. And how cut off from the changes in the outer world should we be, were we incapable of feeling heat and cold.

Nerve-Endings.

Although the end-organs of the nerves of the skin are the simplest of all those belonging to the apparatus of special

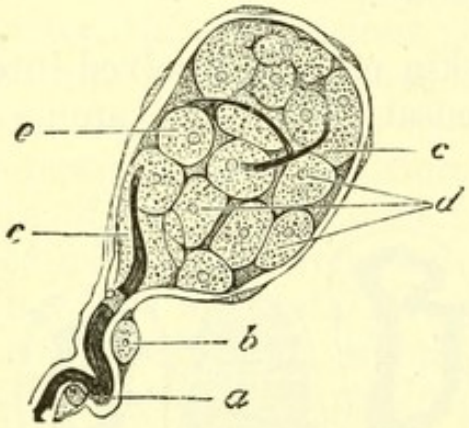


Fig. 197.—End bulb from human conjunctiva, treated with osmic acid, showing cells of core. (Longworth.)

a, Nerve fibre; *b*, nucleus of sheath; *c*, nerve fibre within core; *d*, cells of core.

Fig. 198.—Tactile corpuscle from a duck's tongue, containing two tactile cells between which lies the tactile disc. (Izquierdo.)

sense, yet we have a very imperfect knowledge of their immediate relationships to the different qualities of touch impressions. We know of several different nerve-endings apparently adapted to the reception of certain impressions, but of the exact kinds of stimuli that affect these different terminals we are ignorant.

The peripheral terminals of the sensory nerves, like the other special sense organs, are usually composed of modified epithelial cells, into close relation to which the axis cylinders of nerves can be traced. They may be thus enumerated :—

1. The *Touch-corpuscles* (Meissner) are egg-shaped bodies situated in the papillæ of the true skin, underlying directly the epithelial cells of the rete mucosum. They occupy almost the entire papilla. The nerve fibres seem to be twisted around the corpuscle in a spiral manner, while the axis cylinders enter the body, and the covering of the nerve becomes amalgamated with its outer wall. The touch-corpuscles vary in size in different parts of the skin; usually being larger where the papillæ in which they lie are well-developed. The axis cylinders are said to end in swellings called tactile cells.

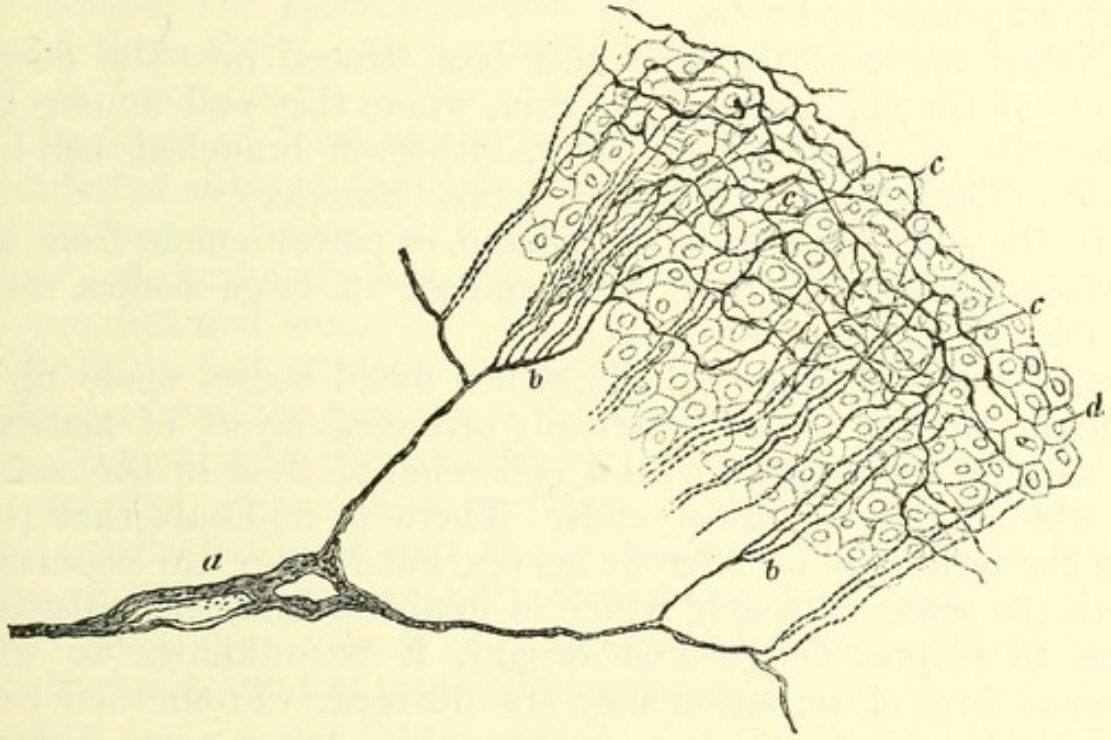


Fig. 199.—Drawing of termination of nerves on the surface of the rabbit's cornea. *a*, Nerve fibre of sub-epithelial network; *b*, Fine fibres entering epithelium; *c*, Intra-epithelial network. (Klein.)

2. *End-bulbs* (Krause) are smaller than the last, and are less generally distributed over the surface of the body, being localised to certain parts. They are chiefly found in the conjunctiva and mucous membranes of the mouth and external generative organs. They consist of a little vesicle containing some fluid and a few large nucleated cells. The axis cylinder terminates between the cells, the membrane which forms the vesicle of the bulb being fused with the sheath of the nerve. Many different shapes and varieties of these bodies have been described, but there seems to be no definite morphological or physiological distinction between the varieties.

3. *Touch-cells* (Merkel) found in the deeper layers of the epidermis of man as well as in the tongues of birds, are large cells of the epithelial type with distinct nuclei and nucleoli. Frequently they are grouped together in masses and surrounded by a sheath of connective tissue ; in which condition they resemble touch-corpuscles.

4. *Free nerve-endings* occur on the surface of the epithelium of the mucous membranes, and are seen on the surface of the cornea (Cohnheim). Here delicate, single strands of nerve fibrils can be seen after gold staining, passing between the epithelial cells and ending at the surface in very minute blunted points or knobs.

Naked nerve-fibrils have also been traced into the deeper layers of the epidermis of the skin, where they end among the soft cells of the mucous layer, either in branched cell-like bodies (Langerhans), or delicate loops (Ranvier).

In the subcutaneous fat-tissue and in parts remote from the surface some sensory nerves terminate in large bodies, easily visible to the naked eye, called—

5. *Pacinian corpuscles.* They are ovoid bodies made up of a great number of concentrically arranged layers of material, of varying consistence, with a collection of fluid in the centre, in which an axis cylinder ends. There is no doubt that they are the terminals of afferent nerves, but if they are connected with the sense of touch, which is doubtful from their distribution in several deep-seated organs, it is unknown to what special form of sensation they are devoted. From their comparatively remote relation to the skin, lying some distance beneath it and not in it, like the other endings mentioned, they are probably connected with the appreciation of pressure sensations rather than those more properly called tactile.

Qualities of Sensation.

The sense of touch is distinguished from ordinary sensibility, and the capability of feeling pain, which is a *general* sensation, and is received and transmitted by different nerve channels. This we know from the facts, (*a*) that pain and touch are appreciated with different keenness in various parts ; (*b*) that some mucous membranes can receive painful but not tactile impressions (conjunctiva) ; and (*c*) that in the spinal cord the sensory and tactile impulses are probably conveyed by distinct tracts. (*d*) Certain narcotic poisons destroy ordinary sensation

without removing the sense of touch. This effect is also brought about by cold ; when the fingers are benumbed, gentle contact excites tactile impressions, while the ordinary sensations of pain can only be aroused by severe pressure.

Either touch or pain sensations may be cut off by disease, independently of each other.

Tactile Sense.

The intensity of the stimulation for the sense of touch must be kept within certain limits in order to be *adequate, i.e.*, capable of exciting the specific mental perceptions. If the stimulus exceed these limits, only a general impression, approaching that of pain, is produced.

The power of forming judgments by touch differs very much in different parts of the body, being generally most keen where the surface is richest in touch corpuscles, namely, the palmar aspect of the hands and feet, and especially the finger-tips, tongue, lips and face.

When we feel a thing in order to learn its properties, we make use of all the qualities of which our sense of touch is made up. We estimate the number of points at which it impinges on our finger-tips, rub it to judge of smoothness, press it to find out its hardness, and at the same time gain some knowledge of its temperature and power of absorbing heat.

To get a clear idea of our complex sense of touch we must consider each kind of impression separately.

Sense of Locality.

By this is meant our power of judging the exact position of any point or points of contact which may be applied to the skin. Thus, if the point of a pin be gently laid on the skin we know at once where we are touched, and if a second pin be applied in the same neighbourhood, we feel the two points of contact and can judge of their relative position.

The delicacy of the sense of locality differs very much in different parts of the skin. It is most accurate in those parts which have been used as touch organs during the slow evolution of the animal kingdom.

The method of testing the delicacy of the sense of locality is that of applying the two points of a blunt compass to different parts of the skin, and, by varying their position, experimentally

determine the nearest distance at which the two points give rise to distinct sensations. The following precautions must be attended to in carrying out this experiment. 1. The points must be simultaneously applied, or two distinct sensations will be produced at abnormally small distances. 2. The force with which the points are applied must be equal and minimal, because excessive pressure causes a diffusion of the stimulus and a blurring of the tactile sense. 3. Commencing with a wide interval and gradually reducing the distance of the points, enables a person to appreciate a less separation than if the smaller distances were used at first. 4. The duration of the stimulus ; two points of contact being distinguished at a much nearer distance if the points be allowed to rest on the part, than when they are only applied for a moment. 5. The temperature and material of the points should be the same. 6. Moisture of the surface makes it more sensitive. 7. Previous or neighbouring stimulation takes from the accuracy of the sensations produced. 8. The temperature of the different parts of the skin should be equal, as cold impairs its sensibility.

The following table gives approximately the nearest distances at which some parts, which may be taken as examples of the more and less sensitive regions of the skin, can recognize the points of contact by their giving rise to two distinct sensations :—

Tip of the tongue	1 mm.
Palmar aspect of the middle finger-tip .	2 „
Tip of the nose	4 „
Back of the hand	15 „
Plantar surface of great toe . . .	18 „
Fore arm, anterior surface . . .	40 „
Front of thigh	55 „
Over ensiform cartilage . . .	50 „
Between scapulæ	70 „

If one point of the compass be kept at the same spot, and the other moved round so as to mark out, in different directions, the limit at which the two points can be distinguished as separate, we get an area of a somewhat circular form, for which the name *sensory circle* has been proposed. It would be convenient to explain this on the simple anatomical basis that the impressions of this area were carried by one nerve-fibre to the brain, and thus but one sensation could be produced in the sensorium. We know this cannot be the true explanation, from

the following facts. 1. No such anatomical relationship is known to exist. 2. By practice we can reduce the area of our sensory circles in a manner that could not be explained by the development of new nerve-fibres. 3. If the two points of the compass be placed near the edges of two well-determined neighbouring sensory circles, and so in relation with the terminals of two nerve-fibres, they will not give distinct impressions ; they require to be separated as much as if they were applied within the boundary of one of the circles where they also give rise to the double perception.

To explain better the sense of locality it has been supposed that sensory circles are made up of numerous small areas, forming a fine mosaic of *touch-fields*, each of which is supplied by one nerve-fibre, and that a certain number of these little fields must intervene between the stimulating points of the compasses in order that the *sensorium* be able to recognize the two impulses as distinct. For, although every touch-field is supplied by a separate nerve-fibril which carries its impulses to the brain, and is therefore quite sensitive, the arrangement of the cells in the sensorium is such that the stimuli carried from two adjoining touch-fields are confused into one sensation. Thus, when an edge is placed on our skin, we do not feel a series of points corresponding to the individual fields with which it comes in contact, but the confusion of the stimuli gives rise to an uninterrupted sensation, and we have a right perception of the object touched.

Sense of Pressure.

The differences in the degree of pressure exercised by a body may be distinguished from the simple tactile or local impression. If we support a part of the body so that no muscular effort be called into play in the support of an increasing series of weights placed upon the same area of skin, we can distinguish tolerably accurately between the different weights. It has been found that if a weight of about 30 grammes be placed on the skin a difference of about 1 gramme can be recognized—that is, we can distinguish between 29 and 30 grammes, if they are applied soon after one another. If the weights employed are smaller, a less difference can be detected ; if larger weights are used the difference must be greater, and it appears that the weight-difference always bears the same proportion to the absolute weight used. We can perceive a difference between $7\frac{1}{4}$ and $7\frac{1}{2}$,

$14\frac{1}{2}$ and 15, 29 and 30, 58 and 60, &c., the discriminating power decreasing in proportion as the absolute degree of stimulation increases.

One of the reasons why the sense of pressure is regarded as distinct from that of locality is, that the former is found not to be most keenly developed in the parts where the impressions of locality are most acute. Thus judgment of pressure can be more accurately made with the skin of the fore-arm than the finger-tip, which is nine times more sensitive than the former to ordinary tactile impressions, while the skin of the abdomen has an accurate sense of pressure though dull to ordinary tactile sensation.

It has been said above that the weights by which pressure-sense is to be tested should be applied rapidly one after the other. This fact depends upon the share taken in the mental judgment by the function we call memory. In a short time the recollection of the impression passes away, and there no longer exists any sensation with which the new stimulation can be compared.

At best we can form but imperfect judgments of pressure by the skin impressions alone. When we want to judge the weight of a body we poise it in the free hand, which is moved up and down so as to bring the muscles which elevate it into repeated action. Hereby we call into action a totally different evidence, namely, the amount of muscle power required to raise the weight in question, and we find we can arrive at much more accurate conclusions by this means. The peculiar recognition of how much muscular effort is expended is commonly spoken of as *muscle-sense*, which may arise from a knowledge of how much voluntary impulse is expended in exciting the muscles to action, but more probably it depends upon afferent impulses arriving at the sensorium from the muscles. By its means we aid the pressure-sense in arriving at accurate conclusions of the weight of bodies, so that in the free hand we can distinguish between 39 grm. and 40 grm.

Temperature Sense.

We are able to judge of the difference in temperature of bodies which come in contact with our skin. Since our sensations have no accurate standard for comparison we are unable to form any exact conception of the absolute temperature of the substances we feel. The sensation of heat or cold,

derived from the skin itself, without its coming into contact with anything but air of moderate temperature, varies considerably, and the judgment of temperature therefore must be imperfect. The skin feels hot when its blood-vessels are full; it feels cold when they are comparatively empty. An object of constant temperature can thus give the impression of being hot or cold according as the skin itself is full or empty of warm blood. But any change in the temperature of its surroundings causes a sensation of change of temperature, which is, however, a purely relative judgment. Thus if the hand be placed in cold water, we have at first the sensation of cold; to which, however, the skin of the hand soon becomes accustomed and no longer feels cold; if now the hand be placed in water somewhat warmer—but not higher in temperature than the atmosphere—we have a feeling of warmth. If the hand be placed in as hot water as the skin can bear, it feels at first unpleasantly hot, but this feeling soon passes away and the sensation is comfortable. If from this hot water it be placed again in the water of the air temperature, this—which before felt warm—feels very cold.

An important item in the estimation of the temperature of an object by the skin depends upon whether it be a good or a bad conductor of heat. Those substances which are good conductors, and therefore, when colder than the body, quickly rob the skin of its heat, are said to feel cold, whilst badly-conducting bodies, of exactly the same temperature, do not feel cold. It is then the rapid loss of heat that gives rise to the sensation of cold.

The power of the skin in recognizing changes of temperature is very accurate, although the power of judging of the absolute degree of temperature is very slight.

By dipping the finger rapidly into water of varying temperature it has been found that the skin can distinguish between temperatures which differ by only $\frac{1}{4}^\circ$ Cent. or $\frac{1}{2}^\circ$ Fahr. The time required for the arrival of temperature impressions at the brain is remarkably long when compared with the rate at which ordinary tactile impulses travel. To judge satisfactorily of the temperature of an object we must feel it for some time.

There must be special nerve-endings which are capable of receiving thermic impressions, because heat or cold applied to the nerve fibres are not capable of giving rise to these sensations. If a small smooth metallic point, at an even temperature (slightly above or below the normal body-heat), be moved very gently and slowly over the surface of the skin, some parts feel

no temperature change, some feel only increased heat, and others only cold. These "cold-" and "heat-perceiving" areas are said to possess different kinds of nerve-terminals, the distribution of which is, in the main, similar in different individuals.

These nerve-endings are not the same as those that receive touch and pressure impressions, because the appreciation of differences of temperature is very delicately developed in the parts where the tactile sensations are not most acute. Thus the cheeks and the eyelids are especially sensitive to changes of temperature, a fact known to the barber who approaches the curling-tongs to his cheek to measure its temperature. The middle of the chest is very sensitive to heat, while it is dull in feeling tactile impressions. In the hand heat appreciation is not developed in a due proportion to the keenness of its tactile sensibility. The larger the surface exposed to changes of temperature the more accurate the judgment at which we can arrive—the slightest changes being at once recognized when the entire surface of the body is exposed to them. The foregoing facts are well known to persons in the habit of testing the temperature of a warm bath without the aid of a thermometer; they do not use the limited surface of a sensitive tactile finger-tip but plunge the entire arm into the water.

Great extremes of heat or cold, such in fact as would act as stimuli to a nerve fibre, do not give rise to sensations of different temperatures, but simply excite feelings of pain. Thus, if we plunge our hand into a freezing mixture, or into extremely hot water, it is difficult to say at once whether it be hot or cold—in both cases pain being the only sensation produced.

General Sensations.

We call general sensations those feelings, pleasurable or otherwise, which can be excited, without our being able to refer them to external objects, compare their sensation with those of the special senses, or even describe their exact mode of perception. Under this head are enumerated Pain, Hunger, Thirst, Nausea, Giddiness, Shivering, Titillation, Fatigue, &c.

Of these only *pain* can be referred to its origin, but the attempt to localize pain with exactness soon shows how very different is our power, in the case of pain and in the case of tactile impressions. Thus when we strike our "funny-bone" (the ulnar nerve passing over the condyle of the humerus), the

locality of the pain is not exactly to be determined, for it shoots down the arm to the little finger, and is indefinitely spread over the region to which the nerve is distributed.

In studying the laws which govern the perception of painful impressions we must make the experiments upon ourselves, since we alone can form conclusions from the sensations produced.

The best way to carry out experiments upon pain is to use extremes of temperature, as we can thus graduate the stimulation.

The application of a liquid over 50° C., or below 2° C., causes pain. The suddenness of application to the part, its duration, and the extent of surface, as well as the previous temperature, have important influence on the amount of pain produced.

The variation in character of pain seems to be related in some way to the mode of its production, but we are unable to assign any definite cause for these differences. Such terms as shooting, stabbing, burning, throbbing, boring, racking, dragging pain, are frequently used, and may be of diagnostic value, but we have only an indistinct knowledge that throbbing depends on excessive vascular distension in a part, that sharp pains are produced by sudden excitation of a nerve, and the dull pains by the more permanent stimulation of a part less well supplied with nerves.

Further, the pain we suffer is a complex mental process, made up of many items, of which real sensory impressions form but a small part. When a part is to be lanced, patients often cry out most loudly before they are touched with the knife, and show intense feeling when they look at the blood flowing from the wound, though their mental emotion made the real pain imperceptible.

Hunger and *thirst* are peculiar and indefinite sensations which are experienced when these appetites remain unsatisfied. The exact part of the nervous system in which these impressions arise has not been determined. They are, however, said to be associated with peculiar sensations in the stomach and throat respectively. In the same way the venereal appetite, though associated with local sensations, cannot be referred to any one part of the nervous system.

Nausea is also a sensation which cannot be attributed to any part of the nervous centres. It commonly arises in response to afferent impulses, from nasal, pharyngeal, gastric, or other visceral irritation. It is antagonistic to the appetites just

named. All the sensations that give rise to or precede nausea are associated in our minds with disagreeable impressions, and no doubt mental operations have much to do with its production.

Nausea may come from irregular movement, as that of the sea, but sea-sickness may be purely emotional as in cases where vomiting begins before the individual goes on board.

Certain conditions of the blood flowing through the nerve centres also cause nausea, as when certain emetics are injected into the blood.

Giddiness, which consists of a feeling of inability to keep the normal balance, is often produced in connection with the last by irregular movements, but more surely by a rotatory motion of the body. Other afferent influences may give rise to it, viz., from the stomach, in some cases of irritation ; from the eye, when we look from a height ; from the semicircular canals of the ear by rotation of the body ; and also from starving or poisoning the nerve centres, as in anæmia or alcoholic toxæmia.

Shivering is the result of a peculiar nervous effect produced by afferent influences of an unpleasant kind, the sudden application of cold to the skin, a revolting sight, a shrill noise, or an intensely nasty taste—all excite a nervous condition which makes us shiver.

Titillation follows light stimulation of certain parts of the cutaneous surfaces. It is a peculiar general sensation, in moderation not disagreeable, and usually accompanied by a tendency to meaningless laughter and other involuntary reflex movements.

CHAPTER XXX.

TASTE AND SMELL.

Sense of Taste.

Next to the sense of touch, which is unevenly distributed over the whole cutaneous surface, taste is anatomically the least accurately localised. Though confined to the mouth, its more accurate limitations are not easily fixed. The point, sides, and posterior part of the dorsum of the tongue can appreciate tastes; and probably parts of the palate also have the power, but in a much less degree. Indeed, though "the palate" is often spoken of as if it were the seat of taste, it really enjoys an insignificant share of this function compared with the tongue.

The power of being stimulated by various tastes is not restricted to the terminals of any one nerve, but is shared by some of those of at least three trunks, which also transmit impulses arising from other forms of stimulation. The glosso-pharyngeal division of the 8th pair sends branches to the posterior part of the tongue, which are no doubt connected with the special taste organs. The lingual branches of the 5th—commonly called the gustatory nerves—have also terminals capable of being excited by taste, and probably some fibres of the chorda tympani are employed in this function.

Special organs.—In the furrows around the circumvallate papillæ, and also, but more sparsely, on the sides of the fungiform papillæ of the tongue, are found peculiar organs called "taste-buds" or "taste-goblets." They are embedded in the stratified epithelium, with the cells of which their outer layers are intimately connected. They are flask-shaped bodies, composed of concentric series of modified epithelial cells arranged like the staves of a barrel, pinched together at the base and at the free surface, where they closely surround the projecting points of the central elements. These consist of nucleated bars, supposed to be the nerve terminals. The

arrangement somewhat resembles the construction of a ripe artichoke.

Nerves can be seen entering these bodies, and are in all probability directly connected with the modified epithelial cells of which they are made up. The relation of the glosso-pharyngeal nerves to these taste-buds has been shown by the fact that in the rabbit (in which animal they are crowded together in a special organ so as to be easily found) they degenerate, and in a few months disappear, after one of these nerves has been cut.

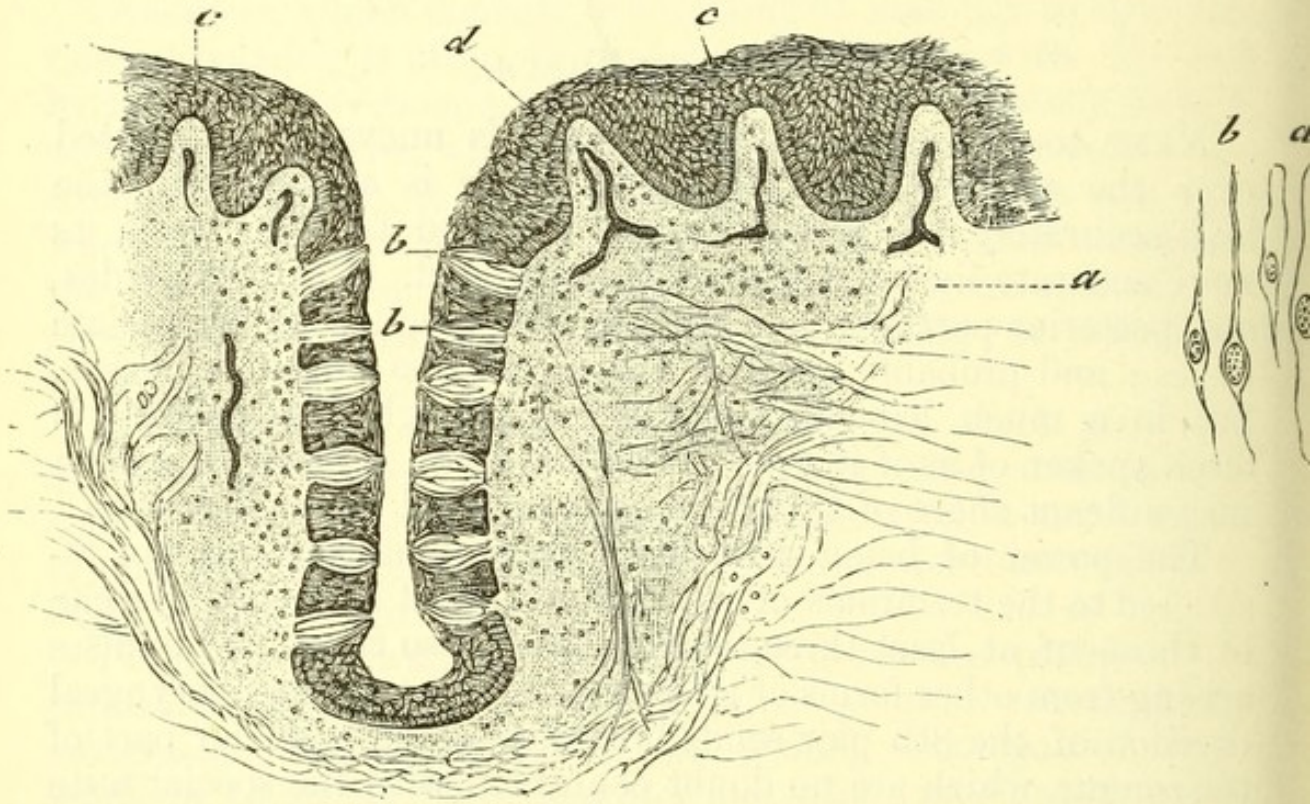


Fig. 200.—Section through depression between two circumvallate papillæ, showing taste-buds. (Cadiat.)

a, fibrous tissue of papilla; *d* and *c*, epithelial covering of papilla; *b*, taste-buds. On the right *a*, *b*, show the separate cells of a taste-bud.

Tastes.—The genuine taste sensations are very few. Much of what we commonly call taste depends almost exclusively upon the smell of the substance, and we usually confuse the impressions derived from these two senses. Many of the comestibles, the taste of which we most prize, have really no taste, but only a smell which we habitually confound with taste, having mingled the experience obtained from the two senses. Thus, if the draft of air be carefully excluded from the nose, wine, onion, &c., may easily be proved to have no taste. Hence the familiar rule of holding the nose, adopted in taking medicine

with a nasty "taste." The different tastes have been divided into four, viz., *sweet, sour, bitter, and salty*, under some one or other of which headings all our tastes, properly so called, would naturally fall. Though this classification has no just claim to being a chemical one, it is interesting to know that each taste pretty well corresponds to a distinct group of substances chemically allied one to the other. Thus, acids are sour, alkaloids are bitter, the soluble neutral salts of the alkalis are salty, and polyatomic alcohols, as glycerine, grape-sugar, &c., are sweet.

These substances probably act on the nerve terminals as chemical stimuli, because they must be in solution to be appreciated. If solid particles be placed on the tongue they must be dissolved in the mouth fluid before they can excite the taste organs.

In order to explain the appreciation of the different tastes, we may imagine that there are different kinds of terminals, each of which is or is not influenced by various substances as they possess a special sweet, sour, bitter, or salt energy. From these different terminals pass fibres bearing impulses to certain central cells, each of which is capable of exciting a sweet, sour, bitter, or salty sensation, as the case may be.

Sense of Smell.

The numerous delicate nerves which pass from the olfactory bulb to the mucous membrane of the upper and part of the middle meatus of the nose, form the special nerves of smell. When certain subtle particles we call odours come in contact with the terminals of these nerves they excite impulses which, on arriving in the special centres of the brain, give rise to the impressions of smell.

Anatomically the relations of the olfactory region are well defined. Its mucous membrane is not covered with motile cilia, as is that of the rest of the nasal cavity ; it is less vascular, and is peculiarly pigmented, looking yellow to the naked eye when compared with the neighbouring membrane. The epithelial cells are elongated into peculiar cylinders, between which lie long thin rods, ending on the surface in free hair-like processes. The deeper extremities of these rod-shaped filaments expand to surround a nucleus, and are then continued into a network of filaments, into which prolongations of the epithelial cells also seem to pass, and in which the delicate fibrils of the olfactory nerve can be traced. The existence of

direct communication between the nerves and the rod-shaped filaments and the epithelial cells is satisfactorily established in some animals.

The odorous particles must be in the form of gases, in order to be carried by the air into the olfactory region, and the air must be kept in motion, by sniffing it in and out of the nasal cavity, in order to excite the nerve terminals, which are not influenced by the odours of air absolutely at rest, though it be in contact with the mucous membrane of the olfactory tract.

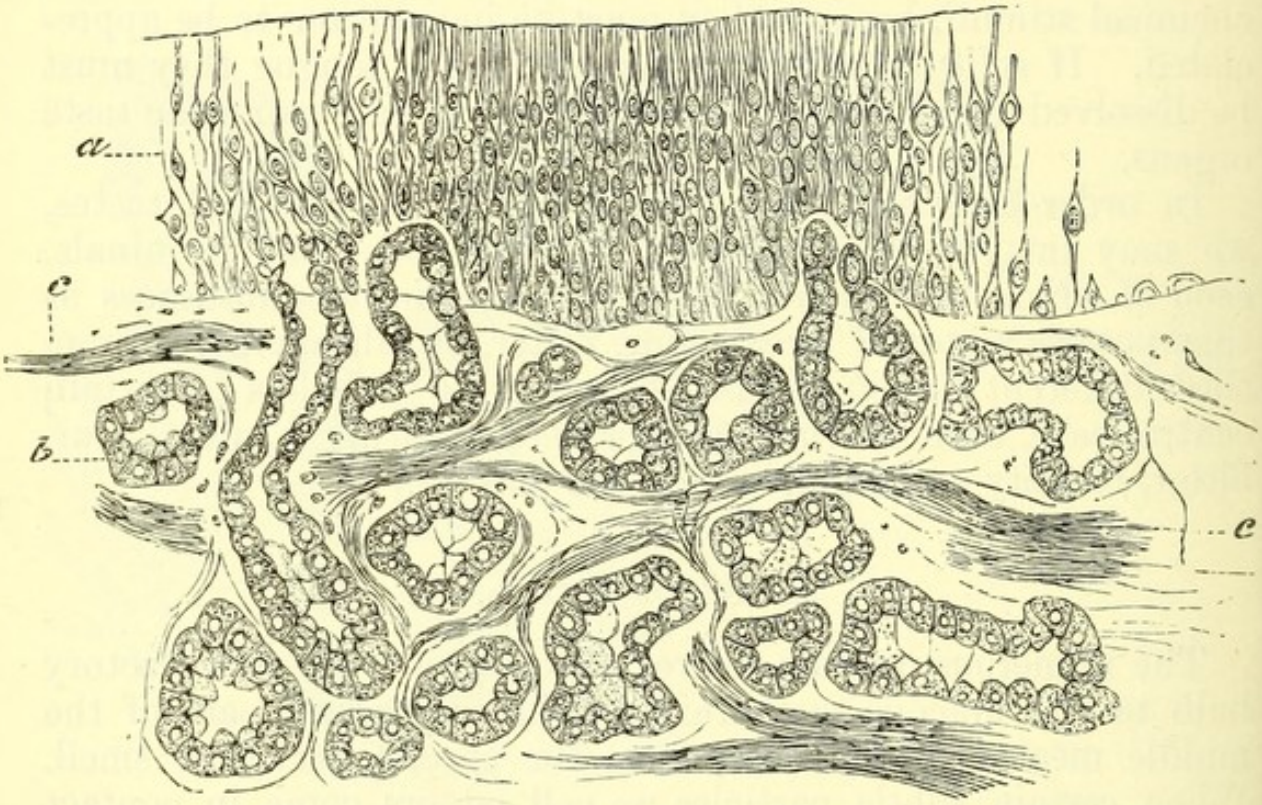


Fig. 201.—Section through the mucous membrane of the nasal fossa in the level of the olfactive region.

a, Epithelial cells and bundles of nerves; *b*, Glands separated from each other by bundles of nerves, *c*. (Cadiat.)

The extreme delicacy of appreciation of odours by the olfactory nerve-terminals is very remarkable. Even in human beings, whose sense of smell is but poorly developed when compared with that of animals, an amount of odorous substance can be perceived which the finest chemical tests fail to appreciate. Thus Valentin has estimated that the two-millionth of a milligram of musk is sufficient to excite the specific energy of a man's olfactory apparatus.

No satisfactory classification of odours has been made out. The common division into agreeable and disagreeable smells,

or scents and stinks, is dissimilar in different individuals, and therefore cannot have a physiological basis.

With smell as with taste, no degree of intensity of stimulation can be said to produce pain, though disgust, nausea, vomiting, and many other nervous operations may be induced by various smells. The appetites are remarkably under the control of this special sense, being either excited or annulled by different excitations of the olfactory nerves.

CHAPTER XXXI.

VISION.

NEXT in importance to those impulses which we receive from the skin are those conveyed to the brain from the outer world by the second pair of cranial, or the optic nerves.

The ending of the optic nerve differs from any of those met with in the skin, by being enclosed in a very specially arranged organ—the eyeball—an apparatus for bending the rays of light, so that they exactly reach the delicate sheet of complicated nerve-ending which is here spread out. Only the blood and other tissues of the eye come in contact with the endings of the optic nerve, which are thus placed out of the way of ordinary nerve stimulation.

Further, the light, of which the optic nerves convey intelligence to the brain, is not properly a nerve stimulus, being merely the waving of an imponderable medium, the existence of which is assumed. Besides the special arrangements in the eyeball for bringing the rays of light to bear on the nerve-endings, there must here be some extremely sensitive arrangement by which the ether-waves, which we call light, can be converted into a nerve stimulus, or in some way made to affect the nerve terminals in the retina.

By means of the sense of sight we obtain a knowledge of objects at a distance from us, because all these objects reflect more or less light, and thus make different impressions upon the terminals of the optic nerve forming the outer layer of the retina.

Light, then, is the *adequate stimulus* for the retinal nerve-endings, and the impulse caused by light is the only impression the optic nerve is in the habit of carrying to our sensoria, where the sensation of light is formed and distributed among the cells of the brain so as to enable us to come to visual judgments and conclusions. As already mentioned, no matter what stimulus, electric, mechanical, or other be applied to the fibres

of the optic nerve, the sensation produced is simply light, and this is thought of as if it came through the eye from the outer world.

The study of the function of vision may be divided into :

1. The path the light takes on its way through the eye to reach the retina.
2. The molecular changes in the retina which give rise to stimulation of the optic nerves.
3. The sensations arising in the sensorium as the result of the molecular changes set up in the cerebral nerve-cells by the impulses from the optic nerve.
4. The visual perceptions and judgments which our consciousness is capable of elaborating from the visual sensations.

The Tunics of the Eyeball.

The organ of vision of vertebrate animals is enclosed in a firm case of fibrous tissue called the *sclerotic coat*, which is continuous with the sheath of the optic nerve. It is seen between the eyelids under the transparent conjunctiva, and known as the white of the eye. It gives shape and protection to the eye, and though translucent, is not transparent. In front a round window-like portion, called the *cornea*, forms the anterior segment of this protecting covering of the eyeball. The cornea is distinguished from the sclerotic not only by its glass-like transparency, but also by being part of a lesser sphere than the sclerotic, and thus projecting a little more than the rest of the bulb.

Closely attached to the inside surface of the sclerotic is a soft, thin, black vascular sheet of tissue called the *choroid coat*, which supplies the eyeball with blood. It is made up chiefly of blood-vessels and stellate, pigmented, connective tissue cells. Its outer layer is traversed by arteries and veins of relatively large size, and its inner layer is composed of a dense network of close-meshed capillary vessels. As the cornea region is approached, the choroid is peculiarly modified and thrown into folds, called *ciliary processes*, forming a series of vascular folds, radiating from the margin of the cornea. At the edge of the cornea the choroid is more firmly attached to the sclerotic by a circular muscle (*ciliary muscle*), and also by bands of tissue from the posterior surface of the cornea which hold it in position ; the fibres of the ciliary muscle, running under the ciliary processes, radiate from the margin of the cornea towards

the choroid, to which they are attached. In a modified form, known as the *iris*, this vascular and pigmented coat of the eye leaves the sclerotic, and hangs freely in a fluid, being recognised through the clear cornea as a coloured circular curtain, attached

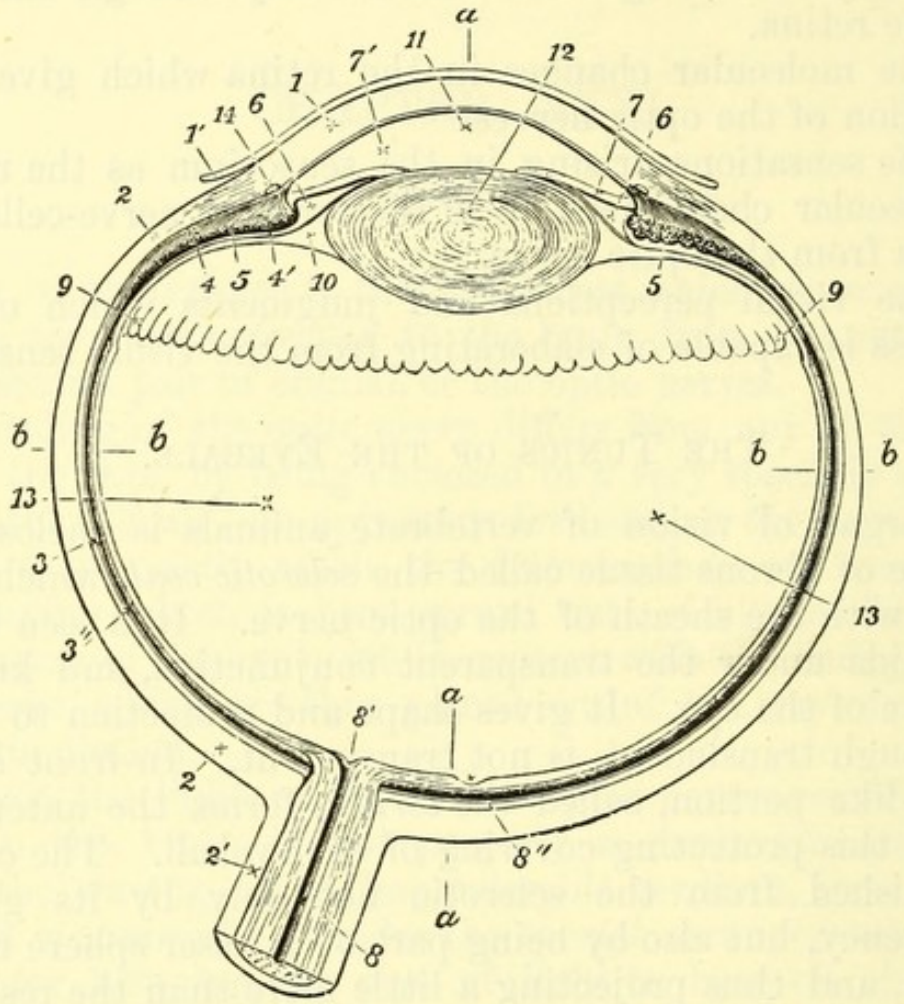


Fig. 202.—Diagram of a horizontal section through the human eye.

1. Cornea ; 1′. Conjunctiva ; 2. Sclerotic ; 3. Choroid ; 4. Ciliary processes ; 4′. Ciliary muscle ; 5. Suspensory ligament of lens ; 6. So-called posterior chamber, between the iris and the lens ; 7. Iris ; 7′. Anterior chamber in front of the iris ; 8. Optic nerve ; 8′. Entrance of central artery of the retina ; 8″. Central depression of retina or yellow spot ; 9. Anterior limit of the retina ; 10. Canal of Petit in front of the hyaloid membrane ; 11. Aqueous chamber ; 12. Crystalline lens ; 13. Vitreous humour ; 14. Circular venous sinus which lies around the cornea ; *a*—*a*, anterior-posterior, and *b*—*b*, transverse axis of bulb.

to the inside of the periphery of the cornea, having a central aperture, which looks black, and is familiarly known as the *pupil*. The pupil is merely an opening in the iris, which allows the rays of light to pass into the interior of the eyeball.

Besides supplying nutrition to the non-vascular central parts of the eyeball, the choroid is useful in vision by preventing the

reflection of the light from the background of the eye in such a way as would cause irregularity of its distribution, and thus dazzle and interfere with the distinctness of the image. The choroid is elastic, and can move over the neighbouring sclerotic ; it can be drawn forwards by the contraction of the radiating ciliary muscle, which acts as a tensor of the choroid membrane.

The iris has a special power of motion, by means of which the opening in it can be made smaller, so as to regulate the amount of light admitted to the eye, and cut off more or less of the rays which would pass through the margin of the dioptric media. The importance of this will be better understood further on.

Within the choroid coat, and in immediate contact with it, is the nervous coat, or *retina*, formed by the expansion of the optic nerve, which passes towards the sclerotic obliquely, and enters it somewhat to the nasal side of the axis of the eye. The retina lines all the back part of the eyeball, and stretching forwards, becomes fused with the ciliary processes, where, however, the nervous elements of the coat are wanting. The fibrils of the optic nerve reach the inner surface of the coats of the eye, and lie in immediate relation to the transparent medium, which occupies the greater part of the bulb. The fibres then lie internally to their terminals, which turn outwards and are set against the choroid coat. The ultimate nerve-endings are situated in pigmented protoplasmic cells, which form the outer layer of the retina.

The Dioptric Media of the Eyeball.

The transparent substances which fill the eyeball are, together with the *cornea*, called the dioptric media. The *aqueous humour* lies in contact with the posterior surface of the cornea, and just fills the prominence which is formed by this part of the eye. It is in this fluid that the moveable iris is stretched and separates the aqueous department of the eye into anterior and posterior chambers. The *vitreous humour* occupies much the larger share of the eyeball. It lies in apposition to the retina, being separated from it only by a thin transparent structure, called the *hyaloid membrane*, which encloses the clear gelatinous vitreous humour, and is fused with the ciliary part of the retina and choroid. The vitreous humour is developed from the young connective tissue of the mesoblast, and we find in the

adult that mucus is the most abundant chemical substance in its texture, though the branched cells of the original mucous tissue have nearly all disappeared.

The most important of the dioptric media is the *crystalline lens*. It is placed between the aqueous and the vitreous humours, just behind the iris, which lies in contact with its anterior surface. It is like a strong magnifying glass, biconvex in shape, the posterior surface being more convex than

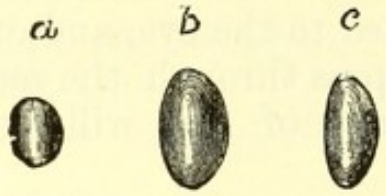


Fig. 203.—Diagram of lens viewed from the side at different periods of life. *a*, at birth ; *b*, Adult ; *c*, Old age. (Allen Thomson.)

the anterior. The lens is much harder than the vitreous humour, but its outer layers are little denser than a stiff jelly. It is enclosed by a firm elastic capsule, which is drawn tightly over the anterior surface, and influences its shape. The lens is held in its position by the *suspensory ligament*, a thickened part of the hyaloid mem-

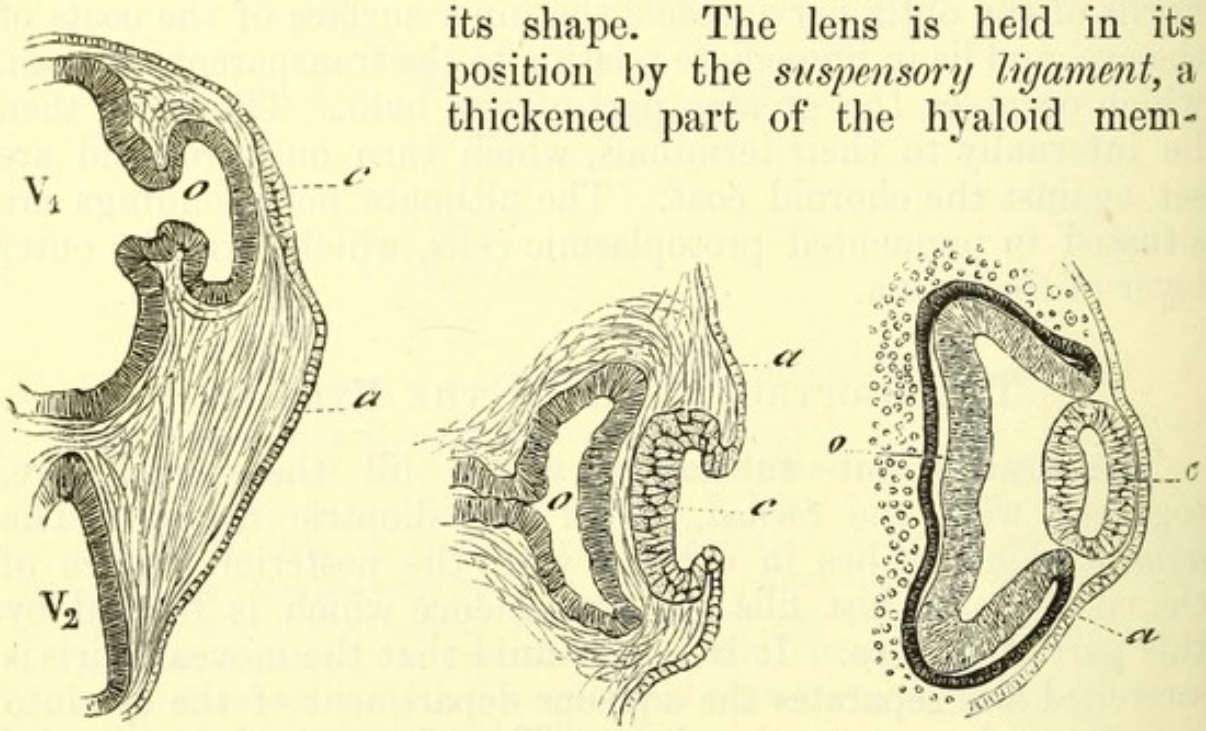


Fig. 204.—Showing early stages of the development of the lens. *c*, Epithelial tissue about to form the lens ; *o*, Optic cup ; *a*, Epidermis. (Cadiat.)

brane, which is continued forwards and attached to the anterior surface of the capsule, near its margin. The lens and its capsule, together with the vitreous humour, may be said to be enclosed in the hyaloid membrane, which, in

front, is thickened and attached to the ciliary part of the choroid and the capsule. Thus any tension exercised by the suspensory ligament tends to tighten the anterior part of the capsule, and flatten the anterior surface of the lens.

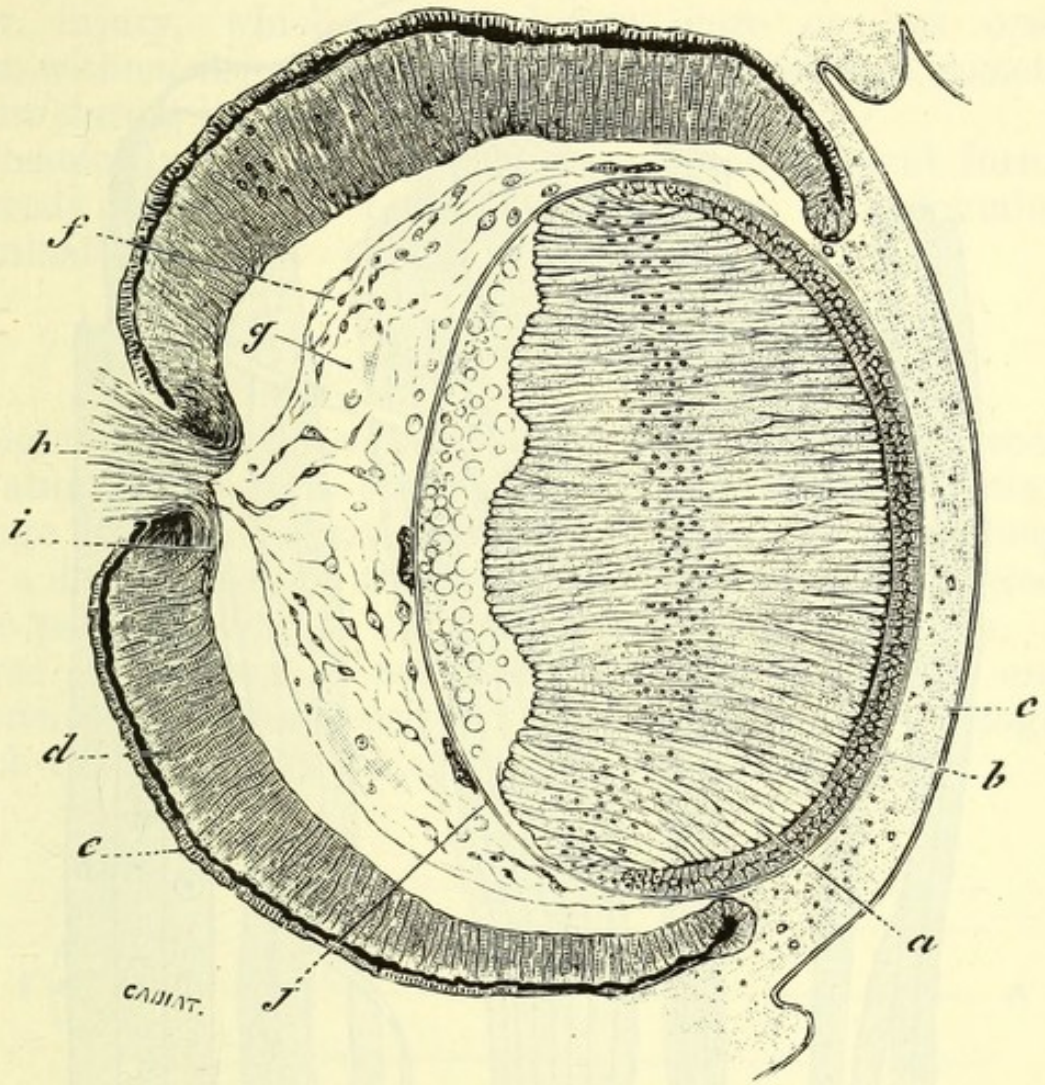


Fig. 205.—A further stage of the development of the lens. (Cadiat.)

a, Elongating epithelial cells forming lens ; *b*, Capsule ; *c*, Cutaneous tissue becoming conjunctiva ; *d*, *e*, Two layers of optic cup forming retina ; *f*, Cell of mucous tissue of the vitreous humour ; *g*, Intercellular substance ; *h*, Developing optic nerve.

The shape of the lens varies at different times of life, being nearly spherical in the infant and tending to become less convex in old age (Fig. 203). The lens is developed from the outer layer of the embryo by the gradual thickening and growing inwards of the epithelium, which meets the optic cup, and after a time is cut off from the parent tissue. The stages of its development may be followed in the accompanying woodcuts (Figs. 204 and 205).

The lens is composed of a number of peculiar band-like cells, derived from the epithelium. These are cemented together in parallel rows, eccentrically arranged in layers. These bands

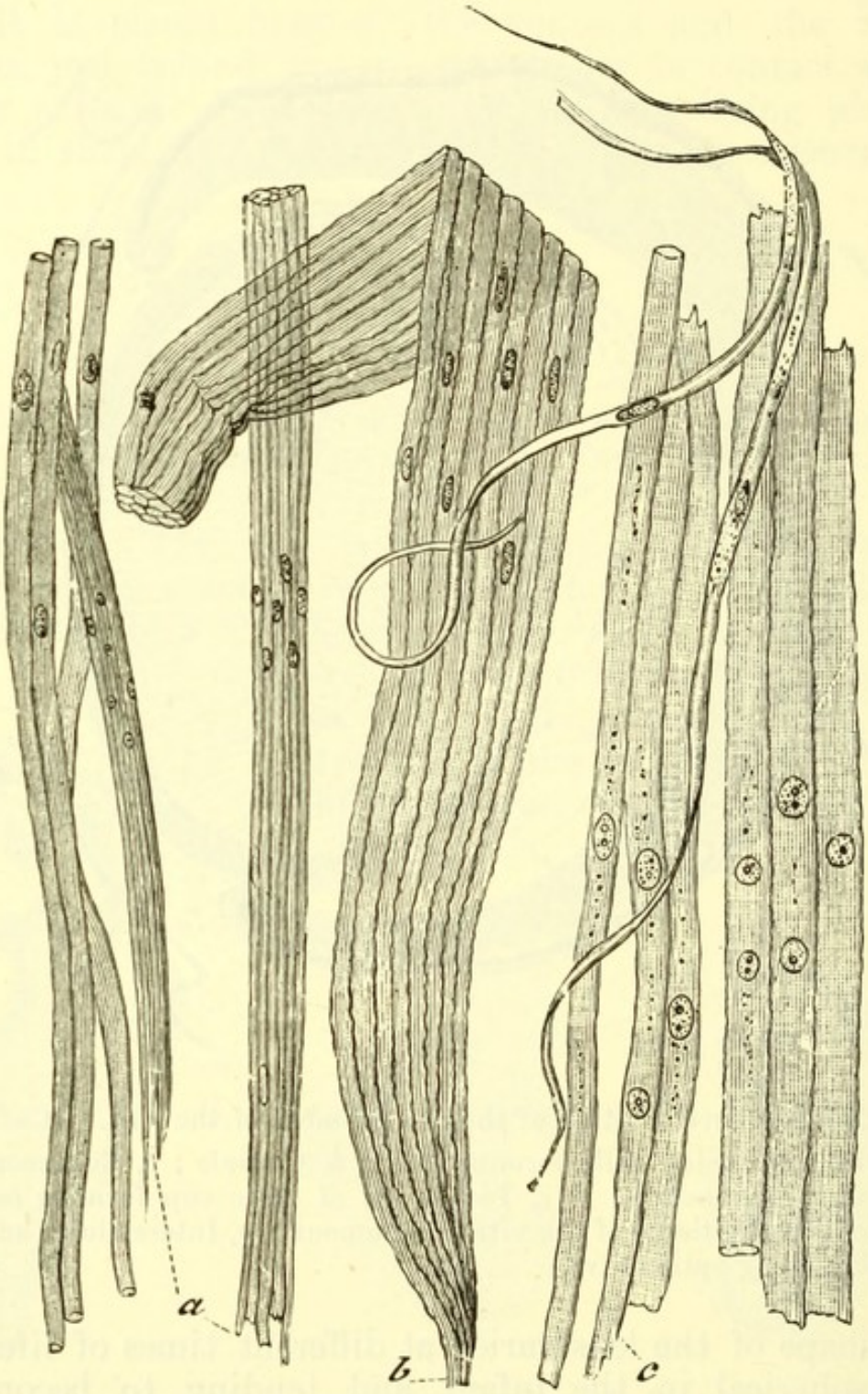


Fig. 206.—Fragment of lens teazed out to show the separate fibres. (Cadiat.)
a, *b*, and *c*, show fibres with different sized nuclei.

are hexagonal in transverse section, and in the younger periods of life may be seen to contain nuclei.

In the living state the lens is perfectly transparent, but after

death it becomes slightly opaque. The nutriment for the adult lens is derived from the vessels of the choroid, which, however, do not come into direct communication with its texture. On this account the nutrition of the lens is not so perfect as that of many other tissues, and is but imperfectly repaired after injury, which always leaves more or less opacity. Even without injury, opacity, giving rise to cataract, sometimes occurs during life.

Chemically, the lens is made up of globulin, and furnishes a ready source for obtaining this form of albumin for examination.

Dioptrics of the Eye.

Light travels through any even transparent body, such as the atmosphere, in a straight line. But when it meets any change in density, particularly when it has to pass obliquely into a denser medium, the ray is bent so as to run in a direction more perpendicular to the surface of the denser body. The degree of bending or *refraction* of the rays depends on the difference in optical density of the two media and the angle at which the ray strikes the surface of the more dense.

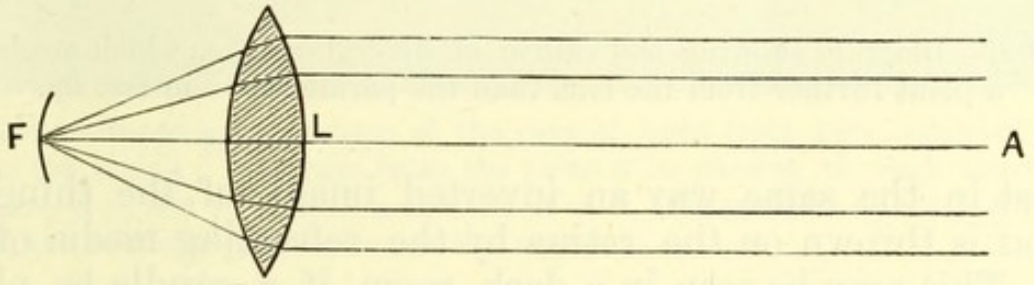


Fig. 207.—Diagram showing the course of parallel rays of light from A, in their passage through a biconvex lens L, in which they are so refracted as to bend towards and come to a focus at a point F.

On its way to the sensitive retina, the light has to pass through the various transparent media just named, viz., the cornea, the aqueous humour, the crystalline lens, and the vitreous humour. On entering these media, which have different densities, the rays of light emitted by any luminous body become bent or refracted, so that they are brought to a focus on the retina, just in the same way as parallel rays of light from the sun may be focussed on a near object by means of an ordinary convex lens.

Only so much light reaches the fundus of the eye as can pass through the opening in the iris, so that a comparatively narrow and variable beam is admitted to the chamber in which the nerve-endings are spread out for its reception.

If we hold a biconvex lens at a distance from the eye and look out of the window through it, we see an inverted image of the landscape. If we place a piece of transparent paper behind the lens, we can throw a representation of the picture on it, which will be seen to be inverted. This power of convex lenses is employed in the instrument used for taking photographs called a *camera*, which consists of a box or chamber into which the light is allowed to pass through a convex lens, so that an inverted image of the objects before it is thrown upon a screen of ground glass within the box. When the sensitive plate replaces the screen, the light coming through the lens makes a photograph.

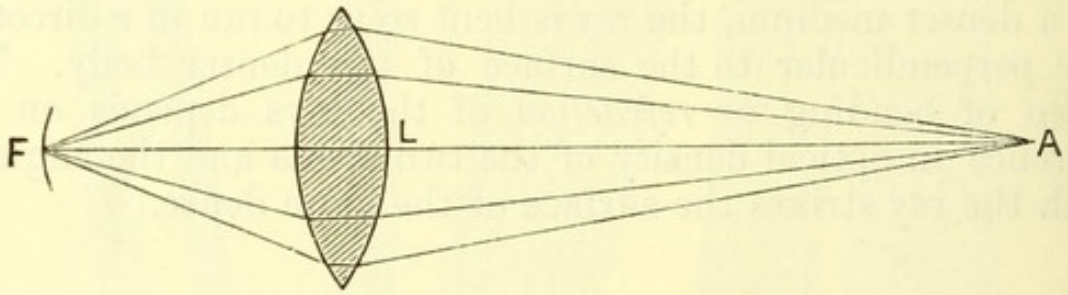


Fig. 208.—Diagram showing the course of diverging rays, which are bent to a point further from the lens than the parallel rays in last fig.

Just in the same way an inverted image of the things we look at is thrown on the retina by the refracting media of the eye. This may be seen in a dark room, if a candle be placed at a suitable distance in front of the cornea of an eye taken from a recently-killed white rabbit. When cleared of fat and other opaque tissues, the sclerotic is transparent enough to act as a screen upon which the inverted candle flame can be recognised.

Though our organ of vision is often compared to a *camera obscura*, the refractions of light which occur in it are far more complex than those taking place in that simple instrument. In the latter we have only two media—the glass lens and the air; in the eye, on the other hand, we have several, which are known to have a distinct refractive influence on the rays which pass through the pupil.

Three Media and Refracting Surfaces.

Since the surfaces of the cornea are practically parallel, we may neglect the difference between it and the aqueous humour, and look upon the two as one medium, having in front the shape of the anterior surface of the cornea, and behind, the anterior surface of the lens, so as to form a concavo-convex lens. We thus have only three media to consider, viz. : (1) the aqueous humour and cornea ; (2) the lens and its capsule ; and (3) the vitreous humour. And only three refracting surfaces need be enumerated, viz. : (1) the anterior surface of the cornea ; (2) the anterior surface of the lens ; and (3) the posterior surface of the lens.

These refracting surfaces may all be looked upon as portions of spheres whose centres lie in the same right line, and hence may be said to have a common axis. The eye may be regarded

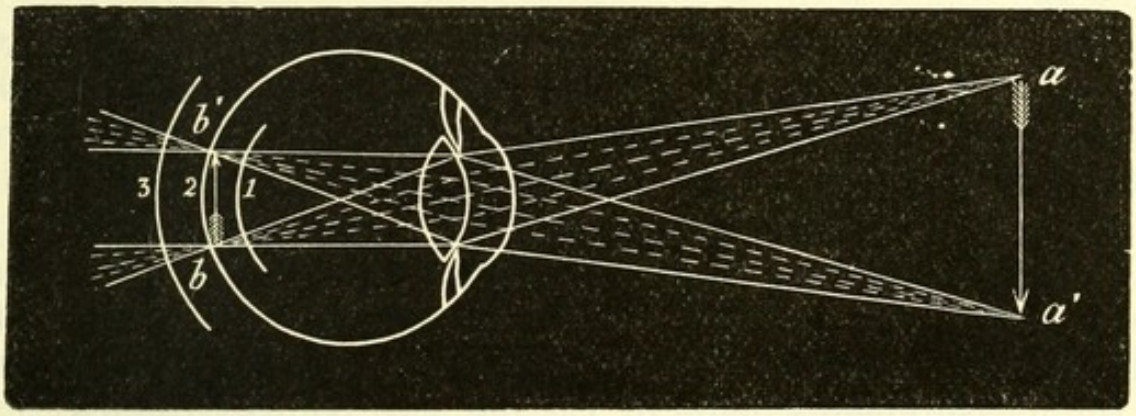


Fig. 209.—Showing the course of the rays of light from two luminous points to the retina. The rays from the point *a* on passing through the cornea, lens, &c., are collected on the retina at *b*. Those from *a'* meet at *b'*, and thus the lower point becomes the upper.

as an optical system, centred round an axis which passes through the middle point of the cornea in front, and the central depression (fovea centralis) of the retina behind. This is spoken of as the optic axis of the eye.

The rays of light entering the eye are most strongly refracted at the surface of the cornea, because they have to pass from the rare medium, the air, to the denser cornea and aqueous humour. So also more bending of the rays occurs between the aqueous humour and the anterior surface of the lens than between the posterior surface of the lens and the vitreous humour.

The lens is not of the same density throughout, but denser in the centre, and being made up of layers, the central part refracts more than the outer layers.

The manner in which the *inversion of the image* is produced by a convex lens, is shown in the accompanying figure, in which the lines correspond to the rays passing from two points through the lens. If the arrow *a a'* be taken for the object, from either extremity of it rays pass through, and are more or less bent by the lens. It will be sufficient to follow the course of three rays from the head of the arrow. One of these passes through the centre of the lens, and leaves it in the same direction which it entered, because the two surfaces at the points where it entered and left may be regarded as parallel, and so cause no refraction. The rays which do not pass through the centre are bent on entering and on leaving the lens, so that they all meet at the same point and there produce an image of the head of the arrow, at *b'*. In the same way the feather end of the arrow is produced at *b*; the position of the image of the object is thus reversed by the light rays passing through the lens.

In a biconvex lens, with two surfaces of the same degree of convexity, the central point through which the rays pass without being refracted is easily made out, as it is the geometrical centre of the lens. This central point is spoken of as the optical centre. With systems of lenses of varying convexity, and of more than one in number, as we have in the eye, where the rays of light are bent at different surfaces, it is much more difficult to determine the optical centre. However, by means of the measurements made by Listing, two points close together are known, which may be said to correspond practically with the optical centres of the eye; they lie in the lens, between its centre and posterior surface. The path of the various rays may thus be exactly made out.*

The rays which come from a distant luminous point and fall upon the eye, are refracted by the cornea and aqueous humour, so as to be made *convergent* on their way to the lens; they are then further bent at the surfaces of the lens, so that they are brought exactly to a point on the retina. That is to say, for distant luminous points, the retina lies exactly in the plane of focus of the dioptric media of the normal eye.

* The impossibility of making clear the important relationships, such as nodal points, and other constants of the eye in a short text-book, and the deterrent effect exerted upon the mind of a junior student by brief incomprehensible statements, have induced the author to omit this part of the subject. He must refer those who are anxious to learn the cardinal points of the eye, to the more advanced text-books.

This convergence of the rays to a point on the retina, is the first essential for seeing clear and distinct images ; for if the rays from each point of a luminous body were not united on the retina as points, the effects of the different rays from the various points of a body would become mixed, and there would be loss of definition of its image.

The rays from any bright point which enter the eye through the pupil may be imagined to form a luminous cone, the point of whieh lics at the retina, and its base at the pupil. After their union at the point of the cone, the rays would diverge again if the retina were not there to receive them.

Scheiner's Experiment.

It may be seen from the foregoing figure that if the retina, which normally would lie at 2, were placed nearer the dioptric apparatus, say at 1, or further from it, at 3, it would not meet the exact point of the luminous cone, but would receive the rays either before they came to a point, or after they had diverged from it. Thus indistinct rings of light would be seen instead of one luminous point, and an image would be blurred and indefinite.

From this it follows that the eye, when quite passive, can only get an exact image of bodies which are placed at a certain distance from it, just as, for any given state of a camera, only those bodies in one plane come into focus and give a clear picture on the screen. If the dioptric apparatus of the eye were rigid and unalterable, since the relation of the retina to it is permanently the same, we could only see those objects clearly which are at a given distance from the eye. We know, however, that we see as distinct an image of distant as of near objects, and we can look through the window at a distant tree, or can adjust our eyes so as to see a fly walking on the window-pane. We cannot see both distinctly at the same moment. This power of focussing may be demonstrated by what is known

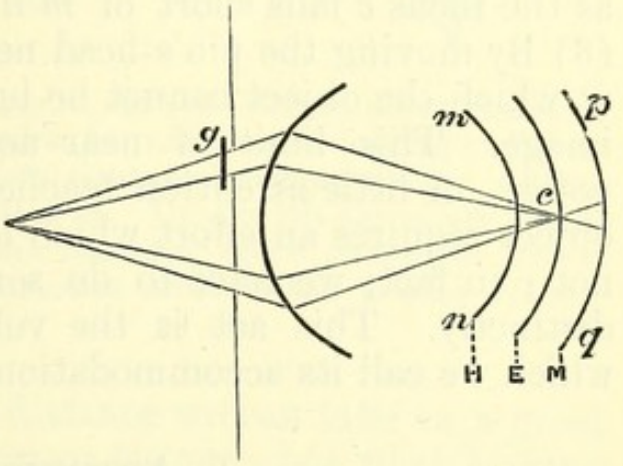


Fig. 210.—To illustrate Scheiner's experiment ; for explanation, see text.

as Scheiner's experiment, which is carried out in the following way.

Two pinholes are made in a card at a distance from each other not wider than the diameter of the pupil. The card is then brought close to the eye, so that a small object—such as the head of a bright pin—can be seen through the holes. The dioptric media being fixed, moving the object nearer to or further from the eye would have the same effect as changing the relation of the retina to *m n* or *p q* in fig. 210, by means of which we may explain the following observations: (1) The eye being fixed upon the object (of which only one image is seen), move the pin rapidly away; two objects now appear, showing that the rays coming through the holes have met before they reach the retina, as at *p q*. (2) Move the pin near the eye; again two very blurred objects are seen, for the rays have not met when they strike the retina, as at *m n*. (3) Keeping the object in the same position, alter the gaze, as if to look first at distant and then at near objects; in both extremes two images are seen. (4) When the object is in exact focus as at *c*, the closure of one of the holes does not affect the single image. (5) When two images are seen, closing the right-hand hole at *g* causes the right or left image to disappear according as the focus *c* falls short of *m n* or is beyond *p q*, the retina. (6) By moving the pin's-head nearer the eye, a point is reached at which the object cannot be brought to a focus as a single image. This limit of near accommodation marks the near point. A little attention teaches us that looking at the near object requires an effort which looking at the distant one does not; in fact, we have to do something to see things near us distinctly. This act is the voluntary adjustment of the eye which we call its accommodation for near vision.

Accommodation.

The difference of distance for which we can adjust our eyes is great, so that our *range of distinct vision* is very extensive. As already stated, the normal eye is considered to be constructed so that parallel rays of light, *i.e.*, those coming from practically infinite distance, are brought to a focus on the retina. This is why we see the stars—which are practically infinitely remote from us—as mere luminous points. It is therefore impossible to fix a *far limit* to our power of distant vision. The nearer an object is brought to our eyes, the more effort is required to

see it distinctly, until at last a point is reached where we cannot get a clear outline, no matter how we "strain our eyes." For a normal eye, called the *emmetropic eye*, this *near limit* is about 12 cm., or 5 inches, but it varies in different individuals.

For objects that are over 10 mètres distance very little change in the eye is required to see each distinctly, and the nearer the object approaches the more frequently the adjustment of the eye has to be altered to see it clearly. When the eye is focussed for any point within the limits of distinct vision a certain range of objects at different distances from the eye can be recognized without moving the adjustment. The range of this power is measured on the line of vision, and

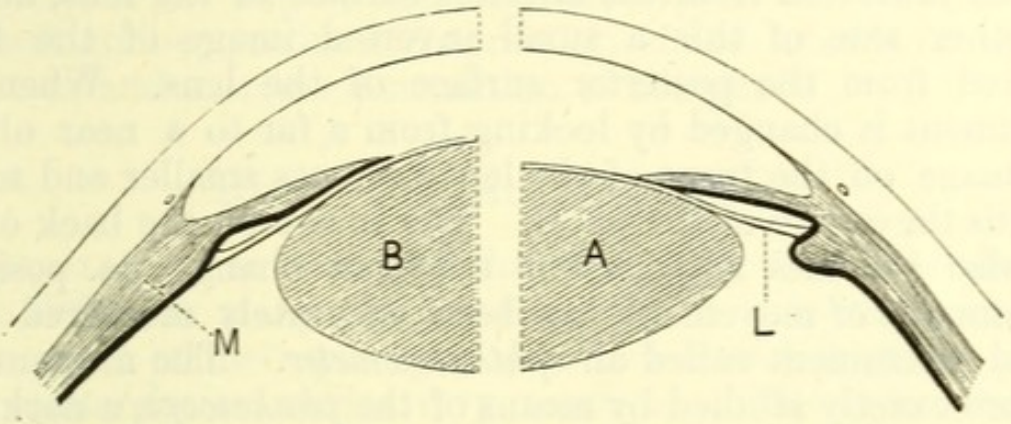


Fig. 211.—Diagram showing the changes in the lens during accommodation. The muscle on the right is supposed to be passive as in looking at distant objects, the ligament (L) is therefore tight, and compresses the anterior surface of the lens (A) so as to flatten it. On the left the ciliary muscle (M) is contracting so as to relax the ligament, which allows the lens to become more convex. This contraction occurs when looking at near objects.

called the *focal depth*. In the distance we can take in a great depth of landscape, without effort or fatigue ; but when looking at near objects the focal depth is less, and we must constantly accommodate our eyes afresh in order to see clearly objects at slightly different distances because of the shallowness of the focal depth in the nearer parts of visual distance.

The *method* by which the accommodation of the eye is effected differs from anything that can be applied to an artificial optical instrument, and is more perfect.

The following alterations are observed to occur in the eye during active accommodation, *i.e.*, when looking at near objects. (1) The iris contracts so that the pupil becomes smaller ; (2)

the central part of the anterior surface of the crystalline lens moves slightly forwards, pushing before it the pupillary margin of the iris, so that the lens becomes more convex ; (3) the posterior surface of the lens also becomes more convex owing to the general change of shape of the lens, but the centre of this surface does not change its position ; (4) both eyes converge.

These changes can be seen in the accompanying diagram, showing a section of the lens, cornea, and ciliary region (Fig. 211), in the left-hand side of which the lens is drawn in the position it assumes when accommodated for near objects. These movements can be seen in life by observing the changes in relative positions, &c., of the reflections of a candle flame thrown from the cornea and the two surfaces of the lens. On the cornea is seen a bright upright flame ; next comes a large diffused reflection from the anterior surface of the lens, and at the other side of this a small inverted image of the flame reflected from the posterior surface of the lens. When the adjustment is changed by looking from a far to a near object, the image on the front of the lens becomes smaller and moves towards the centre of the pupil. The image on the back of the lens also becomes smaller but does not change its position. The amount of movement has been accurately measured by a special instrument called an *ophthalmometer*. The motions can be more exactly studied by means of the *phakoscope*, a dark box, in which prisms are placed before the observed eye, and each image is made double. The change in relative position of the two is more readily recognised than a mere change of size of the one.

Muscular mechanism of accommodation.—The alteration in the shape of the lens is accomplished by the action of the muscular layer already named, which radiates from the edge of the cornea to the ciliary region of the choroid coat, where it is attached. When the ciliary muscle contracts it draws the choroid coat and the connections of the suspensory ligament of the lens slightly forwards, the junction of the cornea and sclerotic being its fixed point. Under ordinary circumstances, the eye being at rest, the suspensory ligament is tense and exerts a radial traction on the anterior part of the capsule of the lens, tending to stretch it flat ; this affects the shape of the soft lens and reduces its convexity. When the ciliary muscle shortens it draws forwards the attachment of the suspensory ligament, relaxes it, and removes the tension of the capsule, so that the unconstrained elastic lens bulges into its natural form.

The posterior surface cannot extend backwards, because there it is in contact with the vitreous humour, which is held more firmly against it by the increased tension of the hyaloid membrane during the contraction of the ciliary muscle.

Some circular muscular fibres help to relax the ligament and relieve it from the increased pressure which the contraction of the radiating fibres must indirectly cause on the vitreous humour.

The act of accommodation is voluntary, the nerve bearing the impulse to the ciliary muscle, comes from the 3rd nerve by the ciliary branches of the lenticular ganglion. The action of the iris is associated with that of the ciliary muscle. The local application of the alkaloid of the belladonna plant (atropine) causes paralysis of the ciliary muscle and wide dilatation of the pupil ; and the alkaloid of the Calabar bean (physostigmine) produces contraction of the muscle of accommodation and extreme contraction of the pupil.

Defects of Accommodation.

Myopia.—It has been said that the "near limit" of distinct vision differs in many persons from the twelve centimeters of the normal emmetropic eye, and it is found that the power of accommodation varies very much in different individuals. Thus in "short-sighted" people, who have *myopic* eyes, *i.e.*, in which parallel rays are focussed short of the retina, the near limit may only be half the normal, *i.e.*, five centimeters, and the far limit, which is normally indefinite, is found to be within a comparatively short distance of the eye. They, therefore, cannot see distant objects clearly, since the rays are focussed before the retina is reached, and then diverging, cause diffusion circles and a blurred picture. The work of their accommodation is also much more laborious, since they can only see in that part of the range of accommodation where the adjustment has to be altered for slight variations of distance. The defect can be made much less distressing by the use of concave glasses, which make parallel rays strike the cornea as divergent ones, and thus allow them to be focussed on the retina.

Hypermetropia.—Another abnormality is "long sight." In the hypermetropic eye, parallel rays of light are brought to a focus at a point beyond the retina, so that divergent or parallel rays cause diffusion circles and a blurred image. This may be

corrected by means of convex glasses which make the rays convergent before they strike the corneal surface, and thus enable them to be sooner brought to a focus by the dioptric media of the eye.

Presbyopia is the name given to a change in the perfectness of accommodation frequently accompanying old age. The lens probably becomes less elastic and the ciliary muscle weaker, so that the change in form required to see near objects is difficult or impossible to attain. Biconvex lenses help to overcome the difficulty.

Defects of Dioptric Apparatus.

In common with all dioptric instruments the eye has certain optical defects which tend to interfere with the distinctness of the image.

Chromatic aberration is due to the breaking up of white light into several colours, owing to the different coloured rays of which ordinary light is composed, possessing different degrees of refrangibility. We see this in the spectrum and in the coloured rings of the marginal part of a biconvex lens made of a single kind of glass. This form of aberration can be corrected by making lenses of two kinds of glass, one of which counteracts the dispersion caused by the other. Optical instruments may thus be made achromatic. In the eye this defect is minimised by the iris, which cuts off the marginal rays in which it is most apt to occur. Possibly the different density of the various parts of the dioptric media may have a correcting effect on the chromatism of the eye. Further correction takes place in the nerve-centres which receive the sensation, for just as we mentally re-invert the image, we are unconscious of the colour. At any rate, the chromatic aberration is so slight that it needs certain artifices to make it observable.

Spherical aberration depends upon the fact that luminous rays, on passing through a convex lens, strike the various parts of its surface at different angles, and hence are differently refracted. The rays striking the margin of the lens are more bent than those passing through the centre, and hence the former come sooner to a focus. Thus a luminous point gives rise to a diffused figure, which is circular in perfectly centered dioptric systems, but is stellate in some eyes where the centering of the lenses is not absolutely accurate. Spherical aberration causes us no inconvenience, as the density of the lens being

greater at the centre than at the margin largely corrects this form of aberration, as and when the iris is contracted, it only allows the more central rays to pass, in which its influence is not noticed.

Another optical defect in our eyes is *astigmatism*, depending upon some irregularity of the curvature of the cornea, which may be bent more in a horizontal than in a vertical plane, or *vice versâ*. In either of these cases the light in the vertical and horizontal planes will be differently refracted, so that lines drawn in the two directions will require different adjustments to see them distinctly. This may be recognized if we gaze with one eye at the centre from which many sharply-defined lines radiate : some of the lines cannot be seen quite distinctly, unless we move the eye or change its accommodation. When the greater curvature extends evenly over the whole diameter of the cornea it gives rise to what is called *regular astigmatism*, and when the unevenness is localized to one part of the corneal surface it is called *irregular astigmatism*.

The astigmatism which may be called physiological is not noticed by the individual, but pathological astigmatism often occurs and requires cylindrical glasses to correct it.

Entoptic images are those which depend on the presence of some opacity or difference in density in the transparent media of the eye itself. They look like variously-shaped specks moving over the field of vision. They are only remarkable when we look at an evenly illuminated object or through a pin-hole in a black card. In using the microscope they often annoy the unpractised observer.

The Iris.

Functions.—It has already been mentioned that the motions of the iris alter the size of the *pupillary aperture* through which the rays of light must pass, and while it *regulates* the amount of light admitted, it also acts like the *diaphragm* of an optical instrument, and normally cuts off a large amount of the marginal rays. The great importance of not allowing the rays which would traverse the margin of the lens to enter the eyeball can be understood after what has been said of spherical and chromatic aberration. The iris also contracts when the eye is *adjusted for near vision*, independent of the amount of light by which the object is illuminated. This action is of advantage, because the more convex the lens became in viewing near

objects, the greater would be the aberration of the marginal rays, therefore, if the iris did not contract in near vision, the closer an object were brought to the eye, the greater would be the tendency to indistinctness caused by spherical aberration.

In *structure*, the iris consists of a framework of delicate connective tissue, like that of the choroid coat, containing many blood-vessels. On its posterior surface is a dense layer of pigment cells called the uvea, which gives the eye its colour. The act of contracting the pupil is performed by a very definite set of *unstriated muscular fibres* forming the sphincter which surrounds the margin of the pupil. The sphincter muscle

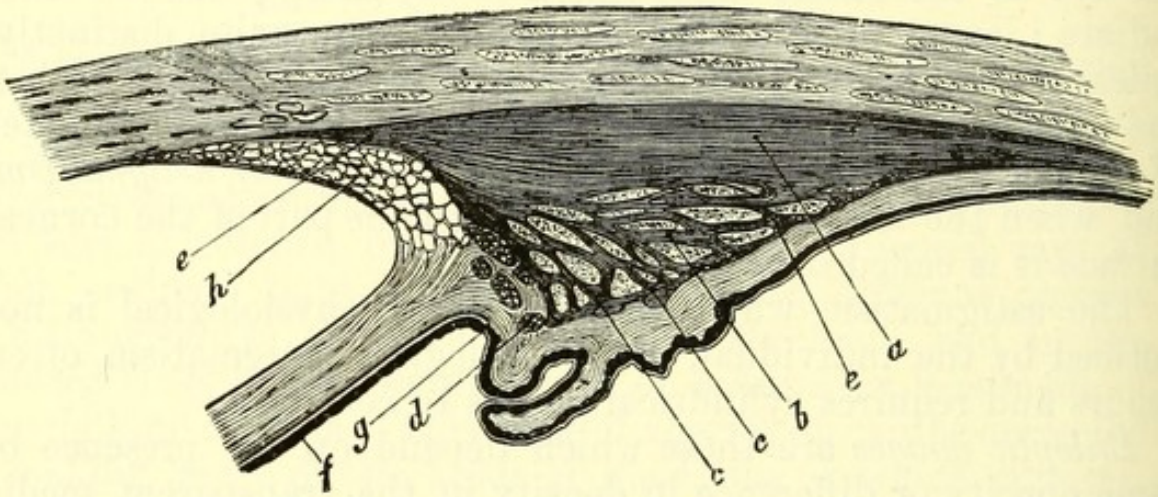


Fig. 212.—Section through the ciliary region, showing the relation of the iris (*f*) to the choroid (*g*) and the ciliary muscle (*a*) which arises from the margin of the cornea at (*e*), and passes towards the choroid to the right, where it separates the latter from the sclerotic. Some bundles of circular fibres are shown, one marked (*d*).

seems always to be more or less in action, because if it be paralysed, the pupil dilates. The muscular character of the dilator mechanism has been doubted from the fact that radiating muscular fibres have not been satisfactorily demonstrated under the microscope. Certainly the sphincter is the most distinctly contractile, for strong electric stimulation always causes contraction of the pupil, and shortly after death the pupils dilate from the relaxation of the sphincter. If we admit the active dilatation of the pupil, we must assume that the power of the sphincter dies more quickly than that of the dilator, or that it at once relaxes when it has lost the stimulus reflected from the retina. There appears to be no difficulty in explaining the dilatation of the pupil as the effect of the elasticity of the tissue and the changes in vasomotor influences.

Nervous Mechanisms Controlling the Iris.

When the sympathetic in the neck is cut, the pupil becomes considerably contracted. Hence it has been argued that nerves supplying the dilator are derived from the sympathetic. It may also be explained by supposing that the sympathetic normally conveys inhibitory impulses to the sphincter muscle, as stimulation of these fibres leads to dilatation of the pupil (Gaskell). These fibres are supposed to take origin in the grey matter of the cervical spinal cord. The sympathetic also supplies the walls of the vessels, and thus controls the amount of blood going to the iris, and this contraction of the pupil has been explained as due to vascular engorgement. It is argued that though the vasomotor mechanisms may co-operate in dilatation, they cannot be its only cause, as the widening of the pupil may occur in a bloodless eye. Since the other tissues are elastic, and antagonise the sphincter, paralysis of that muscle would give rise to dilatation even in anæmic mydriasis.

The *constricting nerve mechanism* of the sphincter muscle is distinct, and more definitely understood. Its common action is reflex : the stimulus starts in the retina, and travels along the optic nerve as an afferent channel to the corpora quadrigemina, where there is a centre governing the contractions of both irides. The efferent impulses are sent by the third nerve to the lenticular ganglion, and thence by the short ciliary nerves to the eyeball.

In accommodation for near objects three muscles act together, their movements being "associated" by the central nerve mechanisms. The same voluntary effort that causes the *ciliary muscle* to contract, makes the *sphincter* of the iris contract, and also causes the *internal rectus* to move the eye inwards. The voluntary nerve centre must be in intimate relation with the reflex centre, which keeps up the tonic action of the sphincter iridis.

We have then *central* governors for the ciliary and iris movements. The ciliary muscle, and reflexly the sphincter of the pupil, are caused to act by the will. The sphincter is also excited by means of a reflex centre, receiving stimulus from the retina. The dilator of the pupil, if a muscle, is also kept in gentle tonic action, or the sphincter may be partially inhibited by the impulses sent from the spinal cord with the vaso-motor impulses, *viâ* the sympathetic. Some think that the blood supply and tissue elasticity explain the dilatation.

Further, from the undoubted facts (1) that some reflex contraction of the pupil may be produced by stimulating the retina, even when the eye is cut off from the brain centres, and (2) that the local effect of atropine in dilating, and Calabar bean in narrowing the pupil, seem in a measure independent of the central nerve organs, it has been concluded that there must also be some local nerve mechanism in the eye which is capable of reflecting impulses, and is directly affected by these poisons.

The student must carefully bear in mind all the circumstances under which the pupils contract, namely :—

1. The application of strong light to either retina, causes reflex stimulation of the ciliary nerves of both eyes.
2. Stimulation of the nasal or ophthalmic branches of the fifth afferent nerve reflexly excites the sphincter.
3. Contraction of the pupil is "associated" with accommodation for near objects.
4. Similar "associated" contraction always accompanies inward movement of the eyeball.
5. During sleep, or as the result of vasomotor disturbances in the brain (anæmia), the pupil contracts.
6. Under the influence of physostigmine, nicotine, and morphine.
7. From any stimulation of the optic or third nerves or of the corpora quadrigemina.

The circumstances in which the pupils are found to be dilated are equally important from a practical point of view, namely :—

1. In the dark or with insensitive retinæ.
2. Irritation of the cervical sympathetic.
3. Under the influence of atropine, daturine, &c.
4. In asphyxia or dyspnœa from venosity of the blood.
5. Painful sensations from the skin, &c.

The Ophthalmoscope.

When we look into the eye, in whatever position the source of light, the pupil appears quite black. The reason of this is that the retina can only be made visible by the light reflected outwards from it, and that the portion of the rays which is reflected by the retina is so refracted in passing out of the eye, that it precedes only the same path as that travelled by the light on its way from the point of illumination to the eye. Consequently, unless the eye of the observer be placed directly in this path,

none of these reflected rays can reach it to enable him to see the fundus.

That is to say, the lens and other refractive media that bend the rays of the ingoing cone of light to a focus on the retina, also bend those of the outgoing cone reflected from the retina to a focus at the point of illumination.

The fact that the blackness of the interior of the eye is caused by the dioptric media, can be shown by a simple

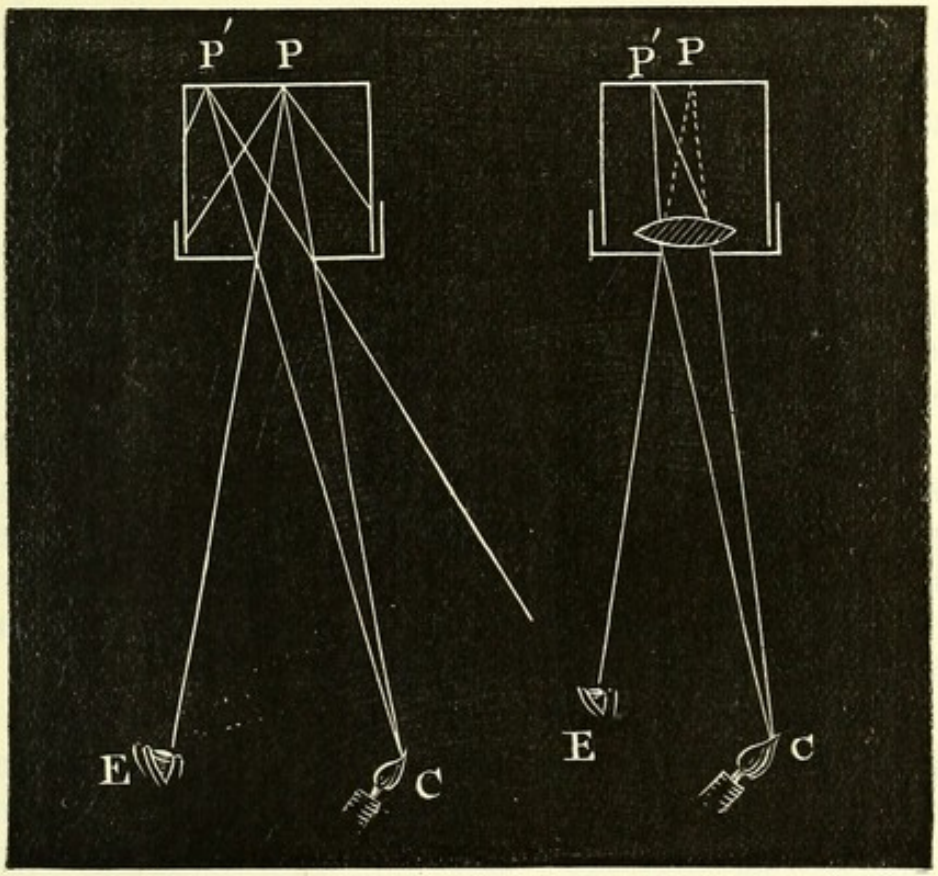


Fig. 213.—Diagram showing the effect of a lens on the rays of light reflected from the paper (retina) in the experiment given in the text. E. Observer's eye. C. Point of illumination. On the left the reflected rays diverge, and some pass to E. On the right they are refracted by the lens to form a cone.*

experiment. Blacken the inside of a pill-box (about an inch deep), paste printed paper on the bottom, and cut a round hole half an inch in diameter in the lid. By illuminating the interior of the box obliquely the print can be easily recognised. If a convex lens of one inch focus be placed behind the opening, the paper cannot even be seen, and the opening looks black like the pupil with any position of the light. The paths traversed by the rays in this experiment may be seen in Fig. 213.

In the left-hand figure of the above woodcut the first case is

* "How to Use the Ophthalmoscope," by Edgar A. Brown, p. 32.

illustrated. Here the divergent rays passing from the candle C to the surface P P′ are reflected in various directions from it; those which strike the blackened interior of the box are absorbed; others emerge through the hole in the lid, and reaching the eye placed at E, enable the print at P to be seen.

The second case is shown in the right-hand figure. Here, instead of diverging till they reach the bottom of the box, the rays are refracted by the lens to a focus at the point P′, from which they pass back through the lens, and are thereby bent to a cone converging to the source of light. No rays pass in the direction E, so the interior of the box looks quite black.

In attempting, then, to view the fundus, the observer must either place his head in the line of light, or the light in the line between the observed eye and his own; in short, his eye must lie in the line of reflection, in order to see the fundus. If we could see through the source of light, the above object would be accomplished. Helmholtz, by reflecting light into the eye by means of transparent glass plates, originally succeeded in seeing through the plates some of the rays reflected from the fundus. In this method, however, the power which enables the glass plates to reflect the luminous rays towards the eye, also robs the observer of much of the light sent back from the retina by reflecting it towards the source of light, and the remaining rays which penetrate the glass cannot give a clear image of the retina.

A simple instrument, the *ophthalmoscope*, is now in general use for examining the retina. This consists of a concave mirror of short focal distance, which is substituted for the transparent reflecting plates. The rays converging from the mirror to the eye are brought to a focus on the retina, and thence some are reflected outwards, and converged by the dioptric media to the hole in the centre of the mirror, behind which the observer's eye is placed to receive the cone of converging rays.

If the observer place his eye and the mirror at a distance of about 3 cm. from the observed eye, and the refraction of both eyes be normal, he can see an enlarged virtual image of the fundus. If the refraction of either eye be abnormal, it must be corrected by a suitable lens placed behind the aperture in the mirror. This is called the *direct method* of examination.

To overcome the inconvenience and difficulty of this mode of examination the *indirect method* is usually employed. In it a convex lens of 20 or 40 diopters is used in addition, enabling the observation to be made at a more convenient distance.

When the eye has been illuminated, the lens is placed at its proper focal distance (2 or 1 inches respectively) in front of the eye. By the converging power of the lens a real inverted image of the fundus is formed in the air a couple of inches to the observer's side of the lens, and can be seen by him through the aperture in the mirror, if he hold his head at a distance to suit his refraction.

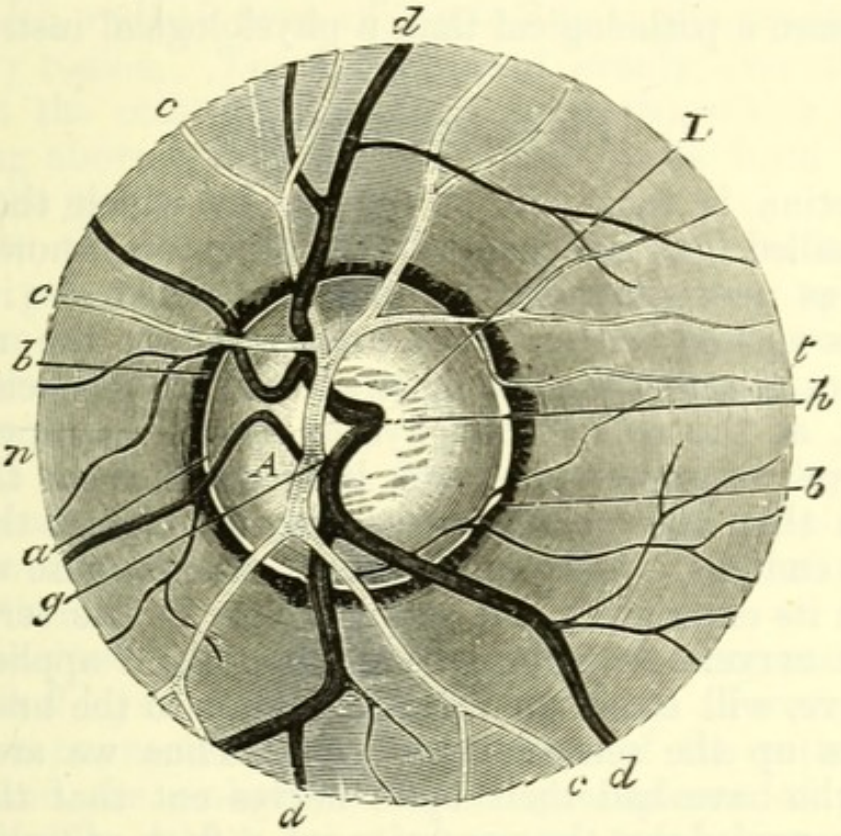


Fig. 214.—Ophthalmoscopic view of fundus of eye, in which the central artery (*g* and *c*) and the corresponding veins (*h* and *d*) are seen coursing through the retina from the optic disc (*A*).

With this instrument a round whitish part is seen a little to the nasal side of the axis of the eye, where the nerve pierces the dark choroid coat. This is called the optic disc. The fundus now, when lighted up, does not look black, but is of a lurid red colour, owing to the great vascularity of the choroid coat. Over this red field are seen a number of blood-vessels, which start from the centre of the optic disc, and radiating over the fundus send branches to the most anterior parts that can be seen. These are the branches of the vessel which runs in the centre of the nerve. In the very axis of the eye a peculiar depression, free from branches of the blood-vessels, can be seen. This central depression (fovea centralis) differs a little in colour from the neighbouring parts during life, and turns yellow at

death, and hence has been called the "yellow spot." The retina is so transparent that we cannot see it with the ophthalmoscope, but the radiating vessels (central arteries and veins of the retina) lie in it, and are devoted to the nutrition of the nervous structure only.

The ophthalmoscope has proved of inestimable value not only to the ophthalmologist, but also to the physician, as a means of arriving at an accurate knowledge of disease. Hence it has become more a pathological than a physiological instrument.

Light Impressions.

The retina is that part of the eye by which the physical motions called *light* are changed into what are known physiologically as nerve-impulses, by means of which the impression of light is excited in the brain. In reaching the retina the light is not altered from the light with which physicists experiment, but at the retina this physical motion is stopped. The optic nerves no more convey the light waves from the eye to the brain than the tactile nerves carry the objects that stimulate their endings. They only send a nerve-impulse which the retina, on its exposure to the light, excites in the terminals of the optic nerve. Any form of stimulation, if applied to the optic nerve, will cause an impulse to pass to the brain, which there sets up the sensation of light. Thus we are told by persons who have had their optic nerves cut that the section was accompanied by the sensation of a flash of light but not pain. Any violent injury of the eye-ball causes a flash of light to be experienced. Also, without violent injury, if we close the eyes and turn them to one side and then press through the lid with the point of a pencil on the other side of the eye-ball, we have a sensation of a point or ring of light from the retinal stimulation. Thus we say that the specific energy of the optic nerves excites a sensation of light, and the adequate stimulus of the nerve terminals of the organ of vision is light. The first question that arises is, what part of the retina performs this important work of stimulating the optic nerve when light impinges on its terminals?

The Function of the Retina.

The retina is a complex peripheral nervous mechanism composed of many elements, the special functions of which are not

adequately known. It spreads over the fundus of the eye, but where the nerve pierces the coats of the eyeball there is nothing but nerve fibres, and hence no retina, properly so called, exists at the *optic disc*.

The structure of the retina varies in different parts, but the following layers can be recognised in most regions (Fig. 215). The exceptions will be mentioned afterwards.

Lying next to the hyaloid membrane is the layer of *nerve fibres* which radiate from the optic disc to the ora serrata near the ciliary region. The fibres spread evenly over the fundus except at the central point (fovea centralis), which they avoid by passing above and below it. These fibres form the inner layer of the retina.

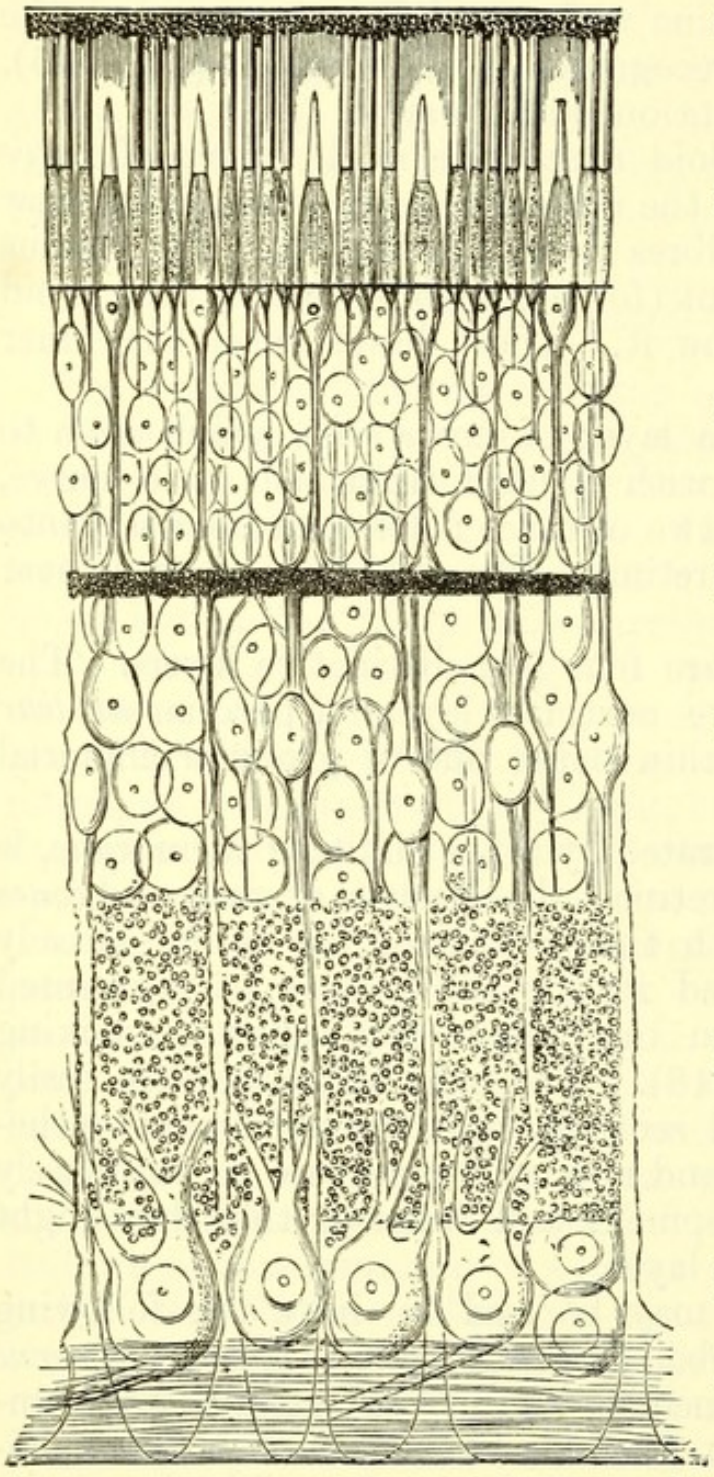
Next to the fibres is a layer of *nerve cells*, which seem to have one pole connected with a fibre from the optic nerve, while from the other side two or three poles send processes into the adjacent layers of the retina. The cells are numerous near the yellow spot.

Outside the foregoing are four less distinctive layers. The first is broad and *granular;* next, two layers of peculiar *nuclear* bodies are found, with a thin dense one of granular material between them.

Outside these, and separated by a fine limiting membrane, is the terminal layer of the retina. It consists of *rods and cones* which are connected with those parts of the retina already named, and are embedded in the protoplasm of pigmented epithelial cells, which, on their outer face, show a striking hexagonal outline (Fig. 218). The rods and cones are easily torn away in histological sections from the pigmented epithelium, but the epithelium and rods and cones are so intimately connected in their development and function that they ought to be regarded as a single layer.

A retinal nerve fibril may be said to have the following course : entering the eyeball from the optic nerve at the *porus opticus*, it reaches the immediate vicinity of the hyaloid membrane, and runs a certain distance in contact with that membrane, it then turns outwards towards the choroid and enters a nerve cell. From the nerve cell pass a couple of filaments which traverse the various granular and nuclear layers—where they probably inosculate with the filaments from other cells—and finally terminate in a rod or a cone. The rods and cones are the ultimate terminals of the nerves, and they lie in the active protoplasm of the peculiar, pigmented epithelial cells.

This outer layer, consisting of rods and cones lodged in epithelial protoplasm, is the effective part of the retina. Of this we have the following evidence :—



Pigmented epithelium lying next to the choroid coat.

Rods and cones with their extremities embedded in the epithelial cells.

External nuclear layer.

External granular layer.

Internal nuclear layer.

Internal granular layer.

Layer of nerve cells.

Nerve fibre layer in which the retinal vessels run next to the vitreous humour.

Fig. 215.—Diagrammatic section of retina showing the relation of the different layers in the posterior part of the fundus (not the *macula lutea*). (Schultze.)

1. The *anatomical fact* that the rods and cones must be regarded as the nerve terminals of the optic nerve.

2. That the macula lutea, where the retina is chiefly made up of the cone layer, is very much the most sensitive part, and

near the ora serrata, where the rods and cones are less developed, sight is least acute.

3. *The blind spot.*—From the facts that where the optic nerve enters the eyeball there are no rods and cones, and that though the nerve fibres are fully exposed to the light, they

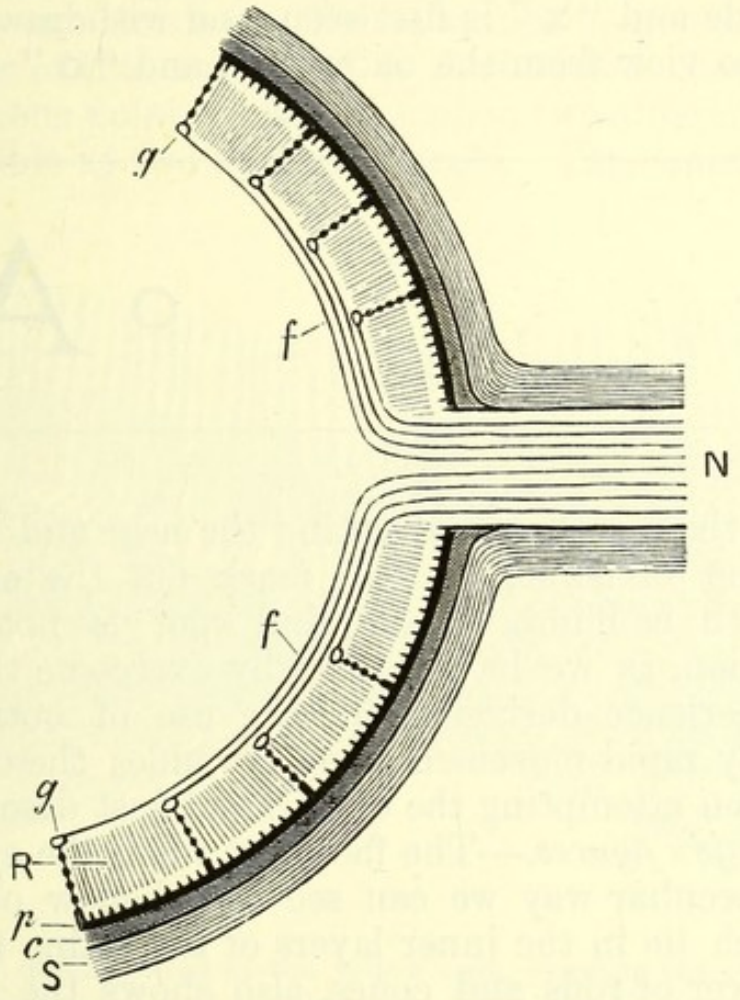
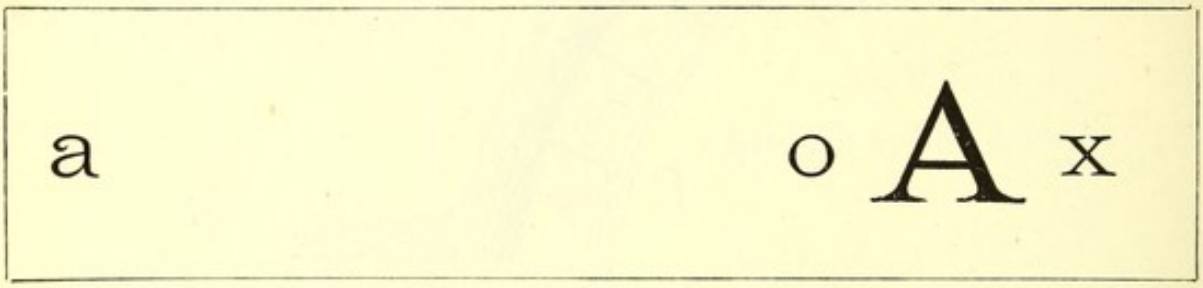


Fig. 216.—Showing the course of the fibres of the optic nerve N, as they pass along the inner surface of retina R, to meet the ganglion cells *g*, whence special communications pass outwards to the layer of rods and cones in the pigment layer *p*, next the choroid *c*, within the sclerotic *s*.

cannot appreciate it, this part, the optic disc, is called the "blind spot." This shows that the nerve fibres are quite insensitive to light, and that we must look to the terminals for its appreciation. The existence of the blind spot can be demonstrated as follows. Shut the left eye, and hold the left thumb, at ordinary reading distance, in front of the other eye. While the right eye is fixed on the left thumb, bring the right thumb to within about four inches, and move it slowly an inch or so, from side to side. A little practice soon enables one to

find a place when the right thumb nail disappears. It also can be demonstrated by keeping the right eye, the left being closed, *fixed on the small letter* "a" and moving the page to or from the eye very slowly ; a distance (about 10 inches) may thus be reached when the large letter "A" is quite lost. On approaching the page when "A" is invisible, the letter reappears from the inner side and "x" is first seen ; on withdrawing the page it comes into view from the outer side, and "o" is first seen.



By varying the direction and noting the near and far limits of "A's" being invisible, one can mark out the extent of the fundus which is blind. This blind spot is not noticed in ordinary vision, as we have habitually overcome the deficiency by the experience derived from the use of both eyes since infancy. By rapid movements one eye hides the deficiency, as is found when attempting the experiment just described.

4. *Purkinje's figures.*—The fact that when the eye is illuminated in a peculiar way we can see the shadow of the blood-vessels which lie in the inner layers of the retina thrown upon the outer layer of rods and cones, also shows the latter to be the sensitive part. This phenomenon, known as "Purkinje's figures," can be demonstrated as follows. Close the left eye in a dark room, with an evenly dull-coloured wall, and while you stare fixedly at the wall with the right eye turned inwards hold a candle to its outer side so that the light can reach the fundus of the eye from the side. With a little practice the least motion of the candle will bring out an arborescent figure on the wall, which exactly corresponds to the retinal vessels. It may also be seen by arranging a microscope so as to show a bright light, on looking into the instrument and either moving it or the head slightly but constantly, the shadows of the retinal vessels will be clearly seen as though they were under the instrument.

Retinal Stimulation.

Point of greatest sensitiveness.—As in the perception of two points of contact with the skin, so we find the retina ceases to be able to distinguish the difference between two luminous points, if they be brought to a focus at a distance of less than ·002 mm. from one another. This distance nearly corresponds to the diameter of the cones, and it is supposed that the rays from two luminous points must come upon two different cones in order to be visible as two distinct objects. The cones are, however, very irregularly distributed over the retina, being packed closely together at the yellow spot, and scattered more and more widely apart as one passes to the peripheral parts of the retina. It is only at the yellow spot that the cones, which are here very thin, are so close together as ·002 mm., so that this estimation of the size of visual areas could only hold good of the yellow spot, and towards the peripheral parts the power of discrimination must be much less keen. This is found to be the case, for in ordinary vision everything to be seen clearly with a sharp outline must be brought upon the yellow spot. This is spoken of as "direct vision." The images falling on the other parts of the retina are but dim and indistinct outlines, and these are spoken of as "indirect vision."

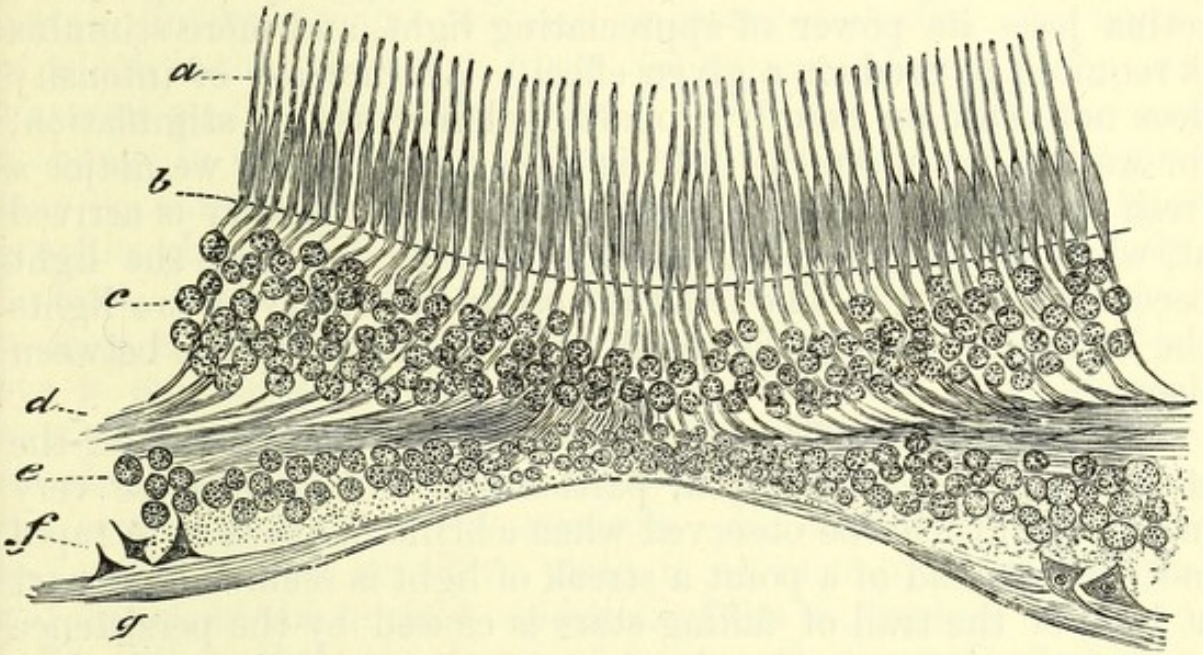


Fig. 217.—Section of the retina at the yellow spot, showing the great number of cones (*a*) at this point, and the thinness of the other layers. (Cadiat.)

Variations in stimulation.—The stimulus need only be applied for a very short time to cause a distinct sensation, for we can readily see a single electric spark; and it need only affect an extremely small part of the retina, as a minute speck of light can be seen by direct vision, and a very feeble ray suffices to stimulate the retina. The amount of stimulation produced depends upon (1) the intensity of the light, *i.e.*, the amount of light received in a given area; (2) the duration of its application; (3) the extent of retina to which it is applied; (4) the part of the retina stimulated; (5) the darker the background the weaker the illumination we can distinguish, *i.e.*, the greater the stimulating effect of a weak light; (6) by fatigue the retina loses its power of appreciating light, and more stimulus is required to produce a given effect. An increase of intensity does not cause an exactly proportional increase of stimulation, for we find the more the light is intensified the less we notice a fresh increment of light, until a degree of intensity is arrived at, when no further addition can be detected, and the light becomes blinding. The less the absolute intensity of two lights the better we distinguish any difference that may exist between them.

Duration.—The effect lasts for an appreciable time after the stimulus has been removed, particularly if the light be very intense. This can be observed when a brilliant point is in rapid motion; instead of a point a streak of light is seen. Thus part at least of the trail of falling stars is caused by the persistence of the stimulation, and a luminous body rapidly rotated gives the impression of a circle of fire.

When the stimulus is very intense, such as an electric light, or when we look at a bright object like the globe of a lamp steadily for some time, the effect persists, and after the eyes are shut we see a faint image of the object. This is called the *positive after image.* If the retina be exposed to a bright light until it be fatigued, and then suddenly turning we gaze at a white wall, the bright part or the positive after image is replaced by a dark figure which is termed the *negative after image.*

A strong stimulus applied to the retina spreads from the part upon which the bright image falls to those in its immediate neighbourhood, so that the bright object looks larger. This phenomenon is called *irradiation.* It helps to explain many of the peculiarities of vision.

Excitation of Nerve Impulse.

The question now arises, how do the retinæ, or rather their outer layers, convert light into a nerve stimulus? It would appear quite out of the question that the 394 to 760 billions of waves of light per second could mechanically excite the nerve terminals, as the waves of sound are believed to excite the endings of the auditory nerve. We know that light has a very distinct action on many chemical combinations, such as reducing salts of silver and gold, &c. We, therefore, imagine that the light waves may set up, in the outer layer of the retina, certain intermolecular motions or *chemical changes*, the result of which is that the nerve fibres are stimulated to activity and transmit an impulse to the brain. The light possibly produces a change in the outer layer of the retina which in some respects may be compared to that which occurs on a sensitive photographic plate. The comparison is true in some respects only, because, while the chemical change on the sensitive plate persists so as to give rise to a permanent photograph, in the eye it only lasts for the brief moment during which we can recognise the positive after image. We have seen, in a previous chapter, that in muscle considerable chemical change, causing the contraction, is rapidly repaired. In a similar manner in the retina a new sensitive plate is at once produced by the restoration of the normal condition of the molecules.

The view that the layer of rods and cones undergoes a chemical change on exposure to light which suffices to excite the optic nerve, receives support from the observation that a colour of a red or purplish hue exists in the outer part of the rods and that this colour changes when exposed to the light. But this so-called *visual purple* has not an inseparable connection with vision, since it is absent where the retina is most sensitive, *i.e.*, the fovea centralis, where there are no rods, and further, frogs with blanched eyes, seem to see quite well. Certain rays of light have a distinct *thermic influence*, and hence the possibility exists that the nerve impulse is started in the retina by some delicate thermic stimulus.

Against the chemical and thermic origin of the retinal stimulation may be urged the fact that the rays of the spectrum which are most efficient in exciting chemical and thermic effects (ultra-violet and ultra-red respectively) do not excite any nerve impulse in the retina.

The *pigmented epithelial cells* of the retina have been observed to change their shape slightly, and definitely to alter the position of the pigment granules they contain when exposed to light. When we remember how sensitive to light is the protoplasm of many unicellular infusoria, we cannot be surprised that the protoplasm of the retinal epithelium is affected by it. In the pigment cells of the frog's skin we are familiar with a change in shape and in the arrangement of their pigment granules in response to different light stimuli. We know further that in the nervous centres nerve impulses often

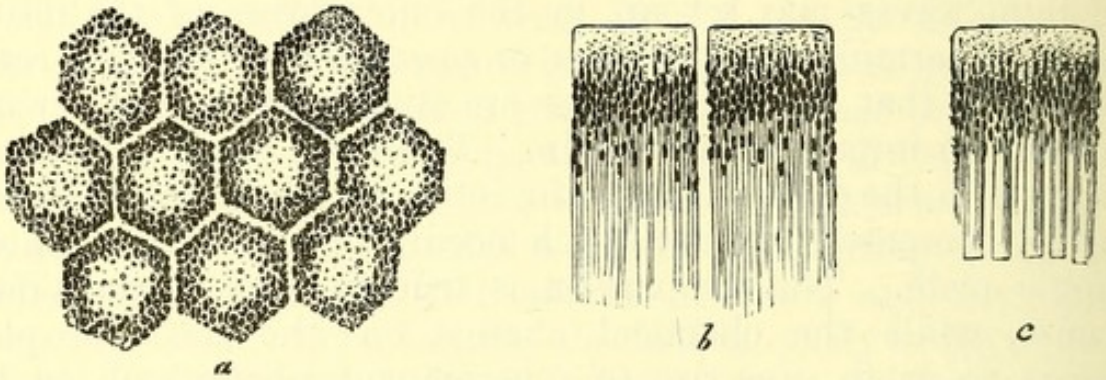


Fig. 218.—Epithelial cells of the retina. *a*, Seen from the outer surface ; *b*, Seen from the side as in a section of the retina ; *c*, shows some rods projecting into the pigmented protoplasm.

originate in protoplasm under the influence of slight changes in temperature or nutrition. It would hardly be too much to assume, then, that the retinal epithelium has some important share in the transformation of light into a nerve stimulus. The arguments pointing to the rods and cones as the essential part of the retina apply equally well to the pigmented epithelium, for they are so dovetailed one into the other that practically they form but one layer. They are not known to be connected with the nerve fibres, but they may still be influenced by the light, and communicate the effect to the contiguous nerve terminals, which appear to be elaborately adapted to the appreciation of subtle forms of stimulation.

Colour Perceptions.

If a beam of white sun-light be allowed to pass through an angular piece of glass it is decomposed into a number of colours which may be seen by looking through the prism, or may be thrown on a screen, like that of a camera. These colours,

which look like a thin slice of a rain-bow, are together called the *spectrum*. The white solar light is thus shown to be a compound of rays of several colours which possess different degrees of refrangibility and hence are separated on their way through the prism. The violet rays are the most bent, and the red the least, so that these form the two extremes of the visible spectrum. The difference of colour depends upon the different lengths of the waves, the vibrations of violet (762 billions per sec.) being much more rapid than those of red (394 billions per sec.). Beyond the visible spectrum at the red end there are other rays which though they look black to the eye, are capable of transmitting heat. This thermic power is best developed in these ultra-red rays, and fades gradually towards the other end of the spectrum. Outside the violet are ultra-violet rays, which, though non-exciting to the retina, are very active in inducing many chemical changes. Only those ether vibrations which have a medium length, can stimulate the retina.

If two different colours be mixed before reaching the retina, or be applied to it in very rapid succession one after the other, an impression is produced which differs from both the colours when looked at separately; thus violet and red give the impression of purple, a colour not in the spectrum. If all the colours of the spectrum in the same proportion and with the same brightness fall upon the retina, the result is white light. This we know from the common experience of ordinary white light, which is really a mixture of all the colours of the spectrum, and we can see it with a "colour top" painted to imitate the colours of the spectrum. When the top is spinning, the colours meet the eye in such rapid succession that the stimulus of each falls on the retina before that of the others has faded away, and thus many colours are practically applied to the retina at the same time, and the top looks nearly white.

It has been found that certain pairs of colours taken from the spectrum when mixed in a certain proportion produce white. These are *complementary* to one another. The complementary colours are :—

Red and peacock-blue.	Yellow and indigo.
Orange and deep blue.	Greenish-yellow and violet.

If colours which lie nearer to each other in the spectrum than these complementary colours be mixed, the result is some colour which is to be found in the spectrum between the two selected colours.

The perception of the vast variety of shades of colour that we can distinguish, can only be explained by means of this colour-mixing. We may suppose (with Hering) that there are three varieties of material in the retina, each of which gives rise to antagonistic or complementary colour sensations, according as they undergo increased or decreased molecular activity. These antagonistic states being produced by the complementary colours. Thus one substance gives the sensation of black or white, another red or green, another yellow or blue, according as they are in exalted or diminished activity. A varying degree of these stimulations can be easily shown to give many differences of shade.

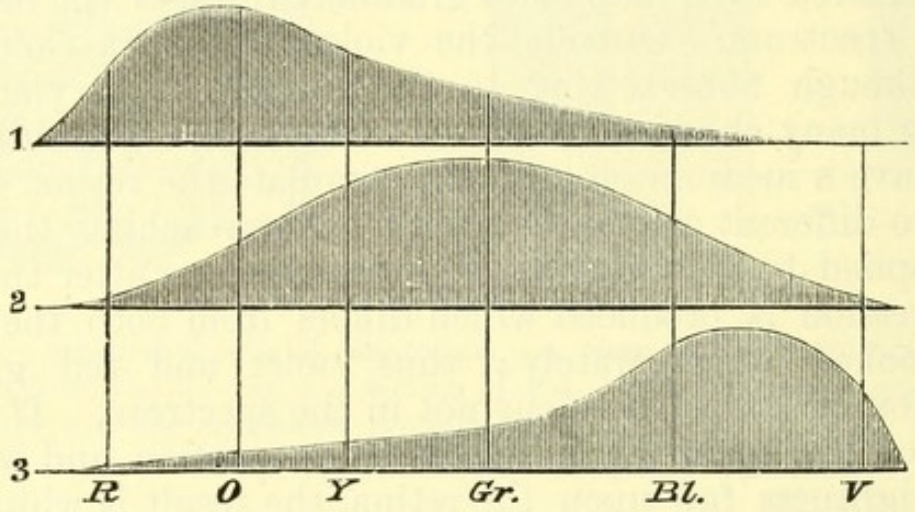


Fig. 219.—Diagram of the three Primary Sensations: 1 = red; 2 = green; 3 = violet.

The letters below are the initials of the colours of the spectrum.

The height of the shaded part gives extent to which the several primary sensations are excited by different kinds of light in the spectrum.

Or we may assume that there are three primary colours which overlap one another in the spectrum so as to produce all the various tints. These are *red*, *green*, and *violet*; the arrangement of which may be diagrammatically explained (Fig. 219).

We must in this case further assume (Young, Helmholtz) that there are in the retina three special sets of nerve terminals, each of which is selectively stimulated by red, green, or violet respectively, and the innumerable shades of colour we see, depend upon mixtures of different strengths of these primary colours, producing different degrees of stimulation of each set of nerve terminals.

The view that such special nerve apparatus exists for red, green, and violet is supported by the fact that the most anterior

or marginal part of the retina is incapable of being stimulated by red objects, which look black when only seen by this part of the retina. This inability to see red may extend over the whole retina, as is found in some persons who may be said to be "red blind." If we investigate our negative after images, after looking for a long time at a red object, we find them to be greenish blue. That is to say, the nervous mechanism for receiving red impressions is fatigued, and that of its complementary colour is easily stimulated.

Mental Operations in Vision.

Our visual sensations enable us to perceive the existence, position, and correct form of the various objects around us. For visual perception much more is necessary than the mere perfection of the dioptric media of the eye, and of the retinal nerve-mechanisms. Besides the changes produced in the retina by light and the excitations in the nerve cells of the visual centre, there must be psychical action in other cells of the cortex of the brain. This psychical action of the brain consists of a series of conclusions drawn from the experiences gained by our visual and other sensations.

Our ideas of external objects are not in exact accord with the image produced on the retina and transmitted to the brain, but are the result of a kind of argument carried on unconsciously in our minds. Thus when no light reaches the retina, we say (without what we call thought) that it is dark; our retina being unstimulated, no impulse is communicated, and the sensation of blackness arises in our sensorium. When luminous rays are reflected to the retina from various objects around us, the physiological impulse starts from the eye, but in the brain, by unconscious psychical activity it is referred in our minds to the objects around us, so that mentally we project into the outer world what really occurs in the eye. So also, from habit, we re-invert in our minds the image which is thrown on the retina upside-down, by the lens, and so unconscious are we of the psychical act that we find it hard to believe that our eyes really receive the image of every thing inverted, and our minds have to reinstate it to the upright position.

One of the most important means employed to enable us to form accurate visual perceptions is the varied motion which the eyeballs are capable of performing.

Movements of the Eyeballs.

The eyeballs may be regarded as spherical bodies, lying in loosely fitted sockets of connective tissue padded with fat, in which they can move or revolve freely in all directions, in a limited degree. The muscles which act directly on the eyeball are six in number. Four *recti* passing from the back of the orbit are attached to the eyeball, one at each side and one above and below, not far from the cornea. These move the front of the eye to the right or left, up or down respectively. Two *oblique* passing nearly horizontally outwards, and a little backwards, are attached to the upper and under surface of the eyeball respectively. These muscles can slightly rotate the eye on its antero-posterior axis, the upper one drawing the upper part of the eyeball inwards, and its antagonist the lower, drawing the lower part inwards, so as to rotate the eyeball in an opposite direction round the same axis.

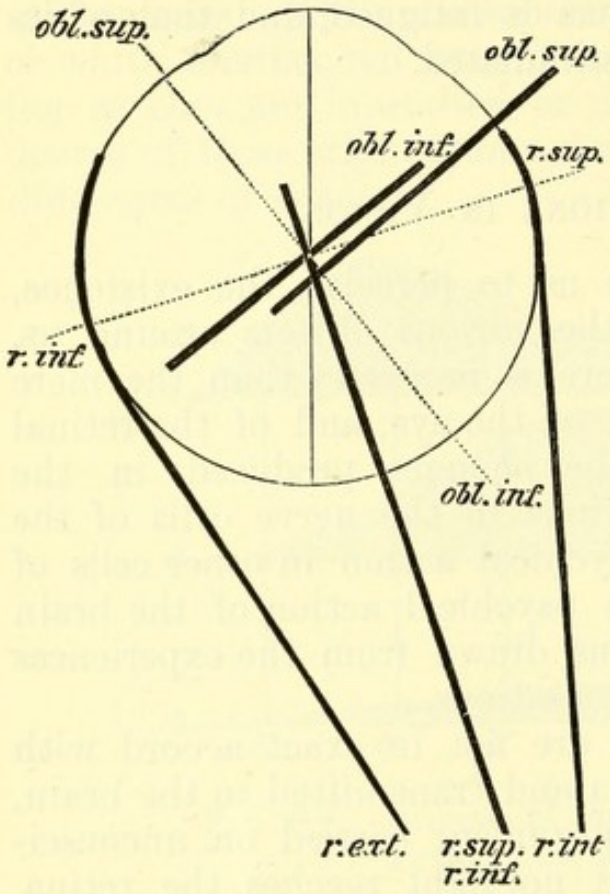


Fig. 220.—Diagram of the direction of action of the muscles of the eyeball, which is shown by the dark lines. The axes of the rotation caused by the oblique and upper and lower recti are shown by the dotted lines. The inner and outer recti rotate the ball on its vertical axis, which is cut across. The abbreviated names of the muscles are affixed to the lines.

The internal and external recti draw the centre of the cornea to or from the median line respectively, directly opposing one another.

As the direction of the superior and inferior recti is different from that of the axis of the eyeball, they draw the outer edge of the cornea, not its centre, up and down respectively and at the same time tend to give the eyeball a slight rotation in the same direction as the corresponding oblique muscles. The tendency to rotation is counteracted by the antagonistic oblique muscle when simple elevation or depression is performed.

Thus pure abduction or adduction only requires the unaided action of the internal or external recti, while direct depression of the eye requires the combined action of the inferior rectus and superior oblique, and direct elevation requires the superior rectus and inferior oblique to act together. The oblique movements are accomplished by various combined co-ordinations of movement of the different muscles.

From the foregoing it is obvious that the simplest movements of the eye require the co-operation of different muscles.

The diagram shows the directions towards which the different muscles tend to draw the eyeball.

In the ordinary movements of both eyes more than this is necessary. Both eyes must move in the same direction at the same time, now to the right, now to the left, so that while the external rectus moves the right eye to the right side, the internal rectus moves the other eye in the same direction. The co-ordination of the movements of the eyeball is so arranged, that the contractions of the external and internal recti of opposite sides must occur together, and are called "associated movements." This associated movement has been acquired by the habit of voluntarily directing both eyes at the same object, and has gradually become involuntary, for few persons have the power of exerting control over the muscles of one eye alone.

Binocular Vision.

When we look at an object with both eyes we have a separate image thrown upon each retina, and therefore two sets of impulses are sent to the sensorium, one from the right and one from the left eye. Yet we are only conscious of the occurrence of one stimulation. The reason of this is, that experience has taught us that similar images thrown upon certain parts of the two retinæ correspond to the same object, and in our minds we fuse the sensations caused by the two images so that they produce but one idea.

These points of the retina which are thus habitually stimulated by the same objects are called "corresponding points."

Besides being of great use in making up for such deficiencies as the blind spots (which are not corresponding points) binocular vision is useful for the following purpcses :—

To judge of *distance*. When using one eye only, some knowledge of distance may be gathered by the force employed

to accommodate, but a much more accurate judgment can be formed when both eyes are used and the muscular sense of the ocular muscles, employed in converging the eye-balls for near objects, gives further evidence of their distance.

In judging of *size*, in the same way, with one eye, we can only have an idea of the apparent size of an object, which will vary with its distance. With a knowledge of apparent size and distance such as is gained by binocular vision, we can come to a fairly accurate conclusion as to the size of an object.

To judge of the relative distances of objects so as to see *depth* in the picture before our eyes, binocular vision is necessary. If one eye alone is used we see a flat picture without having an accurate idea of the relative distances of the different objects. With each eye, however, we get a slightly different view of each object, and thus we are helped to a conclusion as to their exact distances and shapes, and arrive at fairly correct judgments as to their form, &c.

CHAPTER XXXII.

HEARING.

JUST as impulses travelling along the optic nerves can only give rise, in the sensorium, to impressions of light, so impulses passing to the sensorium *viâ* the auditory nerve, can only excite impressions of sound, and any stimulation of that nerve gives rise to sound sensations.

The peripheral end of the special nerve of hearing is distributed to an organ of very peculiar construction situated in the internal ear, which, from its complexity, has been called the *labyrinth*. The nerve-endings are spread out between layers of fluid, so that they must be stimulated by very gentle forms of movement ; and when we consider their delicacy, we cannot be surprised that even sound vibrations suffice to stimulate these terminals and transmit nerve impulses to the brain. The organs of hearing of mammalia are so deeply placed in the petrous part of the temporal bone, that special mechanisms have to be adopted to convey the sound with sufficient intensity from the air to the fine nerve-terminals. These make up a complex piece of anatomy which will be briefly referred to presently.

SOUND.

Before attempting to describe the complex mechanisms by which sound is conveyed from the air to the nerve-endings, some notion must be formed of what sound is from a merely physical standpoint. By means of the sense of hearing we form an idea of sound, and here the knowledge of sound ends with many, since they only think of it as something they can hear. A physicist, however, regards sound in a different way. He knows that it is produced by the vibrations of elastic bodies, such as a tense string, a metal rod, or an elastic membrane. These vibrations, being communicated to the air, are conveyed by it to special nerve-endings, where they set up

a nerve impulse. The impulse is transmitted along the nerve to the brain, and there gives rise to the sensation with which we are familiar as sound.

The vibrations of the air are wave-like movements depending upon a series of changes of density in the gases, the particles of which move towards or from one another, and transmit the motion to their neighbours, so as to propagate the sound wave. To demonstrate these vibrations a special apparatus must be used.

When a tuning-fork is struck it is thrown into vibration, and a sound is given forth. But the vibrations are often so rapid and so small, that the motion of the tuning-fork cannot be appreciated by the eye. But if a fine point be attached to one prong of the tuning-fork—or, indeed, any elastic body, such as a bar of metal—and this point be brought into contact with a moving smoked surface, such as has been already described for similar records, a little wavy line is drawn, showing that the vibrating fork moves up and down at an even and regular rate. Each up and down stroke indicates a vibration. The length of the wave, as drawn on the evenly-moving surface of the recorder, shows the amount of time occupied by each vibration. This is always found to be the same for a tuning-fork of a given pitch, and thus the recording fork is in constant use by the physiologist as an exact measure of small intervals of time. The *pitch* of the note depends upon the *rate* or *period* of vibration, a tone of a certain pitch being simply a sound caused by so many vibrations per second. The quicker the vibration the higher the note, and the slower the deeper, until at the rate of about thirty per second, no sound is audible. Whether a note be produced by a metal fork, a tense string, or any other vibrating body, if the number of vibrations per second be the same, the note has the same pitch.

The elevation of each vibration as seen in the tracing made by a recording fork is different at different times. When the fork is first struck, the waves are high and well marked; the excursions of the recording prong become less and less extensive as the fork gradually ceases to vibrate, and the sound diminishes; or in other words, as the sound produced becomes fainter, the vibrations become smaller. The amount of excursion made by the vibrating body is spoken of as the *amplitude* of the vibration, and upon it depends the *loudness* or intensity of the sound. The pitch of a tone bears no relation to the amplitude of the waves of vibration, but depends upon their

rate ; while its loudness is quite independent of the period occupied by the vibrations, but is in proportion to the square of the amplitude of the waves.

So far only *tones* or musical notes have been mentioned. They are produced by vibrations occurring at perfectly regular periods. The simpler and more regular the vibrations, the purer the tone. The great majority of the sounds we are accustomed to hear are not pure tones, but are the result of an association of vibrations bearing some relation to one another. When the variety of vibrations is very great, their intervals irregular and out of proportion, they give rise to a discordant sound called a noise. So long as such commensurability exists in the rate of the vibrations as to produce a sound not disagreeable to the sense of hearing, it may be called a note.

By the use of a series of different resonators, each of which is capable of magnifying a certain tone, it can be shown that the clearest and purest notes of our musical instruments are far from being simple tones, but are really compounds of one prominent note or fundamental tone, modified by the addition of numerous *over-tones* or *harmonics*. If one blows forcibly across an orifice leading to a space in which a small amount of air is confined, such as the barrel of a key or the mouth of a short-necked flask or bottle, either a clear shrill or dull booming sound is heard, which varies in pitch according to the proportions of the air-containing cavity. This dull note is a simple tone. It is devoid of character, and in this respect differs greatly from the notes produced by a musical instrument. The notes of every instrument have certain characters or *qualities* which enable even an unpractised ear to distinguish them.

This *quality*, which is independent of the pitch (*i.e.*, rate of vibration), or the intensity (*i.e.*, amplitude of wave), is called the *colour* or *timbre* of the note. It depends on the number, variety, and relative intensity of the over-tones or harmonics, which accompany the notes. So that really the *timbre* or quality of a note, and therefore the special characters of the different musical instruments, is produced by their impurity, or the complexity of the over-tones which aid in producing them.

All elastic bodies can vibrate, and therefore are capable of conducting sounds. Sound vibrations can be transmitted from one body to another placed in contact with it. From a hard material the waves are readily communicated to the air, and

this is the ordinary medium by means of which sound is transmitted to our organs of hearing. In the old experiment of placing a small bell under the glass of an air-pump, and making the tongue strike after the air has been removed, the fact that no sound is produced shows that the medium of the air is essential for the transmission of sound-vibrations.

The transmission of waves of sound from the air to more dense materials, such as those which surround our auditory nerve-terminals, takes place with much greater difficulty than that from a solid to the air, and we find a variety of contrivances by which the gentle air-waves, arriving at the ear, are collected and intensified on their way to the labyrinth.

The medium of the air is not necessary in order that sound may reach the internal ear. Nor is the route through the outer canal, and the drum and its membrane, the only one by which the vibrations can arrive at the cochlea. The solid bone which surrounds the labyrinth is in direct communication with all the bones of the head, and sound can travel along these bones, and reach the nerve-endings. This can easily be proved by placing the handle of a vibrating tuning-fork against the forehead, or better still against the incisor teeth. The sound, although previously hardly audible, at once becomes quite distinct, or even appears loud.

This direct conduction through the bones of the head is, under normal conditions, of little use to man ; but attempts have been made, in cases where the ordinary auditory passages were rendered inefficient by disease, to gather the vibrations on an elastic plate, and apply this to the teeth. This direct conduction of sound is very valuable in determining the seat of disease in cases of deafness. So long as a clear sensation of sound reaches the brain through the bones of the head, we know that the important nerve-endings and their central connections are unimpaired, and conclude that the disease lies in the mechanical conducting parts of the hearing organ.

In fishes, where the labyrinth is the only existing part of the auditory apparatus, it is embedded in the cranium, and the sound waves arriving through the medium of water, are directly conveyed to the nerve-endings by the bones of the head. An air-containing tympanum would rather impede the hearing of these animals.

The parts of the ear through which sound passes before it reaches the nerve, are separated into three departments, viz.:—

(1) the auditory canal and external ear ; (2) the middle ear, tympanum or drum, which is shut off from the air by the tympanic membrane ; and (3) the labyrinth.

Conduction of Sound-vibrations through the External Ear.

External ear.—In man, the muscles are so poorly developed that he can hardly move the external ear or pinna perceptibly, and the part commonly called the ear is of little use. We know this, because the outer ear may be quite removed without materially affecting the power of hearing. The sound reflected from the pinna may be excluded, without reducing the intensity of that heard, by placing a little tube in the auditory canal. Birds hear well without any outer ear. But the moveable ears of many animals are, no doubt, useful in helping them to ascertain the direction of a sound by catching more of the vibrations coming towards their pinna. That the external ear may be of some use, even to man, one is led to believe, by the natural readiness with which a person with dull hearing supplements it by means of his hand. In this act the ear is pushed away from the head to an angle of about forty-five degrees, and its projection is considerably increased.

External auditory meatus.—The auditory canal is a crooked and irregular passage, getting rather wider as it approaches the tympanic cavity. It is the seat of some short, stiff hairs, which help to prevent the entrance of foreign matters. It is supplied with a peculiar modification of sweat glands, which secrete a waxy material that helps to keep the walls of the canal and the outside of the membrane moist and soft.

The elastic column of air in any circumscribed space resounds more readily to some one tone, varying according to the capacity of the space ; thus resonators of different pitch are formed. Different tubes give different notes when blown into, so the auditory canal has a note of its own, and if the canal be short, the note is one of very high pitch. When a tone of the same pitch as that to which the canal is tuned strikes the ear, it is unpleasantly magnified, and such sounds are called shrill and disagreeable. Upon the more ordinary sound-vibrations, however, the auditory canal has little or no effect.

Conduction of Sound-vibrations through the Tympanum.

The end of the auditory canal is closed by the *membrana tympani*, which slopes obliquely from above downwards and inwards, in which direction its size is greater than if it were straight across the canal. This membrane is not flat, for the central point is drawn in by the handle of the *malleus*, which is firmly attached to it. The membrane is thus held in the shape of a very blunt cone, somewhat like a Japanese umbrella, the apex of which points inwards towards the cavity of the drum. The peculiar form of the membrane of the drum is of great importance for distinct hearing.

As every confined volume of air has a certain *proper tone* to which it resonates readily, so a membrane of a given size and tension has a proper tone (*self-tone*), the vibration period of which it follows naturally. This tone varies with the tension, as may be seen in a common drum, the note of which can be changed with the tension of its parchment; the tenser the membrane, the higher the pitch. If the membrane of the drum of our ears were set to one tone, our hearing would be imperfect and unpleasant, for we should be wearied by the reiteration and persistence of the one note. This does not occur; the tympanic membrane has no marked self-tone, and no succession of vibrations follows the first effect of the sound waves.

Any self-tone is prevented by the conical shape of the membrane, which is partly due to the traction of the handle of the malleus. If a stretched membrane, such as that of a drum, be drawn out at its centre, so that it is no longer a flat surface, its tension is different at the centre and the periphery, being greatest at that point at which it is drawn, and gradually decreasing towards the margin. Since the existence of a tone of a definite pitch depends upon a certain degree of tension, if no two parts of the membrane are similarly tense, no one tone can be more conspicuous than another. This is the case with the tympanic membrane.

The independent vibrations of the membrane are further prevented by the tympanic ossicles. These little bones do not vibrate molecularly, but move *en masse* in time with the sound-vibrations which they deaden. If a substance incapable of vibrating be attached to the membrane of a common drum, it

ceases to vibrate. A touch of the finger to the membrane suffices to check the sound produced by a drum. The handle of the malleus, which is joined to the other bones, being fixed to the membrane, acts in this way as a damper, and checks the continuance of any vibration in the membrana tympani.

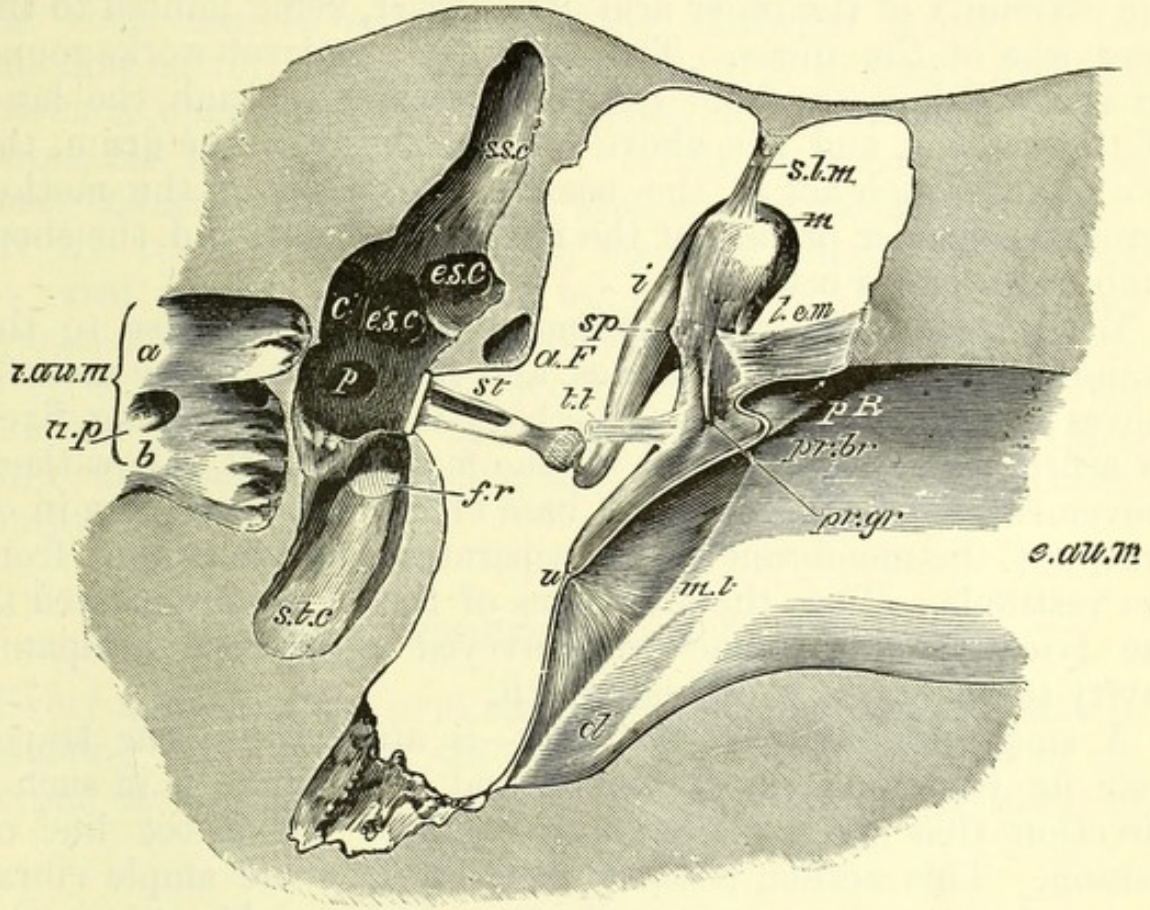


Fig. 221.—Diagram of the tympanum, showing the relation of the ossicles to the tympanic membrane and the internal ear. The tympanum is cut through nearly transversely, and the cavity viewed from the front (left ear). (Schäfer.)

Membrane, *m.t*, of the drum to which the handle of the malleus, *m*, is attached at *u*. Head of malleus, *m*, which is held in position by its suspensory ligament *s.l.m.*, and external ligament *l.e.m.*; long process of incus, *i.*, connecting malleus and stapes *s.t.*, the base of which closes the oval opening of the vestibule *p*. External auditory meatus *e.au.m.* Internal auditory meatus *i.au.m*, where the two parts of the auditory nerve enter, *a* and *b*.

A small muscle, called the tensor tympani, is attached to the malleus, so as to draw it towards the cavity of the tympanum.

The motions occurring in the membrane of the drum are conveyed across the tympanic cavity by means of the three small bones known as the *malleus*, the *incus*, and the *stapes*.

These ossicles form an angular lever, one arm of which (the handle of the malleus) is attached to the centre of the tympanic membrane, and the other shorter arm (the long limb of the incus) unites with the stapes, the base of which is held by the secondary tympanic membrane in the oval opening leading into the vestibule. The stapes is attached at right angles to the extremity of the inner arm of the lever, being jointed to the long arm of the incus. This little angular lever works round an axis which passes from before backwards through the head of the malleus, and lies above the membrane of the drum, the two points which act as the bearings or pivots of the motion being the slender process of the malleus in front, and the short limb of the incus behind.

When the tympanic membrane vibrates in response to the sound waves of the air, it moves, and the handle of the malleus moves in and out with it. The body of the incus, being fixed by a firm joint to the head of the malleus, must follow these movements, and cause the oval base of the stapes to press in or draw out the membrane which separates the tympanum from the vestibule. Thus the vibrations of the air communicated to the tympanic membrane are conveyed across the tympanic cavity to the liquid in the labyrinth.

A small muscle—the stapedius—is attached to the stapes near its junction with the incus, and pulls upon it in such a direction that the bone is drawn out of the direct line of motion. This action, possibly, reduces the more ample vibrations of the tympanic membrane, which might injure the delicate mechanism of the labyrinth.

Eustachian Tube.

The tympanum is connected with the pharynx by means of the Eustachian tube which, though habitually closed, is opened for a moment, by swallowing and other motions of the pharynx. On these occasions air can pass in or out of the tympanum, so that the pressure on both sides of the membrane of the drum is equalised. When there is too much or too little air in the tympanic cavity, the tympanic movements are impeded. This difficulty is felt during a cold in the head, when the tube is occluded, and the oxygen being absorbed, the pressure in the tympanic cavity is reduced. Or in performing what is known as Valsalva's experiment, *i.e.*, holding the nose and blowing air into it, whereby the Eustachian tubes are opened, and too much air

is often retained in the tympanum, so that the pressure from within is higher than that from without, and hearing becomes dull. If the act of swallowing be then performed, the feeling of tension leaves the ears as the excess of air escapes, and hearing becomes as acute as before.

The Eustachian tube also acts as a way of escape for any fluid that may be secreted by the epithelial lining of the tympanic cavity. The amount of fluid is so small, that the occasional opening of the tube suffices, under ordinary circumstances, for its complete escape. When increased by disease, it may collect in the tympanum, and require catheterisation.

If the tubes were permanently open, we should suffer from two great disadvantages. At every breath, during ordinary respiration, some change in tension of the air contained in the cavity of the drum would occur and impair hearing; the vibrations of the air in the pharynx, produced by the voice, would enter the drum directly, and give rise to an exaggerated shouting noise.

Conduction through the Labyrinth.

Every motion of the oval base of the stapes causes a wave to pass along the liquid in the labyrinth. The bony case of the internal ear being firm, the wave travels through all parts of

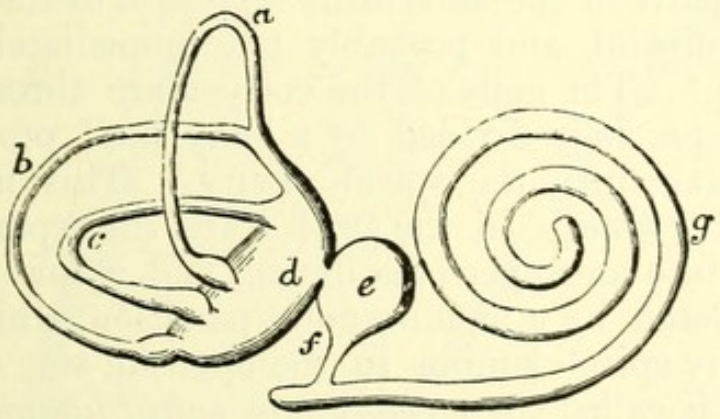


Fig. 222.—Diagram of the membranous labyrinth, all of which is filled with endolymph and surrounded by perilymph. *a*, *b*, *c*, semicircular canals opening into the ventricle *d*; *e*, the saccule from which the uniting canal, *f*, leads into the membranous canal of the cochlea, *g*. (Cleland.)

the internal ear. Through the *cochlea* it arrives at the *inner tympanic membrane* which closes the *fenestra rotunda*, and separates the cavity of the tympanum from the scala tympani of the cochlea. The waves have a very complex route in

passing from the *fenestra ovalis* closed by the stapes to the membrane closing the cochlea. By means of the liquid lying around the membranous labyrinth—*perilymph*—the waves pass up the *vestibular spiral* of the cochlea, and arriving at its summit, they descend by the *tympanic spiral* to the fenestra rotunda. In this course they pass over and under the fluid—*endolymph*—contained in the membranous canal of the cochlea in which the special nerve terminations are placed.

For the construction of the labyrinth the student is referred to the text-books of anatomy, as space only admits of a brief account of the special arrangements of the nerve-ending.

Terminals of the Auditory Nerve.

The nervous mechanisms which are most important for the appreciation of tones are those situated in the cochlea.

The nerve-endings found in the membranous sacs in the vestibule are connected with peculiar epitheloid cells, to which are attached fine bristle-like processes. These processes lie in the *endolymph*, and are related to calcerous masses called *otoliths*. Waves in this endolymph possibly bring the otoliths into collision with the hairs, and thus give a stimulus to the nerve-endings. Noises may be heard from this, but no impressions of tone can be appreciated. The use of the nerves going to the other parts of the labyrinth—*ampullæ* of the *semicircular canals*—is doubtful, and probably not immediately connected with hearing.* The coils of the cochlea are throughout their entire length partially divided by a bony shelf projecting from the central axis into the spiral cavity. This is called the *osseous spiral lamina*. In the fresh state the separation of the spiral canal into an upper (vestibular) and a lower (tympanic) coil is completed by a membranous partition, which stretches from the bony spiral lamina to the opposite side of the spiral canal. This is called the *membranous spiral lamina*, and forms the base upon which the special nerve-endings of the organ of hearing are placed. An extremely delicate membrane called the *membrane of Reissner* stretches from the upper side of the spiral partition obliquely upwards to the outer wall of the spiral cavity, so as to form a canal and cover the special organ, shutting off a portion of the vestibular coil which lies over the

* Compare equilibration, in connection with which they will be described.

membranous spiral lamina. The *canal of the cochlea* thus formed is triangular in section. Its floor is made up chiefly of

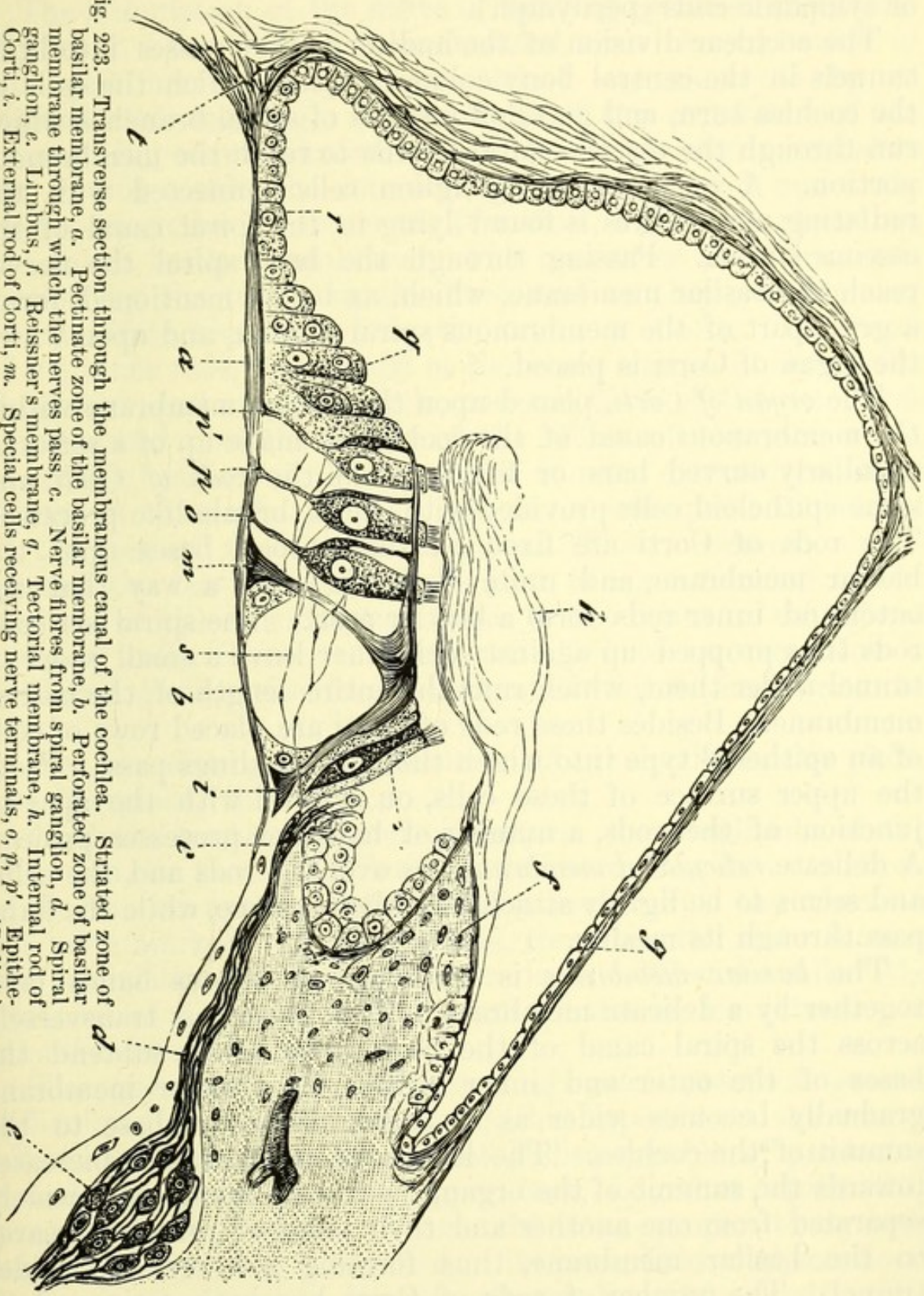


Fig. 223.—Transverse section through the membranous canal of the cochlea. Striated zone of basilar membrane, *a*. Pectinate zone of the basilar membrane, *b*. Perforated zone of basilar membrane through which the nerves pass, *c*. Nerve fibres from spiral ganglion, *d*. Spiral ganglion, *e*. Limbus, *f*. Reissner's membrane, *g*. Tectorial membrane, *h*. Internal rod of Corti, *i*. External rod of Corti, *m*. Special cells receiving nerve terminals, *o*, *p*, *p'*. Epithelial cells covering the basilar membrane, *q*. Nerve fibres, *s*. Spiral ligament, *t*. (Cadiat.)

the membranous spiral lamina, particularly the part called the *basilar membrane*, while the oblique roof is composed of only the thin membrane of Reissner. The canal follows the turns

of the cochlea, lying between the vestibular coil and that leading to the tympanum, and is filled with a fluid (endolymph) which is quite separate and distinct from that in the vestibular or tympanic coils (perilymph).

The cochlear division of the auditory nerve passes into little tunnels in the central bony column around which the coils of the cochlea turn, and gives off a series of spiral branches which run through the osseous spiral lamina to reach the membranous portion. A collection of ganglion cells connected with the radiating nerve-fibres is found lying in the spiral canal of the osseous lamina. Passing through the bony spiral the nerves reach the basilar membrane, which, as before mentioned, forms a great part of the membranous spiral lamina, and upon which the organ of Corti is placed.

The *organ of Corti*, placed upon the basilar membrane within the membranous canal of the cochlea, is made up of a series of peculiarly curved bars or fibres, called the *rods of Corti*, and some epitheloid cells provided with short, bristle-like processes. The rods of Corti are fixed by their broad bases upon the basilar membrane, and unite above in such a way that the outer and inner rods form a bow or arch. The spiral series of rods thus propped up against each other leave a small space or tunnel under them, which runs the entire length of the basilar membrane. Besides these rods of Corti are placed rows of cells of an epithelial type into which the nerve-endings pass. From the upper surface of these cells, on a level with the apex or junction of the rods, a number of hair-like processes project. A delicate *reticulated membrane* lies over the rods and the cells, and seems to be lightly attached to their surface, while the hairs pass through its meshes.

The *basilar membrane* is made up of fibrous bands held together by a delicate membrane. The fibres pass transversely across the spiral canal of the cochlea, so as to subtend the bases of the outer and inner rods. The basilar membrane gradually becomes wider as it passes from the base to the summit of the cochlea. The length of the rods also increases towards the summit of the organ, their bases being more widely separated from one another and their point of junction nearer to the basilar membrane, thus forming a lower and wider tunnel. The number of rods of Corti has been estimated at 6,000 inner, and 4,500 outer.

Stimulation of the Auditory Nerve.

The stimulation of the nerve of hearing by sound-vibrations of the air is less difficult to understand than the excitation of the optic nerve by light-waves which are conveyed by an imponderable medium. The motions of the membrane of the drum, being communicated in the manner already indicated to the liquids within the internal ear, pass over and under the cells connected with the nerve terminals, which are placed on the elastic basilar membrane. The transverse fibres are set in motion by the waves in the fluid, and as they vibrate they communicate the motion to the organ of Corti. The bases of the inner rods, being fixed at the inner margin of the basilar membrane, can move but little, and the bases of the outer rods being placed near the middle of the fibres of the membrane, where the motion of the vibrations is most extensive, a slight change in their relative positions, and a consequent movement of the apex of the bow takes place. This movement at the apex of the bow, where the rods join, is communicated by the medium of the reticular membrane to the hairs in the special auditory cells, thence to the nerves, where an excitation is produced giving rise to the transmission of an impulse to the brain.

We can distinguish differences of (1) loudness, (2) pitch, and (3) quality in sounds.

Since the *loudness* depends simply on the amplitude of the vibration, we have no difficulty in understanding how variations in it can be appreciated, since the more ample the vibration the more marked the motion, and, therefore, the more intense the stimulation of the nerve terminals. What we called the loudness of a sound simply means greater or less intensity of stimulation of the nerve.

The perception of difference of *pitch* presents greater difficulty. As already mentioned, this depends on the rate of vibrations. We know that most bodies capable of producing sound vibrations have a proper tone, *i.e.*, that which they produce when struck. When the tone proper to a body capable of vibrating is sounded in its immediate neighbourhood, it also is set vibrating through the medium of the air. If a clear tone be sung loudly over the strings of a piano, a kind of sympathetic echo will be heard to come from the strings corresponding to the notes sounded. In the basilar membrane we

have practically a series of strings of different length—since the membrane gets wider as it passes from below upwards to the summit of the cochlea—and therefore a great variety of proper tones. With a high note a fibre of one part of the membrane will readily fall into vibration, and with a low note a fibre of another part. Different nerve fibrils are in relation to these different parts, and we may conclude that tones of different pitch stimulate distinct nerve-terminals, and are conveyed to the brain by separate nerve-channels. Impulses arriving at certain brain-cells give rise to the idea of high tones, and impulses coming to others cause the impression of low tones. There are about a sufficient number of fibres in the basilar membrane for all the notes we can hear, viz., from about 33 to 38,000 waves in the second.

The rods of Corti cannot be the essential vibrating agents for receiving the motion, because they are absent in birds which appreciate and reproduce various notes ; and they are too few for the notes we hear. Further, the rods are not elastic, and not well suited for vibration. It may therefore be concluded that they only act as levers which convey the vibrations of the fibres of the basilar membrane to the nerve-endings in the auditory cells.

The explanation of our wonderful appreciation of the delicate shades of *quality* of tone is still more difficult. Even persons with indifferently good ears, as musicians say, and no special musical education, can at once distinguish between the quality of the same note when sounded on a violin, a piano, and a flute. When a note is sung against the strings of a piano, however pure its tone, a great number of strings are set vibrating. Not only does the string of that note vibrate, but also all those that have a certain simple numerical relation to its vibrations. In fact, all its over-tones resound. In the cochlea we suppose the same to take place with the fibres of the basilar membrane. Not only does the one fibre whose proper tone is sounded vibrate in response, but also all those which represent the varied over-tones or harmonics. It has already been pointed out that the *quality* of a tone depends on the relative number, force, and arrangement of harmonics, which invariably accompany a musical note with a definite character.

When a note arrives at the auditory nerve-terminals, one of these is strongly stimulated by the fundamental tone, and many others slightly by the different over-tones. The com-

plexity of the impression increases with the impurity of the tone. Thus, a crowd of impulses, corresponding to a congeries of tones of varying intricacy, is transmitted to the brain-cells, by which it is analysed. It then gives rise to the conception of some special quality such as we, by experience, associate with a violin, flute, or piano, as the case may be.

With regard to the judgment of the distance of sound, it need only be remarked that it chiefly depends on former experience of the habitual quality and intensity of sound. A faint sound with the same quality that we familiarly attribute to loud sound seems to us to be far away. Thus, sounds reaching our labyrinths by the cranial bones appear distant, and ventriloquists deceive us by imitating the character of distant sounds.

The direction from which sound comes is chiefly judged by the difference of intensity with which it is heard by one or other ear. When we cannot form any idea of whence a sound comes we turn our heads one way or the other in order to present one ear more directly to the origin of the sound. When a sound is either directly behind or before us we cannot judge from which position it really comes, unless the head be slightly turned to one side or the other before the vibrations have ceased to be audible.

CHAPTER XXXIII.

CENTRAL NERVOUS ORGANS.

THE central part of the nervous system, or *cerebro-spinal axis*, consists of the "spinal cord" (*medulla spinalis*), the "bulb" (*medulla oblongata*), and the "brain."

The central nervous organs are composed of nerve-cells and nerve-fibres, held together by a peculiar and very delicate form of connective tissue, known as *Neuroglia*. In this nervous tissue two distinct kinds of substance can be recognised: (1) *a white substance*, composed of unbranched cell-processes, or nerve fibres, with a medullary sheath, and (2) *a grey substance*, consisting of a dense feltwork of branched cell-processes, either naked axis cylinders, or fibrils with a fine myelin-sheath, with numerous ganglion cells interspersed between them.

In the brain the grey substance is distributed chiefly on the surface, forming a kind of grey *cortex*, which follows all the irregularities of the convolutions.

In the spinal cord the grey matter is situated inside, and the white outside. If viewed longitudinally the grey substance of the cord forms separate columns on either side, which extend throughout its entire length and are considerably thicker in the cervical and lumbar regions. These grey columns, together with their connections with the roots of the spinal nerves, divide the white substance of the cord into more or less distinct regions called the posterior and antero-lateral white columns.

The structure and general properties of the elements of nervous tissue have been described in Chapter XXVII. The functions there enumerated belong also to the fibres and cells of the cerebro-spinal axis, and therefore require no further general description here.

Besides having the power of *conducting*, *reflecting*, *co-ordinating*, *inhibiting*, *retaining*, and *originating* impulses, we must attribute to the activity of the nerve-cells of the brain the various mental phenomena, such as feeling, thought,

volition, memory, &c., forms of activity which may be excited either by impulses arriving from without, or by the automatic action of the cells of the cerebral cortex.

The Spinal Cord.

The spinal cord being the great bond of connection between the brain and the majority of the peripheral nerves, is necessarily a *conductor* of the first importance. From the quantity of nerve-cells lying in its grey matter, it must also exercise the function of a governing organ. It may be regarded as consisting of a longitudinal series of *segments*, containing nerve centres of two kinds, reflex and automatic, enclosed by white substance.

White Matter of the Cord.

Methods of Investigation.

Anatomical methods.—Anatomical investigation shows that the spinal cord is not merely a collection or aggregation of the fibres that pass into it. In the first place, the spinal nerves, if bundled together, would be much larger than the cord, even at its thickest part ; and secondly it does not taper evenly towards its lower extremity, as it should were each succeeding pair of roots a direct loss of thickness. The question then arises how are the fibres of the spinal nerves disposed of in the cord.

The *posterior roots* of the spinal nerves pass through the white substance to reach the posterior grey column, where they are distributed to neighbouring parts of the grey substance in which they are lost, without their union with the cells being obvious or immediate. Others pass into the posterior white columns to reach distant segments of the cord.

The fibres of the *anterior roots*, traverse the superficial white part of the cord in irregular bundles on their way to reach the anterior grey columns, into the cells of which many can be directly traced. The other processes from these cells pass into the fibrillar network, which makes up the great mass of the grey substance and is in communication with the distant parts of the cord and brain. The fibres of each anterior root spring from the cells of one spinal segment only.

Anatomy may thus be said to leave us in the dark in regard to the paths traversed in the cord by the impulses on their way to or from the root of the spinal nerves.

Histology teaches us that the grey and white matter of the cord consist respectively of—(1.) Innumerable fibrils and cells, and (2.) Medullated fibres variously connected with the different groups of cells and the roots of the spinal nerves.

Since ordinary histological research fails to show the complex connections of the fibres of the spinal cord, other methods have been resorted to in attempting to discover their course. Of these the two following have given good results :—

Developmental method.—The medullary sheath of the fibres in different white tracts of the cord is perfected at different ages of an animal, and Flechsig found that by tracing the course of the imperfectly developed fibres the functional relations of certain tracts could be arrived at. The main conclusions thus determined are ; the first fibres to appear are the root-fibres, connecting the cord with the periphery, the sensory earlier than the motor ; the second series to appear are those intercentral fibres which connect the nerve cells at different levels in the grey matter ; the third series formed are the afferent fibres carrying centripetal impulses from the cord to the bulb, cerebellum and cerebrum ; the last to develope are the pyramidal tracts which convey impulses from the cortex to the cord. It is here important to notice that these latter fibres only appear as the cortex is being developed, and they grow downwards, pushing their way through the other tracts, thus confirming the evidence of their function, derived from the study of other methods (Fig. 224).

Degenerative method.—We believe that every nerve fibre has in some part of its course a nerve cell which provides for its nutrition. In other words, we may regard a nerve fibre simply as a long process of a cell protected by a sheath. If then the fibre be divided, that part cut away from the nerve cell degenerates. If one half of the cord be cut across, a degenerative process (*sclerosis*, finally forming scar-tissue), soon follows the section in certain tracts, and is easily recognised histologically. By carefully tracing the course of the degenerated tracts, after section or pathological lesion, their connections with other parts of the nervous centres can be determined. On studying their distribution, two large areas of degeneration are found in the part of the cord below the lesion ; and in the part above, there are three chief areas, differing in position from those in the lower portion.

On comparing these facts with knowledge obtained by other methods, the "Wallerian Law of Degeneration" has been

framed, viz.—That, in the cord, fibres degenerate in the direction in which they normally carry impulses. Looked at from another point of view, we may state it as follows :—In the cord, fibres which carry afferent impulses have their trophic centres at their lower extremity, while those carrying efferent impulses have them at their upper extremity. Every extension of our knowledge tends to corroborate this view.

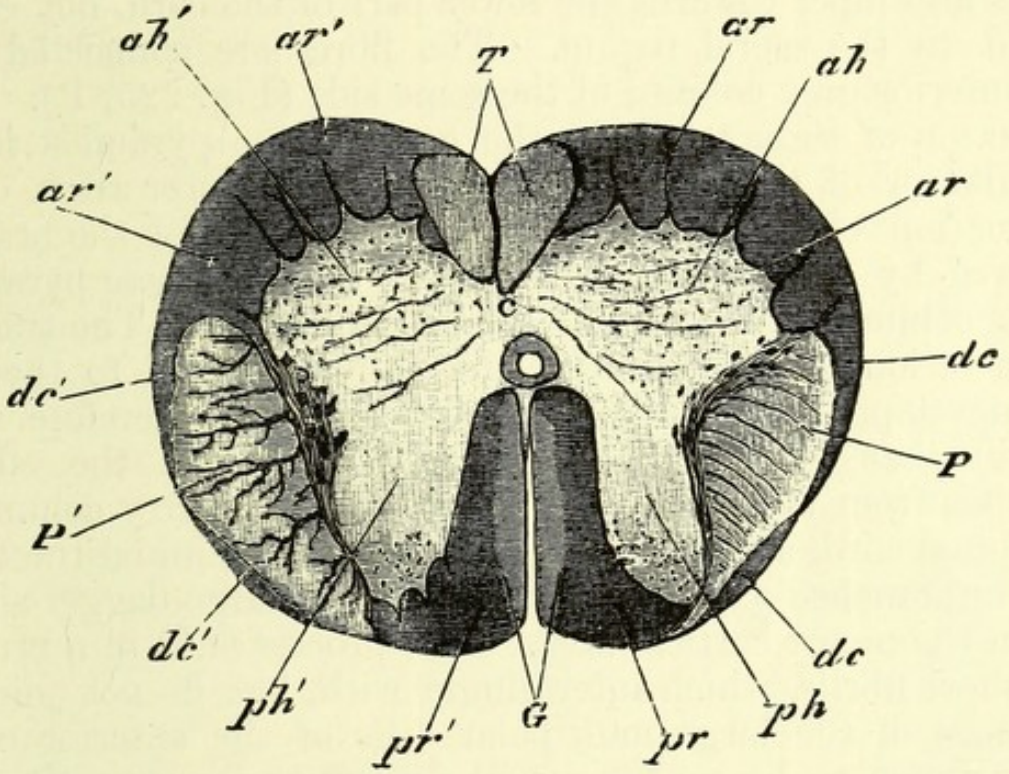


Fig. 224.—Transverse section of the spinal cord of embryo at five months.

G. Columns of Goll. *T.* Direct pyramidal tracts. *P.* Crossed pyramidal tracts. *dc.* Direct cerebellar tract ; *ar.* Anterior root zones ; *pr.* Posterior root zones ; *ah.* Anterior grey column ; *ph.* Posterior grey column.

By these methods the following tracts of white fibres have been made out in the spinal cord :—

I. Tracts showing descending degenerations, *i.e.*, those carrying efferent impulses. There are three of these in each lateral half of the cord, viz. :—

1. The *direct pyramidal tracts* (Türck) (Fig. 225, T), each of which is continuous with the pyramid on the *same side* of the medulla oblongata. They lie on the inner aspect of the anterior white column, and form the immediate boundaries of the anterior median fissure. These tracts taper from above downwards, and terminate about the middle of the dorsal region. The fibres leaving them appear to cross by the

anterior commissure to reach the anterior grey column of the opposite side. This tract is found only in man.

2. The *crossed, or lateral pyramidal tracts* (Fig. 225, P) are continuous with the pyramids of the *opposite side* of the bulb where the crossing of the fibres is completed. They lie in the lateral white columns, occupying their posterior part next to the posterior grey columns, and are separated from the surface by the direct cerebellar tract (*dc*). The crossed pyramidal tracts also taper towards the lower part of the cord, but can be traced to the sacral region. The fibres are connected with the anterior grey column of the same side (Fig. 225, P).

Section of these tracts in the cord, of the pyramids in the medulla, or of the fibres leading from the motor areas, or the destruction of the motor areas in the cortex of the brain, is followed by descending degeneration of both these pyramidal white columns extending to their termination. The tracts of degeneration correspond with the limits assigned to them by the developmental method of research. It therefore seems certain that they are the channels by which the efferent impulses from the brain travel to the anterior grey columns of the spinal cord, and that each fibre of the pyramidal tracts is a long unbranched axis-cylinder process of a large dagger-shaped cell in the motor cortical area. This process ends in a brush of fine short fibrils, which intermingle with, but do not join, the processes of the large multipolar cells of the anterior cornu. There seems to be no functional difference between the fibres of the crossed and the direct pyramidal tracts.

Fig. 225.—Diagram of four transverse sections of the spinal cord in the regions of 3rd and 6th Cervical, 6th Dorsal, and 4th Lumbar nerves, showing the relative positions and amounts of the more important tracts in each region, and the course of a fibre of the best known routes.

The *dotted area* = Long descending tracts. The *linear shading* = Long ascending tracts. C.iii. 3rd Cervical; C.vi. 6th Cervical; D.vi. 6th Dorsal; L.iv. 4th Lumbar.

Descending tracts—

P. *Pyramidal* tract extending to end of cord, and becoming smaller and more superficial below.

T. Türk's tract (*direct pyramidal*) tapering to nothing about mid-dorsal region.

Ascending tracts—

Gl. Goll's column (*posterior median*).

Cb. Direct or *dorsal cerebellar* tract, increasing from dorsal region upwards—absent in lumbar region.

Gr. Gower's tract (*ventral cerebellar*) increasing from lumbar region upwards.

L. Lissauer's tract.

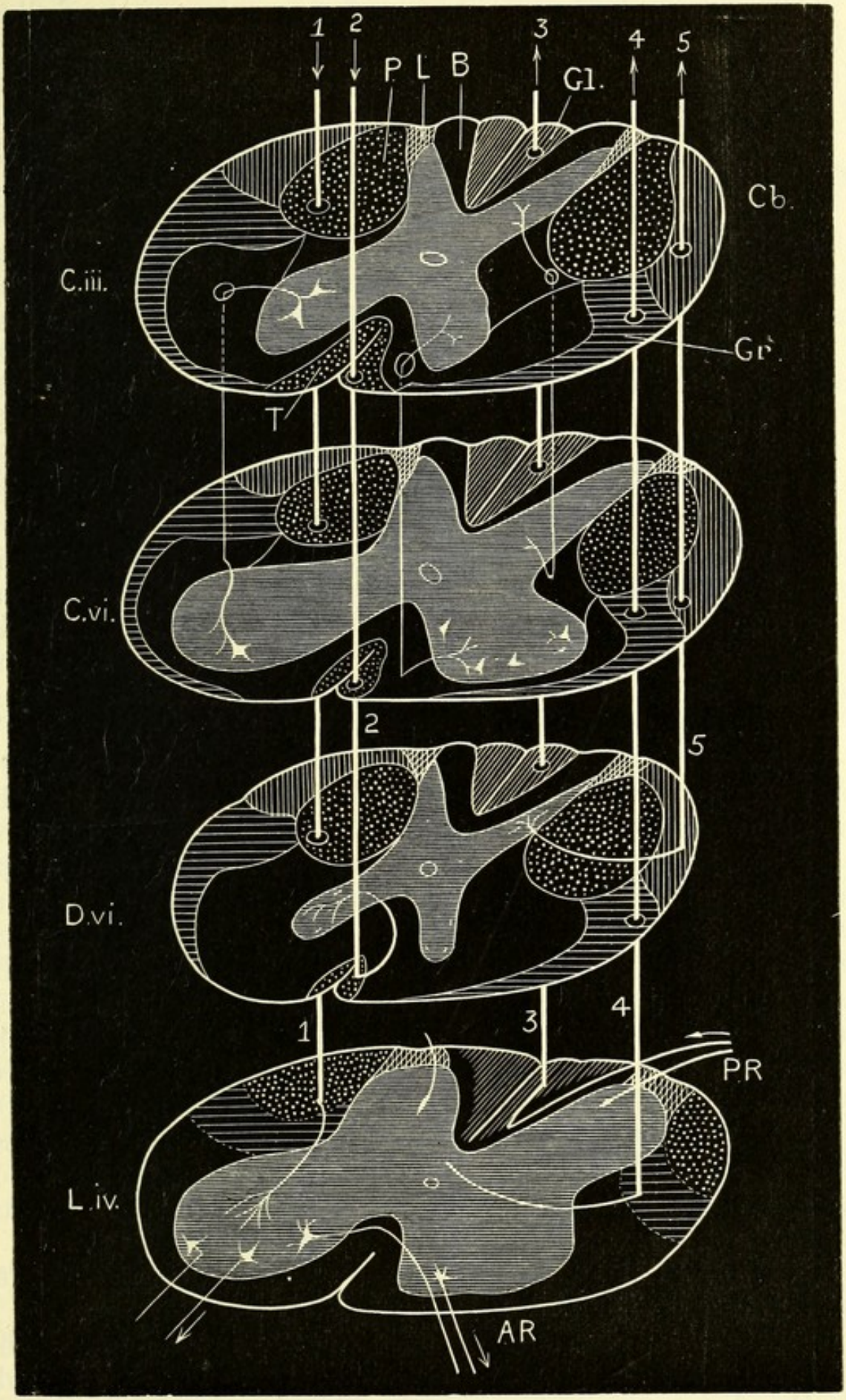


Fig. 225.

3. The *descending cerebellar tract* forms a large set of fibres situated in the antero-lateral column in close relationship to Gower's tract. They are uncrossed, *i.e.*, pass from right half of cord to right side of cerebellum.

II. Tracts which show ascending degeneration and carry afferent impulses. There are three of these on each side, viz. :—

1. The *posterior median column* (Goll) is a thick strand of white fibres, triangular in section (Fig. 225, Gl), which forms the immediate boundary of the posterior median fissure. This tract can be traced along the whole length of the cord. Below it has intimate relations with the nerve roots, as will be described later, and above it terminates in the nucleus gracilis of the bulb. It gradually increases in size from below upwards.

2. The *dorsal cerebellar*, or direct cerebellar, is a narrow tract, which begins somewhat suddenly at about the level of the upper lumbar nerves, and lies on the surface of the cord covering the crossed pyramidal tract (Fig. 225, Cb). It increases in size as it is traced upwards, still retaining its flattened shape, and consists chiefly of nerve fibres of very large diameter. The fibres are believed to originate from the cells of Clarke's vesicular column (see below). Above they are traced into the inferior peduncle of the cerebellum, and are lost in the region of the vermis.

3. *Ventral cerebellar*, the ascending antero-lateral, or Gower's tract. Fibres forming the commencement of this tract can be traced lower down in the cord than is the case with the preceding tract. It forms a narrow layer on the surface of the antero-lateral region of the white matter, extending from between the crossed pyramidal and the dorsal cerebellar tracts, almost to the anterior median fissure (Fig. 225, Gr). At first the tract consists only of a few fibres scattered over this region, but as we trace it upwards the fibres become much more numerous. It has connections below with nerve-cells in the grey matter, the position of which we do not know. Above, it has been traced through the bulb to the region of the pons, where it curls round, forms a part of the superior peduncle of the cerebellum, and is lost in the region of the dentate nucleus. It is developed much later than the direct cerebellar tract.

III. We still have remaining a large amount of the white matter which is disposed in two areas :—

1. *Anterior root zone* is the name given to remainder of the white substance of the anterior white columns after excluding the direct pyramidal tract. These zones do not taper towards the lower part of the cord, but vary in thickness with

the size of the roots of the spinal nerves, being thickest at the cervical and lumbar enlargements.

After transverse section of the cord descending sclerosis can be traced a short distance down these tracts. The direction of the degeneration shows them to be efferent, but from the limited extent of the sclerosis we may suppose that they only carry impulses from the upper to the lower regions of the spinal cord.

2. The *postero-external column* (Burdach) forms the whole of the posterior column with the exception of the postero-median column (Fig. 225, B). It consists of two parts, (1) that immediately surrounding the posterior cornu, known as the posterior root zone and consisting of fibres from the posterior roots on their way to the postero-median column, and (2), intercentral fibres, forming the bulk of the column, which varies in proportion to the size of the roots of the spinal nerves and thickness of the posterior grey column.

Their mode of degeneration teaches us that the former are processes of the ganglia of the roots, and the latter are afferent channels carrying impulses from the cells of the lower parts of the posterior grey columns to those in its upper segments.

Experimental methods.—Besides the foregoing, we learn by experiment the following facts concerning the loss of function which follows transverse sections of the spinal cord.

1. Complete section of the cord is followed by loss of sensation and of voluntary motion in the parts below the point of section (Galen).

2. Section of one side of the cord is followed by complete loss of voluntary movement of all parts on the same side, below the section. As regards sensation, it was formerly stated that sensation of all kinds was lost on the side opposite to, and below the lesion. Later experiments show that the chief loss of feeling, which is only temporary, is on the same side as the lesion. Hyperæsthesia at the margin of the anæsthetic field is often observed. Probably the decussation of the sensory fibres occurs chiefly in the bulb, with minor and varying decussations along the cord.

3. (*a*) If the antero-lateral columns be both cut through, so as to involve the two anterior grey cornua, but leaving the posterior columns intact, voluntary movement is lost on both sides below the lesion.

(*b*) Section of the posterior columns is followed only by an imperfection of the voluntary movement.

(*c*) If the antero-lateral column of one side be cut through,

there is complete loss of voluntary movement of all parts on the same side below the lesion.

4. Section of the posterior columns causes loss of power of co-ordination, but does not cause any loss of sensation. Section of the posterior and of the antero-lateral columns does not abolish sensation, but section of the antero-lateral columns and of the grey matter, with intent to leave only the posterior columns intact, has been observed to cause complete loss of sensation of the parts below. We must not, however, consider these experiments as proving that no forms of sensation are conveyed by the posterior columns.

Pathological observations.—The clinical observation of disease in man, and its comparison with the lesions found post mortem, gives us the most valuable information. This study tends to prove conclusively that the impulses giving rise to voluntary movements are carried by the pyramidal tracts. It is found that there may be loss of tactile, or of muscle sensibility, without loss of sensibility to painful impressions, or *vice versâ*, thus showing that, probably, the paths of these forms of afferent impulses are differently placed in the cord.

It is found too, that when there is analgesia, or loss of the sensation of pain, there is, in nearly every case, a loss of temperature sensation, and *vice versâ ; i.e.*, that the paths for temperature and painful impressions are either identical with, or run very close to one another.

Disease of the posterior columns leads to loss of co-ordination, and this is very frequently accompanied by excess, impairment or loss of tactile sensation. This latter may be due to an accompanying lesion of the posterior roots.

From the foregoing we may draw the following conclusions :—

1. That our knowledge of the path of voluntary motor impulses is definite. They travel from the cortex of the brain directly to the pyramidal tracts, and thence to the cells of the anterior grey columns. The majority of the fibres decussate in the bulb, the remainder in the upper part of the cord.

2. That our knowledge of the paths of sensory impulses is by no means definite. First, we have the negative evidence that the impulses of ordinary sensation do not travel by any of the best known afferent tracts, viz., the postero-median, the dorsal cerebellar, nor by the ventral cerebellar columns. Secondly, we know that impulses giving rise to painful and to temperature sensations are carried by the grey matter, and that these paths

are closely related. And finally we believe that tactile sensibility may be carried by Burdach's column, or by the grey substance.

3. There cannot be the least doubt that many of the tracts of afferent fibres are chiefly employed in carrying impulses which do not affect our consciousness.

4. The impulses producing muscle sensibility are carried up the cord, along the postero-median column.

5. The afferent impulses may cross to the opposite side immediately or soon after entering the cord, but mainly decussate higher up in the region of the bulb or pons.

6. The cells of the grey matter are in communication with their more distant neighbours by means of the white fibres of the root zones.

Grey Matter of the Spinal Cord.

The examination of series of sections of the spinal cord has shown the existence of certain groups of cells which when viewed longitudinally may be called *vesicular*, *cellular* or *grey columns*. Of these four may be named as distinctively marked.

1. The *anterior* (motor) *cellular column* occupies the anterior cornu of the grey matter. It extends throughout the entire length of the cord, the cells being specially numerous where the large motor roots come off. The cells are characterised by their great size and the number of their branches, one of which forms the axis-cylinder of one of the motor fibres passing to the anterior roots of the spinal nerves (Fig. 226, *A*.).

These cells are arranged in groups in the anterior cornu. One in the anterior and inner angle named the inner group; another in the anterior and outer angle, the anterior group; a third placed just posterior and external to this is named the antero-lateral group. The inner group consists of smaller cells than the others and is almost absent in some sections.

2. The *posterior cellular column*, situated in the grey substance of the posterior cornu, is much less obvious than the anterior. The cells are few, small, and mostly spindle-shaped. Their processes are not readily traced to the roots of the spinal nerves (Figs. 226–7–8, *P*.).

3. The *postero-median cellular* or *Clarke's column* lies on the median side of the posterior grey column, so that it forms the inner part of the posterior cornu near its base. The cells are

numerous, but much smaller than those of the anterior vesicular column. Clarke's column is best developed at the junction of the lower dorsal and upper lumbar nerves. It tapers off above and below, and the cells cease to form a continuous

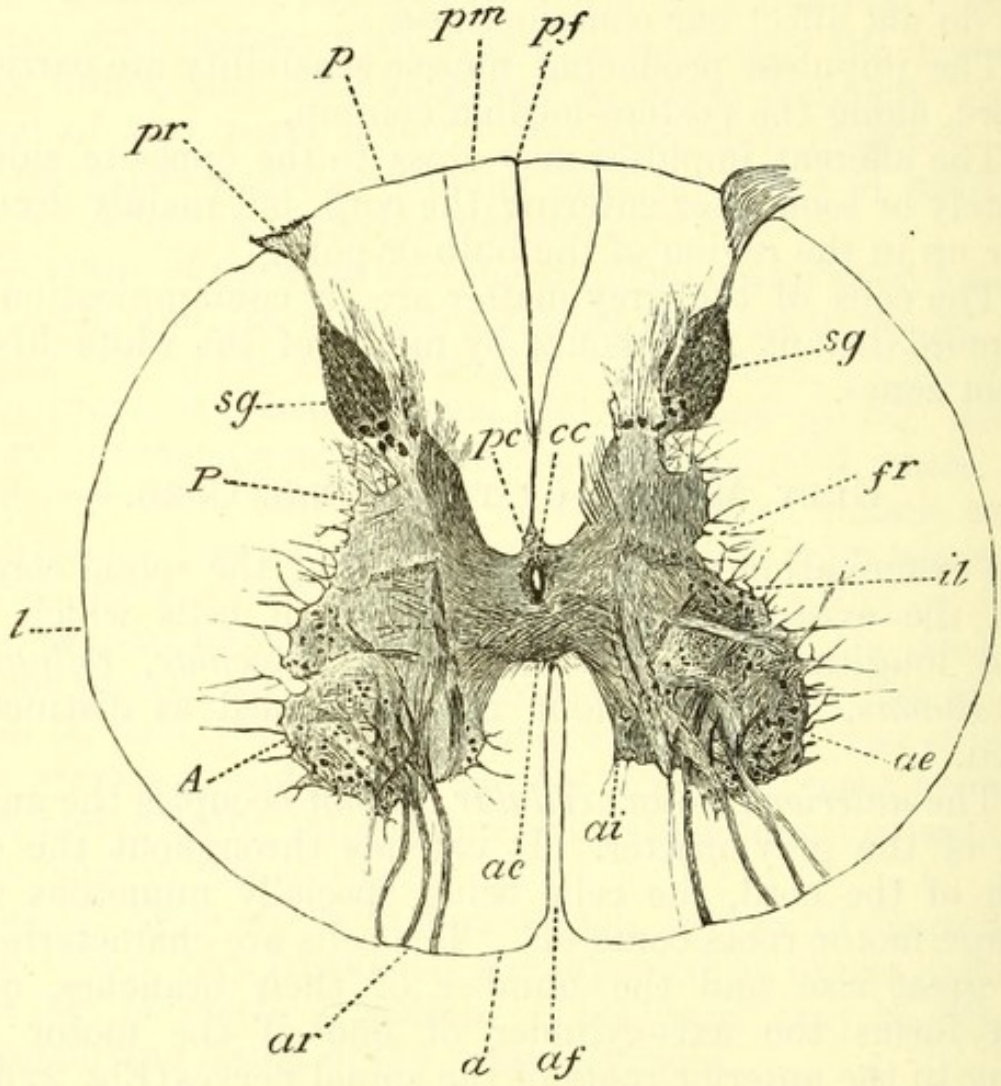


Fig. 226.—Transverse section of the *cervical region* of the spinal cord.

A. Anterior grey column.
a. Anterior white column.
l. Lateral white column.
ac. Anterior commissure.
ar. Anterior roots.
af. Anterior median fissure.
il. Intermedio-lateral grey column.
vc. Vesicular column of Clarke.
P. Posterior grey column.
p. Posterior white column.
pm. Posterior median column.
pc. Posterior commissure.
cc. Central canal.
pr. Posterior roots.
pf. Posterior median fissure.
ae and *ai*. External and internal anterior vesicular columns.
sg. Substantia gelatinosa.

column opposite the seventh cervical nerve. But scattered groups of cells in a corresponding position are found throughout all the cervical cord, and seem to link this cellular column with the vagus nucleus in the medulla (Fig. 227, *vc*.).

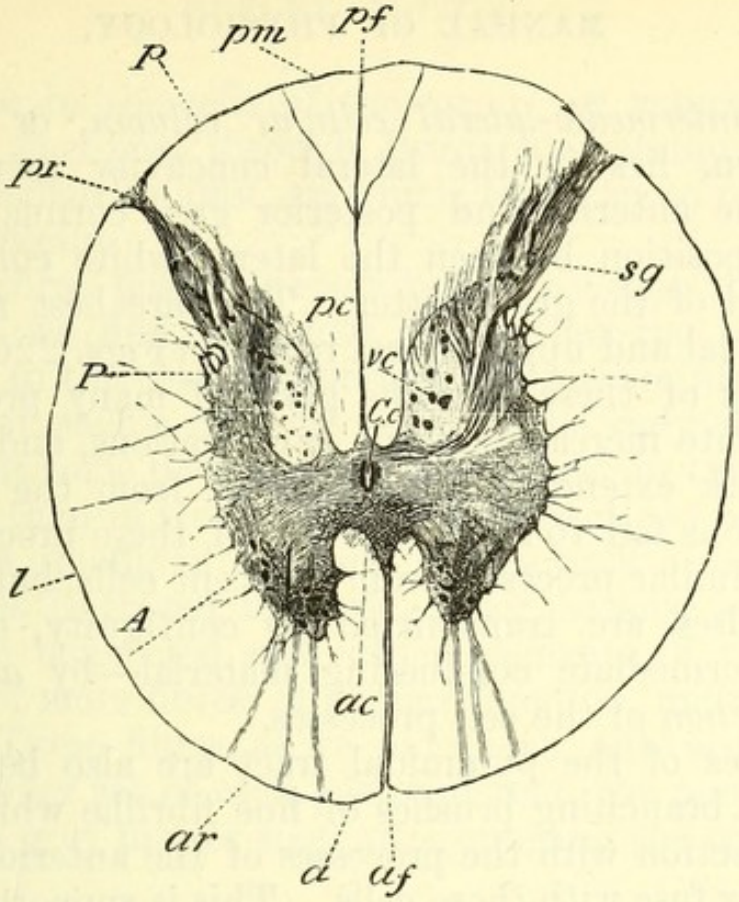


Fig. 227.—Transverse section of the *dorsal region* of the spinal cord. (Bevan Lewis.)

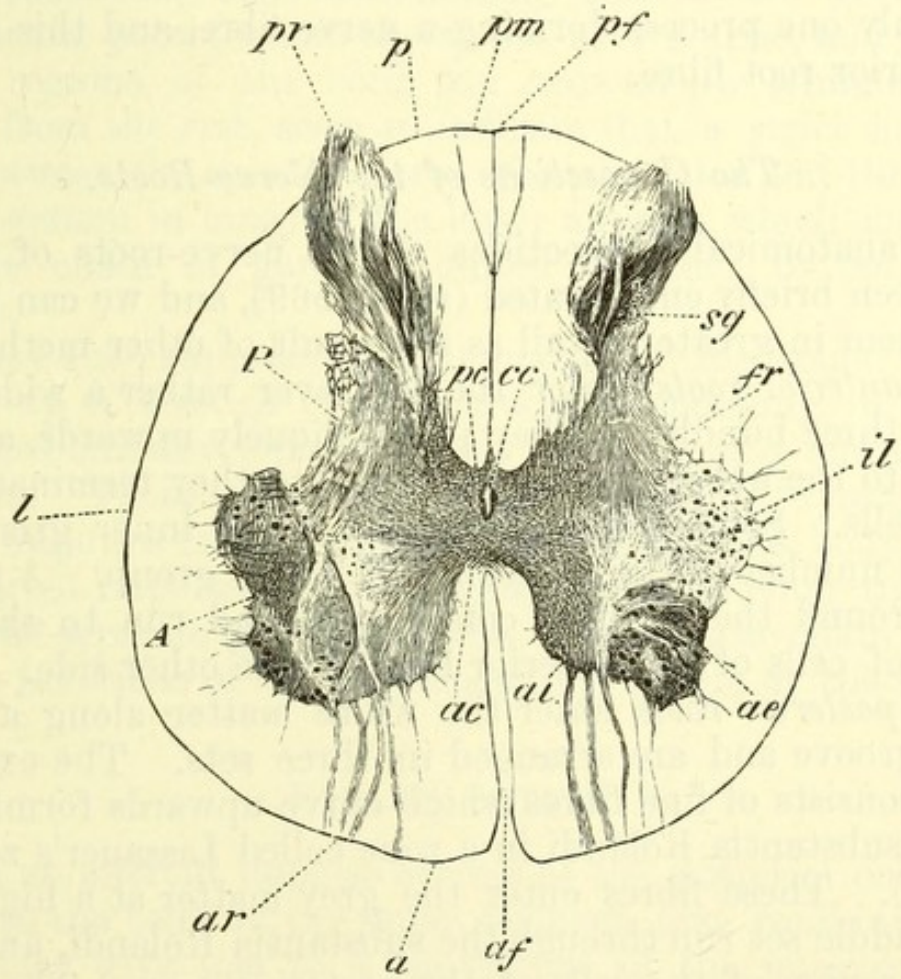


Fig. 228.—Transverse section of the *lumbar region* of the spinal cord (for reference, see description under Fig. 226). (Bevan Lewis.)

4. The *intermedio-lateral cellular column*, or cells of the lateral horn, lies in the lateral concavity seen on section between the anterior and posterior grey cornua. They thus occupy a position between the lateral white column and the central part of the grey matter. They are best marked in the lower cervical and upper dorsal regions (Figs. 226–228, *il.*).

The cells of these columns give off many processes which break up into increasingly fine ramifications, and form a complex network extending some distance from the cell. Recent investigations fail to show that any of these processes actually fuse with similar processes from adjacent cells, but rather imply that impulses are transmitted by contiguity, or through a special intermediate conducting material—by *adjunction* and not *conjunction* of the cell processes.

The fibres of the pyramidal tract are also believed to terminate in branching brushes of fine fibrillæ which come into close connection with the processes of the anterior cells, but do not actually fuse with those cells. This is supported by the fact that the fibres in the pyramidal tracts are by no means equal in number to the cells of the anterior cornua; also that those cells have only one process forming a nerve fibre, and this is always an anterior root fibre.

The Connections of the Nerve-Roots.

The anatomical connections of the nerve-roots of the cord have been briefly enumerated (see p. 569), and we can now deal with them in greater detail as the result of other methods.

The anterior roots enter the cord over rather a wide area in two or three bundles. They pass obliquely upwards, and curve round to the anterior grey cornu where they terminate in the large cells. Some pass to the cells of the inner group, but a greater number to the anterior and lateral group. A few fibres curve round the anterior commissure and run to the middle group of cells of the anterior horn of the other side.

The posterior roots enter the white matter along a longitudinal groove and are arranged in three sets. The external of these consists of fine fibres which curve upwards forming a cap to the substantia Rolandi in a zone called Lissauer's zone (Fig. 225, L). These fibres enter the grey matter at a higher level. The middle set run through the substantia Rolandi, and are lost in the region of the cells of the posterior horn. The inner set form the posterior root zone, lying close to the posterior cornu,

and terminate in the cells of the cornu ; or running upwards and inwards, they pass through Burdach's column, and reach the postero-median column, up which they run to terminate in the nucleus gracilis.

If two or three posterior roots be cut between the ganglion and the cord, we find, as before stated, that the piece of the root attached to the cord degenerates. On examining consecutive sections of such a cord we see that the only degeneration to be found, at some distance above, lies first in the column of Burdach and then in Goll's column, whence it can be traced up to the nucleus gracilis of the bulb. This tract of degeneration decreases as it is traced upwards, either because some of the fibres become connected with other elements of the cord, or because two or more fibres, of similar function, unite to form a single one. These fibres, as we have seen, only account for a part of the inner set of each posterior root, the remainder terminate in the grey matter soon after entering the cord.

The Spinal Cord as a series of Segments.

The fact that cells functionally related are grouped in masses at the points where the spinal nerves arise, and that the various regions of the cord can respond to stimulus when severed from the rest, seem to indicate that a strict homology exists between the spinal centres of vertebrates and the central nervous system in many of the lower animals, which consists of a double chain of ganglia, united together by conducting channels.

We may then suppose the grey matter of the spinal cord to be made up of a series of segments, corresponding in number to the vertebral development, fused together into one continuous organ. These segments may be supposed to receive the afferent impulses from corresponding parts of the body, and to send efferent impulses to muscles capable of moving that part, just as the separate ganglia of the invertebrate chain preside over the functions of the corresponding somite of the animal's body.

Reflex Action.

When an afferent impulse arrives at the posterior column, it spreads to the cells in the same segment, and reaching motor cells it may give rise to a movement of the muscles of the neighbourhood from which the impulse first started. At the

same time an impulse travels to the brain, and there may give rise to a consciousness of the various local events taking place. The action of the cells of the cord is independent of the will, and occurs before the mind is conscious of it. These kinds of movements are called *reflex acts*.

Reflex action forms the most ordinary function of the cells of the spinal cord. The gentlest stimulation may give rise to a complex movement, the execution of which requires many muscles to act together. An unexpected touch to the finger causes a person to withdraw the hand quickly. If greater or more prolonged stimulus be applied, more extensive movements occur, and by the well-arranged co-operation of many muscles, a forcible, definite and familiar action is performed. For example, if the burning head of a match adhere under the thumb-nail, more than a mere withdrawal of the hand takes place. The entire arm is violently shaken, before the will has time to come into operation. We have here a complex and purposeful muscular movement, not planned by the will, but the immediate result of an impulse coming from a single point of the skin, owing to the spreading of the impulse to the cells in the vicinity of the recipient segment. The movement is regular, and performed with a definite purpose, as if it were the result of thought, but since it precedes consciousness, it cannot be a mental act.

If the degree of stimulation be carefully regulated, it will be found that the results obtained by peripheral stimulation depend on (*a*) the strength of the stimulus, and the length of time for which it is applied ; (*b*) the degree of excitability of the cells, and the readiness with which the impulses pass along the conducting channels to the grey matter, and (*c*) the functional activity of the muscles which act as indicators of the reflex effects.

All these points may be easily studied on a frog decapitated about *an hour beforehand*. If the animal be suspended and the toe touched, the foot is gently drawn upwards. If the toe be smartly pinched, the entire limb is forcibly raised ; with intense or prolonged stimulus both legs are violently moved. If a fragment of blotting-paper, moistened in weak acid, be placed on the belly, in a position not easily reached by the foot, a complex series of movements follows. The muscular action is both elaborate and purposeful, and the movements of the headless animal might almost be called ingenious.

Strength and duration of stimulus.—By graduating the

strength of the acid used to moisten a square millimetre of blotting paper, the following results are obtained. When very weak acid is employed only slight movement of one leg is caused. Stronger acid produces a series of reflex movements, spreading to similar muscles of the leg on the other side. If the acid be further strengthened, the movements become violent and extend upwards, first to the upper limb of the same side, then to the upper limb of the opposite side, &c., until the whole body is thrown into convulsion. The impulses spread from the nerve-cells to their neighbours, first transversely across the grey matter to those cells governing the corresponding muscles of the other side, in which, however, the movements are less marked than in those of the side stimulated. Later they spread upwards along the grey matter, first involving those cells on the same side of the cord, and then quickly spreading to the corresponding cells of the other side.

Slight stimulation, when of short duration, and not sufficient to produce immediate response, may, after a time, give rise to definite reflex action, as if the weak impulses arriving at the nerve-cells in the cord were stored up until their sum sufficed to produce a definite reflex movement. This may be seen in animals whose nerve centres are intact, for the cells of more remote parts exercise a kind of checking influence on those in the region receiving the stimulus, and thus the accumulative action (summation) comes more effectively into play. In the human subject, where slight visceral stimulations exist for a long time, this summation may be observed. As an example of this may be named the convulsions that occur in young children, from the prolonged irritation of intestinal worms, or during the painful period of dentition. In some of these cases, even without sensory appreciation of the local excitation, an amount of energy may be accumulated in the grey tracts of the cord, that will bring on the most extensive forms of reflex muscular movement. These movements often differ in character from the regular co-ordinated motion immediately following skin stimulation.

Exalted excitability of the cells.—In certain conditions of the nervous system convulsions can be readily excited. As most striking instances, may be mentioned poisoning with the alkaloid of nux vomica (strychnine), and the state of the blood which is produced by cessation of the respiratory function (asphyxia). These toxic conditions bring about a peculiar

excitable state of the cells or conducting fibres of the spinal cord, in which impulses pass with unwonted facility both transversely and longitudinally from one part to another, and give rise to an excessive degree of action in response to even gentle stimulations. A frog poisoned with strychnine is thrown into general spasm by a slight touch, which normally would only cause it to withdraw the limb. It is noteworthy that this tetanus is not continuous, like voluntary contraction, but is incomplete, with a contraction frequency of about 10 per sec. Though the reflexes are so very readily produced in strychnine poisoning, yet the reflex time is not shortened (see below).

On the other hand, there are many *poisons* which deaden the reflex powers of the cord centres, among which are opium, chloroform, chloral, digitalin, &c. The condition of the blood which may be brought about by very rapid voluntary respiratory movements, has the effect of lowering the excitability of the nerve-cells in the respiratory centre.

We may here mention an experiment which illustrates the great sensibility of the grey matter to deficient nutrition. If the aorta of a rabbit is clamped so as to cut off the blood-supply to the cord for two or three minutes, all reflex actions become lost, and the parts below are completely paralysed both as regards motion and sensation, and may not recover though the circulation be re-established.

Inhibition of Reflex Action.

The great majority of reflex actions may be prevented or controlled by the *will*. The *basal ganglia* and bulb habitually exert a checking or inhibitory influence on the reflex actions of the spinal cord. It is in this way that we account for the facts that a brainless frog readily responds with reflex movements, to stimuli which do not excite the living animal, and that a human being, when asleep, shows reflex action in response to a slight stimulus, that would be quite ineffectual were he awake. For some little time after pithing a frog, constant or regular results are seldom met with, because the section of the upper part of the spinal cord acts as a stimulus to those channels which habitually bear impulses from the brain, and, by exciting them, produces an inhibitory effect. Further, artificial stimulation of the *corpora quadrigemina* and medulla, as shown by the classical experiment of placing a crystal of common salt

upon the optic lobes of a frog (Setschenow), has the effect of checking the reflex action of the cord.

If, while the cord is employed in reflex action, in response to gentle cutaneous stimulation, the central end of a large sensory nerve trunk be stimulated, the reflex action ceases. In short, it may be accepted that strong impulses, arriving at the cord from any direction, enter the network formed by the terminals of afferent fibres, and so engross its functional activity that the weak impulses, which before were able to produce the reflex act, now cannot pass along the pre-occupied channels to reach the motor cells.

This explanation of reflex action by *resistance* to, and *interference* with, the transmission of impulses in the network and nerve-cells of the cord has been said to account for all the phenomena observed.

Reflex-Time.

The reflexion of an impulse from a sensory terminal, through the network and the cells of the spinal cord to a motor or secretory organ, occupies a measurable length of time, which has been estimated at about $\frac{1}{10}$ of a second. As a concrete example to show the various items contributing to reflex-time we may take winking. This simple act, following conjunctival stimulation, occupies about ·066 sec. and requires six steps for its completion, each of which takes a definite time, viz. :—

1. Excitation of peripheral organs . .		x (?)
2. Transmission of afferent nerve impulse .		·0025
3. Passage through the network in cord .	}	·055 – x
4. Excitation of motor cells . . .	}	
5. Transmission of efferent impulse . .		·0025
6. Muscle latency		·006
Total		·066

The time required for the performance of a reflex act varies considerably in different individuals, and in the same individual under different conditions ; of these high temperature and intense stimulation shorten the time, and fatigue or cold lengthen it.

Though in strychnine poisoning all reflex response is so enormously increased, the reflex-time is considerably prolonged.

The delay does not occur in the grey substance of the cord, but in the other parts of the reflex arc, probably from fatigue.

We may then suppose that strychnine renders the nerve-cells more excitable, and removes the resistance of the network, and the impulses, finding no resistance, are rapidly diffused throughout all the cell-territories, and thus convulsive movements are excited in many parts of the body.

Reflex Centres.

Many of the groups of nerve-cells in the cord act as agents, independent of the will, producing movements or secretions essential to the animal economy. Many of their acts are very complex, and require the co-ordinated action of extensive sets of muscles. Such groups of nerve-cells have been called special centres, and many of them have already been described in the preceding chapters. The more important are :

Motor reflexes :—1. The tone of the skeletal muscles is kept up by the act of a series of reflex centres in the cord. The impulses come chiefly from the skin, for tonus disappears when the skin is removed.

2. The tone of the blood-vessels is in part kept up by centres in the spinal cord, the afferent impulses arriving by unknown visceral paths.

3. The cardio-accelerator centre is in the cord.

4. In parturition several muscular contractions, as well as the uterine, are called into play, and are so regularly co-ordinated as to make us believe that they are arranged by a special centre in the spinal cord. The afferent impulses come from the uterus, vagina, &c.

5. A centre for securing the retention of the urine by the tonic contraction of the sphincter muscle of the bladder. This group of nerve-cells is probably kept in action by impulses arriving from the bladder by the afferent nerves.

6. Nearly related to the former is the centre which presides over the evacuation of the bladder. This is excited by impulses arriving from the urethra, near the neck of the bladder. It reflexly sets the detrusor muscle in action.

7. The act of defæcation is accomplished by means of a spinal centre. The action of this centre might (like that presiding over the urinary bladder) be divided into two parts—retention and evacuation—in which volition and intestinal peristalsis play a very important part.

8. The erection of the penis and the ejaculation of the semen are under the control of spinal centres.

Secretory reflexes.—Though these are quite as important as the foregoing, we can as yet say but little concerning the details of their working as the locality of the centres has not been determined, nor the paths of the nervous impulses accurately defined.

There can be no doubt that the secretions in general are under the control of reflex mechanisms, the afferent impulses of which commonly arise in the neighbourhood of the gland. Most of these centres are situated in the cord.

It may be here mentioned that the phenomenon known as "knee jerk" is not a reflex, though it is abolished if the tonic reflex arc be injured. It is simply the response to a sudden mechanical stimulation of a set of muscles, slightly on the stretch by position, and kept tense by reflex tonus.

Co-ordination.

From what has been said concerning the more complex reflex actions, it is clear that the cells of the spinal cord are capable of arranging the discharge of nerve impulses, so as to bring about definite purposeful movements. In fact most of the details of the mode of working of the muscles are under the control of the cells of the spinal cord.

It will help us to understand co-ordination if we suppose the resistance in the grey network of the cord to be great, but that the possible paths are extremely numerous. These paths are made passable by use ; the oftener an impulse traverses a given route the more adapted such a route becomes for future traffic. Thus, by practice, we constantly freshen certain channels of intercommunication between the various cells of the cord and make beaten tracks, along which impulses can pass with facility. By these means groups of nerve-cells acquire the habit of working together and easily exciting complex movements which at first were produced with great labour. The nerve-paths, along which common impulses pass, are formed during the early history of man's development, and the power of performing these actions is transmitted to us ready for immediate application. Other parts connecting groups of cells required for the production of unusual combinations of movements have to be practised by the individual, and much of the difficulty of learning any trade, or special manual dexterity, depends on the necessity of making impulses readily traverse

definite directions, so as to excite certain groups of cells to act synchronously, and to set the required combination of muscles in accurately co-ordinated motion.

When we analyse any one of these movements, we see that even the simplest of them involves the contraction of several muscles and further requires that each muscle should contract to an exact degree of strength, and for an exact period of time. Moreover, in order that the movement be free and steady, it is necessary that opposing muscles should yield to exactly the proper extent, and at the proper moment. A movement thus effected is said to be co-ordinated, and the mechanism by which it is brought about is co-ordination.

Every muscular act excited from the cord is co-ordinated.

In a similar way the secretory acts of the cord are co-ordinated, both glands and muscles simultaneously receiving a co-ordinate amount of blood.

The importance of this technical education of the cells of the spinal cord in the execution of delicate manipulations will be felt if one attempt to imitate the movements of precision which a skilled craftsman, without attention or voluntary effort even, executes in the most careless exercise of his craft. The practice required for such education must be gone through by anyone who attains skill in the simplest special manipulation, from writing a word to playing the violin.

Automatism.

Besides being excited to action by impulses coming from the brain—*volition*—and from the surface—*reflexion*—the groups of cells in the spinal cord may act without any obvious incoming impulse ; that is to say, some of the cells appear to be capable of independent activity. Such groups of nerve-cells are commonly called *automatic centres*. The more we learn of nervous mechanisms in general, the less necessary does it appear to ascribe automatic actions to the spinal cord.

Perhaps the trophic function of the spinal cord is the only automatic power it can be said to possess. The best evidence in this matter is derived from the skeletal muscles. If the motor nerves or roots be cut, or the anterior grey motor columns injured, the paralysed muscles soon undergo fatty degeneration, which does not depend on mere inactivity, for it does not follow cerebral paralysis, in which the integrity of the muscle can be preserved by suitable electric stimulation.

Similar trophic agencies probably influence the other tissues. Thus many affections of the skin, herpes, &c., are attributed to nervous lesions.

On account of the elaborate and purposeful reflex movements performed by decapitated frogs or eels, it has been suggested that in the lower vertebrates the spinal cord is capable of sensation and volition—mental activity—but to follow this assumption, we should have to modify our ideas of volition and sensation, for which consciousness is commonly taken to be a necessary factor. It is, however, important to note that the lower we go in the scale of vertebrate animals the less powerful are the mental faculties, and the more relatively important are the functions presided over by the spinal marrow.

CHAPTER XXXIV.

THE BULB.

THE direct continuation of the spinal cord is called the bulb, or *medulla oblongata*. It consists of representatives of the various parts of the cord with some additional grey matter. The relationship of the different parts of the medulla to those of the spinal cord may be best understood by supposing the posterior median fissure and underlying nerve substance at its upper limit to be split vertically down to the central canal, and the lateral masses separated, so that the grey part becomes spread out on the superior surface, and there forms the floor of the fourth ventricle. The *grey matter* of the medulla oblongata consists of two sets of nuclei ; one being the continuation of the grey columns of the spinal marrow, and the other made up of certain additional grey nodules embedded here and there among the white strands. For a description of the groups of nerve-cells in the bulb and their connections with other parts, works on anatomy must be consulted.

The various *white columns* of the spinal cord are so distributed in the medulla that their course gives some indication of the channels by which impulses are carried through it.

In ascending to the medulla the *posterior white* columns terminate as follows : (1.) Goll's column is more distinctively marked off, and enlarges to form the *funiculus gracilis* containing the gracilis nucleus. (2.) Burdach's column widens in a wedge-like fashion, and is called *funiculus cuneatus*, which contains the cuneate nucleus. It passes on to help to form the inferior peduncle of the cerebellum.

Of the *lateral white columns*, the crossed pyramidal tracts pass, at the *decussation of the pyramids*, to the opposite side to form the pyramidal prominence on the front of the medulla, and are thence continued upward through the pons to the crus cerebri on their way to the motor areas of the cortex. The *direct cerebellar tract* runs into the restiform body to reach the

inferior peduncle and terminates in the cerebellum. The fibres of the *direct pyramidal* tract join the pyramid of their *own side*.

It must be remembered that the bulb is the only route between the spinal cord and the several cranial nerve centres. Through it all the afferent and efferent channels must pass, as they do through the spinal cord. From it, and the prolongation of its grey nuclei in the pons Varolii, several cranial nerves take origin. Thus the medulla is to the cranial nerves (from the fifth to the twelfth) as the spinal cord is to the spinal nerves, but their mode of distribution is different.

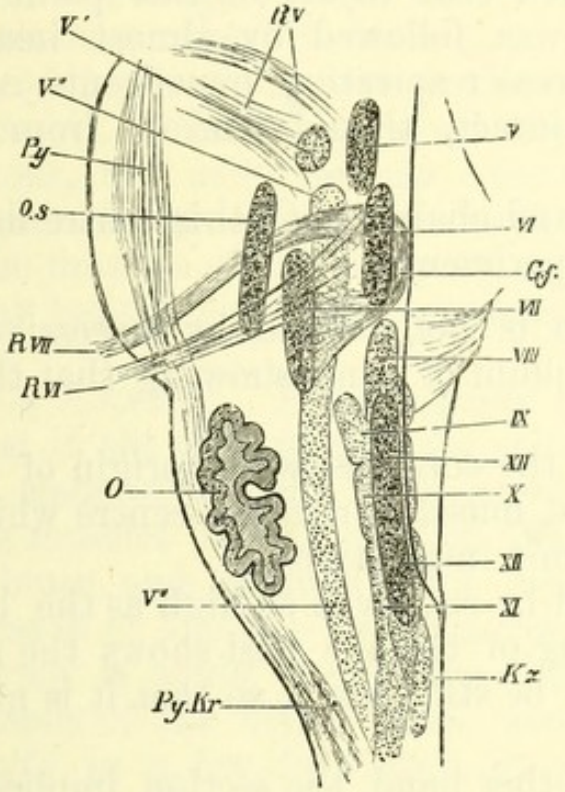


Fig. 229.—Diagram showing the position of the nuclei of the cranial nerves in the medulla oblongata, &c., as if seen in antero-posterior section, looking from the median line towards the right side. The nuclei near the median line are more darkly shaded.

Py, Pyramidal tracts; *PyKr*, Pyramidal decussation; *O*, Olivary body; *Os*, Superior olivary body; *V*, Motor; *V'*, Middle sensory; and *V''*, Lower sensory nuclei of fifth nerve; *R* V, Roots of fifth nerve; VI, Nucleus of sixth nerve; *R* VI, Root of sixth nerve; VII, Nucleus; *Gf*, Knee; and *R* VII, Root of portio dura of seventh nerve; VIII, Auditory; IX, Glosso-pharyngeal; X, Vagus; XI, Accessorius; and XII, Hypoglossal nuclei; *Kz*, Clavate nuclei.

The Bulb as a Central Organ.

A number of groups of ganglion cells with special duties are located in the medulla. Those acts which are most important

for the execution of the vegetative functions, are arranged and governed by the nerve-cells of the medulla. Some of these centres are automatic, though they are variously affected by many impulses arriving from distant points, while others are purely reflex in their action.

The more important centres in the bulb are—

Respiratory Centre. The centre which regulates the respiratory movements is situated in the floor of the fourth ventricle, at the upper and back part of the medulla. Flourens long since showed that injury of this point—the *nœud vital* or vital spot—was followed by almost instant cessation of respiration, whereas respiratory movements continued so long as it remained intact, though cut off from other sources of energy.

The position and character of this centre has been shown by the following experiments :—

1. Respiration is not stopped by successive removal of the cerebrum, cerebellum or pons, showing that the centre is below these parts.

2. Section of the cord below the origin of the phrenics only cuts off the chest muscles from the centre while the diaphragm continues rhythmic inspirations.

3. If the cord be cut, even as high as the lower limit of the bulb, the working of the alæ nasi shows the rhythmic activity of the centre to be still intact, so that it is not situated below this point.

4. If, on the other hand, the section implicate the bulb at 2 or 3 millimetres above the point of the calamus scriptorius, the nasal as well as all other respiratory rhythm ceases, the impulses being now cut off from the facial nerve, which arises above that point. This proves that the origin of this rhythmic activity is destroyed.

5. Lastly, if the vagus and glosso-pharyngeal nerves be divided, after experiments 1 and 3, all sources of afferent impulses are cut off, but as the muscular action continues, we conclude that the centre is rhythmically automatic.

Although we take the respiratory centre as the example of automatic action, its working is influenced by several afferent impulses, so that the normal rhythm of breathing is regulated by reflex action.

The rate of the rhythm is affected by :—

1. The *will*, by which we can alter the rate of breathing, or even stop our breath for a time, *i.e.*, with great difficulty for one minute, shortly after which the "want of breathing" overcomes our volition.

2. Various *peripheral excitations*, *e.g.* a sudden stimulation of a large skin area, as with a dash of cold water, or of the air-passages, as with irritating particles or gases.

3. The *vagi*, which normally regulate the rhythm. For, the mechanical state of the lungs—whether distended as in inspiration or contracted as in expiration—excites the terminals of certain fibres of the vagus, which carry impulses to the centre, and thus hasten or retard its activity.

4. The *condition of the blood* supplied to the centre influences its activity considerably. When the blood flowing through it is abnormally venous, the cells become over-stimulated and produce laboured breathing. When the dyspnœa becomes intense, nearly all the muscles of the body are called into action, and the animal may become convulsed. (Compare p. 323.)

THE VASO-MOTOR CENTRE. It has already been stated that groups of cells exist in the grey part of the spinal cord, which, according to the class of animal, have more or less direct influence upon the muscles in the coats of the vessels. Thus in a frog, whose brain and medulla have been destroyed, in some hours the vessels of the web regain a considerable degree of constriction, which is again lost if the cord be destroyed. In the dog the vessels of the hinder limb recover their tone, more or less perfectly, in a few days after the spinal cord has been cut in the dorsal region, although just after the section they are widely dilated from the paralysis of their muscular coats. In a few days the cells of the cord can learn to accomplish, of their own accord, work which they have been in the habit of doing only under the direction of the higher centre. From this we conclude that though the cord contains local vaso-motor centres distributed throughout its grey matter, these are normally under the control of the vaso-motor centre in the medulla, and this centre is really the chief station from which impulses destined to control all the spinal centres must emanate.

Thus we consider the vessels to be under the direct control of the spinal centres, each regulating the amount of tonic construction of its own vascular area. These spinal centres, in their turn, are correlated with one another and governed by

the higher medullary centre. The latter is further very closely associated with the cardiac centre. In this way it is provided that the vessels are each sufficiently contracted, so that those supplying one area cannot over-relax and take too much blood to the detriment of the others. The loss of this correlation leads to very grave results, as in cases of shock, or in section of the splanchnics, when the vessels of the viscera dilate to such an extent that a great fall of blood pressure follows, and may cause death.

The attempt to localise exactly the position of the medullary vaso-motor cells is not satisfactory. In lower animals—frogs—the cells are evenly diffused throughout the medulla and cord. In man the localisation is difficult to demonstrate, though we have reasons for thinking it much more definitely circumscribed. In the rabbit it has been localised to the floor of the fourth ventricle in the immediate neighbourhood of the respiratory and cardiac centres.

The tonic state of activity of the centre is under the control of many reflex influences, which constantly vary the general tone, or effect local changes in the degree of constriction of this or that vascular area. Among the most striking afferent regulating impulses are those arriving from the heart, the digestive organs and the skin. In some animals, rabbit, a special nerve—the *depressor*—has been discovered, which, passing from the heart to the medulla, keeps the vaso-motor centre informed as to the degree of tension, &c., of the heart cavities. When the heart becomes over-full, impulses pass from it, and check the tonic power of the centre, so as to reduce the arterial pressure against which the ventricle has to act. Electric stimulation of this nerve causes a remarkable fall in the general blood pressure.

The Cardiac Centre.

Although the heart beats regularly when cut off from the nervous centres, its normal rhythm is regulated by nerve-cells in the medulla, from which some fibres of the vagus carry impulses to the heart. The action of this centre is habitually that of a restraining agent lessening the rate of the heart's contractions, and is hence called a tonic inhibitory centre. The activity of the centre is influenced by the condition of many distant parts, such as the cortex of the brain, the

abdominal viscera, &c., which exert a reflex action on the heart through the centre. The *accelerator* agencies, situated in the dorsal region of the cord, are antagonistic to the latter centre, but possibly have connections with the bulb.

In the medulla there exist many other centres of which we know but few connected with the organic functions. Of these the centres for swallowing and vomiting may be mentioned. (See chapter on Digestion.)

CHAPTER XXXV.

THE BRAIN.

To form a general idea of the plan of construction of the brain, it is well to follow its development in the earlier stages of the embryo, from the time when it forms an irregular and thickened part of the tube of tissue, from which is developed the cerebro-spinal axis. We then see that the brain is a modified part of the primitive nervous tube. Three hollow swellings, formed immediately one behind the other, may be observed at the anterior part of the tube soon after its closure. These swellings are called the fore-brain, mid-brain, and hind-brain, and in the future development of the parts give rise respectively to :—

1. Olfactory lobe, retina and optic nerve, the cerebral hemispheres, the 3rd ventricle, and the corpora striata.
2. The nervous matter around the Sylvian aqueduct, including the corpora quadrigemina.
3. The pons, cerebellum and bulb.

The great mass of the brain—the hemispheres—is formed by an excessive development of bud-like processes which grow out from the sides of the fore-brain at an early period, and become elaborately folded backwards, so that in the adult it is difficult to trace the relationship to the original form.

The cells of the brain are, like those of the cord, grouped together in the grey matter, which is found in two positions differing in relation to the white, viz. :—

1. Internal to the white matter : this is continuous with the grey matter of the cord with which it is homologous. The grey matter in the floor of the fourth ventricle around the aqueduct and that lining the third ventricle belong to this category. The optic thalamus is simply an enormous expansion of this region of grey matter.
2. External to the white matter : to this category belong the grey matter of the cortex of the cerebrum, cerebellum and the corpus striatum.

Connecting the various parts of these grey regions are sets of fibres, which may be classified as follows :—

1. Those which act as paths between the different parts of similar masses of grey matter. These may be divided into *unilateral*, *i.e.* those which connect together the cells of a single hemisphere, and *bilateral*, or commissural fibres, which unite corresponding masses of grey matter on either side of the brain.

2. Those which act as paths between dissimilar masses of grey matter. As examples may be named the sets of fibres which pass between the cortex and the basal ganglia, corpora quadrigemina, cerebellum, bulb, and the grey columns of the cord.

It is in the multiplicity and perfectness of these conducting paths rather than in the greater number of nerve-cells that the human brain excels those of the lower animals. We may exemplify this by the progressive development of the corpus callosum, which is absent in the lower vertebrates and attains its highest development in man.

Mid- and Hind-Brain.

Removal of the Cerebral Hemispheres.—It has been shown that a pithed frog, *i.e.*, with spinal cord alone intact, lies flat on its back on a table with its limbs partially extended, and, if hung up, the legs dangle as far as the muscle tone will allow, but a frog with the mid- and hind-brain, as well as the cord, uninjured, cannot be induced to leave its limbs extended on a table. If hung up it will continue to kick and struggle. When placed on its back on a table, such a frog, *i.e.*, deprived only of cerebral hemispheres, will at once sit up in quite a normal attitude. It only seems to have lost its voluntary power from the stolid indifference it shows to all external circumstances that do not amount to actual stimulation.

It can balance itself accurately, jump, swim, swallow, &c., acts far more complex than any of those that can be effected by the cord or bulb, but it only performs these acts when excited to do so by repeated stimulations from its outer surroundings. Thus on a flat surface it sits upright and motionless, never stirring from the spot where it has been placed ; if the surface upon which it sits be inclined in a direction to place its head too low, it turns round to regain its ordinary attitude. If the surface be further inclined, it at first crouches so as not to slip off, and then crawls upwards to find an even

resting place. Plunged into water, it swims perfectly, but on arriving in a shallow part, it either rests quietly with its nose out of the water, and its toes touching the ground, or crawls out to sit on the water's edge, where it can find its balance. When touched on the leg, it jumps away from the stimulus, and in so doing avoids any obvious dark obstacle. It swallows, if a substance be put in its mouth, but does not attempt to eat even if surrounded with food. In short, all movements, even the most complex, may be brought about by adequate stimulation—*spontaneity* only is wanting. The pupil responds by reflex contraction, when the retina is exposed to light; the eyes are closed if the light be intense; and the head may follow the motions of a flame moved from side to side. A sudden or loud noise causes it to move. From the foregoing facts, and the power such a frog has of avoiding a dark object, we may conclude that the impulses arriving from the special sense organs are all duly received at a reflex station, and excite more or less elaborate response, but that the *consciousness* of the arrival of these impulses no longer excites voluntary action.

The removal of the hemispheres of birds and rabbits leaves the animal in a somewhat similar condition; but the response to the special sense impulses is not so definite or well marked, since the animal flies or runs against even the most obvious obstacles.

We may conclude that animals deprived of their cerebral hemispheres can execute all the complex associations of co-ordinated movements necessary for the perfect performance of such acts as standing, walking, flying, &c., which require the exact balancing of the body, called *equilibration*.

Nervous Mechanism of Equilibration.—Balancing the body, whether at rest or in motion, requires the simultaneous co-ordination of very many distant parts. This is accomplished without any effort of the will, or as we have just seen, after the removal of the hemispheres. The elaborate reflex acts required for the perfect execution of equilibration are excited by the following sets of afferent impulses:—

(1.) Those derived from the skin where stimulated by contact with the surrounding medium. The importance of the skin impulses can be seen in a frog which some time previously has been deprived of its hemispheres and been shown to be capable of equilibration. If the skin be removed from the limbs it loses the erect posture and its legs may be extended like those of a pithed animal. In man, the same deficiency in

balancing power can be seen in walking on an uneven surface when the feet are benumbed by cold, or in the familiar condition of the limb being "asleep," when standing or walking can only be performed in the most awkward manner.

(2.) Those impulses arising from the acting muscles, and the moved joints, which indicate to the centres the degree of contraction of the muscles, and the amount of flexion or extension of the joints. This is shown by locomotor ataxy, where the muscle-sense is impaired, and consequently the co-ordination of the movements of the lower limbs becomes so imperfect that the individual can walk or stand only with difficulty.

(3.) From the eyes impulses reach the centres indicating our relation to surrounding objects. By this means we can take our bearings, stand steadily, and walk evenly. The value of these impulses can be readily appreciated by this simple experiment. If we stand with our heels together, the body sways from side to side, but only to a very slight degree; if, however, the eyes be shut while in this position a swaying motion becomes obvious, showing that the equilibrating centre has lost the impulses showing the bearings taken by the visual organs.

(4.) The last set of impulses arises from the semicircular canals of the internal ear, which indicate to the equilibrating centres the movements and positions of the head. If these canals be destroyed, one by one, abnormal movements bearing a definite relationship to the position of the individual canals are performed by the animal. Any one can satisfy himself of the potency of such impulses by placing his head on the handle of a walking-stick, the end of which he fixes on the ground, and running three or four times round the stick as an axis. This sets the fluid in his semicircular canals in motion, and if he now stand upright and attempt to walk directly to an object, he will find his volition powerless, when combated by unusual impulses arising from the internal ear. In an affection of the internal ear, known as Menière's disease, either the cessation of normal guiding impulses, or the reception of new and different ones, produces the sensation of giddiness with inability to perform the ordinary more complex co-ordinated movements of balancing, &c. The unsteadiness of a landsman on board ship depends more upon unaccustomed impulses arriving at his centres from the semicircular canals than upon the irregular movements of the surface upon which he stands. Getting our "sea-legs" simply means learning to counteract the unusual impulses which unsettle the gait. It is interesting to note

that sickness often accompanies the latter form of giddiness just as vomiting is a frequent symptom of Menière's disease.

In the frog these sets of afferent impulses appear to be co-ordinated chiefly in the corpora quadrigemina, which are in this animal well developed in comparison with the cerebellum, but in animals with a well-formed cerebellum it is believed that the centres of these higher combinations lie in that organ.

Forced movements.—After experiments invading the region of the mid- and hind-brain, it is often observed that remarkable and apparently irresistible movements are produced. They vary much in character, but are all grouped together under the title of *forced movements.*

As examples we may mention the so-called circus movement, in which the animal continuously moves round in a circle, sometimes with the injured side, and at others with the sound side, facing the centre of the circle. In another case the animal may revolve in a circle of which the tip of the tail is the centre and the body moves as a radius (clockhand movement). Sometimes the animal, by an irresistible impulse, turns somersaults either backwards, forwards, or laterally so that it continually rolls over and over. If left to itself the animal usually remains quiet, but, on the least attempt to move, these antics are reproduced. The length of time the movements last varies greatly. In severe cases they may lead to complete exhaustion, after which comes a period of quiet, and then some slight stimulus starts another series, again ending in exhaustion. A few rare cases have been reported in which these movements have occurred in man.

Forced movements are especially frequent, after section of the crura cerebri, or of the middle and inferior peduncles of the cerebellum.

Cerebellum.

The *Anatomy* of the Cerebellum teaches us that its structure and connections are sufficiently complex and multiple to admit of very elaborate functions. It consists of a central portion, or *vermis*, and two lateral lobes. All these divisions are folded into lobules, and the superficial part, composed of grey matter, is laminated so as to have an enormous extent of surface in close relation to the vessels of the pia mater. From this we may infer that the grey cortex is the essentially active part of the cerebellum, just as it is in the case of the cerebrum.

In the midst of each lobe is a white stem of medullated fibres branching into the folded leaflets and connecting the cortex with the cerebellar peduncles. In the middle of these stems there are several grey nuclei.

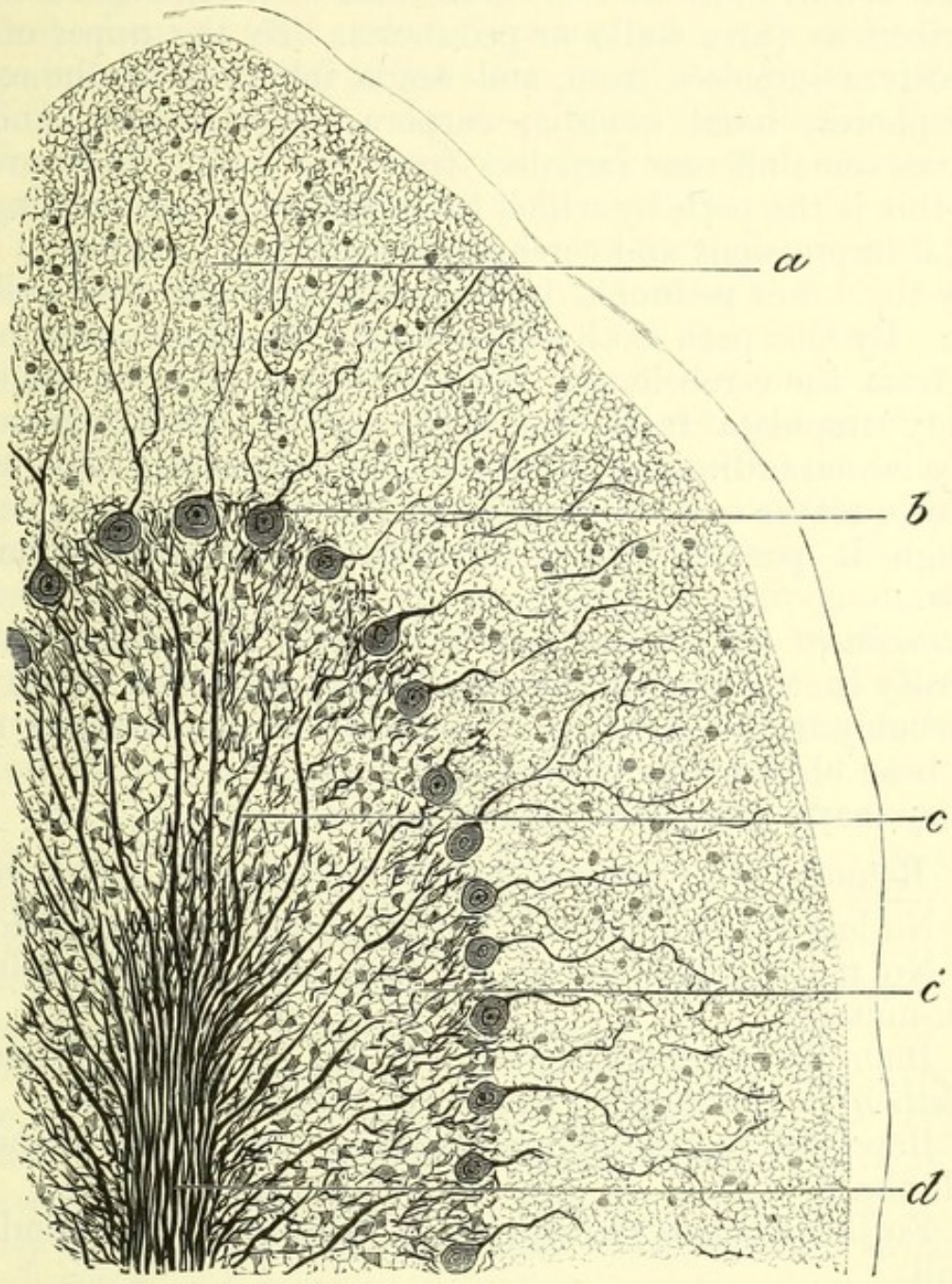


Fig. 230.—Section through a part of the cerebellum.

a, Molecular layer into which pass the branches of Purkinje's cells, *b*; *d*, Medullary centre from which medullated fibres pass through the granular layer of nervous and neuroglia cells to reach the cells of Purkinje.

The cortical substance may be said to consist of three layers. (1) an internal granular layer; (2) a layer of cells; and (3) an outer layer of fibrils enclosing some cells. The large pear-shaped cells (Purkinje) of the middle layer send long fibres

branching towards the surface which become lost in the network of the external layer. From the base of these cells a single fibre passes into the internal granular layer, may be towards the medullated fibres of the white stem.

The connections of the cerebellum with other parts may be described as three stalks or peduncles. By the upper of these it receives impulses from, and sends impulses to, the cerebral hemispheres, basal ganglia, corpora quadrigemina, and also receives some afferent impulses from the cord. It is probable that this is the path by which the visual impulses exciting both mental impressions and cerebellar equilibration travel.

By the lower peduncle it is connected with the bulb and cord. By this path both afferent and efferent impulses pass to and from the cerebellum. Besides many others, no doubt, the sensory impulses from the skin and muscles, required for cerebellar co-ordination pass by this peduncle. The middle peduncle serves to unite the lateral lobes of the two sides, and through it pass the impulses received from the semicircular canals.

Experiment on the cerebellum, though attended with great difficulty in the higher animals, has given results which agree remarkably in the majority of cases. The most definite results have been obtained in pigeons and dogs.

They may be thus enumerated :—

A. Removal of a part or of the whole cerebellum is followed by :

1. No loss of intelligence, volition, or sensory impressions.

2. No motor paralysis of the respiratory or the voluntary trunk-muscles.

3. Inability to stand, walk, or fly, in a steady manner; (*titubation*) without other signs of muscular paralysis.

4. Repeated ineffectual and agitated movements of the head and limbs.

5. Futile attempts to respond voluntarily to visual and other stimuli.

The amount of the deficiency in each case depends on the amount of substance removed. The effects following injury of the vermis being marked.

B. Stimulation of the cerebellar cortex has been found to cause—

1. Movements of the eyes, varying with the part stimulated.

2. Movements of the muscles of the same side of the body and a tendency to fall towards the side stimulated.

3. If the vermis be irritated in front or behind, "forced movements" are produced, with a tendency to rotation forwards or backwards respectively, *i.e.* somersaults, forward or backward.

From the foregoing observations it has been concluded that the cerebellum directs those movements, which are willed by the cerebral cortex and executed by the voluntary muscles, into harmonious and regular actions and enables them accurately to attain the object in view. In short that the cerebellum acts as the co-ordinator of *voluntary* movements, just as the cord directs ordinary reflex acts, and the bulb controls the automatic respiratory and other unconscious movements, &c.

It has been urged against these conclusions that the animals recover in a comparatively short time, if the removal of the organ be not very complete, and the forced movements, &c. have on this account been attributed to irritation of the parts during or after extirpation. But this inco-ordination has been seen to persist for a year in a dog, otherwise healthy, and the recovery can be explained in the same way as that which follows other nervous lesions, *i.e.*, functional compensation.

Pathological observations in part contradict and in part confirm the experimental evidence. Thus congenital atrophy or very chronic disease may cause a deficiency amounting to ablation without giving rise to any marked want of co-ordination. On the other hand, the very characteristic staggering gait of "cerebellar ataxy," which is known to be associated with lesion of the cerebellum, seems to prove that the experimental evidence is trustworthy, and if the pathological lesion progress with rapidity, or involve the vermis, symptoms of want of co-ordination are invariably found.

Comparative anatomy also confirms the views here expressed of the function of the cerebellum. Those animals (reptiles, &c.) which only perform awkward sluggish movements, of such a type as we see executed by the mid- and hind-brain alone, have a poorly developed cerebellum; but those animals which can execute rapid and complex voluntary variations of movement, have the organ relatively well developed.

Crura Cerebri.

Lying beneath the Sylvian aqueduct are two thick strands of nerve substance connecting the pons Varolii with the cerebral hemispheres. These are called the crura cerebri. They diverge slightly in their upward course towards the hemispheres,

and lie just below the corpora quadrigemina. Examination of the crura, by transverse sections, shows a division into two parts. The lower and more anterior part, which can be seen on the base of the brain, is called the base, or *pes crusta*. The posterior or upper part, which lies next to, and is connected with the corpora quadrigemina, is called the *tegmentum*. Anatomically the separation between the two is indicated by some scattered nerve-cells (*locus niger*). The base, or crusta, which is the great bond of union between the spinal cord and the cerebral motor centres, passes into the internal capsule ; and the tegmentum is lost in the grey matter forming the subthalamic region. (Fig. 231.)

The crura form the two bonds of connection between the cerebrum and other parts of the nervous system. The fibres in the crusta are described as being made up of three sets. The innermost (FC) of these passes under the optic thalamus to the anterior limb of the internal capsule, whence it spreads as part of the corona radiata to terminate in the frontal lobes. The median set (Py) consisting of the pyramidal fibres which if traced up are seen to enter the internal capsule, forming the knee and anterior two-thirds of the posterior limb. The lateral set (TOC) also runs to the internal capsule, forming most of the remainder of the posterior limb, and as part of the corona radiata, passes to the occipital and temporal lobes.

Corpora Quadrigemina.

The anterior pair of these bodies or nates, are associated with the lateral corpus geniculatum and together form a nucleus of the optic nerve, in which apparently nearly the whole of the optic tract terminates. Its further connections are by the crus and the optic radiation to the occipital and angular gyri, through the superior peduncle with the cerebellum, and by many fibres to the nuclei of the 3rd, 6th, &c., cranial nerves.

With respect to their function we know that they have something to do with vision. The destruction of one leads to dilatation of the pupil on the same side, and hemianopia of the opposite field of vision. Stimulation leads to contraction of the pupil, and a peculiar cry, which is stated to be characteristic. Pathological lesion involving their destruction leads to blindness, with consequent effects on cerebellar co-ordination. Injury in this region often leads to "forced movements." If the eyes be extirpated the nates become atrophied.

The posterior pair, or testes, with which the internal corpora geniculata are associated, have some connection with the internal ear, probably receiving impulses from the semicircular canals. Their destruction produces inco-ordination, and sometimes "forced movements."

The corpora quadrigemina correspond to the optic lobes of birds, amphibia and fishes. In the frog these lobes perform much of the function of the cerebellum, *i.e.*, equilibration.

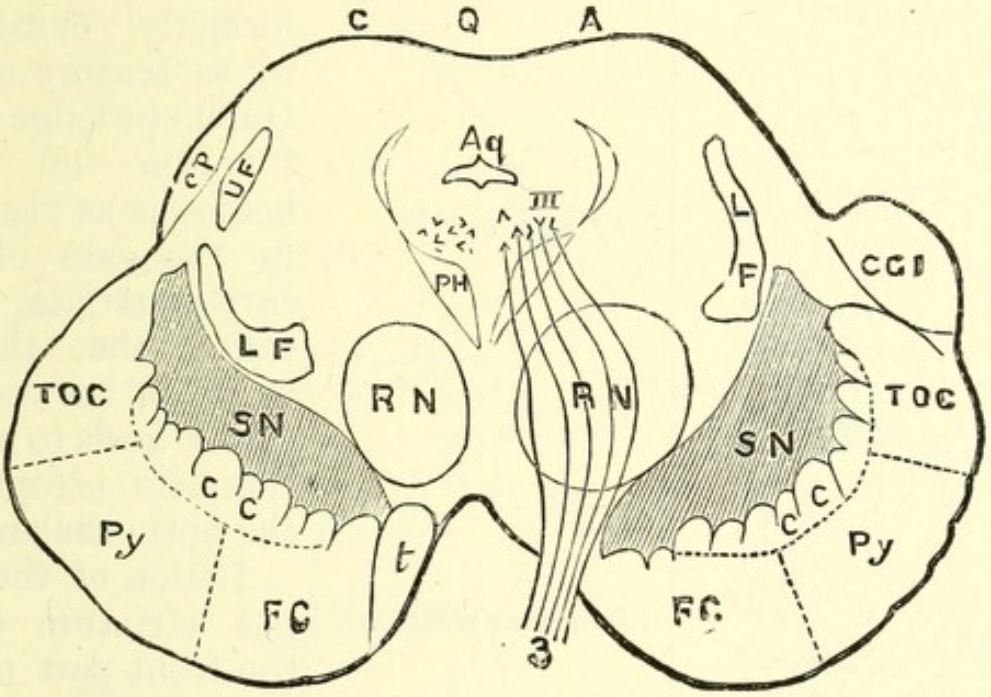


Fig. 231.—Diagram of transverse section of the crus (modified from Wernicke). LF, UF, upper and lower fillet ; C Q A, anterior corp. quad. ; Aq, aqueduct ; III, nucleus of third nerve, 3 ; PH, posterior horizontal fibres ; cp, brachium of post. quad. ; RN, red nucleus ; SN, substantia nigra ; CGI, internal geniculate body ; TOC, temporo-occipital cerebellar fibres ; Py, pyramidal fibres ; FC, fronto-cerebellar fibres ; CC, caudate cerebellar fibres ; t, inner fibres of crusta to tegmentum. (Gower's "Diseases of Nerv. System.")

Basal Ganglia.

The *corpus striatum* consists of two parts, the *lenticular nucleus* and the *caudate nucleus* (Fig. 233) between which runs the anterior limb of the internal capsule. These bodies were formerly considered to be motor nuclei for all parts, but on insufficient grounds. Though electrical stimulation of these bodies is said to cause muscular reaction, disease of them, as long as it does not involve the internal capsule, produces neither motor nor sensory symptoms. Morphologically they are considered as part of the cortex.

Fig. 232.—Section through the cortex of *temporal lobe* of monkey showing the series of layers of nervous cells with different characters. In the *motor areas* characteristic large cells are found in layer No. 5 arranged in "cell clusters."

The *optic thalami* (Fig. 233) form the lateral walls of the third ventricle, and are separated from the lenticular nuclei by the posterior limbs of the internal capsule. These were formerly considered to be sensory nuclei. Our knowledge of the function of these bodies is as vague as in the case of the corpora striata. It is stated that the removal of the cerebral cortex leads to almost complete atrophy of the optic thalami.

Lesion of the corpus striatum or of the front part of the optic thalamus has a marked influence on the production of heat of the body, causing a distinct rise in the temperature of the body.

Cerebral Hemispheres.

There can be but little doubt that the hemispheres have many functions of which we are quite ignorant, but it is now universally regarded as a recognised fact that the brain is the

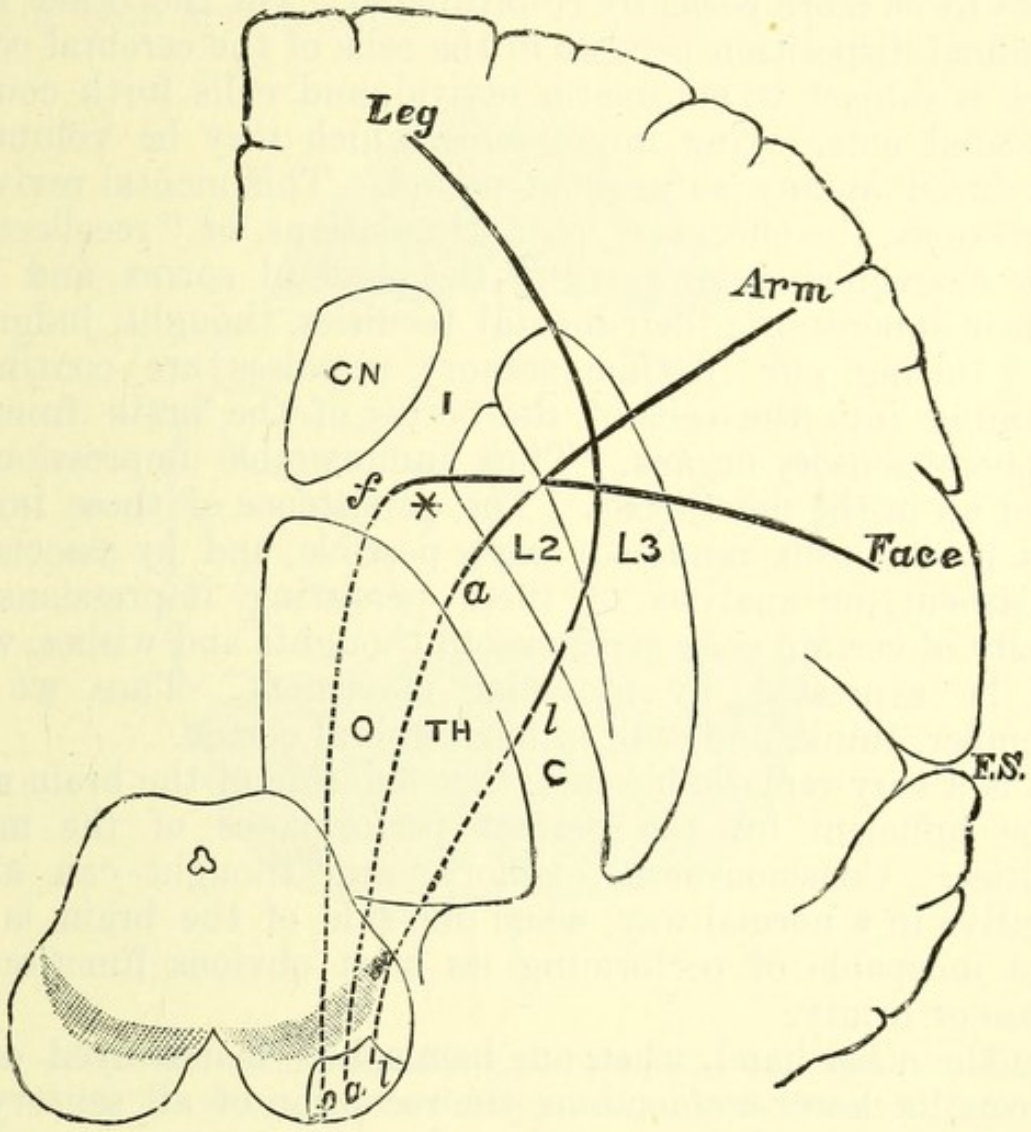


Fig. 233.—Diagram to show the relative position of the several motor tracts in their course from the cortex to the crus. The section through the convolutions is vertical ; that through the internal capsule (I—C) horizontal ; that through the crus again vertical.

CN, caudate nucleus ; O TH, optic thalamus ; L2 and L3, middle and outer parts of the lenticular nucleus ; *f*,*a*,*l*, face, arm, leg fibres. The words indicate the corresponding cortical centres. (Gower's "Diseases of Nerv. System.")

seat of the mental faculties—perception, memory, thought, and volition. The cerebral cortex is the only part of the nervous system in which the subjective perception of the various sensory impulses takes place, and in which impulses are con-

verted into impressions, or mental operations. Some cells of the brain must then differ from those of the lower centres—which simply receive, and discharge impulses—in the fact that an impulse, besides producing an immediate effect in the cortex, leaves in the protoplasm some vestige of that effect.

Repeated excitation of the spinal cells only enables movements to be more perfectly co-ordinated. On the other hand, a residual disposition persists in the cells of the cerebral cortex, which is subject to automatic revival, and calls forth complex correlated acts, laying impressions, which may be voluntarily reproduced at any subsequent period. This mental revival of impressions, the effects of past stimulations, or "recollection," is the characteristic property of the cerebral cortex, and to it the hemispheres owe their mental faculties, thought, judgment, &c. During our lifetime sensory impulses are continually streaming into the cells of the cortex of the brain from the peripheral sensory organs. Thus innumerable impressions are stored up in the nerve-cells. The persistence of these impressions in the cells renders *memory* possible, and by association, adjustment, or analysis of these persisting impressions, the activity of certain cells gives rise to thoughts and wishes, which may be expressed by muscular movement. Thus we feel, remember, think, and will, in our cerebral cortex.

It is a very remarkable fact, that one side of the brain seems to be sufficient for the perfect performance of the mental faculties. Consciousness, memory, and thought can all be operative in a normal way, when one side of the brain is rendered incapable of performing its most obvious functions by disease or injury.

On the other hand, when one hemisphere is destroyed or cut off from its lower connections the reception of all sensory impressions from, and the execution of most voluntary movements on the opposite side of the body, are held in abeyance.

These facts may be shown experimentally, or can be seen in hemiplegia, where one side of the body is paralysed from disease of the opposite hemisphere. The patient is frequently fully conscious, and may possess unimpaired powers of thought and memory, yet he is unable to perceive the sensory impulses coming from one side of his body, or to send voluntary impulses to those muscles which in health are most distinctly under the control of the will; for it must be noted that those muscles which are under the control of the cords, bulb, or basal ganglia in executing associated and bilateral reflex movements

are not paralysed in ordinary hemiplegia, and in most cases of this disease can be influenced by the will.

The cells which act as the immediate receivers of afferent impulses from, and dispensers of efferent impulses to, one or other side of the body, are localized to the hemisphere of the opposite side, while mental operations are diffused over the cortex of both hemispheres.

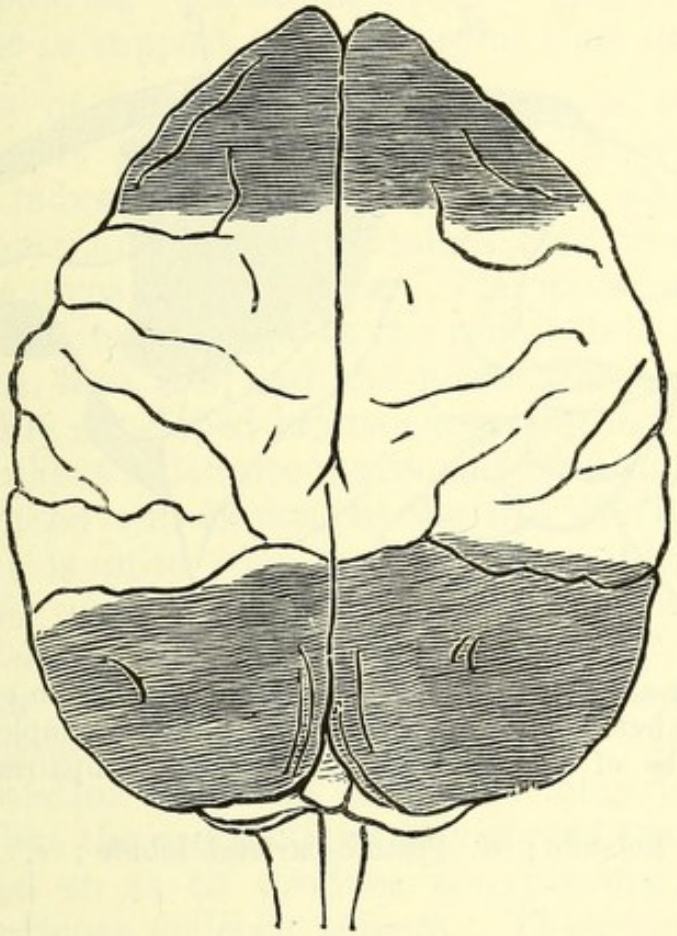


Fig. 234.—The dark shading shows areas which were destroyed in a monkey without giving rise to any functional defect that could be detected. (Ferrier.)

Localisation of the Cerebral Functions.

Some sixty years ago Flourens began to test the functions of the brain by systematic experiment. From the great extent of substance that could be sliced away from any region without interfering with a single special faculty, he concluded, (α) that a small portion of the hemispheres sufficed for the exercise of their function; (β) that all the lobes concur, as an entity, in establishing each of their faculties, and (γ) that when sufficient of the brain substance is removed, for one faculty to be lost, all are lost.

Attempts to test the function of the cortex by stimulation of various kinds were tried with negative results by Flourens and many others.

As local ablation caused no deficiency and local stimulation gave no response, physiologists were satisfied that no special function could be assigned to any special part of the cerebral cortex.

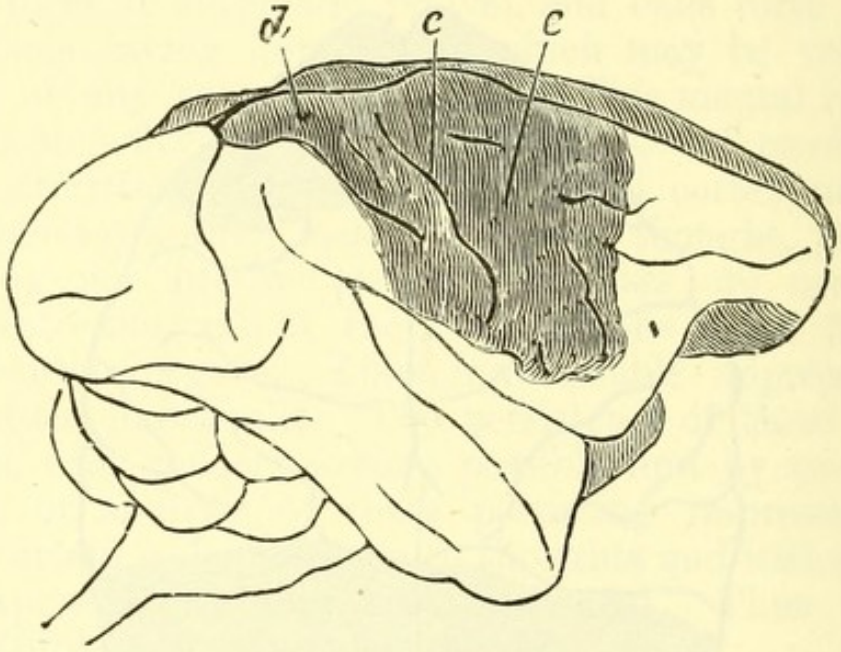


Fig. 235.—Dark shading indicates the extent of a lesion of the grey matter of the right hemisphere of a monkey followed by complete motor paralysis of the limbs of the opposite side, without impairment of sensation. (Ferrier.)

c, Fissure of Rolando; *d*, Postero-parietal lobule; *e*, Ascending frontal convolution.

Within the last twenty-five years attempts to localise functions in the cortex have given more promise; however, at the present day we are still bound by the conclusions of Flourens as regards all the general psychical faculties, the structural representatives of which are so interwoven throughout the cortex, that attempts to unravel them have met with no success, and as regards considerable portions of the brain, particularly the frontal and occipital lobes, removal of which in monkeys causes no loss of faculty.

A new epoch in the history of cerebral physiology was commenced (1870) when Fritsch and Hitzig—soon followed by Ferrier—found that in some parts of the cortex local stimulation was responded to by local muscular contraction.

We now entertain the hope that the point of exit of volun-

tary motor impulses and the points of arrival of sensory impulses may soon be accurately determined.

Here only the briefest review of our rapidly growing knowledge on this subject can be given.

Motor Areas.

The convolutions around the fissure of Rolando are now generally accepted as "the Motor Area." (Fig. 235).

The evidence in support of this may be thus stated :

I. *Excitation* of these convolutions causes definite co-ordinated movement of the muscles of the other side of the body. These movements may be predicted, and follow with striking constancy and accuracy limited electric stimulation of certain definite areas of the cortex. The motor area has been mapped out, in animals as low as the rabbit, into motor centres for the leg, arm, face, &c., and still more accurately in animals with more highly developed brains (dogs and monkeys).

In some monkeys a definite movement of a single digit may be surely predicted and elicited by the will of the operator of experience. It is quite sure that the more highly developed the brain, the more distinctly differentiated are the areas representing definite actions and sets of muscles.

The relation of the various areas representing certain definite movement may be learned from Figs. 236, 237.

If the stimulation be strong it may no longer give rise to a single action, but the contractions may spread from the muscles first stimulated so as to produce convulsions which closely resemble an ordinary epileptic seizure. These convulsions pass through a tonic and clonic stage which are followed by a stage of exhaustion, during which the cortex is not ordinarily excitable.

These convulsions cannot be produced after the motor areas of cortex have been removed from both hemispheres.

The careful clinical study of local epileptic convulsions in man had previously led to their being attributed to local cortical lesions, a speculation which has since been amply confirmed by experiment and pathological experience.

That the movements are not due to diffusion of the electric currents acting on the underlying white fibres of the corona radiata—as some supposed—is (apart from the precision with which they can be reproduced) amply proved by the following facts.

1. Mechanical stimulation of the grey matter of the motor area can also excite local movement.

2. The period between the stimulation and the response (*latency*) is about ·02 sec. longer when the cortex is stimulated than when the movements are brought about directly by stimulating the underlying white fibres.

3. In other parts where the grey matter is equally near to motor tracts, no result follows its electric stimulation.

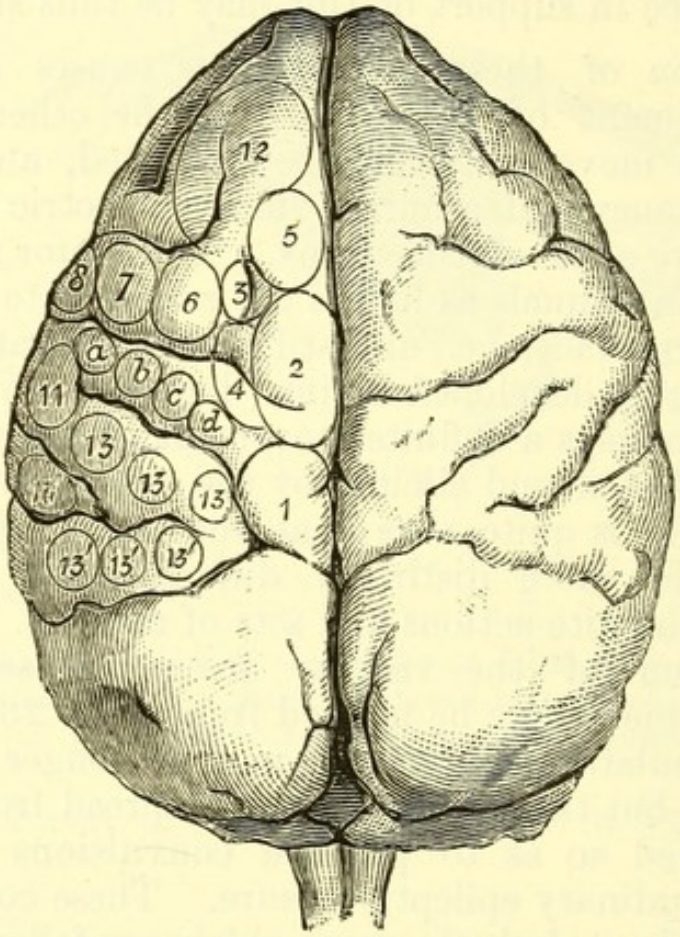


Fig. 236.—Upper surface of the hemispheres of monkey, showing details of motor areas. References as in next figure. (Ferrier.)

4. If the cortex be physiologically separated by a cut of a thin knife, but be allowed to remain exactly *in situ*, so that the subjacent corona radiata is physically equally within range of diffused currents, then stimulation excites no movement.

5. Epileptic convulsions are much more readily produced when the cortex is excited, than when the stimulus is applied to the corona.

The absence from other parts of the cortex of motor response to electric stimulation seems a strong argument in favour of those areas where specific movements are produced, being subservient to the discharge of motor impulses.

It must be here mentioned that stimulation of some other parts (areas of special sense, to be considered presently), also gives rise to local, though perhaps not quite so definite movements. These movements are looked upon as being produced

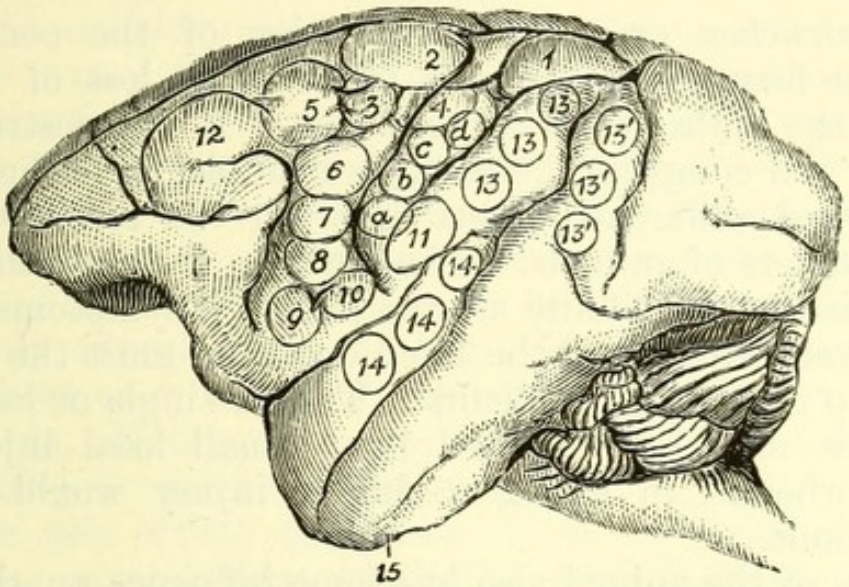


Fig. 237.—Left hemisphere of monkey, showing details of motor areas indicated by the movements following stimulation of,—

1. Superior parietal lobule ; exciting advance of the hind limb.
2. Top of ascending frontal and parietal convolutions ; flexion and outward rotation of thigh ; flexion of toes.
3. On ascending frontal convolution near semi-lunar sulcus ; movements of hind limb, tail, and extremity of trunk.
4. On adjacent margins of ascending frontal and parietal convolution ; adduction and extension of arm, pronation of hand.
5. Top of ascending frontal near superior frontal convolution ; forward extension of arm.

a, *b*, *c*, *d*, On ascending parietal ; movements of various muscles of the fore-arm.

6. Ascending frontal convolution ; flexion of fore-arm and supination of hand which is brought towards mouth.
7. Retraction and elevation of corner of mouth.
8. Elevation of nose and lip.

9 and 10. Opening mouth and motions of tongue.

11. Retraction of angle of mouth.
12. Middle and superior frontal convolutions ; movements of head and eyelids.

13 and 13′. Anterior and posterior limbs of angular gyrus ; movements of eye-balls.

14. Superior tempero-sphenoidal convolution, ear pricked, and head moved.
15. Movement of lip and nostril. (Ferrier.)

by indirect excitation of the motor areas ; for the following reasons. (*a*) The movements are such as would be excited by impressions emanating from special sense organs, *e.g.* turning the eyes and head to one side, pricking the ears and fixing the

eyes, or moving the nostrils, head, &c. (β) The latent period of the movements following stimulation of the areas of special sense is longer than that of those following stimulation of the motor areas proper.

II. *Destruction* or pathological lesion of the convolutions around the fissure of Rolando is followed by loss of voluntary power in the limbs of the opposite side. If the destruction be extensive and complete the result is hemiplegia. (Fig. 235.)

A marked difference exists between the results found in different orders of animals. The lower in the scale the animal, the less distinct or definite are the paralytic symptoms it shows after a given injury, and the more extended must the lesion be in order to give tangible results. Thus a single or local group of muscles may be paralyzed by a small local injury in a monkey, whereas in a dog a similar injury would give no definite result.

The age of the animal also has some influence on the results of lesion : the older the animal the more marked the paralysis following a given lesion. Thus in puppies up to the 10th day all the motor area may be destroyed without in any way influencing their powers of movement, which continue to develop in a normal manner.

It is a striking fact—which has been urged against the theory of cerebral localization—that after destruction of the motor areas the voluntary function of the muscles returns after the lapse of a variable and often surprisingly short interval.

The more limited the injury, the younger and the lower in the animal scale the object of experiment, the more rapidly does recovery take place. Thus, while in man (as we know from pathology) and in the monkey the destruction of a small area causes protracted paralysis, in the cat, dog, &c., an improvement can be noticed a few hours after the operation, and even after the most extensive lesions that can be executed on the cortex, fair recovery of locomotion takes place.

Convincing evidence that this area is the normal point of exit of motor impulses is given by the anatomical relations of these convolutions to the direct motor tracts—as demonstrated by the degeneration method. The degeneration can be traced through the corona radiata, internal capsule, crusta, bulbar pyramidal tract to the grey matter of the spinal cord, showing that medullated fibres pass, in a course uninterrupted by cell-stations, from the cortex directly to the anterior cornua of the

grey spinal matter. These must be the channels of volitional motor impulses.

Before experimental destruction of the motor areas had taught us the facts just mentioned, pathology had given some strikingly suggestive and confirmatory evidence. One point we owe to pathology alone, as it affects speech, a faculty enjoyed only by man. It is found that lesion implicating the third frontal convolution on the *left side* is invariably associated with the loss of the power of speaking—*aphasia*—a frequent concomitant of hemiplegia of the right side of the body. This convolution is close to, or the same as, the motor centre for the muscles of the tongue and mouth, &c., and it would appear that it is only educated on the left side—in right-handed people—for those co-ordinations requisite for framing vocal sounds into words. Hence the posterior part of the left third frontal convolution is called the speech centre.

There also exists conclusive evidence that in man the ascending convolutions (Rolandic area) have the same motor functions as in the monkey. Pathological destruction of local areas causes paralysis, and irritative disease causes convulsions of corresponding parts on the opposite side of the body. In man and monkeys a rigid state of the muscles supervenes after prolonged paralysis caused by destructive lesions of the cortex. Lesions in other parts confined to the cortex cause no persistent paralysis. The descending degeneration which marks out the direct motor tract is well seen in man long after motor cortical lesions, and accurately confirms the results of experimental degeneration.

It is noteworthy that in the motor area of the brain larger ganglion cells are found than in any other part of the cortex. These cells resemble, but are larger than, the large motor cells of the anterior cornu of the cord.

Sensory Areas.

The want of the direct indicator, motion, which helps us in testing the functions of the motor areas, makes the investigation of sensory areas less certain and conclusive. Independent of this fact it is quite clear, from the evidence to be mentioned, that the sensory regions are more widely distributed and are less accurately defined than the motor regions.

The evidence may again be conveniently divided into indications obtained by excitation and by destruction.

I. *Excitation* of no part of the cortex has given rise to conclusive signs of common or tactile sensation.

Stimulation of the postero-lateral regions of the cortex (*occipital lobes* and *angular convolution*) causes movement of the head and eyes towards the opposite side suggestive of visual sensation.

Stimulation of the posterior part of the *superior tempero-sphenoidal* convolution causes the animal to prick its ear open and fix its eyes and turn its head towards the opposite side, as if it had heard with that ear. This is best seen in the rabbit and other wild animals, which also give a startled bound.

Stimulation of the anterior part of the medial surface of the *uncinate convolution* is said to cause a kind of torsion of the lip and nostril suggestive of taste or smell. (Fig. 237.)

II. *Destruction* of the *gyrus fornicatus* or of the hippocampal region is said to leave more or less impairment of common and tactile sensation, and total destruction of all these regions causes protracted hemianæsthesia. There is no pathological evidence to make the conclusions drawn from these experiments applicable to man, and the anatomical distribution of the sensory fibres, as their path turns outwards from the internal capsule, seems to prove that it is not.

Removal or experimental destruction of one *occipital lobe* is said to cause hemiopia, and this is confirmed by pathological observation on man. Destruction of the *angular convolution* is followed by temporary blindness of the opposite side. Even bilateral destruction of the angular gyri only gives rise to transient impairment of vision. The destruction of the cortex over the angular gyrus and the occipital lobe on one side, causes very transient ambliopia of the eye on the other side, and more enduring hemiopia on the side opposite to the lesion of both eyes, *i.e.*, paralysis of both retinæ on the same side as the lesion.

To produce permanent loss of sight it is found necessary to destroy the cortex over a very extensive area, viz., both angular gyri and both occipital lobes. It is somewhat remarkable that the blindness in the case of the monkey here referred to was followed by atrophy of the optic nerve. (Fig. 238.)

Destruction of the *superior tempero-sphenoidal convolution* is followed by loss of hearing on the side opposite to the injury. When the lesion was bilateral the deafness was found to be permanent.

Experimental lesion of the *uncinate convolution* is attended

with great difficulty, and to produce loss of taste and smell extensive injuries have to be made. In the case of smell, comparative anatomy seems to confirm the idea that this region may be called the special centre of this sense, as these parts of the brain are developed in proportion to the acuteness of this very variable faculty.

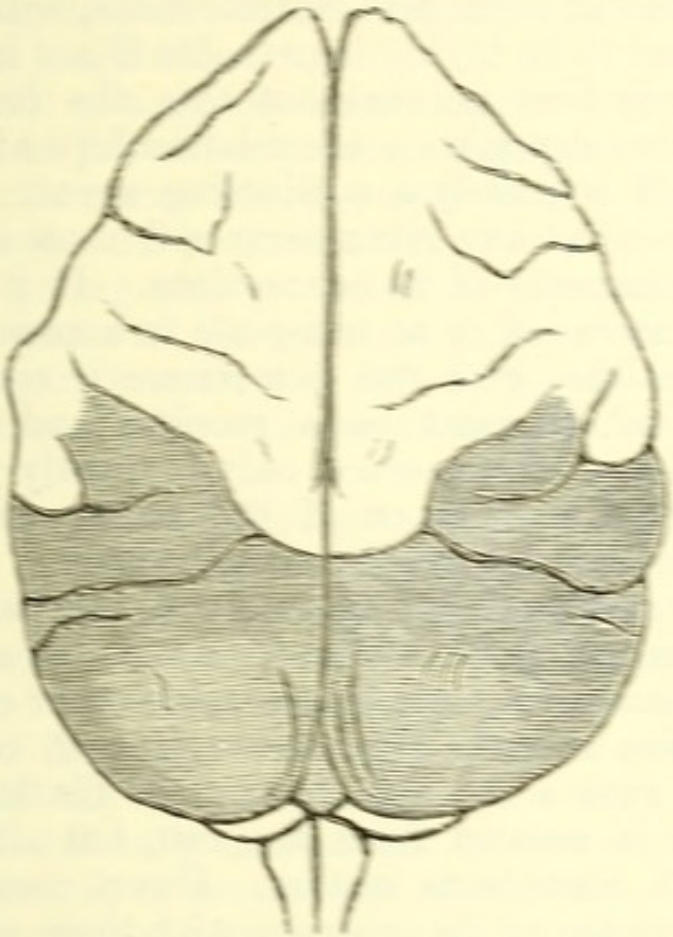


Fig. 238.—The shading shows the great extent of surface destroyed before permanent cortical blindness followed by retinal atrophy was produced: i.e., all posterior lobes and angular gyri.

Conclusions.

There seems no sufficient reason to doubt that the motor area include the points of exit from the brain of the voluntary motor impulses, and there is no useful object in assigning to these regions any other special function, that we cannot demonstrate, although they must be intimately connected with many if not all mental acts in order to execute the function assigned to them.

With regard to the sensory areas, they seem to be too ill-defined and too wide-spread to enable us to restrict their functions to those of which we can obtain experimental proof or pathological evidence. For instance, we cannot believe that

all the grey matter in the angular gyri and occipital lobes are devoted exclusively to the reception of visual impression. Yet all this region must be destroyed before vision finally disappears.

The areas of the cortex employed in receiving sensory impulses and forwarding the impressions so as to arouse mental acts, or record memories, are so dovetailed one into the other that a separation of them into discrete fields, with specific local functions, seems to be highly improbable if not impossible.

It has already been pointed out that the function of any given nerve-fibre depends on the relationships of its terminals. The fibre itself is merely a conducting agent. In the same way the functions of any given nerve-cell must depend on the number and character of its connections. If it be connected with a motor nerve-cell or an end-plate in a muscle, it can only excite impulses that give rise to motion : if connected with a sensory terminal, it must be a receiver and distributor of sensory impulses. If connected only indirectly with the cells of the perceptive centres or of the motor areas it may be devoted to volitional recollection or movement.

In the grey matter of the spinal cord, and still more so, in that of the cerebral cortex, we may assume that all the cells are in intimate connection with innumerable other cells. In fact, we must imagine that the grey matter of both cord and brain is interwoven into a complex texture of fibrils and cells, no part of which is isolated from the rest, but all the elements form part of a contiguous system. Direct continuity of one nerve cell by means of its processes with those of another, has not been made out histologically, and it is probable that the universal communication may be accomplished by means of *adjunction* rather than *conjunction* of the cell-processes.

When we excise, cauterise or stimulate a given point of the complex cortex, we do not know in what way we interfere with the perfect action of the wonderful nervous nexuses which control the organism, because our knowledge is limited to the effects we produce, upon those few functions the activity of which is obvious.

The Mechanism of Speech.

The evolution of mental processes from the impulses derived from the various sensory organs, does not come within the scope of this volume, but it may be useful to consider one

faculty, *speech*, the mechanism of which we may attempt to unravel by studying its physiological growth, which helps us to understand mental acts, and its pathological analysis, which is essential for clinical diagnosis.

The power of using words—either in the form of sound signals, mental symbols or written images—to represent our ideas is inseparably connected with the highest form of animal intelligence, and is the faculty most recently acquired by the animal kingdom.

The existence of a speech centre in the frontal convolution, on the left side, has already been mentioned. This is not the only part of the cortex which subserves the acquirement and use of language. It is merely the point from which emanate the impulses giving rise to articulate expression of language. Several other parts of the cortex are intimately connected with this speech centre proper, and only by the exact correlative action of all these parts can we thoroughly enjoy the use of language.

The development of language may be taken as a gauge of intelligence. It varies much in different races of man, in different individuals of the same race, and, as we must acquire it by education, it varies with the different periods of life. The intelligent and educated man is as far above the untaught savage—whose language consists in sound signals for common natural objects—as the savage is above the dog which can recognise words but can only express his emotions and thoughts by varying intonation, or movements of its body.

The subject may be considered under three headings—

How we (1) *acquire*, (2) *remember*, and (3) *use* words.

Acquisition of Words.

Auditory Perception.—An infant can hear at birth, and learns to discriminate sounds at a very early period, but it has to learn words by a gradual process requiring more time. This commences by hearing certain sounds repeated in connection with certain objects. Soon these sounds are recognised when repeated, and call up visual pictures of the object with which it had previously been associated. Gradually a vocabulary of sound signals is established by the impulses from the auditory region, passing to the sensorium, where residual impressions are left, and words are, as it were, registered in cortical cells.

Now we have pathological evidence that the power of

recognising word-sounds is localized to a part of the cerebral cortex intimately connected, if not quite identical with, the hearing centre, viz., the posterior half of the first temporal convolution on the left side. A lesion of the cortex in this region may destroy this power of recognising spoken words, without interfering with other auditory powers, such as appreciating ordinary and musical sounds, or with the memory of words as symbols of ideas. The person may be able to write and understand written words, articulate well, read aloud, and even speak volubly, (though inaccurately from not being able to correct his speech by his hearing,) and yet he cannot recognise one word of spoken language. This condition has been called "word-deafness." To produce it some flaw must exist, separating the auditory cells from those that store up word memories.

Visual perception.—Some time after a child has learned to recognise word-sounds it begins to study word-images, and in time is taught to read printed or written words. This visual word-perception may be compared to the auditory word perception just mentioned. Here again the images of the words when recognised cause impulses to pass from the visual centres to the higher mental centres in the cells of which the words are registered by repeated identical excitation.

The part of the cortex in which this visual word perception and registration takes place is near the visual centre, but not co-extensive or identical with it, being the hinder part of the parietal lobe on the left side (angular gyrus). Lesion of the cortex in this region gives rise to a condition called word-blindness, in which the power of understanding written or printed words is lost, but the visual power of recognising and discriminating objects in general remains unimpaired. If vision be at first deficient it usually rapidly recovers.

The loss of the power of recognising printed or written words, *i.e.* of reading (alexia) may occur alone, auditory perception of words and speech remaining unimpaired. This condition has been found after lesion of the supramarginal and angular convolution. A patient with alexia can write either spontaneously or from dictation, but irregularly as if with closed eyes, but strange to say he cannot read one word of what he has written.

The patient can see the printing and the separate words and may even be able to say them aloud. By thus transporting the visual perception—which cannot reach the sen-

sorium directly—by sound signals to the auditory portal, the meaning of the reflexly pronounced words may reach the higher centres and be understood. This affection is called "word-blindness," and forms a part of "mind-blindness," with which it is sometimes associated, as the most lasting symptom, for the power of discriminating between general objects sometimes returns, and yet the cortex may remain blind to words.

Memory of Words.

Word registration.—It has been already stated, in speaking of motor co-ordination, that the groups of nerve-cells which frequently act together, get into the habit of performing complex motions with ease, and that by use, certain paths in the nervous centres become, as it were, beaten tracts. Each functional act of a group of nerve-elements is associated with a molecular change which requires some time for its complete restoration, and enables the elements to execute more readily the same kind of action. The resistance in the path of transmission is diminished, and a residual disposition of the protoplasm to undergo the given change persists. This disposition may pass off in time, or it may become permanent by sufficiently frequent repetition. In the facility with which many complex co-ordinations can be executed by the spinal cord, at times unconsciously, we may recognise a kind of motor memory, formed during the long period of training necessary for the perfect performance of such actions.

For the mental process—memory properly so-called—we have no other physical basis than this residuum of molecular change. The impulses exciting a mental process call into play a more or less extensive combination of nerve-elements and leave in them residual dispositions to repeat the same act. Frequent repetition fixes this disposition, and when it is fully established, the act may be recalled by will so that we can recollect the thought or word belonging to the mental process. This residual disposition to repeat such a process may be so marked that the revival takes place automatically, independent of the will, and we say we cannot get a given idea "out of our heads," as sometimes occurs with a popular melody.

Amnesia.—The memory of words is often lost when other matters are perfectly retained in the mind, and while there is

no defect in the sensory or motor word agencies. A person may be able to read, and write from copy, or from dictation, hear and repeat accurately what he hears, yet he may have forgotten all or nearly all his vocabulary. This condition called amnesic aphasia has not been localised in the cortex. It may be associated with more or less general loss of memory (amnesia), but need not be associated with lesion of any of the special centres for visual or auditory perception or for the oral or the graphic use of words. The agencies for the registration and for the utterance of words are perfect, but the power of voluntary revival is lost. There must then be a combination of nerve cells—beyond the visual and auditory registrars and the articulatory and graphic workers—whose function is to store and to keep within reach of the will a vocabulary of words. A patient having lost this word memory can easily repeat the words he hears or can read and understand, but in a short space of time the memory of those words again fails and cannot be revived by the will.

Use of Words.

Articulate.—It has been repeatedly indicated that the use of words in speech and writing requires two distinct mechanisms. The use of spoken language precedes the acquisition of writing by some years. The part of the brain already alluded to as the vocal speech centre, is that most closely connected with all word processes in general. In right-handed persons it is always situated in the left hemisphere, and is in the position of the motor area of the muscles used in articulation, viz. the posterior part of the third frontal convolution and probably part of the adjacent ascending frontal.

Lesion of this region is invariably followed by aphasia of the motor variety, *i.e.*, inability to utter words even when just heard or seen, although understood perfectly, it is frequently associated with amnesia, word-blindness, and less commonly word-deafness.

There may be no loss of power of co-ordination of the muscle used in speech, but the power to originate articulate sounds is gone. The total loss of voluntary speech has been found to follow a lesion no larger than a filbert nut. The person may recognise the errors he makes, can understand what is said to him but cannot repeat the words, in this differing from the simple amnesic condition when he can utter the words but

cannot remember them. He cannot read aloud but may be able to understand written language. He can copy writing or even be able to write spontaneously or do arithmetic. In some instances there may be power to articulate, but the wrong word is produced much to the annoyance of the patient, even the wrong gestures may be made, a nod of assent, when "No," is meant, and *vice versâ*. Occasionally a few words can be uttered and these are repeated on all occasions, with or without their proper meaning.

A person unable to utter one word voluntarily may speak by accident as it were, without thinking, automatically and yet correctly, or he may repeat accurately all the words of a song when singing.

Graphic.—In the affection just described, which may be designated motor aphasia, the power of writing is generally lost (*agraphia*) because most people go through a form of silent articulation of the words to be written, and only by extensive practice can persons express ideas in writing by the independent association of the sensorium with the centres of manual movement. Another reason why agraphia is not more common as an isolated symptom is the frequent occurrence of motor paralysis of the right hand with lesions that would produce it. A sufficient number of cases are on record to show that the loss of power of writing words may be forgotten without motor paralysis, without any form of aphasia, *i.e.*, when auditory and visual perception of words are perfect and the memory and utterance of words normal. The individual may even be able to copy figures and words, or may be able to write with the left hand, showing that the impulses may travel from the region of visual word perception to the arm motor centre, without the mediation of the cells devoted normally to the memory of how to form written words spontaneously.

The various deficiencies of language here enumerated, have been differentiated in order to show that the corresponding centres may suffer or act independently of others, and have therefore separate positions in the cortex, but as a rule these deficiencies are variously associated to form a complex group of symptoms, showing an intimate correlation of their function.

Total Aphasia.

Complete loss of language, comprising word-deafness, word-blindness, amnesia, motor aphasia, and agraphia may exist without paralysis or want of co-ordination of the movements of the muscles engaged in articulation. On the other hand there may be distinctly defective articulation without a trace of any form of aphasia. This is accounted for by the fact that either hemisphere suffices to set the bilaterally associated movements of these muscles in action, so long as their co-ordinating centres in the bulb are uninjured, but injuries of the bulb and lower part of the pons give rise to defective movements of these muscles and consequent loss of articulation. This may vary from "thickness of speech" to complete *anarthria*, when the vocal tones of the larynx alone remain to represent articulate speech.

From the foregoing it would appear that in learning and using language many parts of the cortex are brought into play, viz.:

1. A centre for remembering the sounds of words.
2. A centre for remembering the look of words, printed or written.
3. A centre for the volitional revival (recollection) of words, as representing ideas.
4. A centre for remembering how to utter words.
5. A centre for remembering how to write words.
6. Centres for co-ordination of the muscles of articulation.
7. Centres for the movement and co-ordination of the muscles of the hand and arm in writing.

It is obvious that these relationships cannot be followed out on animals, since they do not possess the faculty of language, but experimental and pathological experience give evidence in favour of the probability that for every faculty a similar wide-spread cohesion of cortical regions obtains, and that the residual molecular changes in cells, giving them a disposition to revive former activities as ideas in response to the will, may be brought about by other auditory and visual perceptions as well as by tastes, smells, touches, and other incoming impulses of which we know nothing.

CHAPTER XXXVI.

REPRODUCTION.

Male and Female Generative Elements.

One of the chief characteristics of living beings is their power of reproduction. As a general rule organisms can, under favourable conditions, give rise to other individuals similar to themselves.

It has been explained (Chap. IV.) how in the lowest forms of animal life the propagation of species may take place by the division of a single cell: thus an amœba reproduces by the cleavage of its mass of protoplasm, separating the main body into two amœbæ. Such a method of reproduction may be purely *asexual*, each individual appearing to have the intrinsic power of reproduction.

As we ascend the animal scale, we find that, just as other functions are executed by certain specially differentiated groups of cells, so reproduction is performed by cells endowed with specific powers. And we find that reproduction requires the co-operation of two kinds of generative elements, each of which is produced by a distinct organ. In the higher organisms these reproductive elements are produced by different individuals of the same species, thereby dividing them into two sexes. This is termed *sexual reproduction*.

The sexual type of reproduction is more widespread than might be at first supposed. It may be recognised in some of the lowest forms of plant life, when conjugation of the protoplasm of apparently identical cells precedes the development of some kinds of spores. In all the more highly developed forms of animal and vegetable life only sexual reproduction is met with. When sexual differentiation is advanced the male organ produces active elements—the spermatozoa; the female organ produces the ovum, which, when fertilised by the spermatozoa, develops into the new individual.

The narrow limits of this work make it necessary to pass over the interesting details of the different modes of reproduction and to confine ourselves to a brief sketch of the reproductive organs of mammalia and the processes which take place in the *uterus* for the housing and nutrition of the offspring. As much of our knowledge of the earlier stages of growth has been gained from the eggs of oviparous animals, frequent reference will have to be made to the development of the chick which can be studied with comparative ease.

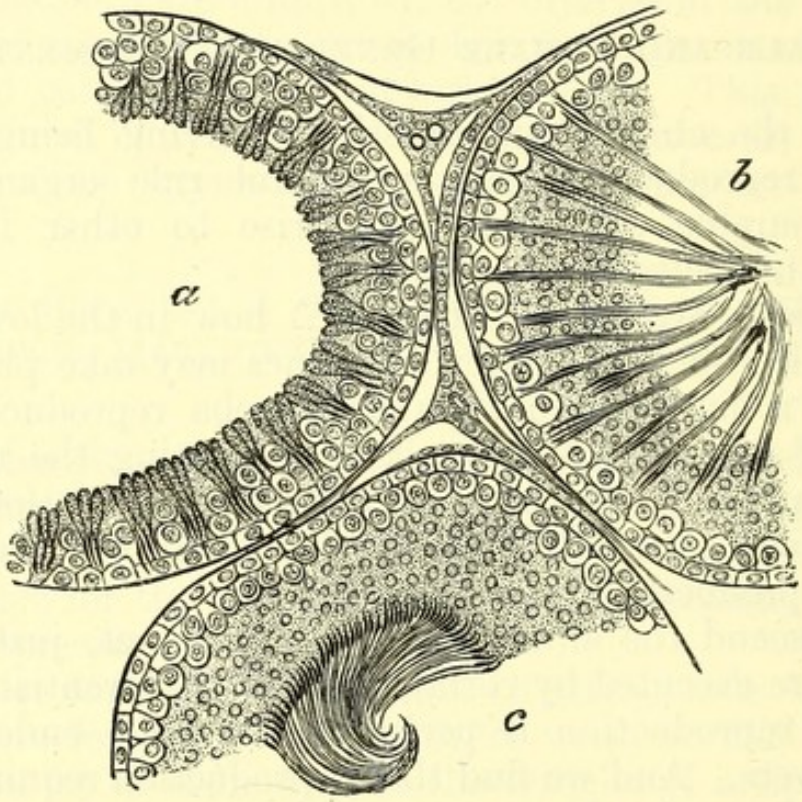


Fig. 239.—Section of the tubuli seminiferi of a rat. (Schäfer.)

a. Tubuli in which the spermatozoa are not fully developed.
b. Spermatczoa more developed. *c*. Spermatozoa fully developed.

The Testicle.

The secreting part of the testes is composed of numerous packets containing coils of long *seminal tubules*. These tubules in the young animal are lined with 2 or 3 similar layers of polyhedral nucleated epithelial cells. After puberty the cells lying near the periphery of the tube (mother-cells) become altered and undergoing active division (see page 15), give rise to rounded daughter cells, which, as they change into *spermatozoa*, have been called *spermatoblasts*. The innermost of the

spermatoblasts become club-shaped and elongated to form spermatozoa, the flattened nucleus persisting at one end to form the head. The young spermatozoa collect into groups with their heads (nuclei) towards the seminal cells, next the wall of the tube, and they become embedded in the inner seminal layer, by the rapid proliferation of its cells. Each of these groups of spermatozoa has apparently been formed from a single "mother-cell;" but in its division this cell has not entirely formed spermatoblasts, for there is still one nucleated piece remaining which apparently is useless and corresponds to that piece of the ovum extruded as the polar globules.

The spermatozoa, when free, are seen to be made up of three parts, (1) the slightly curved and flattened head, which is the altered nucleus of the spermatoblast, (2) the body which is the remnant of the protoplasm of the body of the cell, and (3) the tail or flagellum, which propels the spermatozoa onwards by a spiral or oscillatory movement.

From the seminiferous tubules the spermatozoa have to pass through the epididymis, composed of a complex series of tubules (*vasa efferentia*) and networks (*coni vasculosi*) lined with columnar cells, the free surface of which is covered with long cilia. Thence they pass through the spermatic cord (*vas deferens*) to reach the *vesiculæ seminales*, both of which tubules have very muscular walls and are lined with ciliated epithelium.

The Ovary.

The *ovaries*, which are the homologues of the testes, are fibrous organs of great vascularity lying in a fold of peritoneum at each side of the uterus. On the surface of the ovary is a coat of dense tissue, *tunica albuginea*, which is covered by a layer of columnar epithelial cells, differing essentially from the flattened endothelial cells of the peritoneal serous membrane both in form and function. The cells forming this covering are called the *germ-epithelium*. In a section of the ovary a number of small vesicles of various sizes may be seen scattered throughout the more loosely arranged connective tissue of the deeper parts of the organ. Close to the surface these bodies are very numerous and small, and some may be traced to the surface cells from which they take their origin. These vesicles are called *Graafian follicles*. They contain the essential element—the *ovum*.

The *ovum* is developed from a cell of the germ-epithelium

covering the surface of the ovary. The primordial ovum becomes surrounded by a group of these cells which proliferate rapidly and penetrate the tunica albuginea. They then become embedded in the stroma, where a kind of capsule, derived from the surrounding areolar tissue, encloses the nest of cells, and forms a Graafian follicle. A central cell grows rapidly to form the ovum, the rest increase in number to form the small cells of the tunica granulosa. As the follicle develops, it works its way towards the centre of the ovary, and subsequently approaches the periphery of the organ as a fully-developed *ovisac.*

Microscopically, it is seen to be surrounded by a capsule, *tunica fibrosa*, which is ill defined from the stroma of the ovary in which it lies. Outside this is a layer of capillary blood-vessels, *tunica vasculosa*, and to these two coats collectively the term *tunica propria* is applied.

Inside the tunica propria are granular cells of small size, which occupy a considerable space in the follicle. In the ripe follicle they are heaped up at one spot so as to surround the ovum, which lies embedded in their midst. These cells receive the name of the *tunica granulosa*, and their projecting portion, which encircles the ovum, is called the *discus proligerus.* The remainder of the follicle is filled with a fluid, *liquor folliculi.* The liquid increases as the follicle ripens until the surface is reached, and the vesicle projects on the surface ready to burst.

Ovulation and Menstruation.

After puberty, at intervals averaging about four weeks, a Graafian follicle is ruptured and its ovum set free. Coincidently with the rupture of the follicle, the fimbriated extremity of the Fallopian tube becomes closely approximated to the spot where the follicle lies, so that the ovum instead of falling into the abdominal cavity, passes into the canal of the Fallopian tube, down which it is conveyed to the uterus.

At the period of ripening of the ovum, changes take place in the vascular arrangements of the uterine mucous membrane. Dilated venous spaces which seem to be rudimentary homologues of the venous sinuses of the placenta, are formed in the mucosa and the overlying epithelium perishes. The surface over these spaces thus becomes denuded and allows some blood to exude. These changes form the essentials of *menstruation.*

When the ovum reaches the uterus, if it be unimpregnated, it is cast out with the surface cells of the mucous membrane of the uterus, &c., all together forming the menstrual discharge.

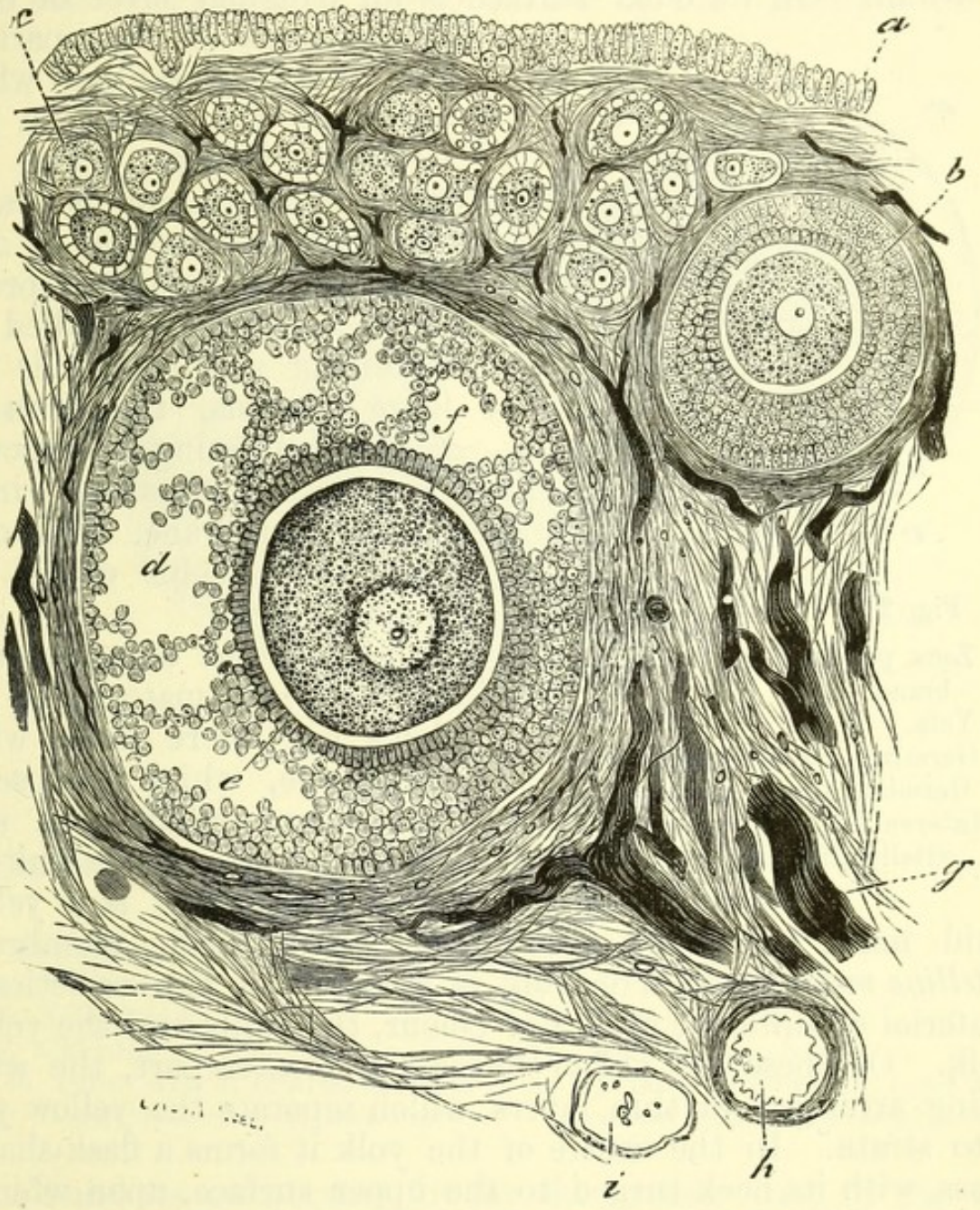


Fig. 240.—Section of the ovary of a cat, showing the origin and the development of Graafian follicles. (Cadiat.)

a. Germ-Epithelium
b. Graafian follicle partly developed.
c. Earliest form of Graafian follicle.
d. Well-developed Graafian follicle.
e. Ovum.
f. Vitelline membrane.
g. Veins.
h, *i*. Small vessels cut across.

If, however, the ovum become impregnated, it remains in the Fallopian tubes some days, during which time the mucous

membrane of the uterus becomes so hypertrophied as to retain the ovum when it reaches that organ.

The human ovum is a cell consisting of a mass of protoplasm enclosing a nucleus and nucleolus, and surrounded by a cell-wall. On its outer surface is an irregular layer of cells, the remains of that part of the tunica granulosa which encircled the ovum in the Graafian follicle. The cell wall of the ovum is called the *vitelline membrane* or *zona pellucida*; the mass of protoplasm it encircles is called the *vitellus* or yolk. In this is a large nucleus, the *germinal vesicle*, consisting of reticular protoplasm contained in a definite membrane. This contains a nucleolus called the *germinal spot*.

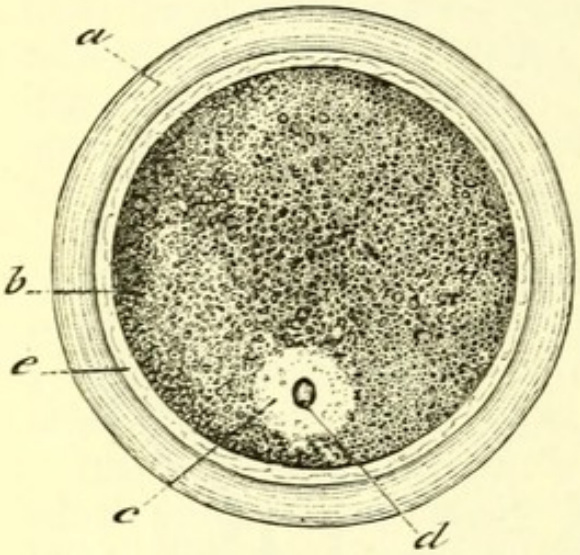


Fig. 241.—Ovum. (Robin.)

a. Zona pellucida or vitelline membrane.
b. Yolk.
c. Germinal vesicle or nucleus.
d. Germinal spot or nucleolus.
e. Interval left by the retraction of the vitellus from the zona pellucida.

Beneath the outer covering of calcareous material of the hen's egg there is a white membrane, which encloses a transparent albuminous substance known as the white of egg. Inside this is a yellow fluid mass, the yolk, surrounded by a delicate membrane, *vitelline membrane*. The yolk is made up of two varieties of material of different shades of colour, the white and the yellow yolk. Of these the yellow forms the greater part, the white being arranged in thin layers, which separate the yellow yolk into strata. In the centre of the yolk it forms a flask-shaped mass, with its neck turned to the upper surface, upon which a portion of the yolk rests called the *cicatricula*. This cicatricula, which lies between the vitelline membrane and the white yolk, is the active growing part of the egg, and out of it is developed the chick and the embryonic membranes.

Extending through the albumin from the vitelline membrane towards the ends of the egg are two twisted membranous cords—the *chalazæ*, which help to keep the yolk in position but allow it to rotate, so that the cicatricula is always the uppermost part of the yolk when the egg is on its side.

The main structural differences between the human ovum taken as a type of mammalian ova and that of a fowl may be gathered from the above description. The peculiarity of the development of the hen's egg is that only a small portion of the yolk is engaged in the formation of the first signs of the

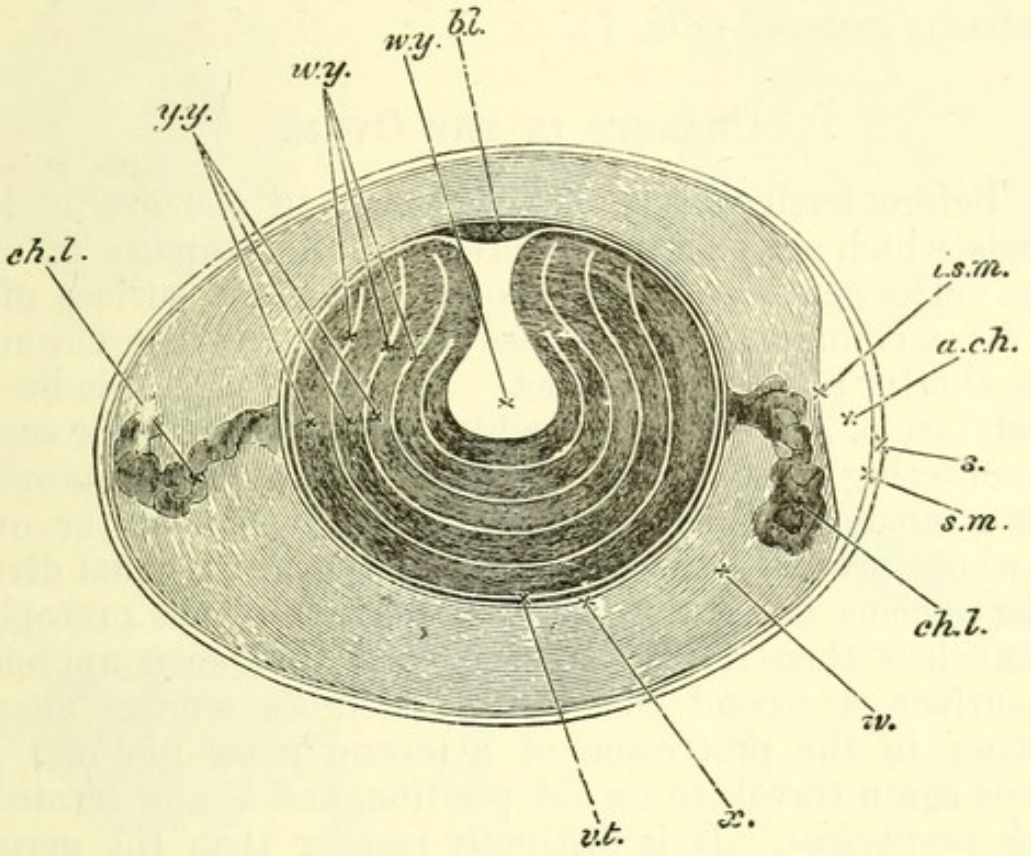


Fig. 242.—Diagram of a section of an unimpregnated fowl's egg. (From Foster and Balfour, after Allen Thomson.)

bl. Blastoderm or cicatricula.
w.y. White yolk.
y.y. Yellow yolk.
ch.l. Chalaza.
i.s.m. Inner layer of shell membrane.
s.m. Outer layer of shell membrane.
s. Shell.
a.ch. Air space.
w. The white of the egg.
vt. Vitelline membrane.
x. The denser albuminous layer which lies next to the vitelline membrane.

chick and its membranes, by far the greater part of the egg, both yolk and albumin, being utilised as nourishment during the subsequent stages of development. Such ova are called *meroblastic*.

After the egg has been laid, it obtains no help from the outside world, except the oxygen of the air and the heat of the mother's body ; it is, as it were, fenced in with a protecting membrane, garrisoned with the quantity of provisions required, and by the warmth of the hen's body stimulated to growth and activity.

The whole of the protoplasm of the human ovum, on the other hand, undergoes segmentation and differentiation in the primary formation of the embryo. Such an ovum is termed *holoblastic*. From the very earliest stage of development the life and growth of the human embryo depend upon supplies from the mother, the ovum not having within itself any store of nutrient material (Fig. 7).

Changes in the Ovum.

1. Before fertilisation, changes occur in the ova of lower animals which are believed to have their homologues in mammalia. The germinal vesicle moves nearer the surface of the egg, its membrane becomes less distinct, and the chromatin fibres shorter and more distinct. An achromatic spindle then appears (see p. 70), one pole of which protrudes from the surface, and collecting some chromatin fibres and a little protoplasm, forms a small cell (*polar globule*) on the surface of the ovum. The whole process seems simply to consist of an equal division of the nucleus but a very unequal division of the protoplasm. The nucleus then returns to the centre, but soon approaches the surface a second time and undergoes similar changes, resulting in the protrusion of a second polar globule. The nucleus again travels to its old position, and is now termed the *female pronucleus*. It is distinctly smaller than the germinal vesicle. The whole of this process is termed the *maturation of the ovum*.

2. On fecundation a spermatozoon enters the protoplasm of the ovum, loses its tail, and its head becomes globular, forming the *male pronucleus*. The protoplasm becomes radiated around the latter, and it approaches the female pronucleus with which it unites to form the *fecundation nucleus*, the whole mass of protoplasm becoming at the same time radiated. By a series of indirect divisions the segmentation sphere thus formed divides at first into two segments, then into four, eight, sixteen, and so on, until a large spherical mass of cells is formed. To this condition the name of *morula* is given, from its likeness to a mulberry. Fluid now collects among the cells, and separates some of them from the others, and they arrange themselves into an outer and inner layer, consisting of different kinds of cells. The inner cells finally become aggregated at one part of the ovum in contact with the outer cells. The ovum now receives the name of the *blastodermic vesicle*.

In the hen's egg the cleavage is confined to the cicatricula or blastoderm, and does not include the rest of the yolk.

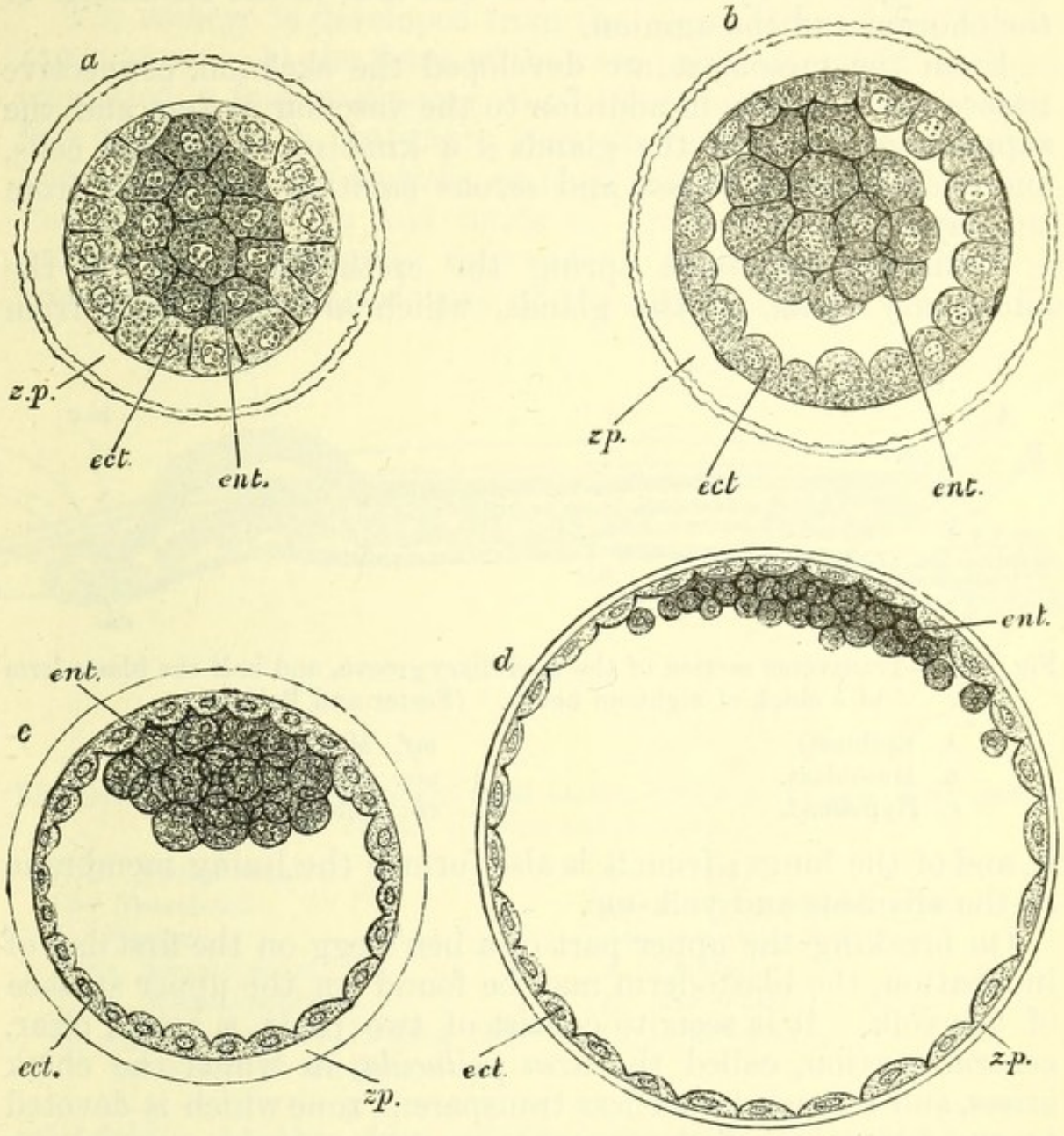


Fig. 243.—Sections of the ovum of a rabbit, showing the formation of the blastodermic vesicle. (E. Van Beneden.)

a, *b*, *c*, *d*, are ova in successive stages of development.
z p. Zona pellucida. *ect.* Ectomeres, or outer cells.
ent. Entomeres, or inner cells.

The cells in the blastodermic vesicle soon form three definite layers, which are called respectively, from their position in the blastoderm, the *epiblast*, the *mesoblast*, and the *hypoblast*.

From these layers are developed the embryo and the membranes surrounding it, each layer forming certain tissues. These may be here enumerated :—

From the epiblast, or outer layer, arise the epidermis of the skin, the skin glands, the brain and spinal cord, and certain parts of the organs of special sense ; it also aids in the formation of the chorion and the amnion.

From the mesoblast are developed the skeleton, connective tissues and muscles, in addition to the vascular system and the supporting tissue of the glands ; a kind of tessellated cells, endothelial, lining vessels and serous cavities, also arises from this layer.

From the hypoblast spring the epithelial lining of the alimentary canal, of the glands, which are diverticula from

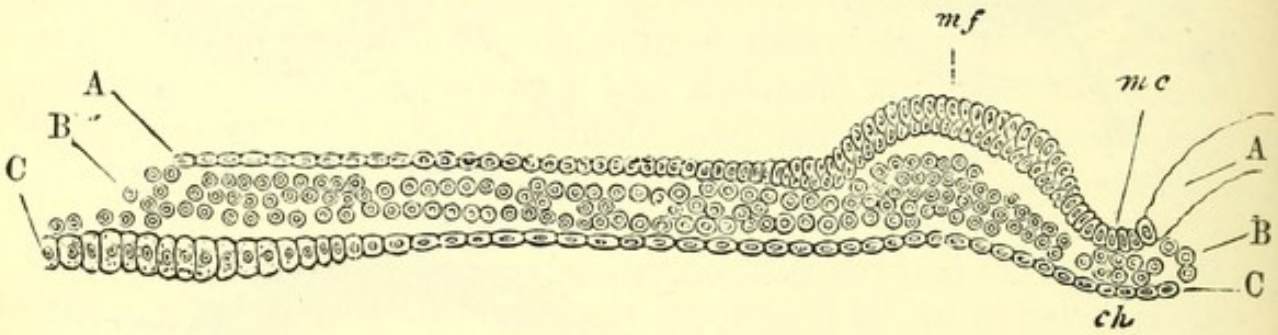


Fig. 244.—Transverse section of the medullary groove, and half the blastoderm of a chick of eighteen hours. (Foster and Balfour.)

A. Epiblast.
B. Mesoblast.
C. Hypoblast.
mf. Medullary fold.
mc. Medullary groove.
ch. Notochord.

it, and of the lungs ; from it is also formed the lining membrane of the allantois and yolk-sac.

On breaking the upper part of a hen's egg on the first day of incubation, the blastoderm may be found on the upper surface of the yolk. It is seen to consist of two parts, a small, clear, central portion, called the *area pellucida*, in which the chick arises, and a much larger less transparent zone which is devoted to the formation of the membranes and vascular appendages for the nutrition of the embryo. This is the *area opaca*.

Towards the end of the first day of incubation the opaque area spreads greatly and its inner margin, that nearest the clear area, becomes mottled. Early on the second day it is coloured and the formation of groups of vascular channels may be recognised. The cells send out branches which unite to form a network, at the nodal points of which nuclei can be seen. At the same time a coloured matter appears in their protoplasm and soon forms little masses, red corpuscles, within the cells. This part of the opaque area is then called the *area vasculosa*. During the same period some of the cells of the

clear area undergo a similar change, and among the mesoblastic cells of the head end of the embryo, a red speck can be seen and soon recognised, by its rhythmic beating, to be the heart.

The embryo is developed from the blastoderm in the following manner. At the front of the area pellucida, which becomes elongated, a fold or dipping in of the blastoderm takes place; this consists of a projecting part above and a groove below, and constitutes the *cephalic*, or head fold. The upper projecting portion of the fold tends to grow forwards, whilst the groove grows gradually backwards. Later on, a similar fold appears at the posterior part of the area pellucida, this is the

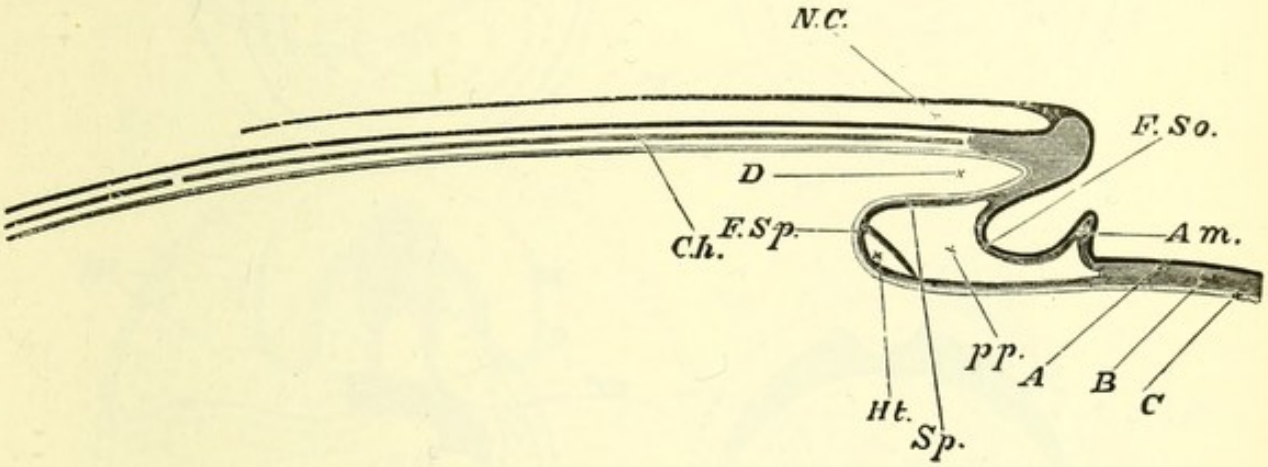


Fig. 245.—Diagrammatic longitudinal section through the axis of an embryo chick. (Foster and Balfour.)

N.C. Neural canal.
Ch. Notochord.
D. Foregut.
F.So. Somatopleure.
F.Sp. Splanchnopleure.
Sp. Splanchnopleure forming the lower wall of the foregut.
Ht. Heart.
pp. Pleuroperitoneal cavity.
Am. Amniotic fold.
A. Epiblast.
B. Mesoblast.
C. Hypoblast.

tail fold. At the sides of the area pellucida folds appear, which tend to grow downwards and inwards so as to reach the under surface of the blastoderm and unite with the head and tail folds.

By the approximation of all these folds a canal is formed—*the embryonal sac*—which is closed above by the main portion of the area pellucida, in front by the head fold, behind by the tail fold, at the sides by the lateral folds, whilst below it is open to the vitellus. This canal ultimately becomes subdivided into an inner tube, the alimentary tract, and an outer one, which forms the body walls, the final place of union of the folds being marked by the umbilicus. It must be clearly

understood that these primary folds which form the embryo include in their layers the epiblast, the whole thickness of the mesoblast, and the hypoblast, whereas the folds giving rise to the membranes only involve the epiblast and with it a portion of the mesoblast (A in Fig. 245).

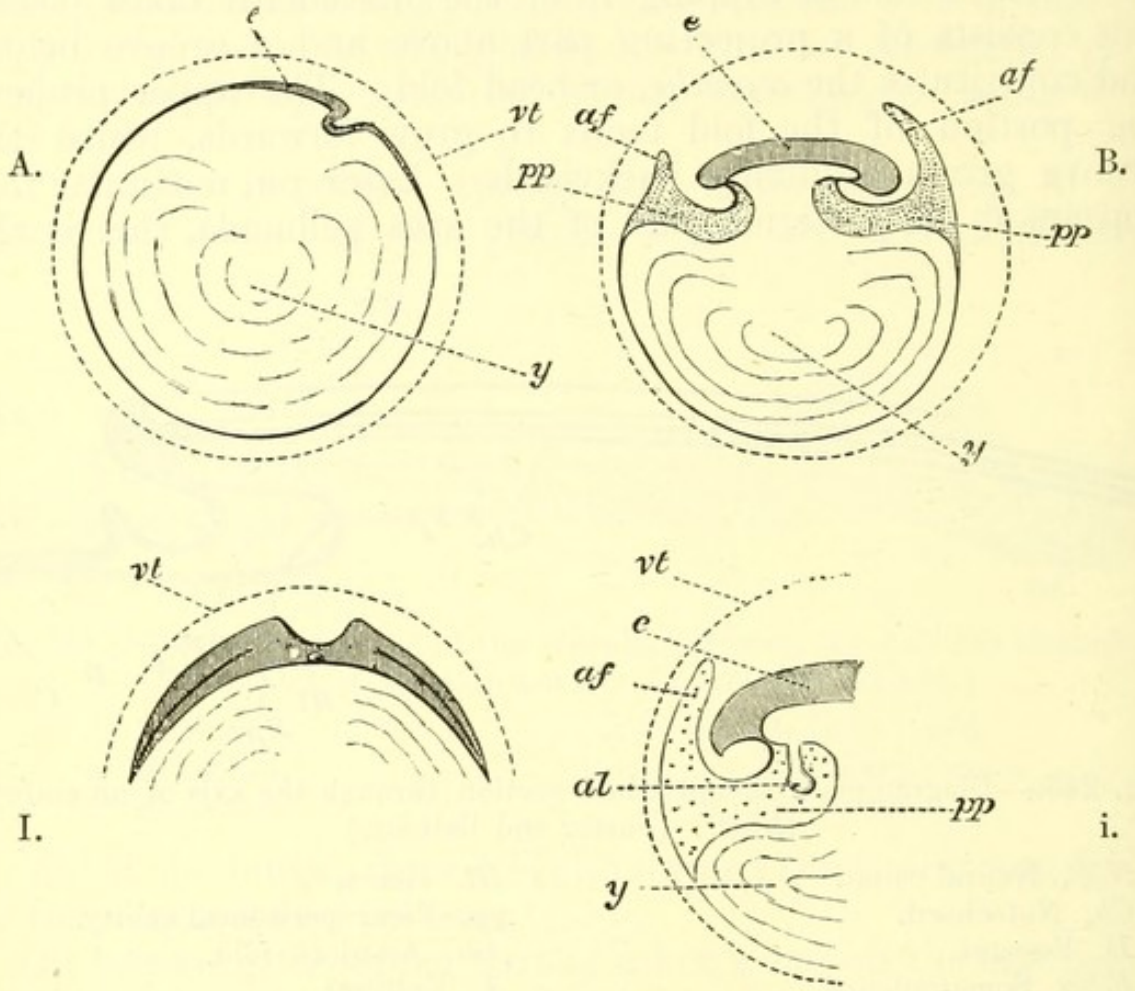


Fig. 246, and the two following woodcuts, are diagrammatic views of sections, through the developing ovum, showing the formation of the membranes of the *chick*. (Foster and Balfour.)

A, B, C, D, E, and F, are vertical sections in the long axis of the embryo at different periods, showing the stages of development of the amnion and of the yolk-sac.

I., II., III., and IV., are transverse sections at about the same stages of development.

i., ii., and iii., give only the posterior part of the longitudinal section, to show three stages in the formation of the allantois.

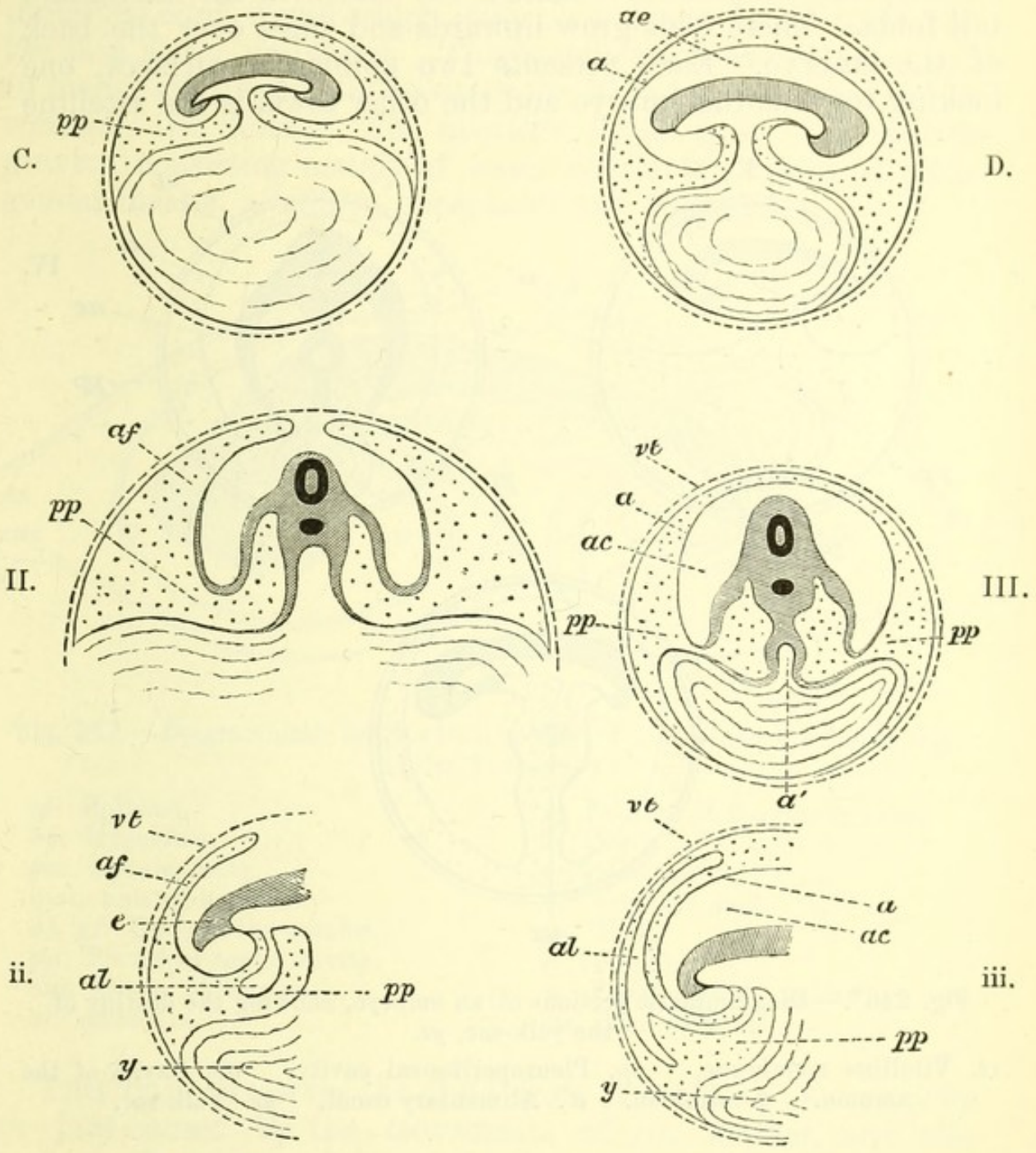
e. Embryo.
y. Yolk.
pp. Pleuroperitoneal fissure.
vt. Vitelline membrane.
af. Amniotic fold.
al. Allantois.

Formation of the Membranes.

(1.) *The Amnion.*—The mesoblast around the embryo becomes thickened, and is split into two distinct layers: this

cleavage is at first confined to the neighbourhood of the embryo, but gradually spreads over the whole blastoderm.

The upper of these two layers of the mesoblast unites with



e. Embryo.
a. Amnion.
a'. Alimentary canal.
vt. Vitelline membrane.
af. Amniotic fold.
ac. Amniotic cavity.
y. Yolk.
al. Allantois.

the epiblast to make the *somatopleure*, which forms the body-walls of the embryo and the amnion. The lower one joins the hypoblast to make the *splanchnopleure*, which forms the walls of

the alimentary canal, of the allantois, and of the yolk-sac. The space intervening between these layers is called the pleuroperitoneal cavity. The cephalic fold is an upward projection of the somatopleure only and the same is the case with the lateral and tail folds. These folds grow upwards and meet over the back of the embryo. Each presents two epiblastic surfaces, one looking towards the embryo and the other towards the vitelline

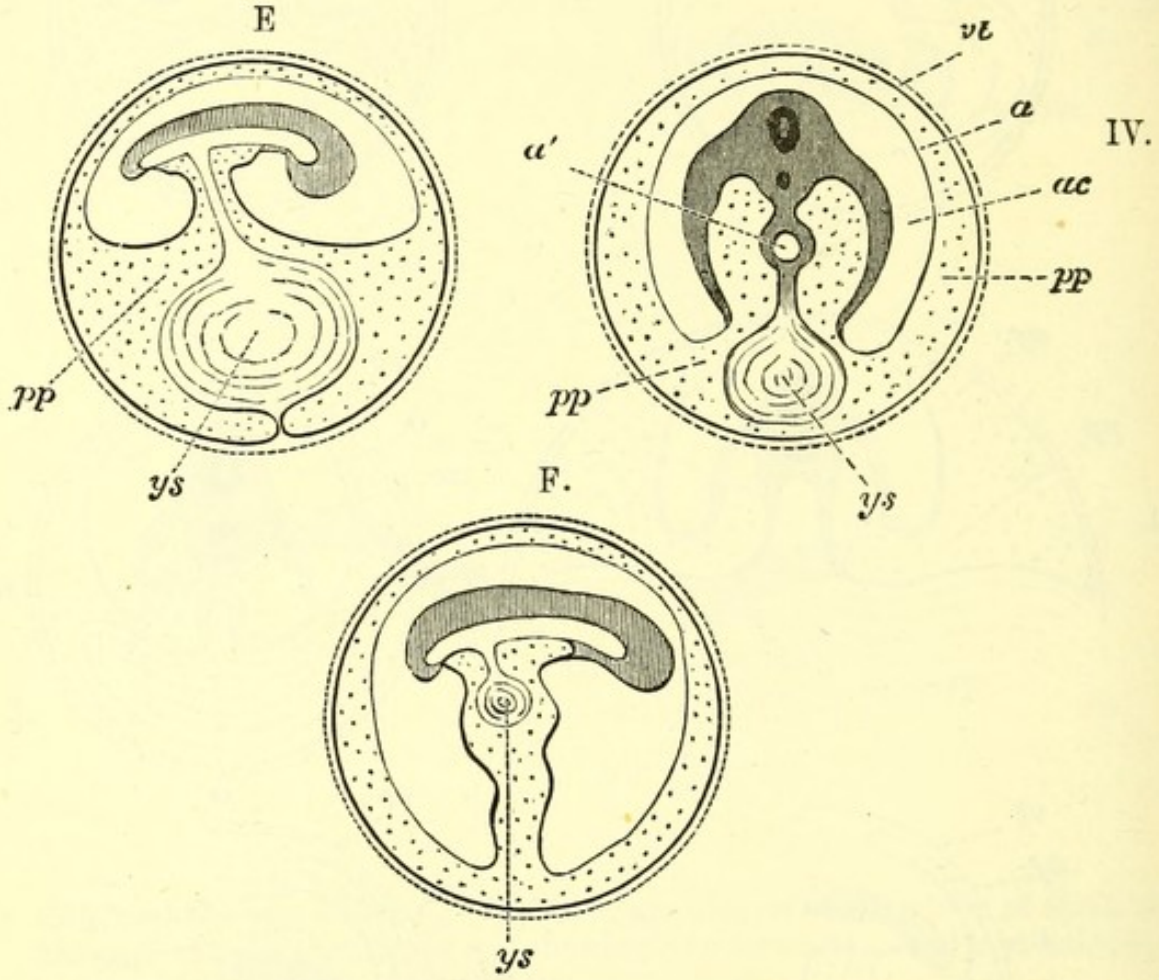


Fig. 246*.—Diagrammatic sections of an embryo, showing the destiny of the yolk-sac, *ys*.

vt. Vitelline membrane. *pp*. Pleuroperitoneal cavity. *ac*. Cavity of the amnion. *a*. Amnion. *a'*. Alimentary canal. *ys*. Yolk-sac.

membrane. As they meet over the back of the embryo the folds become fused, the membranes looking towards the embryo join to form the *true amnion*, whilst those next the vitelline membrane unite to form the *false amnion*, which, separating from the former, retires towards the vitelline membrane, with which it unites to form the chorion.

The true amnion then is a sac formed of an outer layer derived from the mesoblast and an inner layer derived from

the epiblast. The false amnion likewise consists of mesoblast and epiblast layers, but here the epiblast is external. The true amnion is continuous with the skin of the embryo, and when the fœtus is mature, the connection may be traced by the umbilical cord, round which it forms a sheath continuous with the skin at the umbilicus. This membranous sac enlarges, and in mammalia eventually becomes the large bag of liquid which contains the fœtus. The *amniotic liquid* is of low specific gravity, consisting mainly of water containing traces of nitrogenous matter, albumen, phosphates and chlorides.

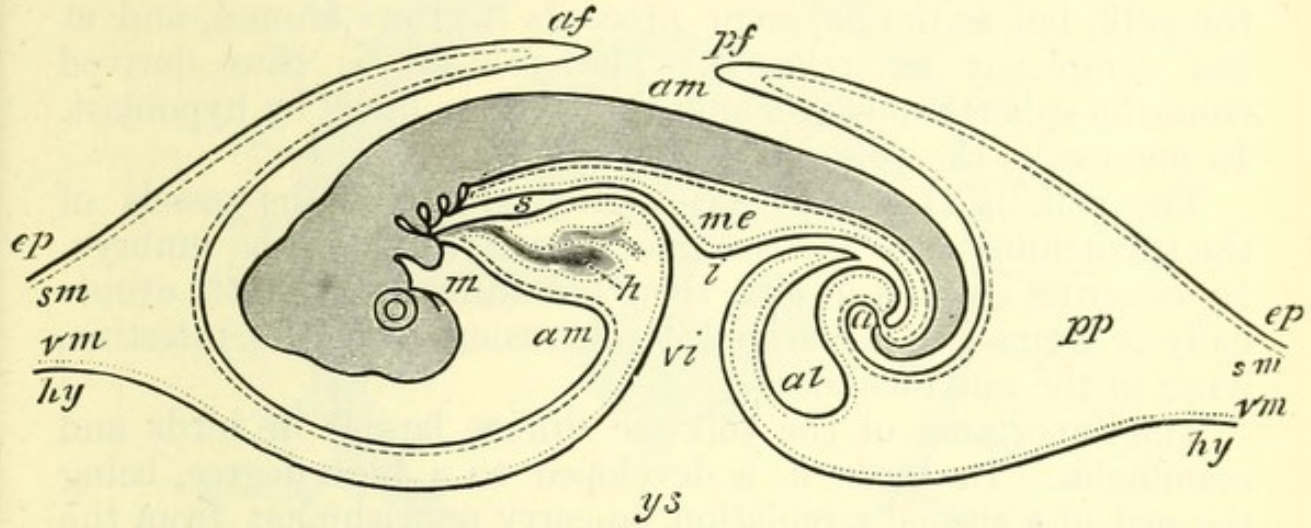


Fig. 247.—Diagrammatic longitudinal section of a chick on the fourth day. (Allen Thomson.)

ep. Epiblast.
hy. Hypoblast.
sm. Somatopleure.
v.m. Splanchnopleure.
af, pf. Folds of the amnion.
pp. Pleuroperitoneal cavity.
am. Cavity of amnion.
al. Allantois.
a. Position of the future anus.
h. Heart.
i. Intestine.
vi. Vitelline duct.
ys. Yolk.
s. Foregut.
m. Position of the mouth.
me. The mesentery.

This fluid preserves the child from the effects of any jolts or jars caused by the movements of the mother, and also protects the uterus of the mother by acting as a buffer between the fœtus and the uterine wall. Before delivery it helps to dilate the os uteri, so that when the amnion is ruptured the head of the fœtus occupies the opening which has been gradually made by the fluid wedge. The outer part of the amniotic membrane, derived from the mesoblast, is of a tougher character than the inner epithelial layer, possesses muscular fibre and is capable of rhythmical contractions.

(2.) *The Yolk-sac* is that part of the blastoderm which envelopes the yolk. After the mesoblast has split into two layers, the splanchnopleure becomes bent inwards at a point some distance from its origin.

By this curve an upper constricted canal is differentiated from the large lower cavity (Fig. 246). This upper canal becomes eventually the alimentary tract, the lower cavity is the yolk-sac, whilst the constricted portion leading from one to the other is the canal leading from the intestine to the yolk, called the *ductus vitello-intestinalis.*

At first the splanchnopleure encloses only the upper part of the yolk, but as development proceeds it grows around, and at last completely encircles it. The yolk-sac is thus derived from the splanchnopleure, and is therefore lined by hypoblast. In mammalia the yolk-sac is very small.

The yolk is absorbed and carried away by the vessels of the splanchnopleure for the general nutrition of the embryo. Its covering shrinks in size, soon becoming small, until eventually it forms but a shrivelled protrusion from the intestine, lying in the umbilical cord.

The importance of the yolk-sac differs largely in birds and mammalia. In birds it is developed to a high degree, being the seat of a special circulation, to carry nourishment from the only source of food supply, the yolk. The vessels are called the *vitelline*, *omphalo-mesenteric* or *omphalo-meseraic* vessels.

(3.) *The allantois*, or urinary vesicle, in the chick is of importance, as the vessels developed in it are used for respiratory purposes, being spread out beneath the porous shell. In the mammalian embryo it is still more important, as it has to perform the double function of respiration and nutrition. The allantois arises at the tail of the embryo, as a budding outwards of that portion of the splanchnopleure which forms the ventral wall of the hinder end of the primitive intestine (Fig. 247). It is lined by hypoblast, and projects into the pleuro-peritoneal cavity. As it grows it extends between the layers of the true and false amnion, growing upwards, and spreading over the dorsal surface of the embryo. When it reaches the periphery of the ovum, it spreads under the chorion as a complete lining, sending processes into the villi of that membrane. It becomes chiefly developed at that part of the chorion which is opposite the *decidua serotina* of the mother. In the mesoblastic layer of the allantois lie the blood-vessels which are connected with large trunks, proceeding from the primitive aortæ to the lower

extremities. They become the important umbilical arteries which will be further described when treating of the fœtal placenta.

As the fœtus becomes developed, the cavity of the allantois becomes gradually obliterated, a part only remaining to form the urinary bladder. A part of its walls forms a fibrous cord,

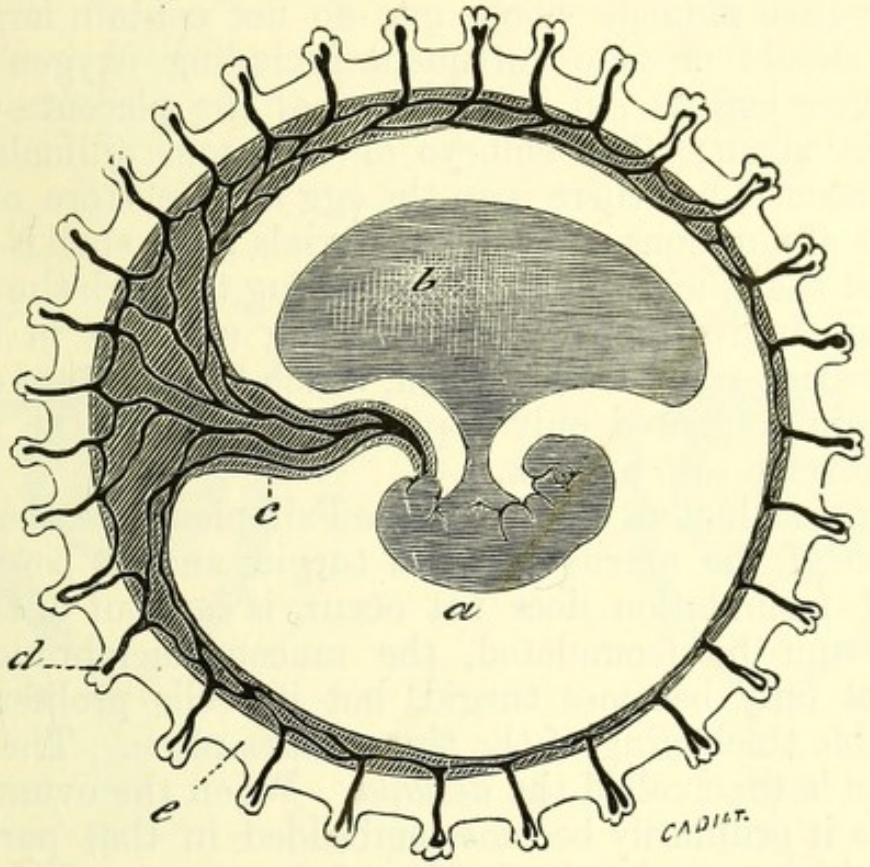


Fig. 248.—Diagram of an embryo, showing the relationship of the vascular allantois to the villi of the chorion. (Cadiat.)

a. Lies in cavity of the amnion under the embryo. *b*. Yolk-sac. *c*. Allantois. *d*. Vessels of the allantois dipping into the villi of the chorion. *e*. Chorion.

which runs from the apex of the bladder to the umbilicus, and is known as the *urachus*.

(4.) *The Chorion* consists simply of the zona pellucida or vitelline membrane, and of that part of the somatopleure forming the false amnion. The chorion at first is a smooth membrane, but villous processes early grow out from it, projecting into the decidua serotina and reflexa. These villi are at first developed equally around the ovum, but as the formation of the placenta proceeds, only those at the point of attachment are further developed and aid in the formation of the fœtal placenta.

The allantois, when it has spread over the chorion, becomes blended with this membrane, and fills the villous processes with the blood-vessels it contains.

The Placenta.

The placenta is essential for the mammalian embryo. It is necessary that animals whose ova do not contain large stores of food, should provide nutriment including oxygen for the life of their embryo; it is by means of the placenta that this is brought about. The embryo of oviparous animals cannot have a placenta, but there is in the egg a large store of highly nutritious albuminous and fatty materials; the shell is pervious to air, and the chick's blood while flowing through the allantois can be oxidised directly. A bird's egg contains in itself all the necessaries, other than oxygen, which the placenta supplies, and when impregnated only requires the heat of the mother's body to develop into a chick.

While a mammalian ovum is in the Fallopian tube, the mucous membrane of the uterus becomes turgid, and, as before mentioned, if fecundation does not occur, is cast out of the body. If the ovum be fecundated, the mucous membrane of the uterus not only becomes turgid, but its cells proliferate, and considerable thickening of the tissue takes place. The mucous membrane is then called the *decidua*. When the ovum reaches the uterus it ordinarily becomes embedded in that part of the decidua which occupies the fundus of the uterus. The decidua here grows excessively, and becomes much thickened, and on either side of the ovum a projection is sent from the decidua which meets around the ovum, and completely encircles it. (Fig. 249.)

The name *decidua vera* is given to the membrane lining the general cavity of the uterus, whilst that part lining the fundus, to which the ovum is attached, is called the *decidua serotina*, and its processes surrounding the ovum receive the name of the *decidua reflexa*.

The placenta is developed from two sources, one arising from the membranes of the fœtus, and the other from the uterine wall.

Relation of the fœtal to maternal placentæ.—The maternal part is formed from the decidua serotina, which becomes much thickened and very vascular.

The fœtal placenta is formed by the chorion sending out a

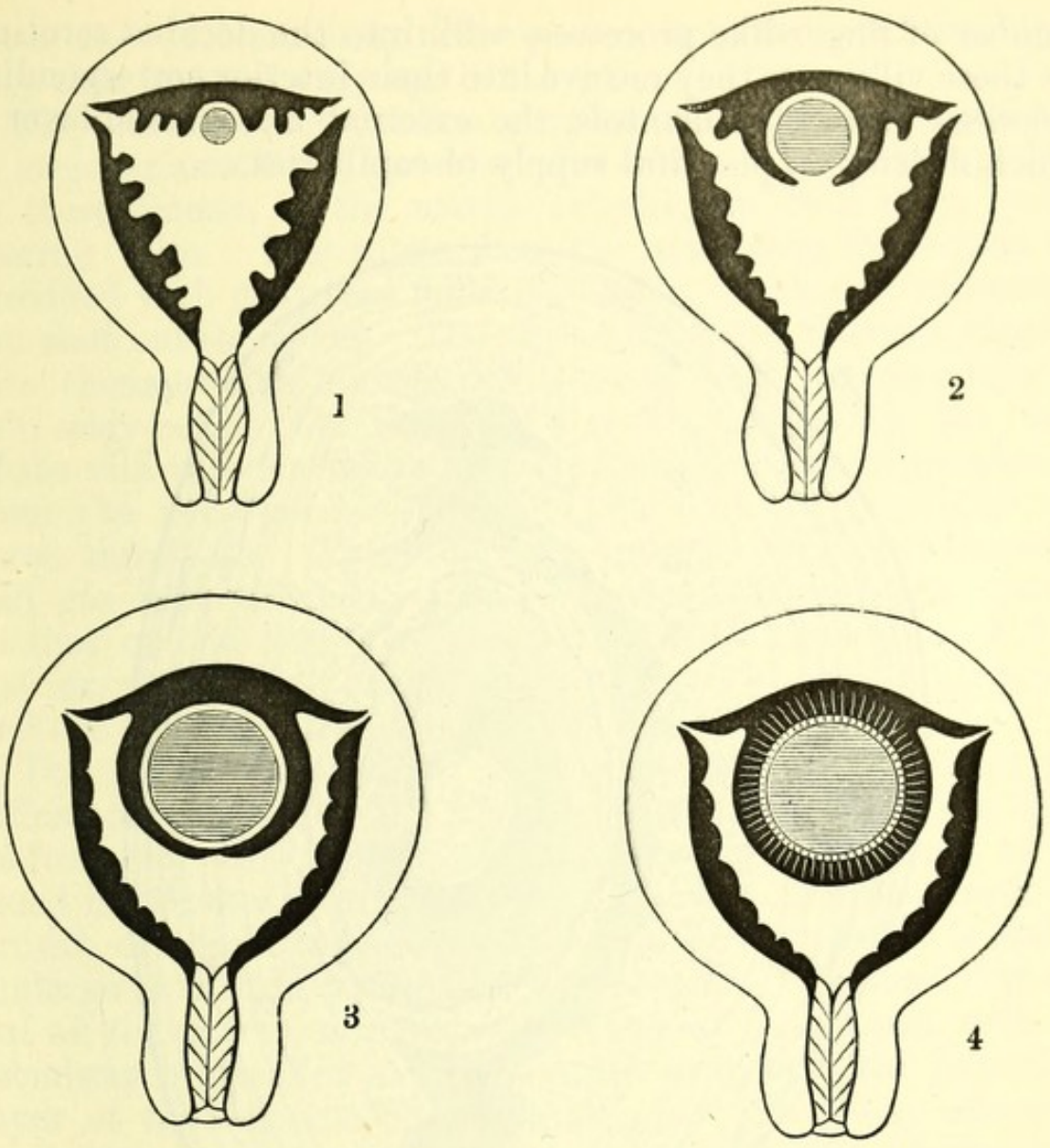


Fig. 249.—Series of diagrams representing the relationship of the decidua to the ovum at different periods. The decidua are coloured black, and the ovum is shaded transversely. In 4 and 5 the vascular processes of the chorion are figured (copied from Dalton).

1. Ovum entering the congested mucous membrane of the fundus—decidua serotina.
2. Decidua reflexa growing round the ovum.
3. Completion of the decidua around the ovum.
4. General growth of villi of the chorion.
5. Special growth of villi at placental attachment, and atrophy of the rest.

number of finger-like processes, villi, into the decidua serotina. As these villi grow they receive into their interior corresponding processes from the allantois, the external mesoblastic layer of which develops a plentiful supply of capillaries.

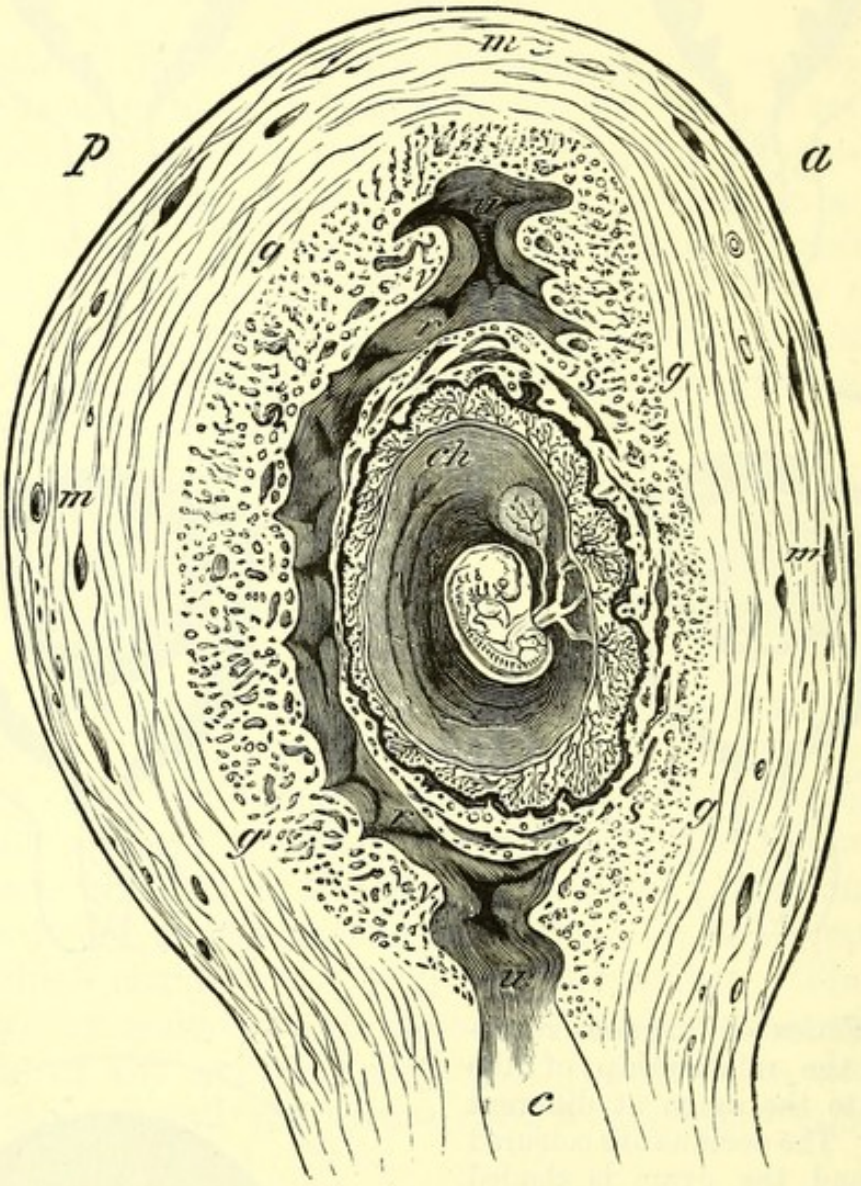


Fig. 250.—Antero-posterior section through a gravid uterus and ovum of five weeks (semi-diagrammatic). (Allen Thomson.)

a. Anterior wall of uterus.
p. Posterior wall of uterus.
m. Muscle substance.
g. Glandular layer.
ss. Decidua serotina.
r. Decidua reflexa.
v. Decidua vera.
ch. Chorion.
u.u. Uterine cavity.
c. Cavity of the cervix.

These capillaries are fed by two vessels, the placental arteries, which are continuations of branches from the dorsal aorta supplying the hind gut. As the villi grow their external coat, formed by the chorion, becomes progressively thinner, until

when the villi are fully developed it is represented only by a very thin layer of scaly epithelial cells.

The vessels of the decidua serotina or maternal placenta end in large sinuses, lined by endothelial cells. The blood is carried to these sinuses by the uterine arteries, and from them by the uterine veins. The inlets from the arteries to the sinuses are provided with unstriped muscular tissue, which on contracting, can shut out the blood. The villi of the fœtal placenta, dipping into these uterine sinuses, are covered with a single layer of thin scaly cells. The fœtal blood is distributed over the walls of the villi in a fine network of capillaries, and is only separated from the maternal blood by the walls of the capillaries and these thin cells. Thus the interchange of nutrient materials and gas is facilitated. This arrangement is somewhat similar to that of the lung alveoli, where the blood is separated from the air, with which it interchanges gases, by the capillary wall and the cells of the lung alveolus.

The nutrient materials from the maternal blood and oxygen diffuse through the walls of the fœtal capillaries. The effete matters, on the other hand, pass from the capillaries to the blood in the uterine sinuses. The placenta increases with the growth of the fœtus till shortly before birth, when it is said to undergo a certain amount of degeneration. In man it is cast out of the uterus, after the expulsion of the fœtus, with the membranes attached to it. It is, however, only the superficial layer of the maternal placenta (the part intimately connected with the fœtal placenta) that is cast off, the deeper layer remaining in the uterus, and undergoing various changes during the reduction of this organ to its normal size.

Though the capillaries of the fœtus are in such close relation to the blood of the mother, it must be distinctly understood that there is no direct communication between the vessels of the fœtus and those of the mother, and therefore it is not possible to inject the vessels of the mother through those of the fœtus, or *vice versâ*.

After the fœtus has been expelled from the uterus its cavity is so small, and the placental site so retracted, that the vessels entering it are pressed upon and occluded by the firm contraction of the uterine muscle. The uterine blood is thus normally prevented from escaping after parturition, and from causing the severe hæmorrhage which sometimes proves fatal.

The uses of the placenta may be briefly summed up as—

(1) *Nutrition.*—It supplies the place of the organs of

digestion by providing the fœtal blood with all necessary nutritive material.

(2) *Respiration.*—It performs the function of the lungs, the

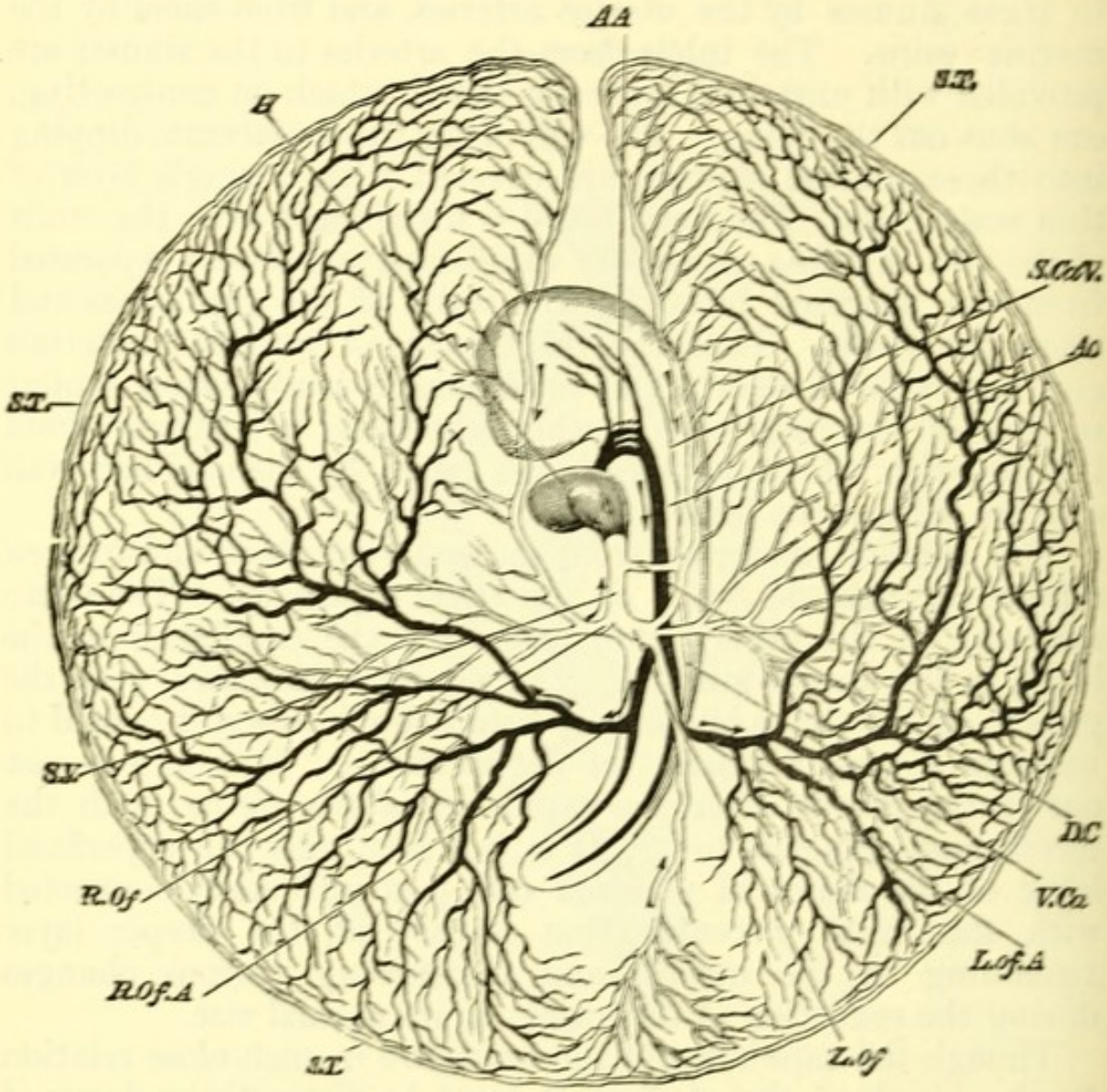


Fig. 251.—Diagram of the circulation of a chick at the end of the third day. (Foster and Balfour.)

H. Heart.
A A. Aortic arches (2nd, 3rd, and 4th).
Ao. Dorsal aorta.
L.of.R., R.of.A. Right and left omphalo-mesenteric arteries.
S.T. Sinus terminalis.
R.of., and L.of. Right and left omphalo-mesenteric veins.
S.V. Sinus venosus.
D.C. Duct of Cuvier.
S.Ca. and V.Ca. Superior and inferior cardinal veins.

fœtal blood receiving oxygen from the blood of the mother, to which it gives up its CO_2.

(3) *Excretion.*—It does duty for the kidneys, removing the urea, &c., from the fœtal blood.

Embryonic Circulation.

The many interesting changes which result in the formation of the circulatory system, must be sought in text books treating of development. A short sketch may be useful here.

The *primitive circulations* of a human embryo may be divided into two phases, which differ in their time of appearance and in the accessory organs to which they are distributed. Though they may, for the sake of clearness, be described as two independent circulations, they are not strictly so, as they exist for a short time coincidently, and arise in connection with one another from the same heart.

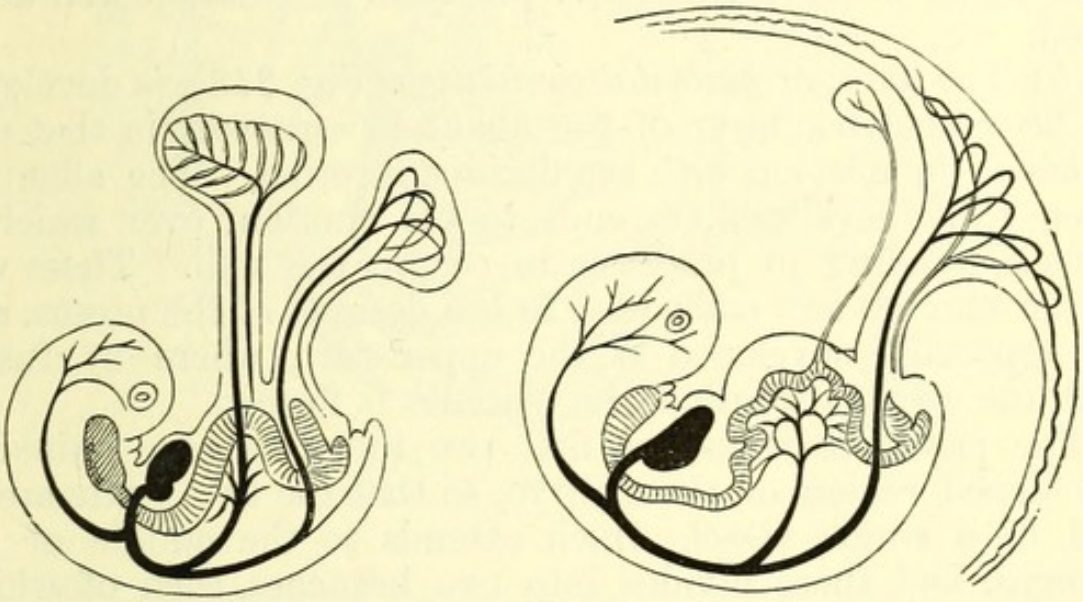


Fig. 252.—Diagrams showing the formation of the vitelline to the placental circulation. The figure on the left shows the vitelline vessels (omphalo-mesenteric) in connection with the heart; in that on the right these vessels are obliterated and the placental circulation is established through the hypogastric arteries. (After Dalton.)

(*a*) The earlier or *vitelline circulation* is that which surrounds the yolk-sac, while the embryo obtains nourishment from the yolk. This is an organ of quite secondary importance in the mammalian embryo; hence this circulation may be better studied in the chick, which depends, throughout its embryonic life, on the vitellus for nourishment. In the human embryo the vitelline circulation is chiefly of importance for the short time immediately preceding the development of the placental circulation.

The aortic bulb is continuous with two vessels which run on either side of the primitive pharynx; these are the aortæ, and

from each of them a large branch is given off. These omphalo-mesenteric arteries pass to the yolk-sac, and there become split up into a number of small vessels, the blood from them being returned partly by corresponding omphalo-mesenteric veins, partly by a large vein running round the periphery of the vascular area known as the *sinus terminalis*. The sinus terminalis opens partly into the right and partly into the left omphalo-mesenteric veins, which subsequently unite into a common venous trunk, called the sinus venosus, which is continuous with the primitive auricle.

This vitelline circulation in the human embryo becomes obliterated after the fifth or sixth week of fœtal life, the yolk then being absorbed, and the placental circulation well developed.

(*b*) The later, or *placental circulation* (Fig. 248), is developed in the mesoblastic layer of the allantois, especially in that part which is in relation with the decidua serotina. The allantois, when fully developed, extends to the chorion, over which it spreads, sending in processes to occupy the villi. These villi of the chorion are embedded in the decidua of the uterus, and are especially developed at the upper part, where by fusion with the decidua serotina, the placenta is formed.

The primitive aortæ, at first two tubes, become united in the dorsal region of the embryo, so that the two aortic arches end in a single vessel, which extends to the middle of the embryo, and there divides into two branches, each of which, in the earliest stage of the embryo, gives off a vitelline or omphalo-mesenteric artery. These vessels decrease in size as the placenta is developed and in importance give place to the allantoic vessels.

From the further branches of the aortæ arise two large vessels, hypogastric arteries, which run to the allantois, and spread out under the chorion, being especially directed to the upper part of this membrane. These form the umbilical arteries, already alluded to in speaking of the allantois, which carry the blood from the aortæ to the fœtal placenta.

Veins arise from the terminal networks of these arteries, and combine at first to form the two umbilical veins. But the venous trunks of the vitelline and allantoic circulation do not remain distinct like the arteries. The umbilical veins convey the blood to the venous trunk formed by the junction of the omphalo-mesenteric veins.

After a time the right umbilical and right omphalo-mesen-

teric veins disappear, and a trunk is formed by the junction of the left umbilical and left omphalo-mesenteric veins which persists as the single umbilical vein. From this branches are

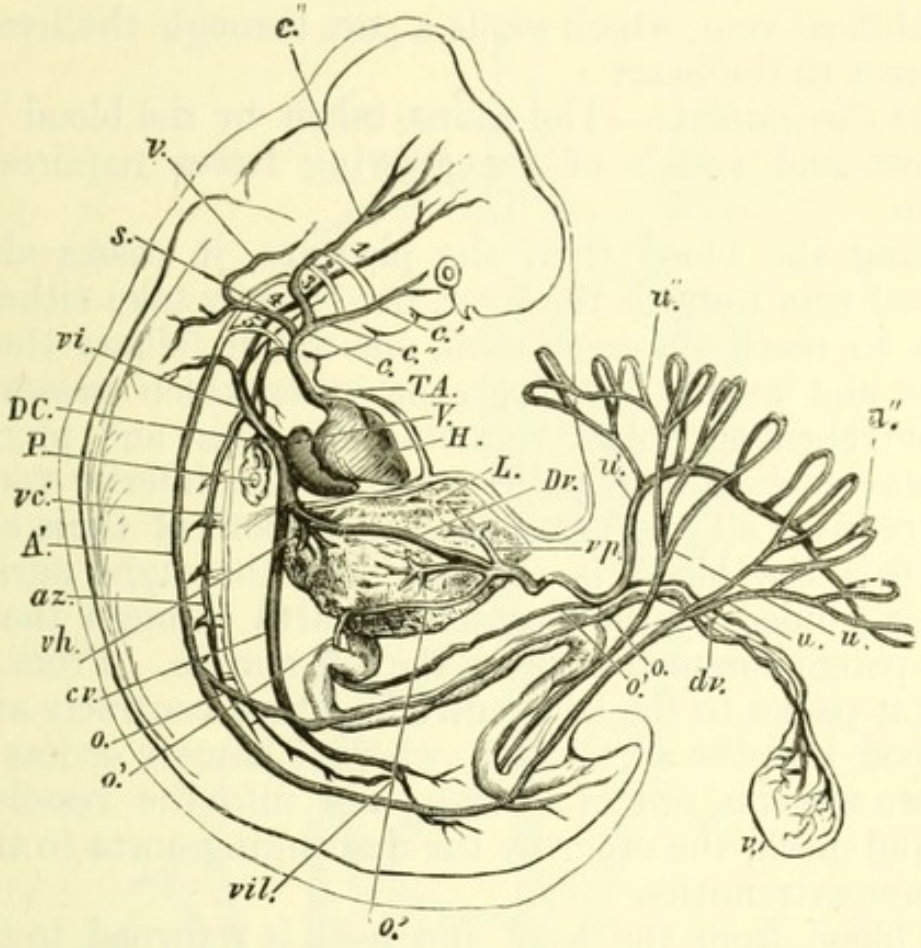


Fig. 253.—Diagram of the vascular system of a human embryo. (Huxley.)

H. Heart.
T.A. Aortic trunk.
c. Common carotid artery.
c'. External carotid artery.
c''. Internal carotid artery.
s. Subclavian artery.
v. Vertebral artery.
1, 2, 3, 4, 5, Aortic arches.
A'. Dorsal aorta.
1. Omphalo-mesenteric artery.
dv. Vitelline duct.
o'. Omphalo-mesenteric vein.
v'. Umbilical vesicle.
vp. Portal vein.
L. Liver.
uu. Umbilical arteries.
u'' u''. Their endings in the placenta.
u'. Umbilical vein.
Dv. Ductus venosus.
vh. Hepatic vein.
cv. Inferior vena cava.
vil. Iliac veins.
az. Vena azygos.
vc. Posterior cardinal vein.
DC. Duct of Cuvier.
P. Lungs.

given off to the liver (*venæ advehentes*), and at a point nearer the heart, vessels are received from the liver (*venæ revehentes*).

To the part of the vessel intervening between the origin of the venæ advehentes and the entrance of the venæ revehentes is given the name of the *ductus venosus.*

Thus it may be seen that in the placental circulation the blood is conveyed from the aorta, by the umbilical arteries, to the fœtal placenta, where it is in close relationship to the blood of the maternal placenta. From the placenta it is returned by the umbilical vein, which sends a part through the liver and a part direct to the heart.

Fœtal Circulation :—The course taken by the blood through the heart and vessels of the growing fœtus requires special mention.

Tracing the blood from the placenta, it passes along the umbilical vein towards the liver, here it may take either of two courses to reach the vena cava, one which follows the ductus venosus and avoids the liver, the other which passes by the venæ advehentes (portal veins) to the liver, and proceeds by the vena revehentes (hepatic veins) to the inferior vena cava, which receives all the blood passing by both of these channels. From this the blood is emptied into the right auricle, and hence is guided by the Eustachian valve through the septum by the patent foramen ovale to the left auricle. From the left auricle it passes to the left ventricle, which contracts and sends the blood into the aortic arch, where it is more or less split up into two streams, one of which passes into the vessels of the head and neck, the other by the descending aorta to the trunk and lower extremities.

The blood from the head and neck is returned to the right auricle by the superior vena cava. The blood from this vein passes through the auricle to the right ventricle, which sends it through the pulmonary artery towards the lungs.

The pulmonary artery, in the embryo, has one very large branch, called the ductus arteriosus, which joins the aorta at a point just below the origin of the vessels of the head and neck ; hence the main part of the blood passing from the right ventricle reaches the aorta by the ductus arteriosus, and only a very small part goes to the lungs, to be returned from them by the pulmonary veins to the left auricle.

The blood from the ductus arteriosus blends, therefore, with that in the aorta which is passing to the viscera and lower extremities. The main part of this blood travels by the two large branches of the aorta, the hypogastric arteries, to the placenta, where it is aërated and purified, &c.

The placenta being the great renovating organ of the blood of the fœtus, it follows that the blood in the umbilical *vein* is the most *arterial* in the fœtal circulation. The blood in all

the other fœtal vessels is more or less mixed. That passing through the right to the left auricle, being a mixture of placental blood and of that in the ascending vena cava, is fairly

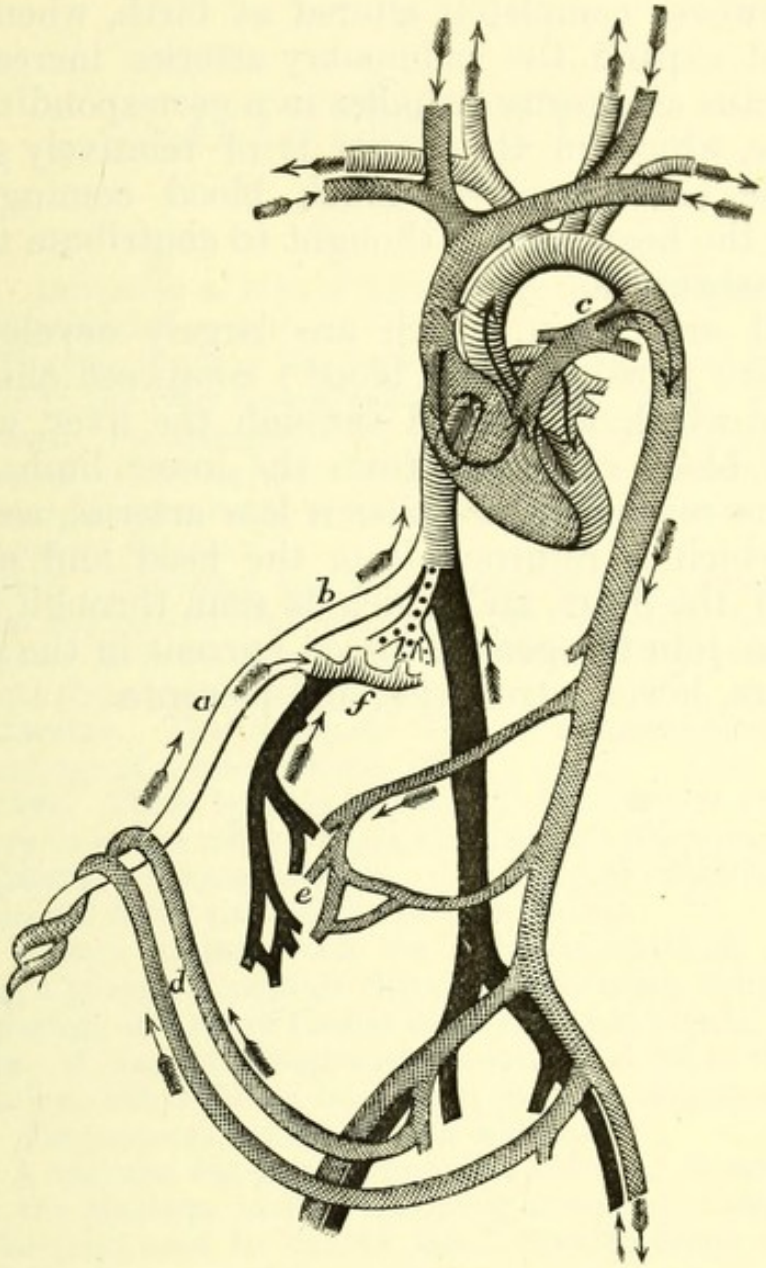


Fig. 254.—Diagram illustrating the circulation through the heart and the principal vessels of a fœtus. (Cleland.)

a. Umbilical vein.
b. Ductus venosus.
f. Portal vein.
e. Vessels to the viscera.
d. Hypogastric arteries.
c. Ductus arteriosus.

arterial. This proceeds thence to the first part of the aorta. But the blood in the descending aorta is relatively impure, as it mainly contains blood which has visited the head and

neck, some of which had previously passed through the lower extremities.

As the fœtal lungs are not called into play until after birth, but little blood passes to them in the fœtus; this state of things is however completely altered at birth, when the lungs of the child expand, the pulmonary arteries increase in size, and the ductus arteriosus dwindles in a corresponding degree.

The liver, which in the fœtus is of relatively greater size than in the adult, receives much blood coming from the placenta to the heart, and is thought to contribute to it several essential constituents.

The head and brain, which are largely developed in the fœtus, receive pure, nutrient blood; composed chiefly of placental blood which has passed through the liver, with a small quantity of blood returning from the lower limbs. The rest of the fœtus receives blood that is less arterial, as it is mixed with that which is returned from the head and neck to the right side of the heart, and which is sent through the ductus arteriosus to join the general blood current in the aorta going to the viscera, lower extremities, and placenta.

GLOSSARY.

Aberration. Deviation of rays of light owing to their unequal refraction in passing through a lens.

Abscissa. The line forming the basis of measurement of graphic records, along which the time measurement is usualiy made.

Accommodation. Focussing the eye for different distances ; it is effected by the lens becoming more convex for near objects, owing to the ciliary muscle drawing forward its choroidal attachment, and relaxing the suspensory ligament.

Acinous glands. Secreting organs composed of small saccules filled with glandular epithelium connected with the twigs of a branched duct.

Adenoid tissue. A delicate felt-work of reticular tissue containing lymph corpuscles (Lymphoid tissue).

Adequate stimulus. The particular form of stimulus which excites the nerve-endings of a special sense organ.

Afferent nerves. Those bearing impulses to the nervous centres from the periphery to excite reflex actions or stimulate the sensorium.

Agminate glands. A name applied to the lymph follicles occurring in groups in the lower part of the small intestine.

Albumins. A term derived from the Latin for white of egg (*albumen*), denoting a group of complex chemical substances obtained from ova, blood-plasma, and many tissues of animals and plants.

Albuminoids. A class of nitrogenous substances allied to the albumins in composition, but differing from them in many important respects.

Albumose. The proteose derivable from albumin.

Allantois. A vascular out-growth from the embryo ; in mammals it helps to form the placenta, and in the chick becomes the respiratory organ.

Alveoli. The term used to denote small cavities found in many parts, such as the air spaces of the lungs.

Amnion. The membranous sac which grows around the embryo and encloses the fœtus, &c., during its development.

Amœba. A unicellular organism consisting of a nucleated mass of protoplasm.

Amorphous. Without definite or regular form ; the opposite of crystalline.

Ampulla. A dilatation on the semi-circular canals of the ear.

Amylolytic. Relating to the conversion of starch into dextrine and grape sugar.

Amylopsin. A ferment in the pancreatic juice, which converts starch into sugar.

Anabolic. A chemical change of constructive tendency taking place in the cells of the tissues during their functional inactivity.

Analgesia. A condition of the nervous centres in which pain cannot be felt, but tactile and other sensations remain unimpaired.

Analysis. A separation into component parts; the splitting up of a chemical compound into its constituents.

Anastomoses. The direct union of blood-vessels without the intervention of a capillary network.

Anelectrotonus. An electric condition of a nerve, resulting from the passage of a current through a part of it; it is confined to the region of the positive pole.

Anode. The positive pole or electrode—*i.e.*, the pole by which the electric current enters.

Apnœa. A state of cessation of the breathing movements from non-excitation or inhibition of the respiratory nerve centre.

Area opaca. The outer zone of the part of the blastoderm from which the fœtal membranes are developed.

Area pellucida. The central spot of the part of the blastoderm from which the embryo chick is developed.

Arteriole. A small artery; usually applied to those vessels the walls of which are largely composed of muscle tissue.

Arthroses. Movable joints having a synovial membrane.

Asphyxia. Literally, cessation of the pulse, such as occurs from interruption of respiration, now used as synonymous with suffocation.

Assimilation. The chemical combination of new material (nutriment) with living tissues. Power to assimilate forms the most characteristic property of living matter.

Astigmatism. Unevenness of the refracting surfaces of the eye; when engaging the entire cornea it is called "regular," and affecting a local part, "irregular" astigmatism.

Atoms. The ultimate indivisible particles of matter.

Atrophy. A wasting from insufficient nutrition.

Automatic. Self-moving—*i.e.*, acting without extrinsic aid; a term applied to the independent activity of certain tissues (such as the nerve centres), the exciting energies of which are not readily determined.

Axis cylinder. The essential conducting part of a nerve fibre, composed of fine strands of protoplasm.

Bacteria. A class of minute fungi occurring in decomposing animal or vegetable substances.

Bilirubin. The red colouring matter of the bile of man and carnivora.

Biliverdin. The greenish colouring matter of the bile of herbivorous animals.

Binocular. Pertaining to vision with two eyes. A combination of the effect of two retinal impressions by means of which the appearances of *distance* and *solidity* are arrived at.

Biology. The science of life, including morphology and physiology.

Blastoderm. The primitive cellular membrane formed by the segmentation of the ovum, in a part of which the embryo is developed.

Blood-pressure. The force exercised by the blood against the walls of the vessels. It is very great in the arteries, and therefore causes a constant stream through the capillaries to the veins.

Bulb. The part of the central nervous axis between the brain and the spinal cord.

Canaliculi. Minute channels connecting the small cell spaces or lacunæ of bone, and containing protoplasmic filaments uniting the neighbouring cells.

Carbohydrates. Compounds of carbon, hydrogen, and oxygen, in which the oxygen and hydrogen exist in the proportions requisite to form water.

Cardiograph. An instrument by means of which the heart's impulse is transmitted, through an air tube, from a tambour on the chest wall to another which makes a record on a moving surface by means of a lever.

Catelectrotonus. An electric state of nerve in the region where the current leaves the nerve, *i.e.*, near the negative pole.

Caseinogen. A proteid of milk readily converted into *casein*.

Cathode. The negative pole or electrode—*i.e.*, the pole by which the electric current leaves.

Cellulose. The substance of which vegetable cell-walls are formed.

Centrifugal. A term given to the impulses carried by *efferent* nerves.

Centripetal. A term given to the impulses carried by *afferent* nerves.

Cerebral vesicles. Primative swellings on the primary neural tube of the early embryo which develop into the brain.

Chemical elements. Substances which cannot be split up into components, and therefore are regarded as simple.

Chlorophyll. The green colouring matter of the cells of plants. It is supposed to be the agent which, under the influence of light, decomposes carbon dioxide and water to form the cellulose and starch of the plant.

Cholesterin. A substance occurring in the bile, white matter of the brain and spinal cord, and in small quantities in many other tissues. Chemically it is a monotomic alcohol.

Chorda dorsalis. The precursor of the vertebral column of the embryo.

Chorion. The outer layer of the membranes of the ovum, part of which becomes vascular, and helps to form the placenta.

Choroid. The vascular coat of the eye-ball.

Chromatic aberration. The alteration of white light into prismatic colours during its passage through a lens.

Chyle. The fluid absorbed from the small intestines by the lacteals.

Chyme. The fluid formed by gastric digestion.

Cilia. Minute vibratile processes which occur on the surface cells of the respiratory and many other epithelial membranes.

Circumvallate. Large papillæ situated at the back of the tongue. They are surrounded by a fossa in the walls of which lie taste buds.

Cloaca. The opening common to the genito-urinary organs into the primitive hind gut of the embryo. The cloaca persists in birds.

Colloid. That condition of quasi-dissolved matter in which it will not diffuse through a membrane such as parchment. The opposite of *crystalloid*.

Colostrum. The first milk secreted after delivery.

Co-ordination. The adjustment of separate actions for a definite result, as when the nerve-centres cause various distinct muscles to act together and produce complex movements.

Curara. A poison causing motor paralysis by impairing the function of the nerve terminals.

Cytod. A living protoplasmic unit which has no nucleus.

Decidua reflexa. The outgrowth of the uterine mucous membrane which surrounds the ovum.

Decidua serotina. That part of the modified mucous membrane of the uterus in which the fecundated ovum is lodged.

Decidua vera. The altered mucous membrane of the uterus, which lines that organ during gestation.

Deglutition. The act of swallowing.

Desquamation. The term used to denote the casting off of the outer layer of the skin.

Dialysis. The diffusion of soluble crystalloid substances through membranes such as parchment.

Diastole. The period of relaxation and rest of the heart's muscle.

Diastatic. Those ferments which produce hydrolysis.

Dicrotic. The double wave of the arterial pulse. The dicrotic wave is seen on the descending part of the pulse curve.

Dioptric media. Transparent bodies, such as those parts of the eye which so refract the light that images come to a focus on the retina.

Discus proligerus. Part of the granular layer of the Graafian follicle surrounding the ovum.

Distal. A term used to denote a part relatively far from the centre.

Ductus arteriosus. A short bond of union between the pulmonary artery and the aorta, which in the fœtus carries blood from the right side of the heart into the aorta.

Ductus venosus. A vessel which, in the fœtus, carries blood from the umbilical vein to the vena cava. After birth it becomes a fibrous cord.

Ductus vitello-intestinalis. The union between the yolk sac and the intestine of the embryo.

Dyspnœa. Difficulty of breathing; a condition in which inordinate respiratory movements are excited by an unusually venous state of the blood in the respiratory nerve centre.

Ectoderm. The outer layer of simple organisms.

Ectosarc. The outer layer or covering of certain unicellular organisms.

Electrodes. The terminals which are applied to a substance in order to complete the circuit in passing a current through it.

Electrotonus. A peculiar electric state of nerves resulting from the passage of a continuous current through them.

Embryo. The name given to the animal at the earliest period of its development.

Emmetropic. A term applied to the normal eye, in which parallel rays of light are brought to a focus at the retina without accommodation.

Emulsification. The suspension of very fine particles in a liquid unable to dissolve them.

Endoderm. The inner layer of simple organisms.

Endogenous reproduction. The formation of new cells or organisms within the body of the parent individual.

Endolymph. The liquid contained within the membranous labyrinth of the ear.

Endosarc. The inner layer of certain unicellular organisms.

Endosmosis. The diffusion of a fluid into a texture.

Endothelium. The single layer of thin cells lining the serous cavities, lymphatic and blood-vessels, and all spaces in the connective tissues (mesoblastic lining cells).

Epiblast. The uppermost of the three layers of the blastoderm, from which are developed the epidermis and the nerve-centres.
Epithelium. The non-vascular cellular tissue developed from the epi- and hypoblast of the blastoderm.
Eupnœa. A term used to denote the normal rhythm of respiratory movements in contradistinction to *dyspnœa* and *apnœa*.
Excito-motor. Impulses which, reflexly, call forth motion.
Excito-secretory. Impulses calling forth the activity of gland cells, commonly applied to afferent influences which act reflexly.

Fibrin. An insoluble form of proteid formed on elastic threads on the coagulation of the blood plasma, &c.
Fibrinogen. A form of globulin obtainable from serous fluids, which, on being added to a liquid containing a certain ferment and a calcium salt gives rise to the formation of fibrin.
Fibroplastin. A term applied by A. Schmidt to paraglobulin or serum-globulin on account of its supposed influence in producing fibrin.
Filiform. A name given to a class of papillæ of the tongue, the points of which taper off to a thread.
Fœtus. The fully-formed embryo while in the uterus or egg.
Fovea centralis. The depression in the centre of the *macula lutea*.
Fungiform. A class of papillæ of the tongue shaped like a toadstool.

Galvanometer. An instrument for measuring the direction and strength of electric currents by means of the deflection of a magnetic needle.
Ganglion. A swelling. Chiefly used to denote swellings on nerves containing nerve corpuscles. Hence any group or mass of nerve cells.
Gastrula. A stage in the development of animals in which they consist of a small sac composed of two layers of cells.
Gemmation. Budding—a process of reproduction in which a bud forms on the parent organism, and finally separates as a distinct being.
Globulin. A form of albumin insoluble in pure water but soluble in weak solutions of common salt.
Glomerulus. A bundle of capillary loops which form part of the Malpighian body of the kidney.
Glycocholic acid. An acid existing in large quantities combined with soda in the bile of man.
Glycogen. Animal starch ; a substance belonging to the carbohydrates, which is made in the liver. It may be readily converted into grape sugar—from which fact it derives its name.
Gustatory. Pertaining to the sense of taste.

Hæmatin. A dark-red amorphous body containing iron ; obtained from the decomposition of the colouring matter of the blood (hæmoglobin).
Hæmatoidin. A substance found in old blood clots, as crystals, which cannot be artificially prepared.
Hæmatoin, or **Hæmatoporphyrin.** Iron-free hæmatin prepared with strong acetic acid.
Hæmin. Hydrochlorate of hæmatin ; easily obtained, as small dark brown crystals, by boiling blood to which some common salt and glacial acetic acid have been added.
Hæmochromogen. Unoxidized hæmatin, the first outcome of the decomposition of hæmoglobin.

Hæmoglobin. Reduced oxyhæmoglobin.

Holoblastic. The form of ovum the entire yolk of which enters into the process of segmentation.

Homœothermic. Even temperatured—a term applied to those animals that keep up a regular temperature, independent of their surroundings—warm-blooded animals.

Hyaloid. Glass-like ; a name given to the delicate membrane enclosing the vitreous humour.

Hydrocarbons. Compounds of carbon and hydrogen.

Hypermetropia. The condition in which the focus of parallel rays of light lies beyond the retina ; also called *long sight.*

Hypertrophy. Increased growth from excessive nutrition.

Hypoblast. The undermost of the layers of the blastoderm, from which the pulmonary and alimentary tracts and their glands are formed.

Infusoria. A name given to a large class of simple organisms which are found in dirty water.

Inhibition. A checking or preventive action exercised by some nervous mechanisms over nerve corpuscles and other active tissues.

Inosit. A sugar peculiar to muscle.

Irradiation. The phenomenon that bright objects appear larger than they really are. It is due to the extension of the effect to those parts of the retina immediately adjacent to where the light rays impinge.

Karyokinesis. A series of changes occurring in the arrangement of the nuclear network prior to the division of the protoplasm of cells.

Katabolic. A chemical change of destructive tendency taking place in the cells of the tissues during the liberation of the energy associated with their functional activity.

Keratine. The characteristic chemical constituent of the horny layer of the skin and epidermal appendages.

Kymograph. An instrument used for recording graphically the undulations of blood-pressure, measured directly from a blood-vessel by means of a manometer.

Lachrymal. Pertaining to the secretion of tears.

Lacunæ. Small spaces in the substance of bone tissue, occupied during life by the bone-cells. They appear black in sections of dry bone owing to their containing air, which replaces the shrivelled cells.

Latency, or Latent period. The time that elapses between the moment of stimulation and the response given by an active tissue.

Leucin. This is a common product of the decomposition of proteids. It is formed in the later stages of pancreatic digestion.

Leucocytes. A term applied to the white blood-corpuscles and lymph cells.

Lumen. The open space seen on section of a tube, vessel or glandular saccule ; the cavity surrounded by the gland cells, in which the secretion collects.

Luscitas. Fixation of the eye-ball in the outer canthus owing to the unopposed action of the external rectus muscle.

Lymph. The liquid collected by the absorbent vessels from the tissues; the return flow of the irrigation stream escaping from the blood-vessels to nourish the tissues.

μ. This letter is used to indicate $\frac{1}{1000}$th of a millimeter and is used as a standard of measurement in histology.

Macula Lutea. That part of the retina near the axis of the eyeball, in which vision is most acute.

Manometer. An instrument for measuring pressure; made of a U-shaped tube containing liquid, commonly mercury.

Medullary sheath. A soft clear sheath around the axis cylinder of medullated nerves, which, owing to its refracting power, gives them a white appearance.

Menstruation. The monthly change in the mucous membrane of the uterus, which accompanies the discharge of the ovum.

Meroblastic. The form of ova in which the yolk does not undergo complete segmentation, as that of birds.

Mesencephalon. Those parts of the brain developed from the middle cerebral vesicle, viz., crura cerebri and corpora quadrigemina.

Mesoblast. The middle of the three layers of the blastoderm from which the connective tissues and vascular apparatus of the embryo are formed.

Metabolism. The intimate chemical changes occurring in the various organs and tissues upon which their nutrition and functions depend.

Metanephros. The hinder portion of the Wolffian body which develops into the kidney and ureter.

Metazoa. A term used to denote all those animals whose ova undergo division, in contradistinction to Protozoa.

Methæmoglobin. A compound formed by oxyhæmoglobin combining more firmly with additional oxygen.

Micrococcus. An extremely minute fungus of a round shape. Micrococci occur in many solutions of decomposing organic matter.

Micturition. The act of voiding urine.

Molecules. The smallest physical particles of matter that can exist in a separate state. They are probably always constituted of two or more atoms.

Morphology. The science which treats of the forms and structure of living beings.

Morula. The stage of development of the ovum after segmentation in which all the young cells are alike, before the blastoderm is formed.

Mucin. The characteristic constituent of mucus.

Mucinogen. A constituent of the secretion of mucous glands.

Mullerian duct. An embryonic structure from which are formed the genital passages in the female, viz. Fallopian tube, uterus, and vagina.

Mydriasis. A dilated state of the pupil.

Myelin. The material of which the medullated sheath of nerve-fibre is composed.

Myograph. An instrument for graphically recording muscle contraction.

Myopia. The condition in which the focus of parallel rays of light falls short of the retina: *short sight.*

Myosin. The substance formed by the coagulation of muscle plasma. It is one of the globulins.

Natural nerve currents. The electrical currents passing through an exposed muscle or nerve while in a state of rest.

Neuroglia. The reticular connective tissue which binds together the elements of the nerve-centres.

Non-polarizable electrodes. Electric terminals specially constructed so as not to set up secondary currents on application to moist living tissues.

Notochord. The primitive vertebral axis of the embryo.

Nucleolus. A small spot observable in some nuclei.

Nucleus. A central part of a cell differentiated from the main protoplasm, commonly round, but sometimes elongated as in muscle.

Odontoblasts. Living cells lining the pulp-cavity of the interior of a tooth, and presiding over the growth and nutrition of the dentine.

Olfactory. Pertaining to the sense of smell.

Omphalo-mesenteric. The vessels connecting the embryonic circulation with the yolk sac, by the mesenteric branches of the aorta. They are early obliterated in the mammalian fœtus.

Ophthalmoscope. An instrument consisting of a small mirror by which the interior of the eye can be illuminated so that the fundus may be viewed.

Optic cup. The involuted optic vesicle which is developed into the retina, &c.

Osteoblast. The active cells in forming bone.

Osteoliths. Calcareous particles lying in the endolymph.

Oxyhæmoglobin. The colouring matter of the blood-corpuscles.

Paradoxical contraction. The result of excitation of the nerve of a muscle by the electric changes taking place in the nerves of neighbouring muscles.

Paraglobulin. One of the more abundant albumins of the blood—*serum globulin.*

Paramœcium. A unicellular organism composed of a soft mass of protoplasm enclosed in a firmer case, and covered with motile cilia.

Parapeptone. A body produced in gastric digestion during the formation of peptone.

Pepsin. A ferment existing in the gastric juice which converts proteids into peptones.

Peptone. The ultimate products of the hydration of proteids which are produced during digestion ; they are very soluble, and diffuse through a membrane.

Perilymph. The liquid surrounding the membranous labyrinth of the ear.

Peristalsis. The mode of contraction of the muscular walls of certain tubes as the œsophagus and intestine, the effect of which is to cause a progressive constriction, and so force the contents of the tube onwards.

Phakoscope. An instrument for estimating the changes in the shape of the lens during accommodation by doubling the reflected images with a prism.

Placenta. The organ by means of which the fœtal blood is brought into close relationship to that of the mother, so as to gain nutriment and oxygen, and get rid of effete matters.

Plasma. A term meaning anything formed or moulded ; used in physiology to indicate complex kinds of matter which subserve to the formation of the living tissues.

Poikilothermic. Varying in temperature. A term applied to those animals whose temperature varies with that of the surrounding medium—"cold-blooded animals."

Presbyopia. A loss of power of accommodation for near vision, which accompanies old age.

Prosencephalon. That part of the developing anterior cerebral vesicle from which are formed the olfactory and optic lobes, the hemispheres, and corpora striata and optic thalami.

Proteids. Widely spread proximate principles of organic tissues containing C, O, H, N and S, in definite proportions.

Proteose. Intermediate products in the conversion of proteids into peptones. Probable an intermediate stage of hydration.

Protista. A large group of organisms which remain in the primitive state of a single cell during their lifetime.

Protococcus. A unicellular vegetable organism, the protoplasm of which contains chlorophyll.

Protoplasm. The substance which gives rise to the primitive vital phenomena, seen in unicellular organisms, and which is the chief agent in executing the functions of all the active tissues.

Protovertebræ. The primitive segments of the mesoblast in the site of the future vertebral column.

Protozoa. That division of the protista which has been assigned to the animal kingdom.

Proximal. A term used to denote a part relatively nearer to the centre.

Pseudopodia. Projections thrown out by moving protoplasm, by means of which cells, such as amœbæ, move.

Ptosis. Drooping of the eye-lid accompanying paralysis of the third nerve.

Ptyalin. The ferment of the saliva. In a weak alkaline solution it converts starch into dextrine and sugar.

Reflex action. The activity caused by a ganglion cell reflecting an afferent impulse along an efferent nerve to the neighbourhood of original stimulation.

Reflexion. The return of rays of light from a surface.

Refraction. The bending which rays of light undergo when passing obliquely from one medium to another of different density.

Reticulum. A network ; a term applied to the interlacement of fibres, seen in reticulated connective tissue, &c.

Rheoscopic frog. An arrangement by which the change in the electric current of one muscle of a frog is made to act as a stimulus to the nerve of another.

Saponification. The formation of soap ; the decomposition of oils or fats into salts of the fatty acid and glycerine.

Sarcolactic acid. The principal acid in dead muscle. It has a dextro-rotatory power on polarised light, which ordinary lactic acid does not possess.

Sarcolemma. The delicate sheath surrounding the fibres of skeletal muscles.

Sclerotic. The fibrous coat of the eye-ball.

Sensorium. That part of the nerve centres supposed to receive sensory impressions.

Somatopleure. The subdivision of the mesoblast which, with the attached epiblast, forms the body-walls of the embryo.

Specific gravity. The relation of the weight of a given volume of any substance to the weight of an equal volume of distilled water at 4° C.

Spherical aberration. An indistinctness of the image caused by the difference in refraction at the centre and margin of a lens giving rise to different focal lengths.

Sphygmograph. An instrument for obtaining a graphic representation of the pulse-wave by means of a lever applied to the radial artery at the wrist.

Splanchnopleure. The subdivision of the mesoblast which, with the attached hypoblast forms the chief visceral cavities of the embryo.

Sporadic ganglia. Swellings occurring in the course of the peripheral nerves caused by a group of nerve corpuscles.

Steapsin. A ferment existing in the pancreatic juice which causes or aids the saponification of the fats.

Sudoriferous glands. The small tubular glands of the skin which secrete perspiration.

Summation. The fusion of several single contractions of muscle to form a tetanic contraction ; the accumulation of stimuli.

Sutures. Unions formed by the direct apposition of bones without intervening cartilage. They do not permit of motion.

Sympathetic nerve. The ganglionic nervous cord on either side of the vertebral column. It transmits most of the vaso-motor impulses coming from the cerebro-spinal centres.

Symphysis. A form of joint without synovial membrane in which the bones are fixed together by fibro-cartilage.

Synthesis. The artificial construction of a chemical compound from simpler materials.

Systole. The period of contraction of the heart's muscle.

Taurocholic acid. An acid existing in combination with soda in the bile.

Tetanus. In physiology is used to denote the prolonged contraction of the skeletal muscles which follows rapidly repeated stimulations.

Thalamencephalon. That part of the anterior cerebral vesicle which is left after the differentiation of the optic thalami, cerebral hemispheres, &c.

Thrombosis. The occlusion of a vessel by a local coagulation of the blood.

Trabeculæ. Supporting bars of tissue passing through some organs, such as those proceeding from the capsule to the interior of the spleen or lymphatic glands.

Trophic. Relating to nutrition.

Trypsin. A ferment in the pancreatic juice which in alkaline solutions converts proteids into peptones.

Tyrosin. A substance formed together with leucin during pancreatic digestion ; it is also produced by putrefaction of proteids.

Urachus. The bond of union which at an early period connects the urinary bladder with the allantois in the embryo ; it is subsequently obliterated in the fœtus.

Vacuoles. Small cavities occurring in cells. They are supposed to have important functions in the unicellular organisms.

Vagus. The nerves distributed to the viscera of the throat, thorax, and abdomen ; the great regulating nerve of the vegetative functions.

Vaso-constrictor. Those impulses which excite contraction of the vascular muscles.

Vaso-dilator. Those impulses which inhibit the action of the vascular muscles.

Vaso-motor. Those nervous mechanisms controlling the movements of the blood-vessels.

Villus. A hair-like process. A term applied to the small projections characteristic of the small intestine. They contain blood-vessels and lacteals, and are important in absorption.

Vitellus. The yolk of the ovum, which in mammals divides completely to form the embryo. In birds only a part divides, and the rest serves to nourish the chick.

Vorticella. Bell animalcule, a bell-shaped unicellular organism with a rudimentary, ciliated mouth cavity and rapidly contractile stalk.

Wolffian body. An embryonic structure, the forerunner of certain parts of the genito-urinary apparatus.

Zymogen. A peculiar substance supposed to give rise to the pancreatic ferments.

INDEX.

Abdominal respiration, 296
Abductor nerve of the eye, 481
Aberration, chromatic and spherical, 530
Abnormal constituents in the urine, 379
Absorbents of stomach, 133
Absorption, 169
— intestinal, 176
— interstitial, 170
— mechanism of, 179
— of salts, 180
— of sugars, 180
— of proteids, 180
— of fats, 182
Accelerator nerve, 251
Accommodation, 526
Achromatic spindle, 70
Achromatine, 11
Acid albumin, 39
Acinous glands, 115
Adequate stimulus, 496
Afferent nerve, 22, 457
Agminate glands, 178
Agraphia, 623
Air passages of lung, 291
— pressure in, 306
— structure of, 291
Albumin, acid, 39
— alkali, 39
— coagulated, 38
— conversion into peptone, 138
— egg, 39
— in the urine, 379
— serum, 39
— syntonin, 39
— tests for, 40
Albuminates, 39
Albuminoids, composition of, 42
Albuminous bodies, 37
— as food, 83
Albumins, classification of, 39
— chemical composition of, 37
— characteristics of, 38
Albumose, primary, 40
Alcoholic fermentation, 57, 58
Alexia, 620
Alimentary canal, 90
Alkali albumin, 39
Allantois, 640
Aloxan, 52
Amido-acids, 44, 47
Amnesia, 621
Amnion, 636
— true, 638
— false, 638
Amœba, 15
— change in form, 77
— effect of stimulation, 79
— life of, 79
— locomotion of, 79
— pseudopodia of, 79
Amœboid movement of white blood corpuscles, 200
Amount of blood in the body, 190
Ampullæ of semicircular canals, 562
Amylopsin, 145
Anelectrotonus, 466
Animal heat, 396
— production of, 399
— income and expenditure of, 399
— starch, 61
Animals, homœothermic, 396
— poikilothermic, 396
Anode, 461

Anterior roots of spinal cord, 476, 569, 580
Aortic valves, 235, 238
Aphasia, 624
Apnœa, 289
Aqueous humour, 517
Area opaca, 634
— pellucida, 634
— vasculosa, 634
Arterial pulse, the, 273
— velocity of wave, 274
— length of wave, 274
— curve, 274, 277
— tone, 282
Arteries, walls of, 253
Arterioles, 254, 262
Arytenoid cartilage, 447
Ascending currents, 469
Asphyxia, 323
Assimilation, 5
Astar stage, 7
Astigmatism, 531
Atmospheric air, 314
Auditory meatus, 557
— nerve, stimulation of, 565
— terminals of, 562
Auerbach's plexus, 112
Auricles, of the heart, 232
Auriculo-ventricular valve, 234, 237
Automatic centres in spinal cord, 588
Automatism, 588
Axis cylinder, 23

Bacterium, 75
Basal ganglia, 605
Basilar membrane, 563
Bile, 151
— acids and pigments in the urine, 379
— composition of, 115
— ducts, 339
— functions of the, 157
— method of obtaining, 115
— pigments, Gmelin's test for, 154
— origin of, 342
— salts, Pettenkofer's test for, 154
— manufacture of, 342
— secretion of, 155
Bilirubin, 153
Biliverdin, 153
Binocular vision, 551
Bladder, evacuation of the, 383
— nervous mechanism of, 582
— passage of the urine to the, 318
Blastoderm, 633
Blastodermic vesicle, 632
Blind spot, 514
Blood, action of re-agents on, 205
— amount of, 189
— arterial, 317
— buffy coat of clot, 218
— carbon dioxide in the, 319
— changes during respiration, 209, 317
— changes in the lungs, 317
— changes in the spleen, 332
— chemistry of the colouring matter, 211
— chemistry of the stroma, 213
— circulation of the, 228
— circumstances influencing coagulation, 219
— clot, 218
— coagulation of the, 216
— coagulation within the vessels, 223
— colourless corpuscles, 199
— colourless corpuscles, origin of, 201
— composition of, 172
— construction of the, 192
— corpuscles, measurement, 198, 202
— corpuscles, number of, 198
— corpuscles, separation from plasma, 193
— crenated red corpuscles, 205
— current, velocity of the, 279
— defibrinated, 219
— density of the, 190
— development of red discs, 213
— enumeration of blood-corpuscles, 206
— gases in the, 214
— glands, 326
— hæmatin of, 211
— hæmatoidin of, 212
— hæmin of, 212
— hæmochromogen of, 211
— lakey, 205
— methæmoglobin of, 211
— of amphioxus, 202

Blood, origin of colourless corpuscles of, 201
— oxygen in the, 210, 318
— oxyhæmoglobin of, 208
— -plasma, coagulation of, 192
— -plasma, chemical composition of, 194
— preparation of oxyhæmoglobin, 208
— red corpuscles of, alteration in shape, 204
— red corpuscles, 201
— red corpuscles, forming rouleaux, 204
— red corpuscles of, relative size in different animals, 203
— red corpuscles, shape in different animals, 202
— -serum, composition of, 197
— specific gravity of the, 190
— spectra of, 212
— spectra of hæmoglobin, 211
— stroma of the, 213
— venous, 318
Blood-pressure, 260
— influence of respiration on, 271
— in the pulmonary circulation, 273
— in the capillaries, 266
— in the veins, 266
— measurement by Fick's spring manometer, 269
— measurement by mercurial manometer, 264
— record of, 268
— tracing of, 268
— relative height of, 267
— respiratory wave of, 271
— sustenation of, 261
— variations of, 267
Blood-vessels, 252
— clotting of blood in the, 223
— action of depressor nerve on, 284
— nervous control of the, 281
— relative capacity of, 257
— vaso-motor centres of, 283
— vaso-motor nerves of, 281
Bone, 31
— composition of, 31
— growth of, 33
Brain, development of, 596
— effect of stimulation of, 611
— functions of the, 607
— mid and hind brain, 597
Brain, recovery after injury of, 572
— result of removal of parts of, 614
— structure of, 606
Breaking shock, 461
Bronchial tubes, 291
Brownian movement, 65
Brunner's glands, 160
Bulb, the, 590
Butter as food, 90

Calabar bean, 529
Calculi, urinary, 380
Canal of cochlea, 563
Canaliculi of bone, 32
Capillaries, 255
— lymphatic, 171
Carbohydrates, 56
— as food, 83, 393
Carbon, 6
Carbon dioxide in the blood, 319
Carbonates in the tissues, 52
Cardiac centre, 594
— cycle, 238
— ganglia, 249
— glands of stomach, 132
— impulse, 242
— movements, 340
— mechanism, 228
Cardiograph, 243
Cartilage, 30
Casein, 41, 357
Caseinogen, 357
Catacrotic pulse, 276
Catelectrotonus, 466
Cathode, 461
Cell-contents, 9
Cell-wall, 11
Cells, animal, 9
— development of, 68
— differentiated, 13
— division of, 68
— fat-, 12
— ganglion-, 23, 472
— germination of, 55
— goblet-, 176
— gland-, 116
— history of, 73
— liver, 9
— of mucous tissue, 27
— nucleus and nucleolus of, 9
— pigment, 12
— reproduction of, 68
— varieties of, 13

Cells, vegetable, 8
Cellular theory, 8
Cellulose, 61
Cerebellum, 600
Cerebral hemispheres, 607
— functions, localization of, 609
Cerebro-spinal axis, 568
Cerebrum, 561
Chalaza, 630
Cheese as food, 90
Chemistry of the body, 35
— of respiration, 314
Chlorophyll, 77
Cholesterin, 154
Cholin, 53
Chondrin, 42
Chorion, 641
Choroid, 515
Chromatic aberration, 530
Chyle, 184
Cicatricula, 632
Ciliary ganglion, 485
— processes, 515
Ciliated epithelium, 20
Circulation of the blood, 228
— physical forces of the, 259
Circumvallate papillæ, 115, 509
Clot of blood, 218
Coagulation of the blood, 216
Cochlea, 561
— canal of the, 563
— organ of Corti in, 564
Cold-blooded animals, 396
Colostrum, 357
Colourless blood-corpuscles, origin of, 201
Colourless corpuscles of blood, 199
Colour-blindness, 549
— perceptions, 546
Columns of cord, 571, 577 (see Tracts)
Columnar epithelium, 20
Connective tissue, 27
— tissues, classification of, 18
Constrictors of pharynx, 100
Contractile tissues, 407
Convulsions, epileptic, 612
— respiratory, 323
Co-ordination, 587
Cord, spinal, segments of, 569, 581
Cornea, 517
Corpora quadrigemina, 604
— striatum, 605
Corpuscles, blood, 198, 202
Corpuscles, enumeration of blood, 198
— lymph, 167
Corti, organ of, 564
Costal respiration, 296
Coughing, 302
Cranial nerves, 480
Cricoid cartilage, 446
Crura cerebri, 603
Crusta petrosa, 98
Crying, 302
Crystalline lens at different periods, 518
— fibres of, 520
Crystals of hæmoglobin, 208
Curara, 418
Currents, ascending and descending, 469
Cutaneous desquamation, 363
Cytod, 9

Decidua reflexa, 642
— serotina, 642
— vera, 642
Defæcation, mechanism of, 110
Deglutition, 100
— nervous mechanism of, 103
Dentine, 97
Depressor nerve, 284
Derived albumins, 39
Degenerative method, 570
Deutero-albumose, 40
Developmental method of studying tracts of spinal cord, 570
Dextrine, 61
Dextrose, 57
Diabetes, 349
Diaphragm, 297
Diaster, 71
Diastole of heart, 219
Dicrotic pulse, 275
Diet tables, 393
Differentiated cells, 13
Diffusion, 306
Digestion, alimentary tract, 95
— of carbohydrates, 129, 150
— of fats, 150
— of proteids, 138, 149
— mechanism of, 75
— movements of the intestines, 108
— small intestine, 159
— stomach, 132
Discus proligerus, 628

Discus vitello intestinalis, 640
Division of egg cell, 73, 630, 633
Dorsal muscles, 299
Drum of ear, 558
Du Bois Reymond's induction coil, 419 ; myograph, 426
Ductless glands, 326
Ductus arteriosus, 659
— venosus, 649
Duodenum, 96, 159
Dyspnœa, 309

Ear, cochlea, 563
— eustachian tube of, 560
— external, 557
— labyrinth of, 561
— membrani tympani of, 560
— organ of Corti, 564
— ossicles of the, 559
— semicircular canals of, 562, 600
Ectoderm, 16
Efferent nerve, 22, 457
Egg albumin, 39
Eggs as food, 91
Elastin, 42
Electrodes, non-polarisable, 415
Electrotonus, 465
Embryonic circulation, 647
Emmetropic eye, 427
Emulsification of fat, 150, 158
Enamel, 97
End-bulbs, 499
Endoderm, 16
Endogenous reproduction, 68
Endolymph, 562
Endothelium, development of, 32, 175
Entoptic images, 531
Epiblast, 17, 634
Epiglottis, 447
Epithelial tissues, 18, 20
Equilibration, nervous mechanism, 598
Eupnœa, 309
Eustachian tube, 560
— valve, 650
Excretions, 361
Expiration, 300
Expired air, 315
External auditory meatus, 557
Extrinsic cardiac nerves, 250
Eye, abductor nerve of the, 481
— accommodation, 526
Eye, blind spot of, 514
— development of, 518
— dioptrics of the, 521
— inversion of image by the, 522
— motor oculi nerve, 480
— pigment cells of the retina, 546
— refraction of the, 523
— tunics of the, 515
— yellow spot, 543
Eye-ball, dioptric media of the, 521
Eye-balls, movement of the, 550

Fæces, composition of, 163
Fallopian tube, 630
Fat, absorption of, 182
Fats as food, 61
Fat cells, 11
— emulsion, 150, 158
Fats, 61
Fehling's solution, 57
Fenestra ovalis, 562
— rotunda, 561
Fibrin, 193, 197
— ferment, 222
Fibrinogen, 222
Fibrinoplastin, 222
Fick's spring manometer, 263
Filiform papillæ, 115
Fistula, gastric, 135
— intestinal, 162
— pancreatic, 145
Fœtal circulation, 650
Follicles of Lieberkühn, 161
Food, 82
— albuminous bodies, 83
— carbohydrates, 83, 393
— classification, 84
— diet table, 393
— digestibility of, 86
— excessive consumption of, 392
— fats, 61
— requirements, 86
— tables, 393
Food-stuffs, 84
Fovea centralis, 543
Fundus of eye, 537
Fungiform papillæ, 115

Gall bladder, 151, 336
Galvanometer, 415
Ganglia of fifth nerve, 485
— sympathetic, 490, 493

Ganglion, cells of heart, 23
Gases in the blood, 214, 318
— urine, 379
Gastric digestion, 139
— fistula, 135
— glands, 132
— juice, action on food, 137
— juice, artificial, 135
— juice, characters of, 134
— juice, method of obtaining, 135
Galactose, 58
Gastrula stage, 16
Gelatin, 42
Gemmation, 68
General sensations, 506
Germ epithelium, 627
Germinal vesicle, 630
Giddiness, 508
Gills, 289
Gland cells, 116
Glands, acinous, 116
— blood elaborating, 326
— ductless, 327
— excreting, 361
— gastric, 132
— lachrymal, 352
— lymphatic, 173
— mammary, 355
— Meibomian, 355
— mucous, 97, 353
— of stomach, 132
— salivary, 117
— sebaceous, 354
— secreting, 352
— sweat, 61
— thymus, 329
— thyroid, 328
Glandular epithelium, 20
Glisson, capsule of, 138
Globin, 213
Globulins, 39
Glœocapsa, 68
Glomerulus of kidney, 367
Glosso-pharyngeal nerve, 486
Glottis, shape of opening of, 448
Glucoses, 57
Gluten, 92
Glycin, 44
Glycocine, 44
Glycocholic acid, 49
Glycocoll, 44
Glycogen, 61
— composition, 347
Glycogen, preparation of, 347
— properties, 348
Glycogenic function of liver, 347
Gmelin's test, 154
Goblet-cells, 20, 176
Graafian follicle, 627
Grape sugar, 57
— in the urine, 379
Graphic method, 264, 426
Green vegetables as food, 93

Hæmatin, 211
Hæmatoidin, 153, 212
Hæmin, 212
Hæmochromogen, 211
Hæmoglobin crystals, 208
— decomposition of, 211
— spectra of, 210
Haversian system, 32
Hearing, 553
— external ear, 557
— organ of Corti, 564
— tympanum, 560
Heart, 232
— accelerator nerves of, 251
— action of the valves of, 233
— afferent cardiac nerves, 252
— anatomy of, 232
— atropine, curara, digitalis, nicotin, action of, 252
— Bidder's ganglion, 249
— centres, 249, 594
— movements, 340
— cardiograph, 243
— capacity of, 232
— cause of sounds of, 244
— cycle of, 238
— diastole of, 339
— depressor nerve, 284
— extrinsic nerves, 250
— first sound of, 244
— inhibitory nerves of, 250
— innervation of, 246
— intrinsic nerves, 247
— muscle of, 234, 409
— nerve cells of, 23
— passive interval, 240
— second sound of, 244
— semilunar valves, 236, 237
— Stannius's experiment, 249
— systole of, 239
— vagus, action of, 250
— valves of, 234

Heart, work done by the, 281
Heart's impulse, 242
Heat, animal, 396
— expenditure of, 401
— income, 399
— production of, 399
— value of food, 400
Heat perceiving areas, 506
Henle's tubules, 365
Hepatic artery and vein, 136, 338
Hetero-albumose, 40
Hiccough, 302
Hippuric acid, 49, 377
Histology, 1
Holoblastic ovum, 632
Homœothermic animals, 396
Hunger and thirst, 507
Hyaline cartilage, 30
Hydra, neuro-muscular cells of, 21
Hydrocele fluid, 222
Hyaloplasm, 10
Hypermetropia, 529
Hypoblast, 12, 17, 634
Hypoglossal nerve, 489

Idiosyncrasy, 86
Ileo-cæcal valves, 110
Incus, 559
Indican, 377
Indifferent cells, 12
Indol, 53
Induced shock, 419
Induction coil, 419
Infusoria, 80
Inhibition, 474
— of heart, 250
— of reflex, 584
Innervation of the heart, 246
Inorganic bodies, 62
— substances, 5
Inosit, 58
Inspiration, 295
— muscles of, 297
Intercellular substance, 11
Intercostal muscles, 299
Interlobular vein, 338
Internal respiration, 320
Interrupted current, 420
Interstitial absorption, 170
Intestinal absorption, 176
— digestion, 144, 162, 165
— fistula, 162
— juice, function of, 162
Intestinal juice, secretion of, 162
— movements, nervous mechanism of, 112
— secretion, method of obtaining, 161
Intestine, histology of small, 159
— large, 163
— lymph follicles of, 178
— small, 159
Intestines, movements of the, 108
Intima, 255
Intralobular vein, 338
Inversion of image, 522
Iris, functions of the, 531
— nervous control of, 533
— structure, 532
Irradiation, 544
Irrespirable gases, 321

Jejunum, 96

Karyokinesis, 11, 69
Keratin, 43, 363
Kidney, 364
— blood vessels of, 366
— tubules of, 365
Krause's end bulbs, 499
Kreatin, 50
Kreatinin, 51
— in the urine, 377
Kymograph, 265, 269

Labyrinth of ear, 561
Lachrymal glands, 352
Lactation, 359
Lacteals, 176
Lactic fermentation, 59
Lactose, 59
Lacunæ of bone, 31
Lakey blood, 205
Large intestine, 163
Larynx, 446
— muscles of, 448
Latent period, 427, 428
Laughing, 302
Law of Contraction, 469
Lecithin, 5, 54
Leeuwenhoek, 201
Leucin, 47
— and tyrosin in the urine, 379
— in pancreatic digestion, 149

Leucocytes, 199
Leucocythemia, 199, 332
Levatores costarum, 299
Levers, the three orders of, 441
Lieberkühn's follicles, 161
Light, 538
Liquor folliculi, 628
— sanguinis, 112
Liver, 335
— capillaries of, 235
— cells, 9, 338
— glycogenic function of, 347
— lobules of, 336
— uremic function of, 343
Localisation of Cerebral function, 609
Ludwig's kymograph, 265
Lung, structure of, 290
Lymph and chyle, characters of, 184
— composition of, 184
— corpuscles, 184
— follicles in intestine, 178
— hearts, 187
— movement of the, 185
— spaces, 170
— vascular system, 172
— vessels, 174
— valves in, 187
Lymphatic gland, 173
— system, 172
— vessels, 174
Lymphatics, 170

Making Shock, 461
Malassez' apparatus for the enumeration of blood corpuscles, 206
Malleus, 559
Malpighian body of spleen, 331, 333
Maltose, 59
Mammary glands, 355
— — during lactation, 356
Manometer, Fick's, 269
— mercurial, 263
Marey's sphygmograph, 276
— tambour, 243
Mastication, 97
Meat as food, 90
Mechanical stimulation of muscle, 418
— — of nerve, 459
Mechanism of absorption, 179
— of speech, 618
Medulla oblongata, 590
— — as central organ, 591
Medulla oblongata, cardiac centre, 594
— — respiratory centre in, 592
— — roots of nerves in, 591
— — vasa motor centre in, 593
Medulla spinalis, 568
Medullary fold, 634
— sheath, 23
Medullated nerve fibres, 22, 456
Meibomian glands, 355
Meissner's plexus, 113
Membrana tympani, 558
Membrane of Reissner, 562
Membranous spiral lamina, 562
Memory, 607, 621
Menstruation, 628
Meroblastic ovum, 631
Mesoblast, 12, 17, 634
Metabolism, 6
— of muscle, 413
Metakinesis, 71
Metazoa, 15
Methæmoglobin, 211
Methods of investigation of the cord, 569
Anatomical, 569
Degeneration, 570
Developmental, 570
Experimental, 575
Pathological, 576
Micrococcus, 75
Micturition, 383
Milk, chemical composition of, 88, 358
— as food, 88
— curdling, 357
— mode of secretion, 359
— sugar, 59
— tests, 89
Millon's re-agent, 38
Mitotic, 70
Mitral valve of the heart, 236
Moist chamber, 425
Morphology, 1
Morula stage, 16, 632
Motor areas, 611
— oculi nerve, 480
Mouth, digestion, 115
Movement of chyle and lymph, 187
— of the heart, 240
— of white corpuscles, 200

Mucin, 42
Mucous glands, 117, 352, 353
— tissue, 27
Murexide test for uric acid, 52
Muscle, active state of, 417
— altitude of curve, 331
— changes during contraction, 420
— chemical change in, 420
— composition of, 411
— consistence of, 411
— contraction, single, 426
— — tetanic, 432
— — tonic, 413
— contraction of non-striated, 438
— curves, 426
— death rigor, 437
— Du Bois Reymond's coil, 419
— duration of contraction, 429
— effect of temperature on contraction of, 429, 430
— elasticity of, 413
— electric phenomena, 414
— fatigue, 434
— graphic method, 425
— irritability of, 384, 434
— latent period, 427, 428
— maximal contraction, 431
— natural currents, 414
— negative variation, 422
— non-polarisable electrodes, 415
— non-striated, 25, 438
— of heart, 409
— pigments, 412
— plasma, 411
— properties of, 411
— rate of contractions in insects, 429
— rheoscopic frog, 423
— rigor mortis, 427
— sarcolemma, 25, 409
— single contraction, 426
— sound, 434
— stimulation of, 418
— striated, 24, 408
— summation, 431
— tetanus, 432
— tone, 413
— wave of contraction, 427
Muscles of deglutition, 10
— of the eye-balls, 550
— of the iris, 532
Muscles of the larynx, 449
— of mastication, 98, 99
— of respiration, 300
— the three orders of levers, 441
Muscular fibres of heart, 409
Muscularis mucosæ, 160, 178
Myo-albumin, 412
— globulin, 412
— proteose, 412
Myograph, pendulum, 425
— spring, 426
Myopia, 492
Myosin, 41, 411
Myosinogen, 412

Nausea, 507
Near limit of vision, 527
Negative variation, 464
Nerve, 21
— motor oculi nerve, 480
— trochlear nerve, 481
— trigeminus, or trifacial nerve, 483
— abductor nerve of the eye, 481
— (portio dura) motor nerve of the face, 481
— vagus, 486
— glosso-pharyngeal nerve, 486
— spinal accessory nerve, 489
— hypoglossal nerve, 489
— active state of, 459
— auditory, 562
— axis cylinder of, 23, 456
— — cells, 472
— conductivity of, 466
— electric change in, 464
— electrical properties of, 463
— electrotonus in, 465
— excitability of, 466
— law of contraction of, 469
— — mechanism of heart, 246
— medullary sheath of, 23, 456
— medullated, 23, 456
— Meissner's plexus, 113
— multipolar cells, 23
— natural current in, 463
— negative variation in, 464
— — muscle preparation, 459
— non-medullated, 23, 456
— nodes of Ranvier in, 23, 456
— primitive sheath of, 23, 456
— sensory cells, 498
— spinal, 476

Nerve stained with osmic acid, 22, 456
— stimulation of, 459
— tissue, 21
— velocity of force, 462
Nerves, special physiology of, 476
— afferent, 457
— efferent, 457
— anterior roots of, 476
— posterior roots of, 477
— cranial, 480
— functional classification of, 457
Nerve-cells, 22
— functions of, 472
— in spinal cord, 579
Nerve endings, 471
— in the ear, 563
— in the eye, 540
— in nose, 511
— in the skin, 498
— in tongue, 509
Nerve fibre, chemistry of, 459
— fibres in spinal cord, 568
— centres, 568
Nervous control of the blood vessels, 281
Nervous mechanism of respiration, 307
— — of salivary secretion, 121
— — of urinary secretion, 380
— — of voice, 453
Nervous organs, central, 568
Nerve muscle preparation, 459
Neurin, 54
Neuroglia, 568
Neuro-muscular cells of Hydra, 21
Nitrogenous diet, 389
Non-medullated nerve-fibres, 23, 456
Non-nitrogenous diet, 390
Non-polarisable electrodes, 415
Non-striated muscle, 23, 438
Notochord, 634
Nuclear matrix, 11
— membrane, 11
— network, 11, 69
Nucleo-albumin, 43
Nucleus, method of staining, 10
Nucleolus, 11
Nutrition, 385
Nutritive equilibrium, 389
Nutritive materials in vegetable food, 92
— value of food, 85

Odontoblasts, 99
Œsophagus, 102
Omphalo-mesaraic vessels, see
Omphalo-mesenteric vessels, 647, 648
Ophthalmic ganglion, 485
Ophthalmometer, 528
Ophthalmoscope, 434
Optic nerve, 514, 539
— thalami, 606
Organic substances, 5
— substance, instability of, 6
Organisms, chemical composition of, 4
— death of, 7
— general characters of, 3
— reproduction of, 7
— vital characters of, 65
Origin of white blood corpuscles, 201
Osseous spiral lamina, 562
Ossicles of ear, 559
Ossifying cartilage, 33
Osteoblasts, 33
Otic ganglion, 485
Otoliths, 562
Ovary, 627
Ovisac, 628
Ovoid cells of stomach glands, 133
Ovulation, 628
Ovum, 628
— changes in the, 632
— divisions of, 14
— maturation of, 631
Oxalic acid in the urine, 377
Oxygen in the blood, 210
Oxyhæmoglobin, 208, 318
— composition of, 208
— decomposition of, 211
— preparation of, 209

Pacinian corpuscles, 500
Pain, 506
Pancreas, 144
— changes in the cells during secretion, 146
— nervous influence on the, 146
Pancreatic fistula, 145
— juice, action on fat, 150

Pancreatic juice, action on proteids, 149
— — action on starch, 150
— — artificial, 145
— — characters of, 145
— — mode of secretion, 146
Papillæ of tongue, 115
Paraglobulin (fibrinoplastin), 222
Paramœcium, 79
Paramyosinogen, 412
Peduncles of the cerebellum, 602
Pendulum myograph, Fick's, 425
Pepsin, 134
Peptic cells, 132
Peptones, 41
— absorption of, 180
— tests for, 41
Perilymph, 562
Peristaltic action, 108
Perspiration, 405
Pettenkofer's test for bile salts, 54
Peyer's patches, 178
Phakoscope, 528
Pharynx, muscles of, 100
Phosphates in the urine, 378
Physical forces of the circulation, 259
Physiology, objects of, 1
Pigment cells, 12
— of the eye, 546
Placenta, 642
— circulation in, 648
— functions of the, 645
Plant cell, 8
Plasma, 192
— chemical composition of, 194
— of the blood, coagulation of, 193
— method of obtaining from blood, 192
Pleura, 290
— functions of the, 302
Pneumogastric nerve, 486
Poikilothermic animals, 396
Poisonous gases, 322
Polar globule, 631
Polarising current, 465
Pons Varolii, 591
Portal vein, 336, 338
Portio dura, seventh nerve, 481
— mollis, 562
Posterior roots of spinal nerves, 477
Potatoes as food, 93, 394
Presbyopia, 430
Primitive (medullary) groove, 634
Products of tissue change, 43
Pronucleus, 632
Protamœba, 77
Proteid, tests for, 37
— classification, 38
— solubility, 41
Proteoses, 39
Protista, 15
Proto-albumoses, 40
Protoplasm, 4
— assimilation of, 67
— change in form, 65
— of cell, 10
— structure of, 10
Protoplasmic movements, 65
Protozoa, 15
Pseudopodia of amœba, 66
— of white blood corpuscles, 200
Ptyalin, 129, 130
Puerile breathing, 306
Pulmonary circulation, 232
Pulp cavity of the teeth, 98
Pulse, arterial, 273
— Marey's sphygmograph, 276
— tracings, 275
— rate, 274
— variations in the, 276
— wave, velocity of, 274
Pupil of the eye, 531
Purkinje's cells in the cerebellum, 599
— figures, 542
Putrefactive fermentation in the intestine, 165
Pyloric glands, 133
Pylorus, 105

Quadratus lumborum, 289

Ranvier's nodes, 23, 446
Receptaculum chyli, 172
Recording apparatus, 265
Red blood corpuscles, 201
Reduced hæmoglobin, 211
Reflex action, 22, 581
— inhibition of, 584
— time, 585
Reflex centres, special, 586
Refraction, 521
Reissner's membrane, 562

Rennin, 357
Reproduction, 525
— of cells, 68
Respiration, 268
— abdominal, 296
— asphyxia, 323
— changes in the air, 316
— changes in the blood during, 317
— chemistry of, 314
— complemental air of, 305
— construction of thorax, 293
— costal, 296
— diffusion in, 306
— expiration, 300
— expired air, 316
— external, 288
— frequency of, 295
— functions of the pleura in, 302
— in lower animals, 288
— inspiration, 295
— internal or tissue, 288
— mechanism of, 288
— muscles of, 297
— nervous mechanism of, 307
— of abnormal air, 321
— of poisonous gases, 322
— pressure differences in the air, 306
— reserve air, 305
— residual air, 305
— sounds, 307
— tidal air of, 305
— ventilation, 322
— vital capacity, 305
— vital spot, 308, 592
— volumes of air, 304
Respiratory centre, 308, 592
— movements, 294
— quotient, 317
— rhythm, 310
— sounds, 306
Retention of urine in the bladder, 382
Retiform tissue, 27
Retina, function of the, 543
— pigment cells of, 546
— ophthalmoscopic view of the, 537
— structure of, 540
Rheoscopic frog, 423
Ribs, 293
Rigor mortis, 437
Ritter's tetanus, 460
Rods and cones of the retina, 539
Rods of Corti, 564
Roots of spinal nerves, 476
— connection with cord, 569, 580
Running, 444

Sacculated glands, 116
Saccule of labyrinth, 525
Saliva, action on food, 128
— chemistry of, 119
— collection of, 119
— effect of drugs on secretion of, 121
— nervous mechanism of, 121
— method of secretion, 120
Salivary gland, 117
— histology of, 116
Salts as food, 94
— in the tissues, 63
Saponification, 150
Sarcolemma of muscle, 25, 409
Scaleni muscles, 298
Scaly epithelium, 20
Scheiner's experiment, 525
Sclerotic, 515
Sebaceous glands, 354
Secreting glands, 352
Secretion, 352
— of urine, 369
Segmentation sphere, 632
Semicircular canals, 562
Semilunar valves, 236, 238
Sensations, general, 506
Sense of smell, 511
— taste, 509
— touch, 501
— sight, 514
— hearing, 553
Sensory areas, 615
— excitation of, 616
— destruction of, 616
— roots, 477
Sensory nerve endings, 498
Serum, 197
— separation of, 197
Serum albumin, 196
— composition of, 197
— globulin, 175
Sexual reproduction, 625
Shivering, 508
Sighing, 302
Sight, 514

Skatol, 53
Skeletal muscles, application of, 440
Skin, cutaneous desquamation, 363
— sensations, 497
— glands of, 352
— Krause's end bulbs, 499
— nerve endings in, 498
— sense of temperature, 504
Smell, 511
Sneezing, 302
Sobbing, 302
Somatopleure, 637
Sound, 553
— properties of, 554
— of tuning forks, 554
— vibrations through the tympanum, 558
Special senses, 495
— hearing, 553
— smell, 511
— taste, 509
— touch, 501
— sight, 514
Specific energy, 496
Spectra of blood, 211
— of hæmoglobin, 192
Speech, 453
Spermatozoa, 626
Sphenopalatine ganglia, 485
Spherical aberration, 530
Spheroidal cells of stomach glands, 132
Sphygmograph, 274
Spinal accessory nerve, 489
Spinal cord, 568
— automatism, 588
— cellular columns in the, 579
— collection of nerve-cells in the, 579
— co-ordination, 587
— course of fibres in, 573
— experiments on the, 577
— grey matter, 577
— motor channels, 573
— pyramidal tracts of, 573
— reflex action, 581
— roots of nerves of, 580
— segments of, 581
— sensory channels, 578
— vesicular columns, 579
— white tracts on, 573
Splanchnopleure, 637
Spleen, changes of blood in the, 330
Spleen, extirpation of the, 332
— function of, 334
— structure of, 330
Spongioplasm, 70
Spring myograph, 426
Standing, 441
Stapes, 559
Starch, 59
— as food, 83, 393
— converted into sugar, 129
— microscopic appearance of, 94
— tests for, 60
Starvation, 386
Steapsin, 145
Stomach, digestion, 132
— histology of, 132
— movements of the, 105
— nervous influence on, 106
Stomata, 176
Stratified epithelium, 19
Striated muscle, 24, 408
Stroma of corpuscles, 213
Strychnine, 583
Submaxillary ganglion, 486
Sucrose, 58
Sudoriferous glands, 361
Sulphates in the urine, 378
Summation, 431
Supra-renal capsule, 327
Sweat glands, 361
Sympathetic system, 489
Syntonin, 39
Systemic circulation of the blood, 229
Systole of heart, 339

Tactile impressions, 501
Tambour (Marey's), 243
Taste, 510
Tastebuds, 509
Taurin, 48
Taurocholic acid, 49
Teeth, structure of the, 97
Tegmentum, 604
Temperature, 397
— maintenance of uniform, 402
— measurement of, 396
— normal variations in, 397
— sensations of, 408
Testicle, 626
Tetanus of muscle, 432
— breaking or Ritter's, 460

Thermic stimulation of muscle, 418
— — nerve, 460
Thermometer, clinical, 396
Thirst and hunger, 507
Thoracic duct, 188
— — lymph of, 185
Thorax, construction of, 293
Thrombosis, 225
Thymus gland, 329
Thyroid body, 328
— cartilage, 447
Timbre of a note, 555
Tissue changes in starvation, 386
— bone, 31
— change, products of, 42
— cartilage, 30
— connective, 27
— contractile, 24
— differentiation, 14
— endothelium, 32
— epithelial, 18
— lymphoid, 153
— mucous, 27
— muscle, 24, 408
— nerve, 21, 456
— retiform, 27
— white fibrous, 29
— yellow elastic, 30
Tissues, classification of, 18
Titillation, 508
Tone, 555
— of vessels (arterial), 282
— of muscles, 413
Torula cerevisiæ, 77
Touch, 501
— cells, 500
— corpuscles (Meissner's), 499
— general sensation, 506
— sense of locality, 501
— sense of pressure, 503
— temperature, 504
Tracts of white fibres in cord, 571
— anterior root zone, 574
— crossed pyramidal, 572
— descending cerebellar, 574
— direct pyramidal, 571
— dorsal or direct cerebellar, 574
— posterior external, 575
— posterior median, 574
Tradescantia virginica, 65
Tricuspid valve of the heart, 234
Trigeminus nerve, 483
Trochlear nerve, 481
Trommer's test, 57
Trypsin, 145
Trypsinogen, 148
Tubules of kidney, 365
Tubuli seminiferi, 626
Tunica adventitia, 253
— albuginea, 627
— fibrosa, 628
— granulosa, 620
— intima, 255
— media, 253
— propria, 628
Tympanum of ear, 558
Tyrosin, 47

Unicellular organism, 75
Unstriated muscle, contraction of, 438
Urachus, 641
Urea, 44, 374
— amount eliminated, 375
— artificial preparation of, 45, 375
— composition, 374
— decomposition of, 45
— estimation of, 375
— precursors, 344
— source of, 343
Ureters, 381
Uric acid, 52
— in the urine, 376
— murexide test for, 52
Urinary calculi, 380
— secretion, nervous mechanism of, 380
Urine, 372
— abnormal constituents in the, 379
— chemical composition of, 374
— colouring matter of, 378
— inorganic salts in the, 378
— quantity secreted, 373
— retention of, 382
— secretion of, 369
— source of urea, 343
— specific gravity of, 373
Urobilin, 378
Urochrome, 378
Uterus, 628

Vacuoles, 9
Vagus nerve, 250, 310, 486
— stimulation of, 250
Valsalva's experiment, 560

Valves in lymph vessels, 187
— of heart, 234
— of veins, 257
— of the heart, action of, 235
Valvulæ conniventes, 144
Vasa efferentia, 627
Vaso-motor centre, 282, 593
— nerves, 281
Vegetable cells, 8
— food, 92
Veins, coats of, 256
— valves of, 257
Velocity of the blood current, 279
Venæ advehentes, 649
Vena porta, 336
Ventilation, 322
Ventricles of heart, 231
Vesiculæ seminales, 627
Vessels, lymphatic, 174
Villi, 176
— lacteals in, 176
Vision, 514
— accommodation, 528
— binocular, 551
— conditions affecting, 543
— mental operations in, 549
Visual judgments, 551
Vital capacity, 305
— characters of organisms, 65
— circulation, 647
— phenomena, 8
— spot, 308, 592
Vitelline membrane, 530
Vitreous humour, 517
Vocal cords, 448
Voice and speech, 446
— nervous mechanism of, 453
— properties of the human, 451
Volition, 607
Vomiting, 106
Vorticella, 81

Walking and running, 444
Warm-blooded animals, 396
Waste products of animal body, 43
Water H_2O, 6
Water as food, 93
Weber's method, estimating amount of blood, 190
Welcker's method, estimating amount of blood, 190
White blood corpuscles, 199
— fibro-cartilage, 31
— fibrous tissue, 29
— substance of Schwann, 457
Word-blindness, 621
— -deafness, 620
Words, auditory perception of, 619
— registration of, 621
— visual perception of, 620

Xanthin in the urine, 377
Xanthoproteic test, 38

Yawning, 302
Yeast plant, 77
Yellow elastic tissue, 30
— spot, 543
Yolk of egg, 633
— sac, 640

Zona pellucida, 530
— tendinosa, 232
Zymogen, 148

THE END.

BRADBURY, AGNEW, & CO. LD., PRINTERS, WHITEFRIARS.

BRITISH MEDICAL
Library
ASSOCIATION

[CATALOGUE B]

London, 11, *New Burlington Street*,
May, 1893.

A SELECTION

FROM

J. & A. CHURCHILL'S GENERAL CATALOGUE,

COMPRISING

MOST OF THE RECENT WORKS PUBLISHED BY THEM.

N.B.—J. & A. Churchill's larger Catalogue (A) *which contains over* 600 *works, with a Complete Index to their Subjects, will be sent on application.*

Human Anatomy: a Treatise by various Authors. Edited by HENRY MORRIS, M.A., M.B. Lond., F.R.C.S. Roy. 8vo, with 791 Illustrations, nearly all original, and many of them in several colours, 40s.

Practical Anatomy: a Manual of Dissections. By CHRISTOPHER HEATH, Surgeon to University College Hospital. Eighth Edition. Revised by WILLIAM ANDERSON, F.R.C.S., Surgeon to, and Lecturer on Anatomy at, St. Thomas's Hospital. Crown 8vo, with Coloured Plates and Engravings. [*In the press.*

Wilson's Anatomist's Vade-Mecum. Eleventh Edition, by HENRY E. CLARK, M.R.C.S. Eng., F.F.P.S. Glasg., Professor of Anatomy in St. Mungo's College, Glasgow. Crown 8vo, with 492 Engravings and 26 Coloured Plates, 18s.

An Atlas of Human Anatomy. By Rickman J. GODLEE, M.S., F.R.C.S., Surgeon and late Demonstrator of Anatomy, University College Hospital. With 48 Imp. 4to Plates (112 figures), and a volume of Explanatory Text. 8vo, £4 14s. 6d.

Human Osteology. By Luther Holden, Consulting Surgeon to St. Bartholomew's Hospital. Seventh Edition, edited by CHARLES STEWART, Conservator of the Museum R.C.S., and ROBERT W. REID, M.D., F.R.C.S., Professor of Anatomy in the University of Aberdeen. 8vo, with 59 Lithographic Plates and 75 Engravings, 16s.

By the same Author.

Landmarks, Medical and Surgical. Fourth Edition. 8vo, 3s. 6d.

The Student's Guide to Surgical Anatomy. By EDWARD BELLAMY, F.R.C.S., and Member of the Board of Examiners. Third Edition. Fcap. 8vo, with 81 Engravings, 7s. 6d.

Diagrams of the Nerves of the Human Body, exhibiting their Origin, Divisions, and Connections, with their Distribution to the Various Regions of the Cutaneous Surface, and to all the Muscles. By Sir W. H. FLOWER, K.C.B., F.R.S., F.R.C.S. Third Edition, with 6 Plates. Royal 4to, 12s.

Pathological Anatomy of Diseases. Arranged according to the nomenclature of the R.C.P. Lond. (Student's Guide Series). By NORMAN MOORE, M.D., F.R.C.P., Assistant Physician and Lecturer on Pathological Anatomy to St. Bartholomew's Hospital. Fcap. 8vo, with 111 Engravings, 8s. 6d.

A Manual of Clinical and Practical Pathology. By W. E. WYNTER, M.D., M.R.C.P., F.R.C.S., Medical Registrar to Middlesex Hospital, and F. J. WETHERED, M.D., M.R.C.P., Assistant Physician to Victoria Park Hospital. With 4 Coloured Plates and 67 Engravings. 8vo, 12s. 6d.

Lectures on Pathology: delivered at the London Hospital. By the late HENRY GAWEN SUTTON, M.B., F.R.C.P., Physician to, and Lecturer on Pathology at, the London Hospital. Edited by MAURICE E. PAUL, M.D., and Revised by SAMUEL WILKS, M.D., LL.D., F.R.S. 8vo, 15s.

General Pathology (an Introduction to). By JOHN BLAND SUTTON, F.R.C.S., Sir E. Wilson Lecturer on Pathology, R.C.S.; Assistant Surgeon to, and Lecturer on Anatomy at, Middlesex Hospital. 8vo, with 149 Engravings, 14s.

Atlas of Pathological Anatomy. By Dr. LANCEREAUX. Translated by W. S. GREENFIELD, M.D., Professor of Pathology in the University of Edinburgh. Imp. 8vo, with 70 Coloured Plates, £5 5s.

Atlas of the Central Nervous System. From the larger work of Hirschfeld and Léveillé. Edited by HOWARD H. TOOTH, M.D., F.R.C.P., Assistant Physician to the National Hospital for the Paralysed and Epileptic. With 37 Plates carefully coloured by Hand. Large Imp. 8vo, 40s.

The Human Brain: Histological and Coarse Methods of Research. A Manual for Students and Asylum Medical Officers. By W. BEVAN LEWIS, L.R.C.P. Lond., Medical Superintendent, West Riding Lunatic Asylum. 8vo, with Wood Engravings and Photographs, 8s.

Elements of Human Physiology. (Student's Guide Series.) By ERNEST H. STARLING, M.D., M.R.C.P., Joint Lecturer on Physiology at Guy's Hospital. Fcap. 8vo, with 94 Engravings, 6s. 6d.

Manual of Physiology: for the Use of Junior Students of Medicine. By GERALD F. YEO, M.D., F.R.C.S., F.R.S., Emeritus Professor of Physiology in King's College, London. Second Edition. Crown 8vo, with 318 Engravings, 14s.

Principles of Human Physiology. By W. B. CARPENTER, C.B., M.D., F.R.S. Ninth Edition, by HENRY POWER, M.B., F.R.C.S. 8vo, with 3 Steel Plates and 377 Wood Engravings, 31s. 6d.

Medical Jurisprudence: its Principles and Practice. By ALFRED S. TAYLOR, M.D., F.R.C.P., F.R.S. Third Edition, by THOMAS STEVENSON, M.D., F.R.C.P., Lecturer on Medical Jurisprudence at Guy's Hospital. 2 vols. 8vo, with 188 Engravings, 31s. 6d.

By the same Authors.

A Manual of Medical Jurisprudence. Twelfth Edition. Crown 8vo, with 55 Engravings, 14s.

The Student's Guide to Medical Jurisprudence. By JOHN ABERCROMBIE, M.D., F.R.C.P., Physician to Charing Cross Hospital. Fcap. 8vo, 7s. 6d.

Hospitals, Infirmaries, and Dispensaries: their Construction, Interior Arrangement, and Management; with Descriptions of existing Institutions, and 74 Illustrations. By F. OPPERT, M.D., M.R.C.P.L. Second Edition. Royal 8vo, 12s.

Sanitary Examinations of Water, Air, and Food. A Vade-Mecum for the Medical Officer of Health. By CORNELIUS B. FOX, M.D., F.R.C.P. Second Edition. Crown 8vo, with 110 Engravings, 12s. 6d.

Microscopical Examination of Drinking Water and of Air. By J. D. MACDONALD, M.D., F.R.S., Ex-Professor of Naval Hygiene in the Army Medical School. Second Edition. 8vo, with 25 Plates, 7s. 6d.

Hygiene and Public Health: a Treatise by various Authors. Edited by THOMAS STEVENSON, M.D., F.R.C.P., Lecturer on Chemistry and Medical Jurisprudence at Guy's Hospital; Official Analyst to the Home Office; and SHIRLEY F. MURPHY, Medical Officer of Health of the County of London. In 2 vols., royal 8vo, fully Illustrated. Vol. I., 28s.

A Manual of Practical Hygiene. By the late E. A. PARKES, M.D., F.R.S. Eighth Edition, by J. LANE NOTTER, A.M., M.D., F.R.S., Professor of Military Hygiene in the Army Medical School. 8vo, with 10 Plates and 103 Engravings, 18s.

A Handbook of Hygiene and Sanitary Science. By GEO. WILSON, M.A., M.D., F.R.S.E., D.P.H. Camb. Medical Officer of Health for Mid-Warwickshire. Seventh Edition. Crown 8vo, with Engravings, 12s. 6d.

Public Health Reports. By Sir John Simon, C.B., F.R.S. Edited by EDWARD SEATON, M.D., F.R.C.P. 2 vols. 8vo, with Portrait, 36s.

Hospitals and Asylums of the World: their Origin, History, Construction, Administration, Management, and Legislation. By HENRY C. BURDETT. In 4 vols., super-royal 8vo, and Portfolio. Complete, 168s. Vols. I and II—Asylums: their History, Administration, and Construction, with Plans and Bibliography, 90s. Vols. III and IV—Hospitals: their History, Administration, and Construction, with Plans, Bibliography and Portfolio, 120s.

Mental Diseases: Clinical Lectures. By T. S. CLOUSTON, M.D., F.R.C.P. Edin., Lecturer on Mental Diseases in the University of Edinburgh. Third Edition. Crown 8vo, with 13 Plates, 14s.

Illustrations of the Influence of the Mind upon the Body in Health and Disease: Designed to elucidate the Action of the Imagination. By D. H. TUKE, M.D., F.R.C.P., LL.D. Second Edition. 2 vols. crown 8vo, 15s.

By the same Author.

Prichard and Symonds in Especial Relation to Mental Science. With Chapters on Moral Insanity. 8vo, with 2 Portraits, 5s.

Also.

Reform in the Treatment of the Insane. Early History of the Retreat, York; its Objects and Influence. With a Report of the Celebrations of its Centenary. 8vo, 4s.

A Dictionary of Psychological Medicine, giving the Definition, Etymology, and Synonyms of the Terms used in Medical Psychology; with the Symptoms, Treatment, and Pathology of Insanity; and THE LAW OF LUNACY IN GREAT BRITAIN AND IRELAND. Edited by D. HACK TUKE, M.D., LL.D., assisted by nearly 130 Contributors, British, Continental and American. 2 vols., 1,500 pages, royal 8vo, Illustrated, 42s.

The Journal of Mental Science. Published Quarterly, by Authority of the Medico-Psychological Association. 8vo, 3s. 6d.

Mental Affections of Childhood and Youth (Lettsomian Lectures for 1887, etc.). By J. LANGDON DOWN, M.D., F.R.C.P., Consulting Physician to the London Hospital. 8vo, 6s.

Manual of Midwifery. By Alfred L. Galabin, M.A., M.D., F.R.C.P., Obstetric Physician to, and Lecturer on Midwifery and Diseases of Women at, Guy's Hospital. Second Edition. Crown 8vo, with 249 Engravings, 15s.

The Student's Guide to the Practice of Mid- wifery. By D. LLOYD ROBERTS, M.D., F.R.C.P., Lecturer on Clinical Midwifery and Diseases of Women at the Owens College; Obstetric Physician to the Manchester Royal Infirmary. Fourth Edition. Fcap. 8vo, with Coloured Plates and Wood Engravings.

[*In the press.*

Female Pelvic Organs (The Surgery, Surgical Pathology, and Surgical Anatomy of): in a Series of Plates taken from Nature. With Commentaries, Notes, and Cases. By HENRY SAVAGE, M.D., Consulting Physician to the Samaritan Hospital for Women and Children. Fifth Edition. 4to, Plain, 15s.; Coloured, 35s.

Obstetric Aphorisms: for the Use of Students commencing Midwifery Practice. By JOSEPH G. SWAYNE, M.D. Tenth Edition. Fcap. 8vo, with 20 Engravings. 3s. 6d.

Handbook of Midwifery for Midwives. By J. E. BURTON, L.R.C.P. Lond., Surgeon to the Hospital for Women, Liverpool. Second Edition. With Engravings. Fcap. 8vo, 6s.

Clinical Lectures on Diseases of Women: delivered in St. Bartholomew's Hospital, by J. MATTHEWS DUNCAN, M.D., LL.D., F.R.C.P., F.R.Ss. L. & E., late Obstetric Physician to St. Bartholomew's Hospital. Fourth Edition. 8vo, 16s.

Lectures on Obstetric Operations: including the Treatment of Hæmorrhage, and forming a Guide to the Management of Difficult Labour. By ROBERT BARNES, M.D., F.R.C.P., Consulting Obstetric Physician to St. George's Hospital. Fourth Edition. 8vo, with 121 Engravings, 12s. 6d.

By the same Author.

A Clinical History of Medical and Surgical Diseases of Women. Second Edition. 8vo, with 181 Engravings, 28s.

Gynæcological Operations (Handbook of). By ALBAN H. G. DORAN, F.R.C.S., Surgeon to the Samaritan Hospital. 8vo, with 167 Engravings, 15s.

Diseases of Women. (Student's Guide Series.) By ALFRED L. GALABIN, M.A., M.D., F.R.C.P., Obstetric Physician to, and Lecturer on Midwifery and Diseases of Women at, Guy's Hospital. Fifth Edition. Fcap. 8vo, with 142 Engravings, 8s. 6d.

A Practical Treatise on the Diseases of Women. By T. GAILLARD THOMAS, M.D. Sixth Edition, by PAUL F. MUNDÉ, M.D., Professor of Gynæcology at the New York Polyclinic and at Dartmouth College. Roy. 8vo, with 347 Engravings, 25s.

Abdominal Surgery. By J. Greig Smith, M.A., F.R.S.E., Surgeon to the Bristol Royal Infirmary, and Lecturer on Surgery in the Bristol Medical School. Fourth Edition. 8vo, with 82 Engravings, 21s.

Notes on Gynæcological Nursing. By John BENJAMIN HILLIER, M.D., M.R.C.S. Lecturer on the Diseases of Women and Children in the Yorkshire College, and Surgeon to the Hospital for Women, etc., Leeds. Crown 8vo, 1s. 6d.

Manual of Diseases of Children for Prac- titioners and Students. By W. H. DAY, M.D., Physician to the Samaritan Hospital. Second Edition. Crown 8vo, 12s. 6d.

The Diseases of Children. (Student's Guide Series.) By JAS. F. GOODHART, M.D., F.R.C.P., Physician to Guy's Hospital. Fourth Edition. Fcap. 8vo, 10s. 6d.

A Practical Treatise on Disease in Children. By EUSTACE SMITH, M.D., F.R.C.P., Physician to the King of the Belgians, and to the East London Hospital for Children, etc. Second Edition. 8vo, 22s.

By the same Author.

Clinical Studies of Disease in Children. Second Edition. Post 8vo, 7s. 6d.

Also.

The Wasting Diseases of Infants and Children. Fifth Edition Post 8vo, 8s. 6d.

A Practical Manual of the Diseases of Children. With a Formulary. By EDWARD ELLIS, M.D. Fifth Edition. Crown 8vo, 10s.

A Manual for Hospital Nurses and others engaged in Attending on the Sick, with a Glossary. By EDWARD J. DOMVILLE, Surgeon to the Exeter Lying-in Charity. Seventh Edition. Crown 8vo, 2s. 6d.

A Manual of Nursing, Medical and Surgical. By CHARLES J. CULLINGWORTH, M.D., F.R.C.P., Obstetric Physician to St. Thomas's Hospital. Third Edition. Fcap. 8vo, with Engravings, 2s. 6d.

By the same Author.

A Short Manual for Monthly Nurses. Third Edition. Fcap. 8vo, 1s. 6d.

Materia Medica: a Manual for the Use of Students. By ISAMBARD OWEN, M.D., F.R.C.P., Lecturer on Materia Medica, etc., to St. George's Hospital. Second Edition. Crown 8vo, 6s. 6d.

Materia Medica, Pharmacy, Pharmacology, and Therapeutics. By W. HALE WHITE, M.D., F.R.C.P., Physician to, and Lecturer on Materia Medica and Therapeutics at, Guy's Hospital; Examiner in Materia Medica on the Conjoint Board of the Royal Colleges of Physicians and Surgeons. Fcap. 8vo, 7s. 6d.

Materia Medica and Therapeutics. By Charles D. F. PHILLIPS, M.D., F.R.S. Edin. Vegetable Kingdom—Organic Compounds—Animal Kingdom. 8vo, 25s.

Organic Materia Medica of the British Pharmacopœia, systematically arranged; with Brief Notices of the Remedies contained in the Indian and U.S. Pharmacopœias, and Short Descriptions of their Chief Adulterants and Substitutions. By W. SOUTHALL, F.L.S. Fourth Edition. Crown 8vo, 5s.

Recent Materia Medica. Notes on their Origin and Therapeutics. By F. HARWOOD LESCHER, F.C.S., Pereira Medallist. Fourth Edition. 8vo, 2s. 6d.

Galenic Pharmacy: a Practical Handbook to the Processes of the British Pharmacopœia. By R. A CRIPPS, M.P.S. 8vo, with 76 Engravings, 8s. 6d.

Practical Pharmacy. By Barnard S. Proctor, formerly Lecturer on Pharmacy at the College of Medicine, Newcastle-on-Tyne. Third Edition. 8vo, with 44 Wood Engravings and 32 Lithograph Fac-Simile Prescriptions, 14s.

Selecta è Prescriptis: containing Lists of Terms, Phrases, Contractions and Abbreviations used in Prescriptions, with Explanatory Notes, etc. Also, a Series of Abbreviated Prescriptions and Key to the same, with Translations. By JONATHAN PEREIRA, M.D., F.R.S. Eighteenth Edition, by JOSEPH INCE, F.C.S., F.L.S. 24mo, 5s.

Pocket Formulary and Synopsis of the British and Foreign Pharmacopœias. By HENRY BEASLEY. Eleventh Edition. 18mo, 6s. 6d.

By the same Author.

Druggist's General Receipt-Book. Ninth Edition. 18mo, 6s. 6d.

Also.

Book of Prescriptions: containing upwards of 3,000 Prescriptions collected from the Practice of the most eminent Physicians and Surgeons, English and Foreign. Seventh Edition, 18mo, 6s. 6d.

A Companion to the British Pharmacopœia. By PETER SQUIRE, Revised by his Sons, P. W. and A. H. SQUIRE. Sixteenth Edition. 8vo, 10s. 6d. [*In the press.*

By the same Authors.

The Pharmacopœias of the London Hospitals, arranged in Groups for Easy Reference and Comparison. Sixth Edition. 18mo, 6s.

Royle's Manual of Materia Medica and Therapeutics. Sixth Edition, including additions and alterations in the B.P. 1885. By JOHN HARLEY, M.D., Physician to St. Thomas's Hospital. Crown 8vo, with 139 Engravings, 15s.

The Prescriber's Pharmacopœia: the Medi- cines arranged in Classes according to their Action, with their Composition and Doses. By NESTOR J. C. TIRARD, M.D., F.R.C.P., Professor of Materia Medica and Therapeutics in King's College, London. Sixth Edition. 32mo, bound in leather, 3s.

Year-Book of Pharmacy: containing the Trans- actions of the British Pharmaceutical Conference. Annually. 8vo, 10s.

Manual of Botany: including the Structure, Classification, Properties, Uses, and Functions of Plants. By ROBERT BENTLEY, Emeritus Professor of Botany in King's College and to the Pharmaceutical Society. Fifth Edition. Crown 8vo, with 1,178 Engravings, 15s.

By the same Author.

The Student's Guide to Structural, Morpho- logical, and Physiological Botany. With 660 Engravings. Fcap. 8vo, 7s. 6d.

Also.

The Student's Guide to Systematic Botany, including the Classification of Plants and Descriptive Botany. Fcap, 8vo, with 350 Engravings, 3s. 6d.

Medicinal Plants: being Descriptions with original figures, of the Principal Plants employed in Medicine, and an account of their Properties and Uses. By Prof. BENTLEY and Dr. H. TRIMEN, F.R.S. In 4 vols., large 8vo, with 306 Coloured Plates, bound in Half Morocco, Gilt Edges, £11 11s.

Elementary Practical Biology. Vegetable. By THOMAS W. SHORE, M.D., B.Sc. Lond., Lecturer on Comparative Anatomy at St. Bartholomew's Hospital. 8vo, 6s.

Practical Therapeutics: a Manual. By EDWARD J. WARING, C.I.E., M.D., F.R.C.P., and DUDLEY W. BUXTON, M.D., B.S. Lond. Fourth Edition. Crown 8vo, 14s.

By the same Author.

Bazaar Medicines of India, and Common Medical Plants. With Full Index of Diseases, indicating their Treatment by these and other Agents procurable throughout India, etc. Fourth Edition. Fcap. 8vo, 5s.

Climate and Fevers of India, with a Series of Cases (Croonian Lectures, 1882). By Sir JOSEPH FAYRER, K.C.S.I., M.D. 8vo, with 17 Temperature Charts, 12s.

By the same Author.

The Natural History and Epidemiology of Cholera: being the Annual Oration of the Medical Society of London, 1888. 8vo, 3s. 6d.

A Manual of Family Medicine and Hygiene for India. Published under the Authority of the Government of India. By Sir WILLIAM J. MOORE, K.C.I.E., M.D., late Sugeon-General with the Government of Bombay. Sixth Edition. Post 8vo, with Engravings. [*In the press.*

By the same Author.

A Manual of the Diseases of India: with a Compendium of Diseases generally. Second Edition. Post 8vo, 10s.

Also.

The Constitutional Requirements for Tropical Climates, etc. Crown 8vo, 4s.

The Prevention of Disease in Tropical and Sub-Tropical Campaigns. (Parkes Memorial Prize for 1886.) By ANDREW DUNCAN, M.D., B.S. Lond., F.R.C.S., Surgeon, Bengal Army. 8vo, 12s. 6d.

A Commentary on the Diseases of India. By NORMAN CHEVERS, C.I.E., M.D., F.R.C.S., Deputy Surgeon-General H.M. Indian Army. 8vo, 24s.

Hooper's Physicians' Vade-Mecum: a Manual of the Principles and Practice of Physic. Tenth Edition. By W. A. GUY, F.R.C.P., F.R.S., and J. HARLEY, M.D., F.R.C.P. With 118 Engravings. Fcap. 8vo, 12s. 6d.

The Principles and Practice of Medicine. (Text-book.) By the late C. HILTON FAGGE, M.D., and P. H. PYE-SMITH, M.D., F.R.S., F.R.C.P., Physician to, and Lecturer on Medicine at, Guy's Hospital. Third Edition. 2 vols. 8vo, cloth, 40s.; Half Leather, 46s.

Manual of the Practice of Medicine. By FREDERICK TAYLOR, M.D., F.R.C.P., Physician to, and Lecturer on Medicine at, Guy's Hospital. Third Edition. Cr. 8vo, with Engravings, 15s.

A Dictionary of Practical Medicine. By various writers. Edited by JAS. KINGSTON FOWLER, M.A., M.D., F.R.C.P., Physician to Middlesex Hospital and the Hospital for Consumption. 8vo, cloth, 21s.; half calf, 25s.

The Practice of Medicine. (Student's Guide Series.) By M. CHARTERIS, M.D., Professor of Therapeutics and Materia Medica in the University of Glasgow. Sixth Edition. Fcap. 8vo, with Engravings on Copper and Wood, 9s.

How to Examine the Chest: a Practical Guide for the use of Students. By SAMUEL WEST, M.D., F.R.C.P. Assistant Physician to St. Bartholomew's Hospital. Second Edition. With Engravings. Fcap. 8vo, 5s.

The Bronchi and Pulmonary Blood-vessels: their Anatomy and Nomenclature. By WILLIAM EWART, M.D., F.R.C.P., Physician to St. George's Hospital. 4to, with 20 Illustrations, 21s.

An Atlas of the Pathological Anatomy of the Lungs. By the late WILSON FOX, M.D., F.R.S., F.R.C.P., Physician to H.M. the Queen. With 45 Plates (mostly Coloured) and Engravings. 4to, half-bound in Calf, 70s.

By the same Author.

A Treatise on Diseases of the Lungs and Pleura. Edited by SIDNEY COUPLAND, M.D., F.R.C.P., Physician to Middlesex Hospital. Roy. 8vo, with Engravings; also Portrait and Memoir of the Author, 36s.

The Student's Guide to Diseases of the Chest. By VINCENT D. HARRIS, M.D. Lond., F.R.C.P., Physician to the City of London Hospital for Diseases of the Chest, Victoria Park. Fcap, 8vo, with 55 Illustrations (some Coloured), 7s. 6d.

Antiseptic Dry-Air Treatment of Consump- tion. By JOHN J. HARTNETT, M.D., M.Ch., Q.U.I. With Engravings. Crown 8vo, 3s. 6d.

Guy's Hospital Reports. By the Medical and Surgical Staff. Vol. XXXIII. Third Series. 8vo, 10s. 6d.

St. Thomas's Hospital Reports. By the Medical and Surgical Staff. Vol. XX. New Series. 8vo, 8s. 6d.

Westminster Hospital Reports. By the Medical and Surgical Staff. Vol. VII. 8vo, 6s.

Medical Diagnosis. (Student's Guide Series.) By SAMUEL FENWICK, M.D., F.R.C.P., Physician to the London Hospital. Seventh Edition. Fcap. 8vo, with 117 Engravings, 7s.

By the same Author.

Outlines of Medical Treatment. Third Edition. Crown 8vo, 10s.

Also.

Clinical Lectures on some Obscure Diseases of the Abdomen. Delivered at the London Hospital. 8vo, with Engravings, 7s. 6d.

Also.

The Saliva as a Test for Functional Diseases of the Liver. Crown 8vo, 2s.

The Microscope in Medicine. By Lionel S. BEALE, M.B., F.R.S., Physician to King's College Hospital. Fourth Edition. 8vo, with 86 plates, 21s.

By the same Author.

The Liver. With 24 Plates (85 Figures). 8vo, 5s.

Also.

On Slight Ailments: and on Treating Disease. Third Edition. 8vo, 5s.

Medical Lectures and Essays. By Sir G. JOHNSON, M.D., F.R.C.P., F.R.S., Consulting Physician to King's College Hospital. 8vo, with 46 Engravings, 25s.

By the same Author.

An Essay on Asphyxia (Apnœa). 8vo, 3s.

The Climate of Rome and the Roman Malaria. By Professor TOMMASI-CRUDELI. Translated by CHARLES CRAMOND DICK. Crown 8vo, 5s.

Uric Acid as a Factor in the Causation of Disease. By ALEXANDER HAIG, M.D., F.R.C.P. Physician to the Metropolitan Hospital and the Royal Hospital for Children and Women. With 23 Illustrations, 8vo, 8s. 6d.

Bronchial Affections: Pneumonia and Fibroid Pneumonia (their Pathological Histology) An Original Investigation. By A. G. AULD, M.D., Assistant Physician to the Glasgow Royal Infirmary. 8vo, with Illustrations, 7s. 6d.

Bronchial Asthma: its Pathology and Treatment. By J. B. BERKART, M.D., late Physician to the City of London Hospital for Diseases of the Chest. Second Edition, with 7 Plates (35 Figures). 8vo, 10s. 6d.

Vaccinia and Variola: a Study of their Life History. By JOHN B. BUIST, M.D., F.R.S.E., Teacher of Vaccination for the Local Government Board. Crown 8vo, with 24 Coloured Plates, 7s. 6d.

Treatment of Some of the Forms of Valvular Disease of the Heart. By A. E. SANSOM, M.D., F.R.C.P., Physician to the London Hospital. Second Edition. Fcap. 8vo, with 26 Engravings, 4s. 6d.

Medical Ophthalmoscopy: a Manual and Atlas. By W. R. GOWERS, M.D., F.R.C.P., F.R.S., Physician to the National Hospital for the Paralyzed and Epileptic. Third Edition. Edited with the assistance of MARCUS GUNN, M.B., F.R.C.S., Surgeon to the Royal London Ophthalmic Hospital. With Coloured Plates and Woodcuts. 8vo, 16s.

By the same Author.

A Manual of Diseases of the Nervous System.

VOL. I.—**Diseases of the Nerves and Spinal Cord.** Second Edition. Roy. 8vo, with 179 Engravings, 15s.

VOL. II.—**Diseases of the Brain and Cranial Nerves: General and Functional Diseases of the Nervous System.** Second Edition. 8vo, with many Engravings. [*Preparing.*

Also.

Diagnosis of Diseases of the Brain. Second Edition. 8vo, with Engravings, 7s. 6d.

Also.

Syphilis and the Nervous System: being a Revised Reprint of the Lettsomian Lectures for 1890. Delivered before the Medical Society of London. 8vo, 4s.

The Nervous System, Diseases of. By J. A. ORMEROD, M.D., F.R.C.P., Physician to the National Hospital for the Paralysed and Epileptic. With 66 Illustrations. Fcap. 8vo, 8s. 6d.

Diseases of the Nervous System. Lectures delivered at Guy's Hospital. By SAMUEL WILKS, M.D., F.R.S. Second Edition. 8vo, 18s.

Handbook of the Diseases of the Nervous System. By JAMES ROSS, M.D., F.R.C.P., late Professor of Medicine in the Victoria University, and Physician to the Royal Infirmary, Manchester. Roy. 8vo, with 184 Engravings, 18s.

By the same Author.

Aphasia: being a Contribution to the Subject of the Dissolution of Speech from Cerebral Disease. 8vo, with Engravings, 4s. 6d.

Aphasia, or Loss of Speech: and the Localization of the Faculty of Articulate Language. By Sir FREDERIC BATEMAN, M.D., F.R.C.P., Senior Physician to the Norfolk and Norwich Hospital. 8vo, 16s.

Stammering: its Causes, Treatment, and Cure. By A. G. BERNARD, M.R.C.S., L.R.C.P. Crown 8vo, 2s.

Secondary Degenerations of the Spinal Cord (Gulstonian Lectures, 1889). By HOWARD H. TOOTH, M.D., F.R.C.P., Assistant Physician to the National Hospital for the Paralysed and Epileptic. With Plates and Engravings. 8vo, 3s. 6d.

Diseases of the Nervous System. Clinical Lectures. By THOMAS BUZZARD, M.D., F.R.C.P., Physician to the National Hospital for the Paralysed and Epileptic. With Engravings. 8vo, 15s.

By the same Author.

Some Forms of Paralysis from Peripheral Neuritis; of Gouty, Alcoholic, Diphtheritic, and other origin. Crown 8vo, 5s.

Also.

On the Simulation of Hysteria by Organic Disease of the Nervous System. Crown 8vo, 4s. 6d.

Gout in its Clinical Aspects. By J. Mortimer GRANVILLE, M.D. Crown 8vo, 6s.

Diseases of the Liver: with and without Jaundice. By GEORGE HARLEY, M.D., F.R.C.P., F.R.S. 8vo, with 2 Plates and 36 Engravings, 21s.

Rheumatic Diseases (Differentiation in). By HUGH LANE, Surgeon to the Royal Mineral Water Hospital, Bath, and Hon. Medical Officer to the Royal United Hospital, Bath. Second Edition, much Enlarged, with 8 Plates. Crown 8vo, 3s. 6d.

Diseases of the Abdomen, comprising those of the Stomach and other parts of the Alimentary Canal, Œsophagus, Cæcum, Intestines, and Peritoneum. By S. O. HABERSHON, M.D., F.R.C.P. Fourth Edition. 8vo, with 5 Plates, 21s.

On the Relief of Excessive and Dangerous Tympanites by Puncture of the Abdomen. By JOHN W. OGLE, M.A., M.D., F.R.C.P., Consulting Physician to St. George's Hospital. 8vo, 5s. 6d.

Croonian Lectures on Certain Points con- nected with Diabetes. By F. W. PAVY, M.D., F.R.S., late Physician to Guy's Hospital. 8vo, 4s. 6d.

Acute Intestinal Strangulation, and Chronic Intestinal Obstruction (Mode of Death from). By THOMAS BRYANT, F.R.C.S., Senior Surgeon to Guy's Hospital. 8vo, 3s.

Headaches: their Nature, Causes, and Treat- ment. By W. H. DAY, M.D., Physician to the Samaritan Hospital. Fourth Edition. Crown 8vo, with Engravings, 7s. 6d.

Health Resorts at Home and Abroad. By M. CHARTERIS, M.D., Professor of Therapeutics and Materia Medica in Glasgow University. Second Edition. Crown 8vo, with Map, 5s. 6d.

The Mineral Waters of France, and its Wintering Stations (Medical Guide to). With a Special Map. By A. VINTRAS, M.D., Physician to the French Embassy, and to the French Hospital, London. Second Edition. Crown 8vo, 8s.

Surgery: its Theory and Practice. (Student's Guide.) By WILLIAM J. WALSHAM, F.R.C.S., Senior Assistant Surgeon to, and Lecturer on Anatomy at, St. Bartholomew's Hospital. Fourth Edition. Fcap. 8vo, with 335 Engravings, 12s.

Surgical Emergencies: together with the Emergencies attendant on Parturition and the Treatment of Poisoning. By W. PAUL SWAIN, F.R.C.S., Surgeon to the South Devon and East Cornwall Hospital. Fourth Edition. Crown 8vo, with 120 Engravings, 5s.

Illustrated Ambulance Lectures: to which is added a NURSING LECTURE. By JOHN M. H. MARTIN, M.D., F.R.C.S., Honorary Surgeon to the Blackburn Infirmary. Third Edition. Crown 8vo, with 60 Engravings, 2s.

Operations on the Brain (a Guide to). By ALEC FRASER, Professor of Anatomy, Royal College of Surgeons in Ireland. Illustrated by 42 life-size Plates in Autotype, and 2 Woodcuts in the text. Folio, 63s.

Surgery. By C. W. Mansell Moullin, M.A., M.D. Oxon., F.R.C.S., Surgeon and Lecturer on Physiology to the London Hospital. Large 8vo, with 497 Engravings, 34s.

A Course of Operative Surgery. By CHRISTOPHER HEATH, Surgeon to University College Hospital. Second Edition. With 20 Coloured Plates (180 figures) from Nature, by M. LÉVEILLÉ, and several Woodcuts. Large 8vo, 30s.

By the same Author.

The Student's Guide to Surgical Diagnosis. Second Edition. Fcap. 8vo, 6s. 6d.

Also.

Manual of Minor Surgery and Bandaging. For the use of House-Surgeons, Dressers, and Junior Practitioners. Ninth Edition. Fcap. 8vo, with 146 Engravings, 6s.

Also.

Injuries and Diseases of the Jaws. Third Edition. 8vo, with Plate and 206 Wood Engravings, 14s.

Also.

Lectures on Certain Diseases of the Jaws, Delivered at the R.C.S., England, 1887. 8vo, with 64 Engravings, 2s. 6d.

Also.

Clinical Lectures on Surgical Subjects. Delivered in University College Hospital. Fcap. 8vo, with 23 Engravings, 6s.

The Practice of Surgery: a Manual. By THOMAS BRYANT, Consulting Surgeon to Guy's Hospital. Fourth Edition. 2 vols. crown 8vo, with 750 Engravings (many being Coloured), and including 6 chromo plates, 32s.

By the same Author.

On Tension: Inflammation of Bone, and Head Injuries. Hunterian Lectures, 1888. 8vo, 6s.

The Surgeon's Vade-Mecum: a Manual of Modern Surgery. By R. DRUITT, F.R.C.S. Twelfth Edition. By STANLEY BOYD, M.B., F.R.C.S., Assistant Surgeon and Pathologist to Charing Cross Hospital. Crown 8vo, with 373 Engravings, 16s.

The Operations of Surgery: intended for use on the Dead and Living Subject alike. By W. H. A. JACOBSON, M.A., M.B., M.Ch. Oxon., F.R.C.S., Assistant Surgeon to, and Lecturer on Anatomy at, Guy's Hospital. Second Edition. 8vo, with 235 Illustrations, 30s.

Diseases of Bones and Joints. By Charles MACNAMARA, F.R.C.S., Surgeon to, and Lecturer on Surgery at, the Westminster Hospital. 8vo, with Plates and Engravings, 12s.

Lectures on Orthopædic Surgery. By BERNARD E. BRODHURST, F.R.C.S., Surgeon to the Royal Orthopædic Hospital. Second Edition. 8vo, with Engravings, 12s. 6d.

By the same Author.

On Anchylosis, and the Treatment for the Removal of Deformity and the Restoration of Mobility in Various Joints. Fourth Edition. 8vo, with Engravings, 5s.

Also.

Curvatures and Disease of the Spine. Fourth Edition. 8vo, with Engravings, 7s. 6d.

Surgical Pathology and Morbid Anatomy. (Student's Guide Series.) By ANTHONY A. BOWLBY, F.R.C.S., Assistant Surgeon to St. Bartholomew's Hospital. Second Edition. Fcap. 8vo, with 158 Engravings, 9s.

By the same Author.

Injuries and Diseases of Nerves, and their Surgical Treatment. 8vo, with 20 Plates, 14s.

Illustrations of Clinical Surgery. By JONATHAN HUTCHINSON, F.R.S., Senior Surgeon to the London Hospital. In 23 fasciculi. 6s. 6d. each. Fasc. I. to X. bound, with Appendix and Index, £3 10s. Fasc. XI. to XXIII. bound, with Index, £4 10s.

The Human Foot: its Form and Structure, Functions and Clothing. By THOMAS S. ELLIS, Consulting Surgeon to the Gloucester Infirmary. With 7 Plates and Engravings (50 Figures). 8vo, 7s. 6d.

Clubfoot: its Causes, Pathology, and Treatment. By WM. ADAMS, F.R.C.S., Consulting Surgeon to the Great Northern and other Hospitals. Second Edition. 8vo, with 106 Engravings and 6 Lithographic Plates, 15s.

By the same Author.

Lateral and other Forms of Curvature of the Spine: their Pathology and Treatment. Second Edition. 8vo, with 5 Lithographic Plates and 72 Wood Engravings, 10s. 6d.

Also.

Contraction of the Fingers (Dupuytren's and Congenital Contractions): their Treatment by Subcutaneous Divisions of the Fascia, and Immediate Extension. Also on Hammer Toe; its Curability by Subcutaneous Division. And on The Obliteration of Depressed Cicatrices by a Subcutaneous Operation. 8vo, with 8 Plates and 31 Engravings, 6s. 6d.

Treatment of Internal Derangements of the Knee-Joint, by Operation. By HERBERT W. ALLINGHAM, F.R.C.S., Surgeon to the Great Northern Central Hospital, etc. 8vo, with Engravings, 5s.

Short Manual of Orthopædy. By Heather BIGG, F.R.C.S.Ed., Part I. Deformities and Deficiencies of the Head and Neck. 8vo, 2s. 6d.

Face and Foot Deformities. By Frederick CHURCHILL, C.M. 8vo, with Plates and Illustrations, 10s. 6d.

Royal London Ophthalmic Hospital Reports. By the Medical and Surgical Staff. Vol. XIII, Part 3. 8vo, 5s.

Ophthalmological Society of the United Kingdom. Transactions. Vol. XII. 8vo, 12s. 6d.

The Diseases of the Eye. (Student's Guide Series.) By EDWARD NETTLESHIP, F.R.C.S., Ophthalmic Surgeon to St. Thomas's Hospital. Fifth Edition. Fcap. 8vo, with 164 Engravings and a Coloured Plate illustrating Colour-Blindness, 7s. 6d.

Diseases and Refraction of the Eye. By N. C. MACNAMARA, F.R.C.S., Surgeon to Westminster Hospital, and GUSTAVUS HARTRIDGE, F.R.C.S., Surgeon to the Royal Westminster Ophthalmic Hospital. Fifth Edition. Crown 8vo, with Plate, 156 Engravings, also Test-types, 10s. 6d.

On Diseases and Injuries of the Eye: a Course of Systematic and Clinical Lectures to Students and Medical Practitioners. By J. R. WOLFE, M.D., F.R.C.S.E. With 10 Coloured Plates and 157 Wood Engravings. 8vo, 21s.

Normal and Pathological Histology of the Human Eye and Eyelids. By C. FRED. POLLOCK, M.D., F.R.C.S., and F.R.S.E., Surgeon for Diseases of the Eye to Anderson's College Dispensary, Glasgow. Crown 8vo, with 100 Plates (230 drawings), 15s.

Diseases of the Eye: a Handbook of Ophthal- mic Practice for Students and Practitioners. By G. E. DE SCHWEINITZ, M.D., Professor of Diseases of the Eye in the Philadelphia Polyclinic. With 216 Illustrations, and 2 Chromo-Lithographic Plates. 8vo, 18s.

Atlas of Ophthalmoscopy. Composed of 12 Chromo-lithographic Plates (59 Figures drawn from nature) and Explanatory Text. By RICHARD LIEBREICH, M.R.C.S. Translated by H. ROSBOROUGH SWANZY, M.B. Third Edition, 4to, 40s.

Refraction of the Eye: a Manual for Students. By GUSTAVUS HARTRIDGE, F.R.C.S., Surgeon to the Royal Westminster Ophthalmic Hospital. Sixth Edition. Crown 8vo, with 98 Illustrations, also Test-types, etc., 6s.

By the same Author.

The Ophthalmoscope: a Manual for Students. Crown 8vo, with 63 Illustrations. 4s.

Glaucoma: its Pathology and Treatment. By PRIESTLEY SMITH, Ophthalmic Surgeon to the Queen's Hospital, Birmingham. 8vo, with 64 Engravings and 12 Zinco-photographs 7s. 6d.

Hints on Ophthalmic Out-Patient Practice. By CHARLES HIGGENS, Ophthalmic Surgeon to Guy's Hospital. Third Edition. Fcap. 8vo, 3s.

Eyestrain (commonly called Asthenopia). By ERNEST CLARKE, M.D., B.S. Lond., Surgeon to the Central London Ophthalmic Hospital, Surgeon and Ophthalmic Surgeon to the Miller Hospital. 8vo, with 22 Illustrations, 5s.

Sore Throat: its Nature, Varieties, and Treat- ment. By PROSSER JAMES, M.D. Fifth Edition. Post 8vo, with Coloured Plates and Engravings, 6s. 6d.

Diseases and Injuries of the Ear. By Sir William B. Dalby, F.R.C.S., M.B., Consulting Aural Surgeon to St. George's Hospital. Fourth Edition. Crown 8vo, with 8 Coloured Plates and 38 Wood Engravings. 10s. 6d.

By the same Author.

Short Contributions to Aural Surgery, between 1875 and 1889. Second Edition. 8vo, with Engravings, 3s. 6d.

Endemic Goitre or Thyreocele: its Etiology, Clinical Characters, Pathology, Distribution, Relations to Cretinism, Myxœdema etc., and Treatment. By William Robinson, M.D. 8vo, 5s.

A System of Dental Surgery. By Sir John Tomes, F.R.S., and C. S. Tomes, M.A., F.R.S. Third Edition. Crown 8vo, with 292 Engravings, 15s.

Dental Anatomy, Human and Comparative: A Manual. By Charles S. Tomes, M.A., F.R.S. Third Edition. Crown 8vo, with 212 Engravings, 12s. 6d.

A Manual of Nitrous Oxide Anæsthesia. By J. Frederick W. Silk, M.D. Lond., M.R.C.S., Assistant Anæsthetist to Guy's Hospital, Anæsthetist to the Dental School of Guy's Hospital, and to the Royal Free Hospital. 8vo, with 26 Engravings, 5s.

A Practical Treatise on Mechanical Dentistry. By Joseph Richardson, M.D., D.D.S., late Emeritus Professor of Prosthetic Dentistry in the Indiana Medical College. Fifth Edition. Roy. 8vo, with 458 Engravings, 21s.

Notes on Dental Practice. By Henry C. Quinby, L.D.S.I., late President of the British Dental Association. Second Edition. 8vo, with 92 Illustrations, 8s.

Elements of Dental Materia Medica and Therapeutics, with Pharmacopœia. By James Stocken, L.D.S., R.C.S., Pereira Prizeman for Materia Medica, and Thomas Gaddes, L.D.S. Eng. and Edin. Third Edition. Fcap. 8vo, 7s. 6d.

Papers on Dermatology. By E. D. Mapother, M.D., Ex-Pres. R.C.S.I. 8vo, 3s. 6d.

Atlas of Skin Diseases. By Tilbury Fox, M.D., F.R.C.P. With 72 Coloured Plates. Royal 4to, half morocco, £6 6s.

Diseases of the Skin (Introduction to the Study of). By P. H. PYE-SMITH, M.D., F.R.S., F.R.C.P., Physician to Guy's Hospital. Crown 8vo, with 26 Engravings, 7s. 6d.

Diseases of the Skin: a Practical Treatise for the Use of Students and Practitioners. By J. N. HYDE, A.M., M.D., Professor of Skin and Venereal Diseases, Rush Medical College, Chicago. Second Edition. 8vo, with 2 Coloured Plates and 96 Engravings, 20s.

Leprosy in British Guiana. By John D. Hillis, F.R.C.S., M.R.I.A., Medical Superintendent of the Leper Asylum, British Guiana. Imp. 8vo, with 22 Lithographic Coloured Plates and Wood Engravings, £1 11s. 6d.

Sarcoma and Carcinoma: their Pathology, Diagnosis, and Treatment. By HENRY T. BUTLIN, F.R.C.S., Assistant Surgeon to St. Bartholomew's Hospital. 8vo, with 4 Plates, 8s.

By the same Author.

Malignant Disease of the Larynx (Sarcoma and Carcinoma). 8vo, with 5 Engravings, 5s.

Also.

Operative Surgery of Malignant Disease. 8vo, 14s.

On Cancer: its Allies, and other Tumours; their Medical and Surgical Treatment. By F. A. PURCELL, M.D., M.C., Surgeon to the Cancer Hospital, Brompton. 8vo, with 21 Engravings, 10s. 6d.

Cancers and the Cancer Process: a Treatise, Practical and Theoretic. By HERBERT L. SNOW, M.D., Surgeon to the Cancer Hospital, Brompton. 8vo, with 15 Lithographic Plates. 15s.

By the same Author.

The Re-appearance (Recurrence) of Cancer after apparent Extirpation. 8vo, 5s. 6d.

Also.

The Palliative Treatment of Incurable Cancer. Crown 8vo, 2s. 6d.

Cancerous Affections of the Skin (Epithelioma and Rodent Ulcer). By GEORGE THIN, M.D. Post 8vo, with 8 Engravings, 5s.

Diagnosis and Treatment of Syphilis. By Tom Robinson, M.D., Physician to St. John's Hospital for Diseases of the Skin. Crown 8vo, 3s. 6d.

By the same Author.

Eczema: its Etiology, Pathology, and Treatment. Crown 8vo, 3s. 6d.

Also.

Illustrations of Diseases of the Skin and Syphilis, with Remarks. Fasc. I. with 3 Plates. Imp. 4to, 5s.

Pathology and Treatment of Ringworm. By George Thin, M.D. 8vo, with 21 Engravings, 5s.

Urinary and Renal Derangements and Calculous Disorders. By Lionel S. Beale, F.R.C.P., F.R.S., Physician to King's College Hospital. 8vo, 5s.

Clinical Chemistry of Urine (Outlines of the). By C. A. MacMunn, M.A., M.D. 8vo, with 64 Engravings and Plate of Spectra, 9s.

The Surgical Diseases of the Genito-Urinary Organs, including Syphilis. By E. L. Keyes, M.D., Professor of Genito-Urinary Surgery, Syphiology, and Dermatology in Bellevue Hospital Medical College, New York (a revision of Van Buren and Keyes' Text-book). Roy. 8vo, with 114 Engravings, 21s.

Atlas of Electric Cystoscopy. By Dr. Emil Burckhardt, late of the Surgical Clinique of the University of Bâle, and E. Henry Fenwick, F.R.C.S., Surgeon to the London Hospital and St. Peter's Hospital for Stone. Royal 8vo, with 34 Coloured Plates, embracing 83 Figures. 21s.

Electric Illumination of the Bladder and Urethra, as a Means of Diagnosis of Obscure Vesico-Urethral Diseases. By E. Hurry Fenwick, F.R.C.S., Surgeon to London Hospital and St. Peter's Hospital for Stone. Second Edition. 8vo, with 54 Engravings, 6s. 6d.

By the same Author.

The Cardinal Symptoms of Urinary Disease: their Diagnostic Significance and Treatment. 8vo, with 36 Illustrations, 8s. 6d.

Diseases of the Urinary Organs. Clinical Lectures. By Sir HENRY THOMPSON, F.R.C.S., Emeritus Professor of Clinical Surgery and Consulting Surgeon to University College Hospital. Eighth Edition. 8vo, with 121 Engravings, 10s. 6d.

By the same Author.

Diseases of the Prostate: their Pathology and Treatment. Sixth Edition. 8vo, with 39 Engravings, 6s.

Also.

Surgery of the Urinary Organs. Some Im- portant Points connected therewith. Lectures delivered in the R.C.S. 8vo, with 44 Engravings. Student's Edition, 2s. 6d.

Also.

Practical Lithotomy and Lithotrity; or, an Inquiry into the Best Modes of Removing Stone from the Bladder. Third Edition. 8vo, with 87 Engravings, 10s.

Also.

The Preventive Treatment of Calculous Dis- ease, and the Use of Solvent Remedies. Third Edition. Crown 8vo, 2s. 6d.

Also.

Tumours of the Bladder: their Nature, Symp- toms, and Surgical Treatment. 8vo, with numerous Illustrations, 5s.

Also.

Stricture of the Urethra, and Urinary Fistulæ: their Pathology and Treatment. Fourth Edition. 8vo, with 74 Engravings, 6s.

Also.

The Suprapubic Operation of Opening the Bladder for the Stone and for Tumours. 8vo, with 14 Engravings, 3s. 6d.

The Surgery of the Rectum. By Henry Smith, Emeritus Professor of Surgery in King's College, Consulting Surgeon to the Hospital. Fifth Edition. 8vo, 6s.

Diseases of the Rectum and Anus. By Alfred COOPER, F.R.C.S., Senior Surgeon to St. Mark's Hospital for Fistula; and F. SWINFORD EDWARDS, F.R.C.S., Senior Assistant Surgeon to St. Mark's Hospital. Second Edition, with Illustrations. 8vo, 12s.

Diseases of the Rectum and Anus. By HARRISON CRIPPS, F.R.C.S., Assistant Surgeon to St. Bartholomew's Hospital, etc. Second Edition. 8vo, with 13 Lithographic Plates and numerous Wood Engravings, 12s. 6d.

By the same Author.

Cancer of the Rectum. Especially considered with regard to its Surgical Treatment. Jacksonian Prize Essay. Third Edition. 8vo, with 13 Plates and several Wood Engravings, 6s.

The Diagnosis and Treatment of Diseases of the Rectum. By WILLIAM ALLINGHAM, F.R.C.S., Surgeon to St. Mark's Hospital for Fistula. Fifth Edition. By HERBERT WM. ALLINGHAM, F.R.C.S., Surgeon to the Great Northern Central Hospital, Demonstrator of Anatomy at St. George's Hospital. 8vo, with 53 Engravings, 10s. 6d.

A Medical Vocabulary: an Explanation of all Terms and Phrases used in the various Departments of Medical Science and Practice, their Derivation, Meaning, Application, and Pronunciation. By R. G. MAYNE, M.D., LL.D. Sixth Edition, by W. W. WAGSTAFFE, B.A., F.R.C.S. Crown 8vo, 10s. 6d.

A Short Dictionary of Medical Terms. Being an Abridgment of Mayne's Vocabulary. 64mo, 2s. 6d.

Terminologia Medica Polyglotta: a Concise International Dictionary of Medical Terms (French, Latin, English, German, Italian, Spanish, and Russian). By THEODORE MAXWELL, M.D., B.Sc., F.R.C.S. Edin. Royal 8vo, 16s.

A German-English Dictionary of Medical Terms. By FREDERICK TREVES, F.R.C.S., Surgeon to the London Hospital; and HUGO LANG, B.A. Crown 8vo, half-Persian calf, 12s.

The Medical Adviser in Life Assurance. By Sir E. H. SIEVEKING, M.D., F.R.C.P. Second Edition. Crown 8vo, 6s.

Chemistry, Inorganic and Organic. With Ex- periments. By CHARLES L. BLOXAM. Seventh Edition, by JOHN MILLAR THOMSON, Professor of Chemistry in King's College, London, and ARTHUR G. BLOXAM, Demonstrator of Chemistry in the Royal Agricultural College, Cirencester. 8vo, with 282 Illustrations, 18s.

By the same Author.

Laboratory Teaching; or, Progressive Exer- cises in Practical Chemistry. Fifth Edition. Crown 8vo, with 89 Engravings, 5s. 6d.

Watts' Manual of Chemistry, Theoretical and Practical. By WILLIAM A. TILDEN, D.Sc., F.R.S., Professor of Chemistry in the Mason College, Birmingham.

Physical and Inorganic Chemistry. Second Edition. Crown 8vo, with Coloured Plate of Spectra, and 122 Wood Engravings, 8s. 6d.

Chemistry of Carbon Compounds; or, Organic Chemistry. Second Edition. Crown 8vo, with Engravings, 10s.

Practical Chemistry, and Qualitative Analysis. By FRANK CLOWES, D.Sc. Lond., Professor of Chemistry in the University College, Nottingham. Fifth Edition. Post 8vo, with 57 Engravings and Frontispiece, 7s. 6d.

Quantitative Analysis. By Frank Clowes. D.Sc. Lond., Professor of Chemistry in the University College, Nottingham, and J. BERNARD COLEMAN, Assoc. R. C. Sci. Dublin; Senior Demonstrator of Chemistry in the University College, Nottingham. Post 8vo, with 83 Engravings, 7s. 6d.

Qualitative Analysis. By R. Fresenius. Translated by CHARLES E. GROVES, F.R.S. Tenth Edition. 8vo, with Coloured Plate of Spectra and 46 Engravings, 15s.

By the same Author.

Quantitative Analysis. Seventh Edition.

VOL. I., Translated by A. VACHER. 8vo, with 106 Engravings, 15s.

VOL. II., Parts 1 to 3, Translated by C. E. GROVES, F.R.S. 8vo, with Engravings, 2s. 6d. each.

Practical Chemistry, including Analysis. By JOHN E. BOWMAN and CHARLES L. BLOXAM. Fcap. 8vo. Eighth Edition, with 90 Engravings, 5s. 6d.

Inorganic Chemistry. By Edward Frankland, Ph.D., D.C.L., LL.D., F.R.S., Professor of Chemistry in the Normal School of Science, and FRANCIS R. JAPP, M.A., Ph.D., F.I.C., F.R.S., Professor of Chemistry in the University of Aberdeen. 8vo, with numerous Illustrations on Stone and Wood, 24s.

Organic Chemistry (Outlines of). By H. FORSTER MORLEY, M.A., D.Sc., Joint Editor of Watts' "Dictionary of Chemistry." Crown 8vo, 7s. 6d.

Inorganic Chemistry (A System of). By WILLIAM RAMSAY, Ph.D., F.R.S., Professor of Chemistry in the University College, London. 8vo, with Engravings, 15s.

By the same Author.

Elementary Systematic Chemistry for the Use of Schools and Colleges. With Engravings. Crown 8vo, 4s. 6d.; Interleaved, 5s. 6d.

Valentin's Qualitative Chemical Analysis. Eighth Edition. By Dr. W. R. HODGKINSON, F.R.S.E., Professor of Chemistry and Physics, Royal Military Academy, and Artillery College, Woolwich; assisted by H. CHAPMAN-JONES, F.C.S., Demonstrator in the Royal School of Mines, etc., and F. E. MATTHEWS, Ph.D., of Cooper's Hill College. 8vo, with Engravings and Map of Spectra. [*In the press.*

Analytical Chemistry. Notes for Students in Medicine. By ALBERT J. BERNAYS, Ph.D., F.C.S., F.I.C., late Professor of Chemistry, etc., at St. Thomas's Hospital Medical School. Third Edition. Crown 8vo, 4s. 6d.

Volumetric Analysis (A Systematic Hand-book of); or the Quantitative Estimation of Chemical Substances by Measure, applied to Liquids, Solids, and Gases. By FRANCIS SUTTON, F.C.S., F.I.C., Public Analyst for the County of Norfolk. Sixth Edition. 8vo, with 102 Engravings, 17s. 6d.

Commercial Organic Analysis: a Treatise on the Properties, Modes of Assaying, Proximate Analytical Examination, etc., of the various Organic Chemicals and Products employed in the Arts, Manufactures, Medicine, etc. By ALFRED H. ALLEN, F.I.C., F.C.S., Public Analyst for the West Riding of Yorkshire, the Northern Division of Derbyshire, etc.

VOL. I.—**Alcohols. Neutral Alcoholic Deri-**vatives, Sugars, Starch and its Isomers, Vegetable Acids, etc. With Illustrations. Third Edition. 8vo. [*Preparing.*

VOL. II.—**Fixed Oils and Fats, Hydrocarbons,** Phenols, etc. With Illustrations. Third Edition. 8vo. [*Preparing.*

VOL. III.—Part I. **Aromatic Acids, Tannins,** Dyes, and Colouring Matters. Second Edition. 8vo, 14s.

Part II. **Amines and Ammonium Bases,** Hydrazines, Bases from Tar, Vegetable Alkaloids. Second Edition. 8vo, 18s.

Fuel and its Applications. By E. J. Mills, D.Sc., F.R.S., and F. J. Rowan, C.E. Being Vol. I. of Chemical Technology, or Chemistry in its application to Arts and Manufactures. Edited by Charles E. Groves, F.R.S., and William Thorp, B.Sc. Royal 8vo, with 606 Engravings, 30s.

Potable Waters: their Organic Analysis. By J. A. Blair, M.B., C.M., D.Sc., L.R.C.P. Second Edition. Crown 8vo, 3s. 6d.

Cooley's Cyclopædia of Practical Receipts, and Collateral Information in the Arts, Manufactures, Professions, and Trades: including Medicine, Pharmacy, Hygiene, and Domestic Economy. Seventh Edition, by W. North, M.A. Camb., F.C.S. 2 Vols., Roy. 8vo, with 371 Engravings, 42s.

Chemical Technology: a Manual. By Rudolf von Wagner. Translated and Edited by William Crookes, F.R.S., from the Thirteenth Enlarged German Edition as remodelled by Dr. Ferdinand Fischer. 8vo, with 596 Engravings, 32s.

Technological Handbooks. Edited by John Gardner, F.I.C., F.C.S., and James Cameron, F.I.C.

Brewing, Distilling, and Wine Manu-facture. Crown 8vo, with Engravings, 6s. 6d.

Bleaching, Dyeing, and Calico Printing. With Formulæ. Crown 8vo, with Engravings, 5s.

Oils, Resins, and Varnishes. Crown 8vo, with Engravings, 7s. 6d.

Soaps and Candles. Crown 8vo, with 54 Engravings, 7s.

The Microscope and its Revelations. By the late William B. Carpenter, C.B., M.D., LL.D., F.R.S. Seventh Edition by the Rev. W. H. Dallinger, LL.D., F.R.S. With 21 Plates and 800 Wood Engravings. 8vo, 26s. Half Calf, 30s.

Methods and Formulæ used in the Preparation of Animal and Vegetable Tissues for Microscopical Examination, including the Staining of Bacteria. By Peter Wyatt Squire, F.L.S. Crown 8vo, 3s. 6d.

The Microtomist's Vade-Mecum: a Handbook of the Methods of Microscopic Anatomy. By ARTHUR BOLLES LEE, Assistant in the Russian Laboratory of Zoology at Villefranche-sur-mer (Nice). Third Edition. 8vo. [*In the press.*

The Quarterly Journal of Microscopical Science. Edited by E. RAY LANKESTER, M.A., LL.D., F.R.S.; with the co-operation of ADAM SEDGWICK, M.A., F.R.S., A. MILNES MARSHALL, M.A., D.Sc., M.D., F.R.S., and W. F. R. WELDON, M.A., F.R.S. Each Number, 10s.

Photo-Micrography (Guide to the Science of). By EDWARD C. BOUSFIELD, L.R.C.P. Lond. 8vo, with 34 Engravings and Frontispiece, 6s.

The Principles and Practice of Veterinary Medicine. By WILLIAM WILLIAMS, F.R.C.V.S., F.R.S.E., Principal, and Professor of Veterinary Medicine and Surgery at the New Veterinary College, Edinburgh. Seventh Edition, 8vo, with several Coloured Plates and Woodcuts, 30s.

By the same Author.

The Principles and Practice of Veterinary Surgery. Eighth Edition. 8vo, with 9 Plates and 147 Woodcuts, 30s.

A Pharmacopœia, including the Outlines of Materia Medica and Therapeutics, for the Use of Practitioners and Students of Veterinary Medicine. By RICHARD V. TUSON, F.I.C., late Professor of Chemistry, Materia Medica, and Toxicology at the Royal Veterinary College. Fourth Edition. Post 8vo, 7s. 6d.

The Veterinarian's Pocket Remembrancer: being Concise Directions for the Treatment of Urgent or Rare Cases, embracing Semeiology, Diagnosis, Prognosis, Surgery, Therapeutics, Toxicology, Detection of Poisons by their Appropriate Tests, Hygiene, etc. By GEORGE ARMATAGE, M.R.C.V.S. Second Edition. Post 8vo, 3s.

Chauveau's Comparative Anatomy of the Domesticated Animals. Revised and Enlarged, with the Co-operation of S. ARLOING, Director of the Lyons Veterinary School, and Edited by GEORGE FLEMING, C.B., LL.D., F.R.C.V.S., late Principal Veterinary Surgeon of the British Army. Second English Edition. 8vo, with 585 Engravings, 31s. 6d.

BRITISH MED
Library
ASSOCIATIO

INDEX.

Abercrombie's Medical Jurisprudence, 3
Adams (W.) on Clubfoot, 18
——— on Contractions of the Fingers, etc., 18
——— on Curvature of the Spine, 18
Allen's Commercial Organic Analysis, 26
Allingham (H.) on Derangements of Knee-joint, 18
Allingham (W.) on Diseases of the Rectum, 24
Armatage's Veterinary Pocket Remembrancer, 28
Auld's Bronchial Affections, 12
Barnes (R.) on Obstetric Operations, 6
——— on Diseases of Women, 6
Bateman's Aphasia, 14
Beale on Liver, 12
——— Microscope in Medicine, 12
——— Slight Ailments, 12
——— Urinary and Renal Derangements, 22
Beasley's Book of Prescriptions, 8
——— Druggists' General Receipt Book, 8
——— Pocket Formulary, 8
Bellamy's Surgical Anatomy, 2
Bentley and Trimen's Medicinal Plants, 9
Bentley's Manual of Botany, 9
——— Structural Botany, 9
——— Systematic Botany, 9
Berkart's Bronchial Asthma, 13
Bernard on Stammering, 14
Bernay's Notes on Analytical Chemistry, 26
Bigg's Short Manual of Orthopædy, 18
Blair's Potable Waters, 27
Bloxam's Chemistry, 24
——— Laboratory Teaching, 24
Bousfield's Photo-Micrography, 28
Bowlby's Injuries and Diseases of Nerves, 17
——— Surgical Pathology and Morbid Anatomy, 17
Bowman and Bloxam's Practical Chemistry, 25
Brodhurst's Anchylosis, 17
——— Curvatures, etc., of the Spine, 17
——— Orthopædic Surgery, 17
Bryant's Acute Intestinal Strangulation, 15
——— Practice of Surgery, 16
——— Tension, Inflammation of Bone, Injuries, etc., 16
Buist's Vaccinia and Variola, 13
Burckhardt and Fenwick's Atlas of Electric Cystoscopy, 22
Burdett's Hospitals and Asylums of the World, 4
Burton's Midwifery for Midwives, 5
Butlin's Malignant Disease of the Larynx, 21
——— Operative Surgery of Malignant Disease, 21
——— Sarcoma and Carcinoma, 21
Buzzard's Diseases of the Nervous System, 14
——— Peripheral Neuritis, 14
——— Simulation of Hysteria, 14
Cameron's Oils, Resins, and Varnishes, 27
——— Soaps and Candles, 27
Carpenter and Dallinger on the Microscope, 27
Carpenter's Human Physiology, 3
Charteris on Health Resorts, 15
——— Practice of Medicine, 11
Chauveau's Comparative Anatomy, 28
Chevers' Diseases of India, 10
Churchill's Face and Foot Deformities, 18
Clarke's Eyestrain, 19
Clouston's Lectures on Mental Diseases, 4
Clowes and Coleman's Quantitative Analysis, 25
Clowes' Practical Chemistry, 25

[*Continued on next page.*

Cooley's Cyclopædia of Practical Receipts, 27
Cooper and Edwards' Diseases of the Rectum, 23
Cripps' (H.) Cancer of the Rectum, 24
——— Diseases of the Rectum and Anus, 24
Cripps' (R.A.) Galenic Pharmacy, 8
Cullingworth's Manual of Nursing, 7
————————Short Manual for Monthly Nurses, 7
Dalby's Diseases and Injuries of the Ear, 20
————Short Contributions, 20
Day on Diseases of Children, 6
—— on Headaches, 15
Domville's Manual for Nurses, 7
Doran's Gynæcological Operations, 6
Down's Mental Affections of Childhood, 5
Druitt's Surgeon's Vade-Mecum, 17
Duncan (A.) on Prevention of Diseases in Tropics, 10
Duncan (J. M.) on Diseases of Women, 5
Ellis's (E.) Diseases of Children, 7
Ellis's (T. S.) Human Foot, 17
Ewart's Bronchi and Pulmonary Blood Vessels, 11
Fagge's Principles and Practice of Medicine, 10
Fayrer's Climate and Fevers of India, 10
————Natural History, etc., of Cholera, 10
Fenwick (E. H.), Electric Illumination of Bladder, 22
——— Symptoms of Urinary Diseases, 22
Fenwick's (S.) Medical Diagnosis, 12
———— Obscure Diseases of the Abdomen, 12
———— Outlines of Medical Treatment, 12
———— The Saliva as a Test, 12
Flower's Diagrams of the Nerves, 2
Fowler's Dictionary of Practical Medicine, 11
Fox's (C. B.) Examinations of Water, Air, and Food, 3
Fox's (T.) Atlas of Skin Diseases, 20
Fox (Wilson), Atlas of Pathological Anatomy of the Lungs, 11
—— Treatise on Diseases of the Lungs, 11
Frankland and Japp's Inorganic Chemistry, 25
Fraser's Operations on the Brain, 16
Fresenius' Chemical Analysis, 25
Galabin's Diseases of Women, 6
——— Manual of Midwifery, 5
Gardner's Bleaching, Dyeing, and Calico Printing, 27
————Brewing, Distilling, and Wine Manufacture, 27
Godlee's Atlas of Human Anatomy, 1
Goodhart's Diseases of Children, 6
Gowers' Diseases of the Spinal Cord, 13
——— Manual of Diseases of Nervous System, 13
————Medical Ophthalmoscopy, 13
——— Syphilis and the Nervous System, 13
Granville on Gout, 14
Guy's Hospital Reports, 11
Habershon's Diseases of the Abdomen, 15
Haig's Uric Acid, 12
Harley on Diseases of the Liver, 14
Harris's (V. D.) Diseases of Chest, 11
Hartnett's Consumption, 11
Hartridge's Refraction of the Eye, 19
————Ophthalmoscope, 19
Heath's Certain Diseases of the the Jaws, 16
——— Clinical Lectures on Surgical Subjects, 16
——— Injuries and Diseases of the Jaws, 16
——— Minor Surgery and Bandaging, 16
——— Operative Surgery, 16
——— Practical Anatomy, 1
——— Surgical Diagnosis, 16
Higgens' Ophthalmic Out-patient Practice, 19
Hillier's Notes on Gynæcological Nursing, 6
Hillis' Leprosy in British Guiana, 21
Hirschfeld's Atlas of Central Nervous System, 2
Holden's Human Osteology, 1
——— Landmarks, 1
Hooper's Physicians' Vade Mecum, 10
Hutchinson's Clinical Surgery, 17
Hyde's Diseases of the Skin, 21
Jacobson's Operations of Surgery, 17
James (P.) on Sore Throat, 19
Johnson's Asphyxia, 12
Johnson's Medical Lectures and Essays, 12

Journal of Mental Science, 5
Keyes' Genito-Urinary Organs and Syphilis, 22
Lancereaux's Atlas of Pathological Anatomy, 2
Lane's Rheumatic Diseases, 14
Lee's Microtomists' Vade-Mecum, 28
Lescher's Recent Materia Medica, 8
Lewis (Bevan) on the Human Brain, 3
Liebreich's Atlas of Ophthalmoscopy, 19
Macdonald's (J. D.) Examination of Water and Air, 3
MacMunn's Clinical Chemistry of Urine, 22
Macnamara's Diseases and Refraction of the Eye, 18
——— Diseases of Bones and Joints, 17
Mapother's Papers on Dermatology, 20
Martin's Ambulance Lectures, 15
Maxwell's Terminologia Medica Polyglotta, 24
Mayne's Medical Vocabulary, 24
Microscopical Journal, 28
Mills and Rowan's Fuel and its Applications, 27
Moore's (N.) Pathological Anatomy of Diseases, 2
Moore's (Sir W. J.) Diseases of India, 10
——— Family Medicine, &c., for India, 10
——— Tropical Climates, 10
Morley's Organic Chemistry, 25
Morris's Human Anatomy, 1
Moullin's (Mansell) Surgery, 16
Nettleship's Diseases of the Eye, 18
Ogle on Puncturing the Abdomen, 15
Ophthalmic (Royal London) Hospital Reports, 18
Ophthalmological Society's Transactions, 18
Oppert's Hospitals, Infirmaries, Dispensaries, etc., 3
Ormerod's Diseases of the Nervous System, 13
Owen's Materia Medica, 7
Parkes' Practical Hygiene, 4
Pavy on Diabetes, 15
Pereira's Selecta è Prescriptis, 8
Phillips' Materia Medica and Therapeutics, 7
Pollock's Histology of the Eye and Eyelids, 19
Proctor's Practical Pharmacy, 8
Purcell on Cancer, 21
Pye-Smith's Diseases of the Skin, 21
Quinby's Notes on Dental Practice, 20
Ramsay's Elementary Systematic Chemistry, 26
——— Inorganic Chemistry, 26
Richardson's Mechanical Dentistry, 20
Roberts' (D. Lloyd), Practice of Midwifery, 5
Robinson's (Tom) Eczema, 22
——— Illustrations of Skin Diseases, 22
——— Syphilis, 22
Robinson (W.), Endemic Goitre or Thyreocele, 20
Ross's Aphasia, 14
——— Diseases of the Nervous System, 14
Royle and Harley's Materia Medica, 9
St. Thomas's Hospital Reports, 11
Sansom's Valvular Disease of the Heart, 13
Savage's Female Pelvic Organs, 5
Schweinitz on Diseases of the Eye, 19
Shore's Elementary Practical Biology, 9
Short Dictionary of Medical Terms, 24
Sieveking's Life Assurance, 24
Silk's Manual of Nitrous Oxide, 20
Simon's Public Health Reports, 4
Smith's (E.) Clinical Studies, 7
——— Diseases in Children, 7
——— Wasting Diseases of Infants and Children, 7
Smith's (J. Greig) Abdominal Surgery, 6
Smith's (Henry) Surgery of the Rectum, 23
Smith's (Priestley) Glaucoma, 19
Snow's Cancers and the Cancer Process, 21
——— Palliative Treatment of Cancer, 21
——— Reappearance of Cancer, 21
Southall's Organic Materia Medica, 8
Squire's (P.) Companion to the Pharmacopœia, 8
——— London Hospitals Pharmacopœias, 8
——— Methods and Formulæ, 27
Starling's Elements of Human Physiology, 3
Stevenson and Murphy's Hygiene, 4

[*Continued on next page.*

Stocken's Dental Materia Medica and Therapeutics, 20
Sutton's (F.) Volumetric Analysis, 26
Sutton's (H. G.) Lectures on Pathology, 2
Sutton's (J. B.) General Pathology, 2
Swain's Surgical Emergencies, 15
Swayne's Obstetric Aphorisms, 5
Taylor's (A. S.) Medical Jurisprudence, 3
Taylor's (F.) Practice of Medicine, 10
Thin's Cancerous Affections of the Skin, 21
——Pathology and Treatment of Ringworm, 22
Thomas's Diseases of Women, 6
Thompson's (Sir H.) Calculous Diseases, 23
—— Diseases of the Prostate, 23
—— Diseases of the Urinary Organs, 23
—— Lithotomy and Lithotrity, 23
—— Stricture of the Urethra, 23
—— Suprapubic Operation, 23
—— Surgery of the Urinary Organs, 23
—— Tumours of the Bladder, 23
Tirard's Prescriber's Pharmacopœia, 9
Tomes' (C. S.) Dental Anatomy, 20
Tomes' (J. & C. S.) Dental Surgery, 20
Tommasi-Crudeli's Climate of Rome, 12
Tooth's Spinal Cord, 14
Treves and Lang's German-English Dictionary, 24
Tuke's Dictionary of Psychological Medicine, 5
—— Influence of the Mind upon the Body, 4
—— Prichard and Symonds and Mental Science, 4
—— Reform in the Treatment of the Insane, 4
Tuson's Veterinary Pharmacopœia, 28
Valentin and Hodgkinson's Qualitative Analysis, 26
Vintras on the Mineral Waters, etc., of France, 15
Wagner's Chemical Technology, 27
Walsham's Surgery: its Theory and Practice, 15
Waring's Indian Bazaar Medicines, 9
—— Practical Therapeutics, 9
Watts' Manual of Chemistry, 25
West's (S.) How to Examine the Chest, 11
Westminster Hospital Reports, 11
White's (Hale) Materia Medica, Pharmacy, etc., 7
Wilks' Diseases of the Nervous System, 13
Williams' Veterinary Medicine, 28
——Surgery, 28
Wilson's (Sir E.) Anatomist's Vade-Mecum, 1
Wilson's (G.) Handbook of Hygiene, 4
Wolfe's Diseases and Injuries of the Eye, 19
Wynter and Wethered's Practical Pathology, 2
Year Book of Pharmacy, 9
Yeo's (G. F.) Manual of Physiology, 3

WELLCOME LIBRARY INSTITUTE

LONDON: 11, NEW BURLINGTON STREET.

Pardon & Sons, Printers, Wine Office Court, Fleet Street, London, E.C.

BRITISH MEDICAL ASSOCIATION Library

ley Dunn & Wilson Ltd
PERT CONSERVATORS & BOOKBINDERS