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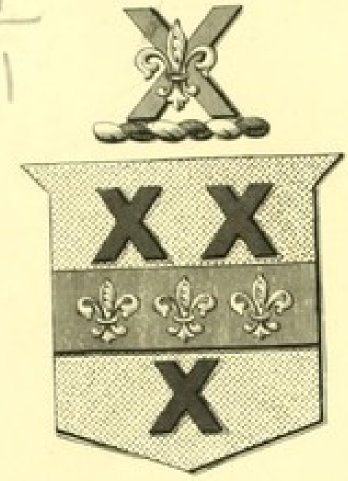

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THE

PHYSIOLOGIST'S NOTE-BOOK:

A SUMMARY OF THE PRESENT STATE OF PHYSIOLOGICAL SCIENCE,

For the Use of Students.

BY

ALEX HILL, M.A., M.D.,

MASTER OF DOWNING COLLEGE, CAMBRIDGE.

WITH THIRTY-SIX PLATES AND BLANK PAGES FOR MS. NOTES.

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PREFACE.

It may be thought that the literature of Systematic Physiology is already complete. Each of the four great English text-books exceeds 1000 pages in length, and there are, in addition, numerous and excellent smaller works. But it may be doubted whether, as the growth of European armaments is said to render war impossible, the dimensions of our standard text-books do not offer an impediment to the conquest of Physiology by the average student.

The object of the "Note-Book" is to assist the student in codifying his knowledge, not to diminish the need for the larger text-books, much less to take the place of lectures and laboratory work.

The "Note-Book" deals with the arguments of Physiology; for it is as well that the student should, from the outset, recognise that the subject, although it has made rapid strides during the last twenty years, is still in an immature and transitional state, and that many most important issues can only be summed up as leaving a balance of evidence on the one side or the other—a balance which subsequent investigation may possibly disturb. I have made an attempt, which might perhaps be carried further with advantage in other scientific text-books, to show the logical sequence of the several points of the argument by their typographical arrangement on the page.

Although amplified and adapted to the existing state of knowledge, the notes are practically in the form in which they have appeared on the black-board for the fifteen years during which I have taken a repetition class in Physiology; the fortnightly papers written by members of the class having borne unmistakable evidence of the advantages to be derived from this method of teaching. The presentation in a graphic way of the outlines of an argument greatly facilitates its comprehension, and in a still higher degree ensures its recollection; and I am strongly persuaded that when a student feels that he has in his mind a picture of his subject which he can project upon paper, he is more likely to think about it and analyse it—more likely to take away from it whatever seems to him irrelevant, and to attach in their proper places the fresh facts and ideas which he meets in books or evolves in the laboratory, than if on each occasion an effort is necessary to give definiteness to a somewhat hazy remembrance of the manner in which the facts were marshalled by his teacher.

If a student could rely upon remembering every word which he has once heard or read, such a book as this would be unnecessary, but experience teaches that he constantly needs to recall arguments, and to make sure of the proper classification of his facts, although he does not need a second time to follow his teacher up all the short steps by which the ascent was first made. With a view to rendering the book useful for rapid recapitulation, I have endeavoured to strike out every word which was not essential to clearness, and thus without, I hope, falling into "telegram-English," to give the text the form which it may be supposed to take in a well-kept note-book. For the same reason the drawings are reduced to diagrams; all details which are not necessary to the comprehension of the principles of construction of the apparatus or organ, as the case may be, are omitted; and it is hoped that the drawings will, in consequence, be easy to grasp, remember, and reproduce.

The majority of the diagrams have been drawn for this book, but I have to thank Messrs. Griffin for allowing me to use a certain number of the illustrations from Landois and Stirling's *Text-Book of Human Physiology*, and am much indebted to Mr. Harry Brownsword for preparing the crystallographic figures which appear in the section on the Chemistry of the Body.

The fragments of other subjects, such as Physics and Chemistry and Anatomy, gross and minute, which make up so large a bulk in most text-books of Physiology, have been omitted from the "Note-Book." They will find their proper place, it is hoped, in other books of the "Note-Book" series.

As it is intended that the "Note-Book" should be essentially a students' book, references to foreign literature are omitted; but the reader's attention is drawn (in a running Bibliography given at the foot of each page) to a number of recent English *mémoires*, as well as to descriptions in text-books which appear to me particularly lucid, and the student is strongly recommended to study the papers and passages referred to.

ALEX HILL.

Downing Lodge, 1893.

TABLE OF CONTENTS.

LIST OF DIAGRAMS.

SECTION I.

BLOOD.

CONSTITUTION:—Corpuscles—Plasma. First separated by *J. Müller* in frog's blood by adding sugar-solution and filtering.

Sp. gr., 1056–1059. In women less than in men; variations of considerable interest, as indicating "condition." Easily determined by squeezing minute drops from a capillary tube into a series of solutions of sodic sulphate of standard specific gravity, and finding the solution in which the drop neither rises nor sinks. Sp. gr. of corpuscles, 1105; of plasma, 1027.

Reaction; alkaline, diminishing after the blood is shed, but never abolished. Due to Na_2HPO_4.

Method.—Glazed litmus-paper or plaster of Paris disc soaked in litmus.

Anatomical Elements:—Red corpuscles, biconcave discs of almost homogeneous substance, without membrane or nucleus; when healthy, soft but fairly tough, and highly elastic; diam. 7·5 μ ($\frac{1}{3200}$ inch).

Number, 5,000,000 to the cubic millimetre, but less in women and variable. Estimated by diluting 100 or 200 times with a mixture of gum-arabic, sodic sulphate, and sodic chloride, or a similar mixture, and counting on a ruled slide which admits a film of known thickness (fig. 3).

Easily altered by reagents (swollen by imbibition, crenated by exosmosis), inclined when shed to run into rouleaux.

The hæmoglobin is uniformly distributed throughout the stroma, but can by many means be separated from it, *e.g.*, by coagulating the hæmoglobin with boracic acid (or in frog's blood by tannic acid) this proteid can be separated in a star-like form, the zooid of Brücke, while the disc of stroma is left uncoloured—the œcoid. When the hæmoglobin is dissolved in the plasma, the blood is "lakey." Each corpuscle contains about 90 % of hæmoglobin to 10 % of stroma.

White or colourless corpuscles or leucocytes, unlike the red, are seen in several forms (or stages) of different size and degrees of granulation; average size, 10 μ ($\frac{1}{2500}$ inch). They contain one or more nuclei, are destitute of envelope, soft, pultaceous, amœboid. Proportion to red, 1 to 350, but higher in boys and in women in pregnancy. More in venous than in arterial blood. Said to be very numerous in blood of splenic vein.

Other Elements.—Platelets or tablets of Bizzozero. Colourless, transparent, homogeneous, hardly visible unless stained; quickly disintegrated in shed blood.

Dowdeswell.—"On some Appearances of the Red Blood-Corpuscles of Man and other Vertebrata," *Quart. Jour. Micr. Sci.*, vol. xxi. p. 154, 1881.

Cutler and Bradford.—"Changes in the Globular Richness of Human Blood," *Jour. of Phys.*, vol. i. p. 427.

Lloyd Jones.—"Variations in the Specific Gravity of the Blood in Health," *Jour. of Phys.*, vol. viii. p. 1, and vol. xii. p. 299.

Gulland.—"The Nature and Varieties of Leucocytes," *Labor. Rep. Roy. Coll. of Phys.*, *Edin.*, vol. iii. p. 106.

Mrs. Hart.—"On the Micrometric Numeration of the Blood-Corpuscles, and the Estimation of their Hæmoglobin," *Quart. Jour. Micr. Sci.*, vol. xxi. p. 132, 1881.

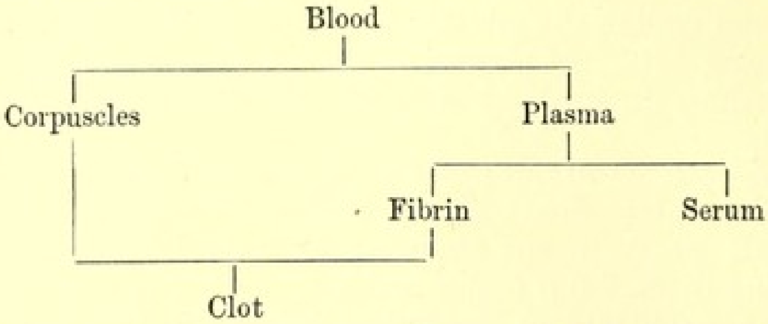
Size, 3 μ. Proportion to red, about 1 to 50. They can be shown by pricking the finger under a drop of sodic chloride solution tinged with methyl-violet.

The hæmatoblasts of Hayem are probably the same elements. Below mammals their place is taken by minute fusiform nucleated cells.

Amorphous matter is found in varying quantities in shed blood :—(A) Some of this is due to disintegration of formed elements, particularly platelets ; such is probably the origin of Zimmermann's "elementary particles" (unless Z.'s description applies to platelets) and Schultze's "granular masses." (B) Particles which can resist the action of water are apparently insoluble food-stuffs (chiefly fatty) ; they are more abundant in animals at the breast.

COAGULATION.

Shed blood begins to clot in 2 or 3 minutes. Granular fibrin-fibrils radiate from many centres. In 10 minutes the corpuscles are entangled in a jelly. After this the jelly contracts, and squeezes out the serum, but not the corpuscles.



The formation of filaments of fibrin can be watched if the blood is much diluted with normal (0·6%) saline solution. If it is "whipped" with a bunch of twigs, the fibrin is separated from the corpuscles. If clotting is delayed (horse-blood, febrile blood, cooled blood), the corpuscles have time to sink a little, leaving a corpuscle-free layer, the *crusta phlogistica* or buffy coat. The part of the clot which contains the fewest corpuscles contracts most, "cupping" the clot.

Explanation of Coagulation by no means settled even now. Present view best grasped by tracing its evolution.

The ancients (*e.g.*, *Hippocrates*) attributed clotting to cold and rest.

1828. *J. Davy* kept blood warm }
W. Hunter shook it up } accelerating clotting.

∴ the cause of clotting is not the cooling and resting of the blood.

1772. *Hewson* ligatured a vein; blood remained liquid until it was opened.

1824. *Scudamore* showed that blood clots more slowly in a closed than in an open flask.

From such experiments it was concluded that contact with air causes coagulation.

Con. Blood clots when shed into a barometric vacuum.

Hæmoglobin is estimated by diluting and comparing with standard jelly, tinted to represent 1 of hæmoglobin in 100 of water. Also by determining amount of iron $\left(\frac{\text{Iron}}{\text{Hæmoglobin}} = \frac{42}{10000}\right)$ = 2·5 grammes for average body-weight. Iron as a drug is useful in simple anæmia, but in "pernicious" anæmia, iron is already in excess for the small number of corpuscles.

Muir.—"Contributions to the Physiology and Pathology of the Blood," *Jour. of Anat. and Phys.*, vol. xxv. pp. 256, 352, 475, 1891.

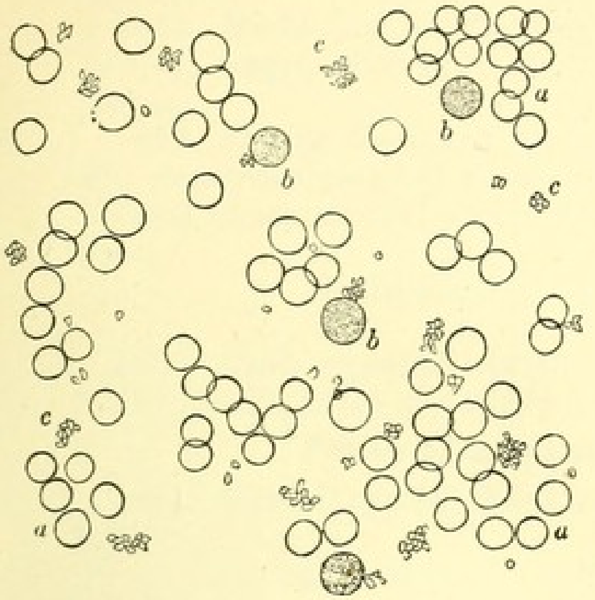


FIG. 1.—Normal human blood. *a*, Red blood-corpuscles; *b*, leucocytes; *c*, platelets.

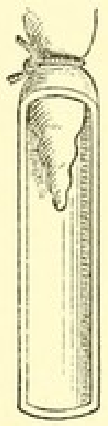


FIG. 2.—Coagulum formed in the femoral artery 56 hours after its ligature (*Erichsen*).

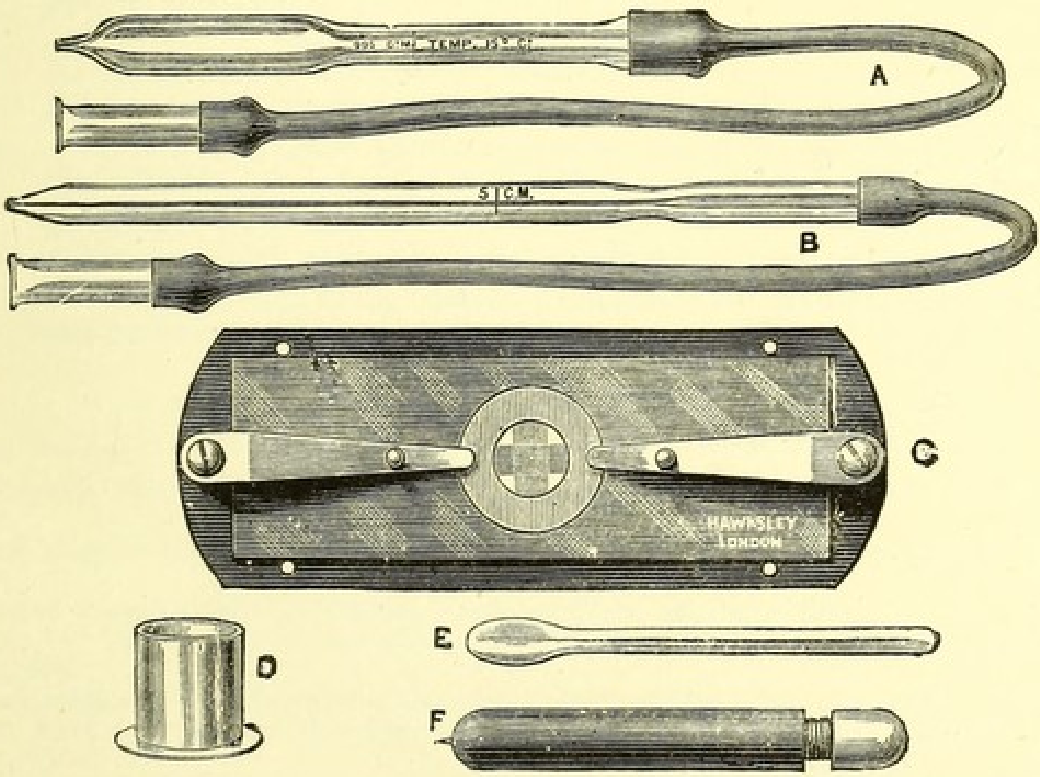


FIG. 3.—Gowers' apparatus for counting blood-corpuscles.—Take up in A 995 c.mm. of diluting solution (sodic sulphate and acetic acid in distilled water; sp. gr. 1025) and discharge it into D. From a finger, pricked by the guarded needle F, obtain in B 5 c.mm. of blood. Mix the blood with the diluting solution with the help of E, and then place some of the mixture on the ruled slide C and secure a cover-glass above it with the clips. The cell on this slide is 0·2 mm. deep; it is ruled in squares of 0·1 mm. The number of corpuscles in 10 squares, multiplied by 10,000, gives the number in 1 c.mm. of blood.

To face p. 2.]

1857. *Brücke*, observing that blood remains liquid for many hours, or even days, while enclosed in a passive tortoise' heart, concluded that the living vessel-wall prevents coagulation.

Chemical Changes which lead to Clotting.

1831. *Müller*, by filtering frog's blood, diluted with a solution containing $\frac{1}{2}\%$ sugar, showed that the property of clotting resides in the plasma.

1830. *Andrew Buchanan* observed that exuded lymph (hydrocele fluid) will sometimes clot, but at other times will not. It clots on the addition of blood, of serum, or of washings from blood clot, particularly from the buffy coat.

Hydrocele-fluid + Serum = Clot.

1859. *Denis* separated certain globulins from plasma (by saturating it with sodic sulphate) in a sticky mass, which he termed "plasmine."

Plasmine, dissolved in water, clots.

1861. *Schmidt* applied Denis' method to hydrocele fluid and serum separately.

Hydrocele | Serum
Fibrinogen + Fibrinoplastin = Clot.

Both these bodies are proteids of the globulin class, but differ markedly from one another. Fibrinoplastin, or, as it is better named, paraglobulin, is less easily precipitated and less easily coagulated than fibrinogen. It is present in serum in large quantity, 4 to 5%.

Fibrinogen can be separated from plasma by addition of about 13% NaCl. Further addition of NaCl or $MgSO_4$ throws down paraglobulin. Fibrinogen coagulates at 56° C.; paraglobulin at 75° C.

If, however, these substances alone are precipitated, as when Schmidt threw them down in a pure state by the CO_2 method, fibrinogen + fibrinoplastin gives no clot.

He imagined, therefore, that a ferment was necessary to promote interaction; to obtain it he coagulated blood with alcohol, and then made a watery extract of the clot.

F.gen. + F.plastin + Ferment = Clot.

Gamgee.—"Some Old and New Experiments on the Fibrin-Ferment," *Jour. of Phys.*, vol. ii. p. 145.

Wooldridge.—"Coagulation of the Blood," *Jour. of Phys.*, vol. iv. pp. 226, 367, and vol. x. p. 329.

Lea and Green.—"Fibrin-Ferment," *Jour. of Phys.*, vol. iv. p. 380.

Green.—"Certain Points connected with the Coagulation of Blood," *Jour. of Phys.*, vol. viii. p. 354.

Wooldridge.—"The Coagulation Question," *Jour. of Phys.*, vol. x. p. 329.

Mrs. Hart.—"Note on the Formation of Fibrine," *Quart. Jour. Micr. Sci.*, vol. xxii. p. 255, 1882.

Shore.—"The Effect of Peptone on the Clotting of Blood and Lymph," *Jour. of Phys.*, vol. xi. p. 561.

Dickinson.—"'Leech-Extract' and its Action on Blood," *Jour. of Phys.*, vol. xi. p. 566.

Haycraft.—"An Account of some Experiments which show that Fibrin-Ferment is Absent from Circulating Blood," *Jour. of Anat. and Phys.*, vol. xxii. p. 172, 1888.

Haycraft and Carlier.—"Morphological Changes that occur in the Human Blood during Coagulation," *Jour. of Anat. and Phys.*, vol. xxii. p. 582, 1888.

Hammarsten pointed out that Schmidt had not taken precautions to make sure that all three are necessary.

Clot ∝ F.gen.—Its weight is not affected by the amount of F.plastin.

F.gen. + "Ferment" = Clot.

It seems clear that the substance called for convenience blood-ferment (*Buchanan* compared the influence of washings from blood-clot to that of rennet) does not properly deserve this name.

Wooldridge showed that compounds of proteid and lecithin dissolved by water from white corpuscles, testicle, and many other tissues act as ferments.

∴ **Fibrinogen** (a globulin soluble in plasma), acted upon by substances set free from disintegrating leucocytes, is changed into fibrin (a globulin insoluble in plasma).

Other Body-fluids Spontaneously Coagulable.—Circulating Lymph, chyle, freshly-exuded (inflammatory) lymph, cerebro-spinal fluid, muscle-plasma.

Circumstances which retard Coagulation.

1. Contact with living walls.
2. Cooling to 0° C.
3. Addition of a neutral salt, *e.g.*, sodic chloride, 10% sol., in volume equal to the blood; equal volume of saturated sodium-sulphate; quarter of its volume of saturated solution of magnesium-sulphate; equal volume 5% sol. of cane-sugar.
4. Contact with oil.
5. Small quantities of caustic alkalies or ammonia.
6. Acetic acid or stream of CO_2.
7. Heating to 56°.

   (5, 6, 7 alter its chemical composition.)
8. Peptone injected into the vessels prevents clotting by inhibiting the activity of "fibrin-ferment." [At the same time it produces anæsthesia.]

   Not if peptone is pure; action really due to accompanying albumoses. Certain diastatic ferments have the same effect.

   Stream of CO_2 gas or addition of lecithin restores power of coagulating.
9. Watery extract of the body of the leech acts in the same way as peptone.

The washings of a blood-clot injected in sufficient quantity into the vessels lead to clotting.

Why does not blood clot in the living vessel?

Living tissue either prevents the formation of the "ferment" which induces the chemical transformation of fibrinogen into fibrin, or else removes the ferment-body or bodies as soon as it, or they, are formed.

Experiments.—Hewson's of the living test-tube. Brücke's of tortoise-heart. Schäfer's cannula inserted into frog's left aorta (the

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Ringer and Sainsbury.—"The Influence of certain Salts upon the Act of Clotting," *Jour. of Phys.*, vol. xi. p. 369.

Lister.—"On the Coagulation of Blood in its Practical Aspects," *Lancet*, 1891, No. 3533, p. 1081.

Halliburton.—"Fibrin-Ferment," *Jour. of Phys.*, vol. ix. p. 229.

Wenckebach.—"Development of the Blood-Corpuscles in the Embryo of *Perca fluviatilis*," *Jour. of Anat. and Phys.*, vol. xix. p. 231, 1885.

Howell.—"The Life-History of the formed Elements of Blood, especially the Red Blood-Corpuscles," *Jour. of Morph.*, vol. iv. p. 57.

Clarkson.—"Report on Hæmal Glands," *Brit. Med. Jour.*, 1891, No. 1595, p. 183.

Gulland.—"On the Function of the Tonsils," *Edin. Med. Jour.*, 1891, p. 435.

right being tied); blood rises in cannula and continues to oscillate with heart's beat until the corpuscles have subsided from the clear liquid plasma.

A certain quantity of "ferment" may be injected into the vessels without causing clotting. It is speedily removed.

What part of the vessel-wall has this influence over coagulation?

Experiments.—When in ligaturing vessels the inner coat is not injured (as by careful compression between two needles), the blood does not coagulate. If the inner coat is injured (by a sharply pulled ligature) or inflamed (phlebitis) it does. ∴ The fluidity of the blood depends upon the integrity of the—

Inner Coat.

How does the inner coat prevent coagulation?

Not completely settled. Apparently some relation exists between the epithelial cells and the (?) leucocytes, which guarantees the removal of "ferment" as soon as formed.

From what elements does the "ferment" come?

Leucocytes?

Pro. 1831. *Buchanan* showed that the buffy coat, which contains the largest proportion of white corpuscles, is the most powerful factor in determining the coagulation of hydrocele-fluid.

Platelets?

Pro. They collect about a thread or needle, introduced into a vessel, before it sets up coagulation.

The blood of embryo-fowls does not clot before the 12th or 14th day of incubation.

LIFE-HISTORY OF RED CORPUSCLES.

Origin.

A. In the early embryo.

(*a*) In all vertebrates they appear very early in development. In Man, for the first three or four weeks, they are formed inside certain cells of the mesoblast called angioblasts. These cells are found in the "vascular area" which surrounds the embryo. Their nuclei proliferate and acquire cell-bodies containing hæmoglobin. The protoplasm of the angioblasts becomes vacuolated, their processes, hollowed-out and united into a system of blood-vessels, within which the nucleated red blood-corpuscles float. Groups of these cells constitute the "blood-islands" of Pander.

This description holds good for all animals below mammals, as well as for the early stages in mammals.

(*b*) During the later periods of embryonic life in mammals, a similar formation of corpuscles goes on in mesoblastic tissue within the embryo, with this difference, however, that the hæmoglobin collects in discs of protoplasm without previous nuclear proliferation. The corpuscles are therefore non-nucleated.

Non-nucleated corpuscles have almost entirely replaced nucleated corpuscles by the end of fœtal life, except in certain sheltered situations within the red marrow of bones where nucleated corpuscles are found throughout life.

(*c*) From end of 1st to end of 3rd month it is supposed that the liver is hæmatopoietic in function.

Pro. 1. It is very large ($\frac{1}{2}$ the body-weight at 8th week).

2. The vessels which bring the blood from the mother break up into capillaries in the liver.

Gulland.—"The Development of Adenoid Tissue, with special reference to the Tonsil and Thymus," *Labor. Rep. Roy. Coll. of Phys., Edin.*, vol. iii. p. 157.

3. The embryo-liver contains protoplasmic cells enclosing corpuscles.

4. The liver intercepts the food-stuffs which pass to the fœtus from the mother. Hence it is supplied with ample material for blood-making. On the other hand its large size may be accounted for simply by the fact that it is a store-house for food, which is drawn upon, as need arises, by the system.

To end of this period corpuscles are spherical granular nucleated cells.

B. Late foetal and adult life.

(*a*) It used to be supposed that the red corpuscles are the transformed white corpuscles; either the whole cell (with disappearance of its nucleus), or its nucleus only being changed in character and colour by impregnation with hæmoglobin.

Con. Absence of any direct evidence.

(*b*) The spleen has been looked upon as a corpuscle-factory. Evidence proves it to be their grave in mammals. It may be their birth-place in fishes and tailed amphibians and embryo-mammals.

(*c*) Marrow of bone when not wholly given up to fat-formation.

Pro. 1. Peculiarly sheltered situation.

2. It contains spherical protoplasmic cells. Some of these develop into fat-cells, others (in red marrow) show traces of hæmoglobin. In this condition they resemble embryonic red blood-corpuscles. In sub-mammals they divide, a new nucleus going to each half. In mammals they cast off a non-nucleated corpuscle. The embryonic cell (hæmatoblast or "Neumann's corpuscle") repeats this operation *ad infinitum*.

The details of this process are not yet certain. *Bizzozero* and *Schäfer* describe the erythroblasts of the marrow as dividing by caryokinesis with subsequent disappearance of the nucleus in one or both daughter-cells. An extra-nuclear formation would be more in accordance with the extra-nuclear formation already described in mesoblastic cells, is suggested by the examination of the perfect red corpuscle, which shows no trace of nucleus, and would account for the persistence of the embryonic corpuscles. *Rindfleisch* points out that caps of coloured protoplasm thrown off from the embryonic corpuscles would assume the form of biconcave discs in the blood-stream. This he illustrates by driving putty-caps through water-pipes; entering the stream as hollow hemispheres, they leave it as biconcave discs.

Duration of Life.

Corpuscles are constantly destroyed and renewed.

Pro. 1. Hæmoglobin is the source of bile-pigment.

2. Foreign blood-corpuscles disappear from the circulation soon after injection.

Perhaps they live for a month, *i.e.*, the interval between two menstrual periods (*Landois*).

Use.—To carry oxygen to the tissues.

Fate.—When worn-out they are destroyed in the spleen.

Pro. 1. Structure highly suggestive of tissue in which changes in the blood

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Hunter.—"Intra-Peritoneal Blood-Transfusion, and the Fate of Absorbed Blood," *Jour. of Anat. and Phys.*, vol. xxi. pp. 138, 264, and 450, 1886.

Gibson.—"The Blood-Forming Organs and Blood-Formation: An Experimental Research," *Jour. of Anat. and Phys.*, vol. xx. pp. 100, 342, 456, 674, 1885.

Hardy.—"The Blood-Corpuscles of the Crustacea, together with a Suggestion as to the Origin of the Crustacean Fibrin-Ferment," *Jour. of Phys.*, vol. xiii. Nos. 1 and 2, p. 165, 1892.

might take place. No capillaries. Lacunæ. Circulation maintained by its own systole.

2. Large blood-eating cells are seen in the spleen. Possibly they are overgrown leucocytes, battening on fragments of red blood-corpuscles.

3. An iron-containing proteid is found amongst the extractives derived from the spleen. It is especially abundant after injection of hæmoglobin into the circulation.

4. The blood from the spleen goes straight to the liver, and there are many reasons for believing that bile-pigment is derived from hæmoglobin, thus—

Hæmoglobin

Bilirubin | Iron-containing proteid

This change is similar to the change which occurs in blood after it is effused into the tissues—

Hæmoglobin

Hæmatoidin | Iron and proteid absorbed

Bilirubin and hæmatoidin (Virchow's) are identical. Both are soluble in alkalies, and in chloroform (in which biliverdin is not soluble), both crystallise in clinorhombic prisms, and give Gmelin's test (play of colours with nitric acid).

LIFE-HISTORY OF LEUCOCYTES.

Leucocytes are not peculiar to blood, but are found throughout the intercellular and large serous spaces of the body. They migrate from the blood-vessels to the tissues and from the tissues into the lymphatic vessels and blood-vessels. They are more widely distributed than red corpuscles, being found in echinoderms and other animals which have no red corpuscles.

A. Their earliest origin in the embryo is not known. Doubtless certain of the mesoblastic cells of the blastoderm become motile as leucocytes.

B. In late embryonic and post-embryonic life.

1. They arise by fission in the circulating blood or lymph.

2. By division in more sheltered situations.

If the tissue in which they multiply is not marked off from ordinary connective tissue except by the number of lymph-corpuscles, or young white blood-corpuscles which it contains, it is called adenoid or diffuse lymphoid tissue.

If the leucocyte-containing tissue is distinctly localised, the patch constitutes a lymph-follicle.

If it has a capsule and lymph-ways which surround the lymph-cords—a lymphatic gland.

Are lymphatic glands organs in which white corpuscles are made?

Pro. 1. The arrangement of the blood-vessels and lymph-ways suggests that corpuscles formed in the lymph-cords are pushed off into the lymphatic circulation.

Halliburton.—"On the Hæmoglobin Crystals of Rodents' Blood," *Quart. Jour. Micr. Sci.*, vol. xxviii. p. 181, 1887.

2. It is stated that lymph coming from lymphatic glands contains more corpuscles than lymph going to them.

3. Lymphatic glands are enlarged in leukæmia.

Con. Whether or not leucocytes are formed in them the glands have certainly a quite different function.

If the leucocytes are particularly busy, the glands next above the seat of injury, inflammation or infection, are enlarged.

To these glands the leucocytes carry the bacteria which they have captured, or the blood-pigment, or foreign bodies which they have picked up.

Soot from the lungs is to be seen in the bronchial lymphatic glands.

Carbon, vermilion, &c., used in tattooing, are to be seen in the lymphatic glands above the tattoo marks.

The pigment-carrying cells collect in the lymph-ways, but very few entering the lymph-cords. The cells gradually degenerate, setting free the particles of pigment.

Use.—There are wide differences of opinion as to the functions of the white blood-corpuscles in health.

A. Do they carry nutriment to the tissues?

Pro. 1. They can carry adventitious substances, as described above.

2. They are to be seen in various degrees of granulation. In the chyle they are loaded with fat-granules and glycogen (they stain black with osmic acid = fat; blood-red with iodine = glycogen).

Do they take up these food-stuffs for their own consumption only, or for the public benefit?

The number of leucocytes in the circulating blood is greatly increased after a meal, as if they were engaged in carrying absorbed nutriment.

B. They make war upon bacteria which find their way into the system.

Pro. Bacteria are to be seen in numbers in the substance of the leucocytes, which are then termed phagocytes.

C. It is possible that the tissue-consuming cells which are found in certain situations are (overgrown) leucocytes busy in removing degenerating material.

E.g., The corpuscle-eating cells of the spleen.

The bone-eating cells (osteo-clasts).

Fate.—1. They probably break up in the circulation.

2. After injuries they escape from the blood-vessels, and, becoming fibro-plasts, are built into cicatricial tissue.

3. If the conditions at the seat of an injury are unfavourable to their existence, and especially if they are asphyxiated for want of oxygen, they lose their power of amœboid movement, become spherical, die, and are then termed pus-corpuscles. The protoplasm of the pus-corpuscles undergoes fatty degeneration.

CIRCULATION.

In small vessels the red corpuscles are seen to pass down the centre of the vessel in the "axial stream." The leucocytes crawl along the vessel-wall, or are rolled over and over in the plasmatic layer, which occupies "Poiseulle's space."

Red corpuscles occupy the axial stream, while the colourless corpuscles

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Durham.—"On Wandering Cells in Echinoderms, &c., more especially with regard to Excretory Functions," *Quart. Jour. Micr. Sci.*, vol. xxxiii. pt. 1, p. 81, 1891.

Ruffer.—"On the Phagocytes of the Alimentary Canal," *Quart. Jour. Micr. Sci.*, vol. xxx. p. 481, 1890.

Metschnikoff.—"Researches on the Intracellular Digestion of Invertebrates," *Quart. Jour. Micr. Sci.*, vol. xxiv. p. 89, 1884.

tend towards the vessel-wall, because the former are heavier than the latter.

Pro. If particles of different specific gravity are carried through a tube by a liquid at a certain rate of flow, the heavier particles tend to occupy the axis of the tube where the flow is most rapid.

DIAPEDESIS.—Colourless corpuscles make their way into the tissues through the walls of the small vessels and capillaries by forcing apart the epithelial cells. This process can only be observed in inflammatory conditions, but is also, presumably, carried out in health.

It is favoured by high intravascular pressure, but is due to the amœboid movements of the leucocytes.

Diapedesis of red corpuscles is observed in pronounced inflammation. The corpuscles are altered remarkably in form by pressure as they pass through the vessel-wall, but regain their shape when in the tissue-spaces.

INFLAMMATION is a condition in which the vessels are dilated, and much of their contents accumulated in the perivascular areas, producing redness, heat, and swelling. The pathological process does not commence with the vessels, but with the tissues by which they are surrounded. The dilation of the vessels is, primarily, an adaptive change, due to the increased metabolism of the tissue-cells. It also allows of increased exudation of plasma and diapedesis of corpuscles.

Whether inflammation commences with changes in the tissues, or with changes in the vessel-walls; and, in the latter case, whether the change depends upon local stimuli or upon nerve-influence, is a matter upon which diverse views are held.[1]

It may be studied in the mesentery, web of foot or tongue of the frog; or in the mesentery, &c., of warm-blooded animals.

Its several stages are:—

1. Dilation of the vessels resulting in a more rapid flow of blood.
2. Slowing of the blood-stream.
3. Peripheral disposition of leucocytes.
4. Diapedesis of leucocytes. This was observed by *Addison* (1842), *Waller* (1846), *Cohnheim* (1867). Eventually diapedesis of red corpuscles occurs. In small vessels the blood-stream may come to a standstill = stasis.

The exuded leucocytes may (*a*) retain their vitality and return into the lymphatic circulation, the inflammation subsiding;

Or (*b*) if the inflammation last for some time, the leucocytes which have migrated into the tissue-spaces undergo changes in structure and appearance: their nuclei become clear, oval, vesicular; cell division occurs; their daughter-cells elongate into "fibro-plasts;" these fibro-plasts take the place of tissue which has been removed. It is a peculiarity of tissue thus formed (cicatricial tissue), that it tends to contract for a very long period, drawing the surrounding normal tissues together, and often producing deformity, *e.g.*, after burns.

(*c*) If the inflammation is severe the leucocytes degenerate; they lose their power of thrusting out pseudopodia; their nuclei break up, and their protoplasm becomes fatty. As "pus" cells they constitute foreign bodies which may remain

[1] See Ziegler's *Pathological Anatomy*, translated by Dr. Donald M'Alister, p. 135 *et seq.*

Hamilton.—"Circulation of the Blood-Corpuscles, considered from a Physical Basis," *Jour. of Phys.*, vol. v. p. 66.

Wharton Jones.—"Report on the State of the Blood and the Blood-Vessels in Inflammation," London, 1891.

Metschnikoff.—"The Ancestral History of the Inflammatory Process," *Quart. Jour. Micr. Sci.*, vol. xxiv. p. 112, 1884.

Fox.—"Functions of the Tonsils," *Jour. of Anat. and Phys.*, vol. xx. p. 559, 1886.

in position until they are very gradually absorbed, or be discharged from the body as "pus."

TRANSFUSION.

Of Foreign Blood.

This can be accomplished in very few cases without fatal results.

In 1667, *Denis* injected 4 oz. of lamb's blood into the blood-vessels of a man.

In 1669, *Lower* injected 10 oz. of sheep's blood into the veins of a certain decayed clergyman named Arthur Coga.[1]

A considerable number of such experiments were performed in France in the belief that the character of an animal could be transferred with its blood.

When the blood of one animal is injected into the vessels of another, one or other set of corpuscles is broken up, leading to fever, coagulation of blood, plugging of the vessels, bloody urine.

Even injection of hæmoglobin is apt to cause coagulation, &c. In small quantities it leads to increased formation of bilirubin, which appears in the urine.

Which set of corpuscles will break up depends upon the animals used. The blood of a dog is, so to speak, stronger than that of a rabbit, causing the corpuscles of the latter to break up.

It is possible, successfully, to replace a large amount of the blood of a dog by that of a horse.

Injection of Homogeneous Blood.

The vessels of a dog will receive an excess of 83% of dog's blood without material alteration of the blood-pressure or permanently injurious effects.

Transfusion is practicable in Man in cases of extreme hæmorrhage (particularly in *post-partum* hæmorrhage), and also in certain rare cases of cholæmia and uræmia, in which there is reason to think that if the patient can be kept alive for a short time, the conditions which lead to the poisoning of the blood will subside.

It may be either direct transfusion, basilic vein being placed in connection with basilic vein; or injection by means of a syringe of defibrinated blood, or of blood kept from coagulating by being received into a 5% solution of sodic phosphate.

Defibrinated blood appears to be as useful as blood which has not coagulated.

QUANTITY OF BLOOD IN THE BODY is estimated by collecting as much of it as possible, and adding the amount remaining in the body, as estimated by chopping the body up and making an extract in salt-solution; the quantity of hæmoglobin contained in this extract is determined by comparison with standard dilutions of hæmoglobin.

$$\frac{\text{Blood}}{\text{Body-weight}} = \frac{1}{13} \text{ in Man, } \frac{1}{13} \text{ in dog, } \frac{1}{20} \text{ in rabbit, } \frac{1}{12{\cdot}5} \text{ in cat.}$$

It is distributed equally between the four following organs or groups of organs:—(1) Heart, lungs, large arteries and veins, (2) liver, (3) muscles, (4) rest of body.

The **Variations** in amount in a limb or in a viscus are estimated by enclosing the organ in a plethysmograph. The fluctuations in the amount supplied to the brain have been observed by adapting a plethysmograph to heads, from which parts of the skull have been exfoliated in disease.

[1] "Inaugural Address in the Section for Physiology, by Dr. Michael Foster," *Transactions of the International Medical Congress*, 1881, vol. i. p. 207.

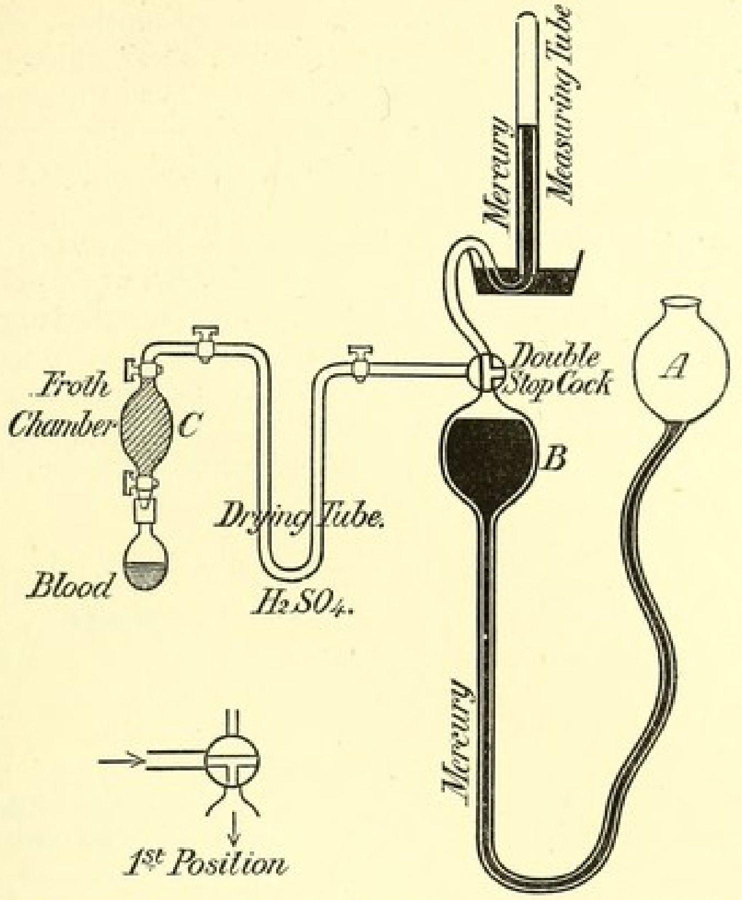


FIG. 4.—Mercury-pump for removing gases from the blood. When A is lowered with the stop-cock in the first position, gas is drawn into the receiver B; the stop-cock is then turned, as shown in the figure, and A being raised, the gas is driven into the measuring tube.

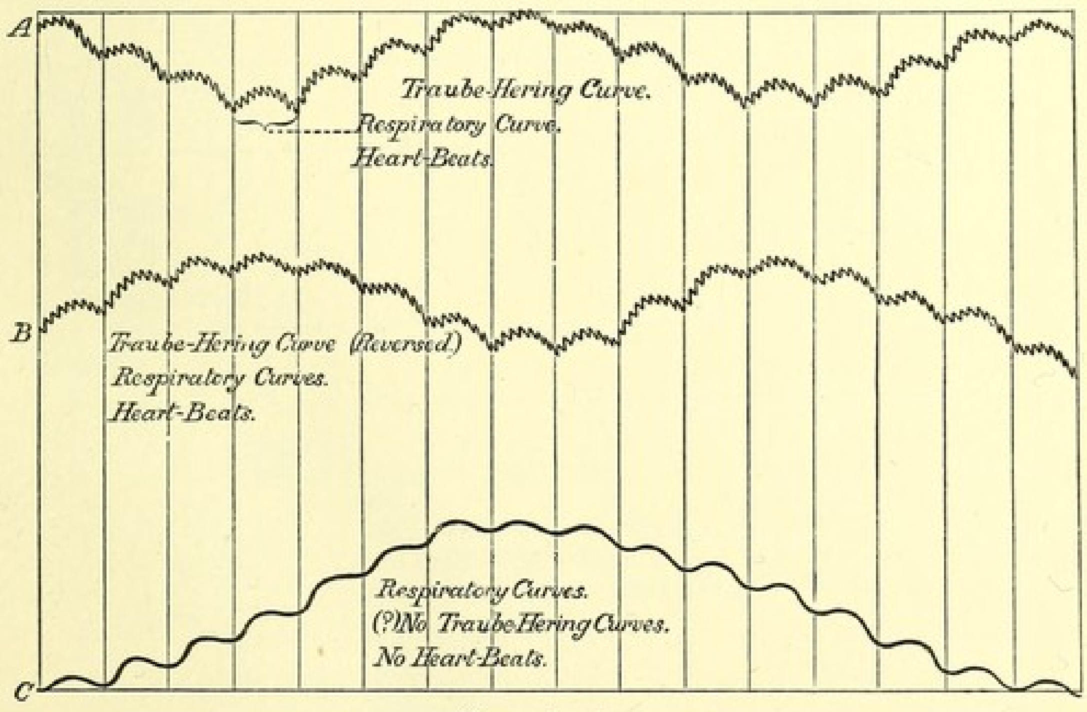


FIG. 5.—Comparison of A, kymographic (blood-pressure) tracing; B, oncographic tracing from the kidney; C, oncographic tracing from the spleen.

To face p. 10.]

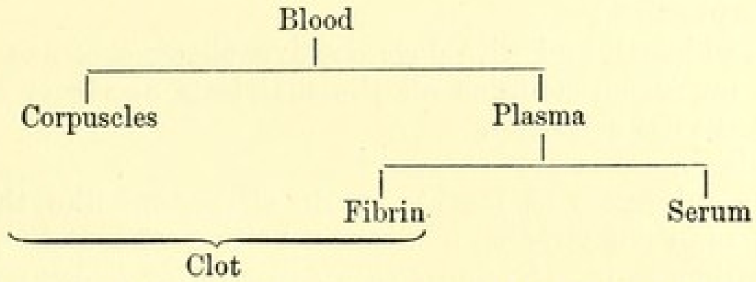
CHEMICAL CONSTITUTION OF BLOOD.

Blood is the only medium by which nutrient materials are carried to the tissues. Some of the food-stuffs are absorbed by the blood-vessels which ramify in the walls of the alimentary tract; others are poured into the venous system, at the junction of the left jugular and subclavian veins, by the thoracic duct. All the oxygen supplied to the tissues is carried by the hæmoglobin of the red corpuscles.

Nutrients pass from the blood into the interstitial lymph, by which the tissue-elements are bathed.

Certain waste-products of the tissues are re-absorbed from the lymph into the blood; others remain for a long time in the circulating lymph.

Hence the blood contains all the food-stuffs and most of the waste-products of the tissues. These two classes cannot be rigidly separated, but a scheme such as the following is a useful aid to memory:—



Plasma = serum + fibrinogen sufficient to make 0·2 to 0·4% fibrin.
Serum = water, 90%; solids, 10%; sp. gr., 1026.

Nutrients.	*Waste-Products.*
Proteids— Serum-globulin (paraglobulin) 3·5%. Serum-albumin, 4·5%. Fibrin-ferment.	Creatin. Uric acid. Xanthin. Hypoxanthin. Hippuric acid. Urea, ·02 to ·04 %.
Carbohydrates. Dextrose, 0·1%.	Lactic acid.
Fats— Palmitin. Stearin. Olein. Soaps (a trace).	Lecithin. Cholesterin.
Oxygen.	Carbonic acid.

Pigment.
Serum-lutein—a lipochrome.

Salts—

Sodic chloride, $NaCl$, 0·5%.
Potassic chloride, KCl.
Sodic bicarbonate, $NaHCO_3$.
Calcic phosphate.
Magnesic ,,
Sodic ,,
Potassic ,,

Halliburton.—"The Proteids of Serum," *Jour. of Phys.*, vol. v. p. 152. (See also Halliburton's *Physiological Chemistry*.)

The form of the phosphates (whether meta- or ortho-phosphates) has not been ascertained. The ash contains more phosphates than exist in serum, owing to the oxidation of phosphorus, which in the serum is combined with organic matter.

Red Corpuscles.—Solids, 25% ; water, 65% ; sp. gr., 1·1.

Respiratory material.

Hæmoglobin, 90% of the solids.

Framework of the Corpuscle.

Proteids, 9%.

Chiefly cell-globulin, which, like that of white corpuscles, is apparently identical with fibrin-ferment ; cell-albumin (doubtful) ; no nucleo-albumin.

Lecithin.

Cholesterin.

Mineral matter, particularly phosphorus and potassium.

White Corpuscles.

Of lymph, of blood, and with degenerative changes of pus. Each cell being an independent organism, contains all the materials necessary for the exhibition of its complicated vital activities.

A. Proteids.

1. Hyaline substance of Rovida, with characters like those of mucin, from which it differs in not yielding a sugar on boiling with H_2SO_4.

= Nucleo-albumin (of *Hammarsten*) or plastin (of *Reinke*). Has been mistaken for myosin.

2. Cell-globulins.

a. Coagulating at 50° C.

b. „ „ 73° C., and having the properties of fibrin-ferment.

3. Cell-albumin.

B. Nuclein in the nuclei ; not easily digestible.

C. Glycogen, fat, lecithin, waste-products, salts.

THE SPLEEN.

Histology.—In its early stages this organ has the appearance of a developing lymphatic gland. In the adult its lymphoid tissue is restricted to certain patches in connection with the outer coat of the arteries, named after their discoverer, Malpighian corpuscles. They are about the size of a pin's head, and in Man very irregular in form and disposition. The rest of the spleen-pulp is a sponge-work formed by the separation of the epithelial cells, which, when placed in apposition, constitute the lining of the arteries. Into the irregular intercommunicating spaces, bounded by these epithelial or connective tissue cells, the blood brought by the splenic arterioles escapes. It lies in the pulp for a time, at rest from the general circulation, and is squeezed out of the pulp into the mouth of the venules by the contraction of the spleen itself. The blood in the pulp is concentrated, owing to the escape of its plasma. Many of its red corpuscles are seen to be in process of disintegration ; leucocytes are very numerous, some of them are much larger than

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Halliburton and Friend.—"The Stromata of the Red Corpuscles," *Jour. of Phys.*, vol. x. p. 532.

Copeman.—"The Crystallisation of Hæmoglobin in Man and the Lower Animals, and of Hæmochromogen of Man," *Jour. of Phys.*, vol. xi. p. 401.

Harris.—"Hæmatin Compounds," *Jour. of Phys.*, vol. v. p. 209.

Mac-Munn.—"Myohæmatin and the Histohæmatins," *Jour. of Phys.*, vol. viii. p. 51 ; also *Phil. Trans.*, part i., 1886.

usual, and contain fragments of the broken-down red corpuscles. It is said that the splenic pulp of young animals and of the adult after hæmorrhage also contains nucleated hæmoglobin-tinged hæmatoblasts. The capsule and trabeculæ are largely composed of plain muscle-fibres.

Extirpation.—The spleen may be removed even in Man without obvious disturbance; lymphatic glands enlarge, and are said to show red corpuscles in their lymph-spaces; the marrow of the long bones becomes red and soft; splenic nodules appear in the omentum; the lymph-follicles of the intestines are said to assume the character of spleen-pulp. Whatever may be the functions of the spleen, it appears that they can be assumed by other organs.

The spleen in action:—It enlarges after a meal, reaching its maximum in about five hours. It enlarges permanently to many times its original size in ague (ague-cake). Quinine causes it to contract. It can be made to contract by the application of electrodes to the wall of the abdomen. The spleen contracts spontaneously with great regularity about once a minute.

> *Roy* took tracings from the spleen by enclosing it in an "oncometer," or specially modified plethysmograph. Splenic oncograms exhibit the rhythmic contraction and dilation of the spleen; they show also the alterations in pressure produced by respiration (see fig. 5, C), but do not show the influence of the beat of the heart. The muscular tissue of the spleen appears to be in a condition of tonic contraction; its enlargement is due to a relaxation of its tone.
>
> *Nerves:*—A. Efferent; stimulation of the peripheral end of either vagus or splanchnic causes contraction.
>
> B. Stimulation of any sensory nerve or of the central end of the vagus causes contraction.
>
> C. Stimulation of the medulla causes contraction. The exact course of neither afferent nor efferent nerves of the spleen has been discovered as yet.

Function.—To remove from the circulation red corpuscles which are unfit to make the tour of the body, and which, if allowed to continue in the blood, might disintegrate and lead to embolism. Many functions have been attributed to the spleen; and the fact that hæmatoblasts are found in its pulp indicates that in the embryo, at any rate, and after hæmorrhage, it may be the seat of corpuscle-formation, but that its true function is as just stated is inferred from the following facts:—

> A. In structure it appears to be peculiarly adapted for the manipulation of the blood; corpuscles are poured-out into its labyrinth, and almost brought to rest in the presence of numerous leucocytes. The circulation is independent of the heart.
>
> B. The blood from the spleen is carried to the liver, the bile pigments secreted by which can be shown to be derived from hæmoglobin.
>
> C. The "extractives" of the spleen are very numerous, indicating that it is the seat of the destruction of proteids:—
>
> > Uric Acid, constant even in the spleen of herbivora.
> >
> > Leucin, one of the bodies formed by the destruction of proteids in the alimentary canal.
> >
> > Xanthin, Hypoxanthin, which occur wherever proteids are being decomposed within the body.
> >
> > Inosite, or muscle-sugar, a symmetrical hexatomic alcohol found in many organs of the body.
> >
> > Fatty acids, &c.
> >
> > Soda and phosphates.
> >
> > Most notable of all, an iron-containing alkali-albumin, found

nowhere else; this indicates that in the spleen hæmoglobin is decomposed thus :—

Hæmoglobin

Pigments	Iron	Proteids
(Antecedent to bile-pigments)	Combined (Iron and Proteids)	Decomposed

D. Many observers have described the actual breaking up of effete red blood-corpuscles by leucocytes. In presence of such an abundant supply of nutriment, some of the leucocytes grow to a large size, and are seen to contain several nuclei and strongly refracting granules.

Leucocytes are, doubtless, formed in the Malpighian corpuscles and other lymphatic portions of the spleen.

THE LYMPHATIC CIRCULATION.

A far larger quantity of the fluid of the body is contained in the lymphatic system than in the blood-vascular system. The weight of lymph is estimated at $\frac{1}{4}$ (*Ludwig*) or $\frac{1}{3}$ (*Krause*) that of the body.

The exact estimation of the amount of lymph is impossible. *Colin* obtained from the thoracic duct of a horse as much as 21 kilos in twenty-four hours; but it is obviously impossible to run off all the lymph unless water is given to the animal, and if water is given this rapidly diffuses into the tissue-spaces and thence into the lymphatic vessels.

Lymph fills up the spaces (lacunæ, interstices) between the cells of the body.

All the tissues of the body obtain their nutrient substances from the lymph, and excrete their waste products into the lymph; oxygen and nutrients pass into the lymph from the blood; carbonic acid and other metabolites return for the most part from the lymph into the blood, by diffusion, although a certain quantity is poured into the blood through the thoracic duct.

The walls of the blood-capillaries prevent the escape of red blood-corpuscles, but cannot restrain leucocytes or soluble substances from passing into the tissue-spaces.

Is lymph simply a filtrate from the blood?

Con. Differences in composition between blood and lymph, and between lymph and cerebro-spinal fluid or ascitic fluid, indicate that changes in the composition of the fluid are introduced during the passage of the body-juices through membranes.

Waymouth Reid[1] has shown that the passage of fluid through a living membrane must not be treated as simple osmosis. As long as the cells of the membrane retain their vitality they modify the process.

Origin of Lymphatic Vessels.—The irregular connective tissue-cells which separate the lacunæ are, at frequent intervals, flattened into epithelial cells, and apposed edge to edge in the walls of lymphatic vessels (lymphatic capillaries). Like commencing veins the lymphatic vessel soon acquires a muscular "media" (in which a few elastic fibres are found), and a connective tissue "adventitia." They were discovered by *Asellius* in 1622.

Serous (or Lymphatic) Cavities, sub-dural and sub-arachnoid, pleural and peritoneal (including the space within the tunica vaginalis), communicate with lymphatic vessels by stomata, protected in varying degrees with small granular

[1] Reid, *Brit. Med. Journal*, Feb. 13, 1892.

guard-cells; branched sub-epithelial cells also project into the epithelium as pseudo-stomata (*Klein*).

The action of the stomata in absorbing fluid can be demonstrated by placing the diaphragm of a recently-killed animal under the microscope without disturbing its attachments to the ribs and vertebral column, and placing a little milk on its surface. The globules of milk disappear through the stomata.

Lymphatic Glands.—As soon as they reach a sheltered situation, *e.g.*, the groin, axilla, neck, root of lungs, &c., several lymphatic vessels combine together to form a lymphatic gland. In principle the gland is a close plexus of lymphatic vessels which invests a bunch of lymph-follicles, and is in turn surrounded by a fibrous capsule, from which plates and trabeculæ pass between and support the follicles. The follicles, which are abundantly supplied with blood, consist of a scanty connective tissue-framework enclosing a vast number of proliferating lymph-corpuscles. The lymph which reaches the gland carries to it débris of tissues and foreign bodies, including microbes. The efferent lymph which leaves the hilus of the gland is, more or less completely, freed from adventitious substances, and is enriched with young leucocytes that have squeezed their way through the follicular membrane.

Physical and Chemical Composition of Lymph.

Reaction; alkaline; sp. gr., 1012–1022. It contains leucocytes. It coagulates, although not so quickly or firmly as blood, yielding ·04 to ·08% of fibrin. Percentage of solids, 1·3.

Proteids,

Serum globulin, } in the same relative proportion as in blood, 0·23%.
Serum albumin }

The total amount of proteid is therefore only about $\frac{1}{30}$ that of blood-plasma, but the proportion which the globulin bears to the albumin has not been disturbed by diffusion.

Extractives.—Urea, &c., in larger quantity than in blood-plasma.

Salts.—Similar to those in blood-plasma and in equal quantities.

Gases.—Free oxygen, *nil*. Carbonic acid in the lymph of the interstices more abundant than in venous blood; in the larger lymphatics, less abundant.

Lymph ought not to be regarded, therefore, as an exudation from blood. Rather is it the primary fluid of the body; the composition of blood and lymph being reciprocally modified by the exchanges which occur through the walls of the blood-vessels suspended in the lymph.

THE THYROID BODY or Gland is a mass of subspherical vesicles unconnected with any ducts, lined by cubical epithelium and filled with a mucilaginous fluid in the young, with "colloid" in the adult. The vesicles are supported by septa of connective tissue containing elastic fibres, and carrying numerous nerves, lymphatics, and blood-vessels. Its abundant blood-supply suggests a connection with the vascular system, but as to the nature of its functions we have merely the following indications:—

Colloid (or meta-albumin) resembles mucin in its physical characters, and, like mucin, yields a reducing sugar when boiled with sulphuric acid. Unlike mucin, it is not precipitable with acetic acid.

In the disease myxœdema, in which the thyroid atrophies, the skin, parotid gland and other organs which normally contain little or no mucin have been

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Handbook of the Physiological Laboratory.—"The Lymphatic System," by Klein, with plates xl. to l.; also "Anatomy of the Lymphatic System," London, 1873.

Horsley.—"Remarks on the Function of the Thyroid Gland: A Critical and Historical Review," *Brit. Med. Jour.*, 1892, No. 1622, and 1623.

found to be rich in this substance (*Ord*, *Charles et al.*). The thyroid was removed from the neck of various animals by *Horsley*, and the tissues examined by *Halliburton*.[1] After thyroidectomy the percentage of mucin in the connective tissues and also in the salivary glands is increased; eventually mucin appears in the blood.

Per Contra.—It must be remembered that in myxœdema, whether natural or experimental, there is a development of young connective tissue which normally yields mucin. This does not, however, account for its appearance in the parotid gland.

Thyroidectomy is also followed by nervous symptoms and general cachexia, as well as by myxœdema.

The thyroid body is enormously hypertrophied in goître.

THE THYMUS BODY is a loosely connected mass of lymph-follicles. Towards the centre of the follicles are found globular nests of epithelial cells known as the "concentric corpuscles of Hassall." They appear to be the vestiges of the tubes of a gland which was functional in the ancestors of the Vertebrata, and of which all traces would probably have been lost had its epithelial coat not been surrounded, like all parts of the respiratory system, with adenoid tissue. For the sake of the adenoid tissue in which leucocytes are developed, the body is retained during the period throughout which corpuscle-formation is most active, *i.e.*, until six years old, when it begins to degenerate. It attains its greatest size when the child is two years old. Numerous "fuchsin-bodies" are found in the thymus. Fuchsin stains fibrous tissue, fibrin, &c., and the bodies in question, appear to be the unabsorbed remnants of atrophied tissue, probably of blood-vessels.

[1] *Cf.* Halliburton's *Chemical Physiology and Pathology*, p. 501 *et seq.*; Clinical Society's *Transactions*, vol. xxi.; Dr. Ord, *Med. Chir. Transactions*, vol. lxi.; Horsley's "Brown Lectures," *Brit. Med. Jour.*, 1885, p. 211.

Kanthack.—"The Thyreo-Glossal Duct," *Jour. of Anat. and Phys.*, vol. xxv. p. 155, 1891.

SECTION II.

VASCULAR SYSTEM.

Plan.—A pump—the heart—in the circuit of a closed system of tubes. The efferent tubes branch, every tube having a smaller sectional area than the trunk from which it sprang, although the sum of the sectional areas of the tubes of a given calibre is always greater than the sum of the sectional areas of the tubes of greater calibre. The single exception to this rule is to be found in the division of the aorta into the two common iliacs, which vessels have often a smaller total bed than the aorta from which they spring (*Paget*). The afferent tubes unite, but the sum of their sectional areas diminishes less rapidly than the sum of the sectional areas of the efferent tubes grows.

The capillaries have a bed (aggregate sectional area) about 800 times that of the aorta.

The united sectional area of the venæ cavæ is about twice that of the aorta, and therefore $\frac{1}{400}$ of that of the capillaries.

The total capacity of the vascular system is about $5\frac{1}{2}$ litres. Of this a variable amount (never less than $\frac{1}{2}$ l. or more than $\frac{3}{4}$ l.) is contained in the heart; about 0·23 litre in the capillaries; the remainder is divided between the arteries and veins, but a very much larger quantity is lodged in the veins than in the arteries.

Physical Conditions.—In a perfect fluid the molecules would move upon one another without mutual resistance. Blood is far from being a perfect fluid; but when the effects of the action of forces upon the blood are being considered, it must be remembered that its molecules offer but little resistance to displacement. If it were a perfect fluid, force applied to one end of a column of blood would be transmitted to the other end without diminution. As a matter of fact, if a system of water-pipes were used for the distribution to the houses of a town, of the force generated by an engine, there would be a considerable loss, due to friction.

In the same way, the velocity with which a column of a perfect fluid would issue from an aperture, would be equal to the velocity acquired by a heavy body in falling freely from the level of the surface of the fluid to the level of the aperture.

The blood-vessels constitute a closed circuit, and, therefore, the fluid in the ascending vessels is exactly supported by the fluid in the descending vessels. If we imagine the fluid columns as devoid of supporting walls, we picture a system which would continue to circulate for ever under the influence of a temporarily acting force; but we have to remember, in considering the physics of the vascular system, that the vessel-walls exercise such an attraction upon the fluid which they contain, that the molecules actually in contact with the walls are

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Roy.—"Influences which Modify the Work of the Heart," *Jour. of Phys.*, vol. i. p. 452.

Howell and Donaldson.—"Volume of Blood sent out of the Left Ventricle in a Single Beat, and Work done by the Heart," *Trans. Roy. Soc.*, 1884, p. 139.

Porter.—"Researches on the Filling of the Heart," *Jour. of Phys.*, vol. xiii. No. 6, p. 513, 1892.

stationary, while those nearer the centre move upon those nearer the wall with a freedom which depends upon the cohesion of the fluid. Blood is a sticky fluid, and its molecules are moved one upon another with comparative difficulty.

The smaller the vessel, the greater is the proportion borne by its inner surface to its cubical contents, and, therefore, the greater the resistance which it offers to the flow of blood.

The resistance is also affected by the condition of the lining epithelium of the vessel. When the lining epithelial cells of the capillaries are, so to speak, clean and smooth, they do not resist the onward flow of the blood so much as when they are soft and sticky.

∴ The work done by the heart is altogether expended in overcoming friction or internal resistance.

Apparatus for determining the physical conditions of the circulating blood.

Pressure in the arteries :—1. First taken by *Stephen Hales*, Rector of Teddington, in 1727. He observed that the blood was thrown to a height of 2 feet above the cut end of the crural artery of a mare. He then connected a long quarter-inch tube with the vessel, using, as his cannula, the trachea of a goose. The blood rose in the tube to the height of 6 to 8 feet, and oscillated with each beat of the heart. *Drawback*, the blood coagulated very quickly after entering the apparatus.

2. *Vierordt* filled the tube with sodic carbonate; very little blood, therefore, entered the tube, and the alkali prevented coagulation.

3. *Ludwig* uses a mercury-manometer (kymograph), supporting on its distal limb a pen which writes on a travelling blackened surface. Carbonate of soda admitted from a pressure-bottle until there is no risk of more than a very little blood entering the apparatus, and this does not coagulate. *Drawback*, the heavy metal mercury continues to oscillate after displacement. It does not show small variations of pressure on the main curve.

4. 1864, *Fick* introduced the "hollow spring-kymograph." A hollow C-shaped metal spring is filled with alcohol. Its upper end is closed, and the lower separated by a membrane from the carbonate of soda in the cannula. The pressure of the carbonate of soda is adjusted by means of a pump. In this apparatus the fluid presents no free surface to the air, and the movements of the end of the spring indicate with great accuracy the changes of pressure in the blood-vessels.

5. *Fick* has found recently that if a tube is closed by a membrane which presses by a button on a *flat spring*, the movements of the spring follow very closely the changes of pressure in the tube.

Blood-pressure in the capillaries can only be estimated by determining the amount of pressure needed to blanch a vascular structure, *e.g.*, the skin of the finger or the ear, the gum, mesentery, &c. By using a weighted glass-plate the pressure in the skin of the hand was found to be 24 mm. Hg. with the hand raised; 54 mm. with the hand hanging down. It was increased fourfold when the veins were occluded.

Velocity.—It may be measured—1. By introducing the two ends of a long bent tube (hæmadromometer) filled with salt-solution into an artery, and noting the time which the blood takes in displacing the salt-solution. If the tube has the same calibre as the artery, the velocity with which the blood drives the salt-solution forward equals the velocity with which it is flowing in the vessel. If the tube is wider or narrower than the artery, the velocity is the product of

$$\text{the observed velocity} \times \frac{\text{the cross section of the tube}}{\text{the cross section of the artery}}.$$

2. A better apparatus for measuring the quantity of blood which passes through a given artery in a given time is the "stromuhr" of *Ludwig*—a bent tube with both limbs dilated. When introduced into the vessel the proximal limb is filled with

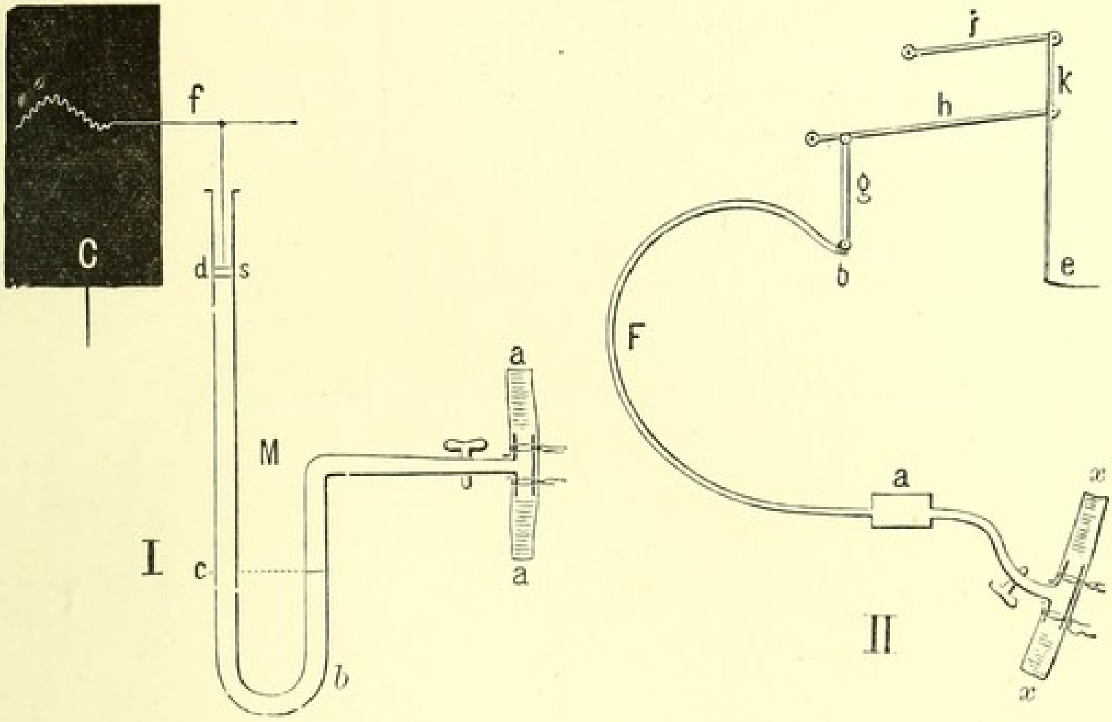

FIG. 6.—I. Diagram illustrating the principles of construction of the mercurial manometer as used for measuring blood-pressure (*Ludwig's* kymograph). *a*, The artery into which a T-piece is tied; *b*, a U-tube filled with mercury; *ds*, the float which carries a pen, *f*, which writes on a blackened revolving cylinder C. The blood-pressure is measured by the number of millimetres at which *ds* stands above *c*.

II. Fick's spring kymograph. *x*, The artery; *a*, a chamber divided by a thin membrane; F, a hollow metallic spring, C-shaped. The cannula is filled with Na_2CO_3, the hollow spring with alcohol. Variations in the pressure within the artery are transmitted to the alcohol and cause the C-spring to open out or close. Its movements are conducted by the levers *g*, *h*, *k*, *f*, to the pen *e*.

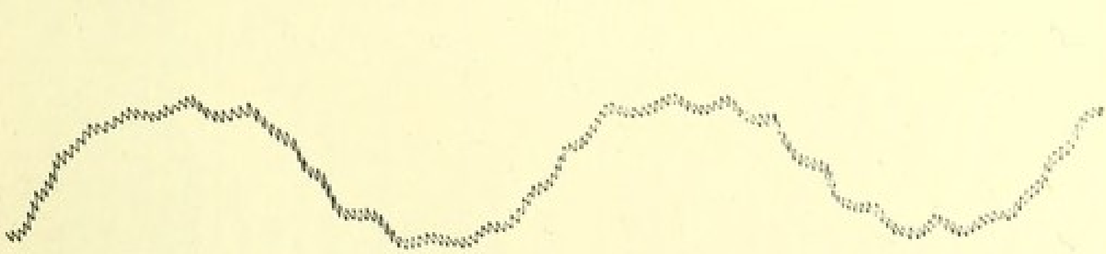

FIG. 7.—A blood-pressure tracing showing Traube-Hering curves, respiratory curves, and beats of the heart.

Comparison of the several Parts of the Blood-Vascular-System.

	Structure.	Function of the several Coats.	Motor.	United Calibre.	Velocity.	Pressure.	Mean Length of Traject.	Time Spent by Blood in Traversing.
Arteries. Aorta.	Media, made up of many layers of elastic tissue, with some white fibrous tissue and muscle.	Receives sudden shock from the heart. Tends to equalise the pressure.	The heart,	1	(600) 400 mm. per sec.	200 mm. Hg.	Arteries 0·5 m.	Less than 10 secs.
Arteries. Brachial.	Adventitia. Circular muscle, alternating with elastic lamellæ. Fenestrated membrane. Sub-epithelial areolar tissue. Epithelium.	Limits distension. Regulates calibre. Convert intermittent into constant pressure. Absorbs foreign matter. Connected with vitality of leucocytes.	Resisted by variable surface tension.	Curve of aggregate sectional area.	150 mm. per sec. (Curve of velocity is complementary to curve of united sectional area.)	120 mm. Hg.		
Capillaries.	Epithelium only (? stomata).	Osmosis, diapedesis.		800	0·75 mm. per sec.	24 to 38 (or 54) mm. Hg.	0·5 mm.	$\frac{2}{3}$ sec.
Veins. Cephalic.	Adventitia, less muscle than in artery. Less elastic tissue. Elastic reticulum in place of fenestrated membrane. Valves.	Supports column of blood.	Vis a tergo. External pressure.			5 mm. Hg.	Veins 0·5 m.	More than 20 secs.
Veins. Venæ Cavæ.	More white fibrous tissue. No valves. Striated muscle near heart.	Do. Commences cardiac cycle.	Aspiration of thorax, (?) elastic dilation of heart.	2	200 mm. per sec. (300)	– 0·1 mm. Hg.		Total, 30 secs.

oil, the distal with salt-solution; as blood enters the proximal limb, the oil is lifted into the distal limb, while the salt-solution enters the distal part of the artery. By fixing the bent tube on a disc which rotates on a pivot about another disc to which the cannulæ are attached, the apparatus can be quickly reversed, so that oil is again in the proximal limb, while the distal limb is filled with blood. The apparatus is reversed as often as necessary, and the quantity of blood which passes through it, even in a long period, easily measured. Further, the upper disc contains a channel cut at right angles to the bent tube. If therefore the apparatus is rotated through 90°, blood passes through the two discs without entering the oil chamber.

Velocity in the capillaries (1) of transparent parts is measured with the microscope. It amounts to 0·5 mm. per second in thin membranes.

2. The circulation in the capillaries of the retina can, under certain circumstances, be observed subjectively—(*a*) in Purkinje's figures; (*b*) when a white cloud is looked at through several thicknesses of cobalt glass. In the latter case red rays being completely excluded, the blood-corpuscles in the vessels on the front of the retina throw *black* shadows on the bacillary layer. We are quite unconscious of the red shadows which they usually cast, but the black shadows attract attention. The velocity in the capillaries of the retina is 0·75 mm.

HEART.

Development.—In its first stage in mammals the heart is double.

The two tubes which subsequently unite to form the single median heart, lie far apart on the blastoderm; for they are formed before the blastoderm has folded in below the embryo to complete the ventral wall of its throat. Each tube consists of delicate epithelium; the epithelial tube is supported on its outer side by an invagination of the splanchnic layer of the mesoblast, which afterwards forms the muscular substance of the heart; the portion of the cavity of the mesoblast, the cœlom, which surrounds this invagination on the outer side, becomes when cut off from the rest of the cœlom the pericardial cavity. The two veins which come from the yolk open into the hinder ends of the two heart-tubes. As the wall of the throat is closed in, the two tubes unite into one; the dilated sinus venosus, which joins the back of the heart, and the bulbus aortæ, which leaves it in front, are separated from the auriculo-ventricular portion of the tube by constricted canals—auricular canal and fretum respectively.

The heart folds into an ∽; the auricular portion being concave downwards, the ventricular concave upwards.

The auricular canal is pushed down into the ventricular, its intruding mouth being divided into the auriculo-ventricular valves.

A series of flaps grow across the cavity, dividing it into right and left auricles, right and left ventricles, pulmonary artery and aorta. The inter-auricular septum is the last portion of the general partition to be closed, the foramen ovale remaining open until birth.

Fœtal Circulation.—In late fœtal life the arterialized blood from the placenta passes through the single umbilical vein to the liver. Some of the blood is carried by the ductus venosus straight to the inferior vena cava, the remainder reaches the cava after traversing the hepatic portal system. It is poured into the right auricle by the inferior vena cava, and is guided by

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Roy and Graham.—"Blood Pressure and its Variations in the Arterioles, Capillaries and Smaller Veins," *Jour. of Phys.*, vol. ii. 323.

Brown.—"Construction of the Ventricles in the Mammalian Heart," *Jour. of Anat. and Phys.*, vol. xxiii. p. 250, 1889.

the Eustachian valve to the foramen ovale, through which it enters the left auricle. The blood from the superior vena cava falls across in front of this stream, through the right auriculo-ventricular aperture into the right ventricle. The two streams of purified and impure blood do not again mingle until they reach the spot where the fifth arch on the left side (the pulmonary artery and ductus arteriosus) unites with the common dorsal aorta, by which time the aortic arch has given off the vessels which carry pure blood to the head.

The tissue which supports the four sets of valves is destitute of muscular fibre. It consists in Man of dense fibrous tissue; in some animals it is cartilaginous or even ossified. Hence it constitutes a plate composed of four rings, lying at right angles to the long axis of the heart. To these rings the valves are attached. They also give attachment to most of the muscular sheets of which the walls of the auricles and ventricles are composed.

The muscular fasciculi of the auricles loop over from one side of the fibrous plate to the other. Superficial fibres also encircle both auricles by common bands which are not connected with the fibrous plate. Annular fibres encircle all the apertures by which vessels open into the auricles, as well as the auricular appendages.

The fasciculi of the ventricles may be divided into two classes which pass insensibly into one another.

A. The annular fibres which occur in the thickest (middle) part of the ventricular wall, and are (*a*) common to both ventricles, (*b*) peculiar to each ventricle.

B. Oblique fibres, which on the anterior surface pass downwards to the left, turn in at the "vortex," and ascend again on the inner surface of the ventricle. For the most part, the front fibres of the left ventricle ascend on the internal surface of the posterior wall of the right ventricle, and *vice versa*. Many of these fasciculi enter the musculi papillares.

The looped fibres are connected with the fibrous plate.

By their contraction they lift the apex upwards, forwards, and to the right, rotating it slightly on its long axis.

Change in Form of the Heart during Contraction.

"The heart erects itself" (*Harvey*).

In diastole the cross-section of the ventricular portion is oval. It becomes round during systole. Is the long diameter altered?

It used to be said that it shortens.

Pro. Three needles passed through the chest wall into the heart. During systole the point of the one passed into the base (*a*) is depressed. The point of the needle (*b*) passed into the middle of the ventricle is depressed, but less than (*a*). (*c*) Passed into the apex, remains stationary.

∴ The base descends towards the apex.

Con. If (*a*) the shape of the heart in diastole is represented by a plaster cast of dog's heart distended under mean pressure (150 mm. Hg), and this be compared with

(*b*) A heart set in heat-rigor in hot potassic bichromate to represent systole, it is found that :—

Mills.—"Physiology of the Heart of the Alligator," *Jour. of Anat. and Phys.*, vol. xx. p. 549, 1886.

Mills.—"Physiology of the Heart of the Snake," *Jour. of Anat. and Phys.*, vol. xxii. p. 1, 1887.

Roy and Adami.—"Contributions to the Physiology and Pathology of the Mammalian Heart," *Brit. Med. Jour.*, 1892, No. 1626, p. 428; *The Lancet*, 1892, No. 3574, p. 455.

Ransom.—"Cardiac Rhythm of Invertebrata," *Jour. of Phys.*, vol. v. p. 261.

M'William.—"Rhythm of the Heart of Fishes," *Jour. of Phys.*, vol. vi. p. 192, and vol. ix. p. 167.

In *b* the long diameter equals that of *a*. All its transverse diameters are less than those in *a*. The circumferences of the auriculo-ventricular valves are greatly diminished.

Mechanism of the Valves.

Function of musculi papillares. *Older view*:—The margins of contiguous valves are fixed by chordæ tendineæ to prevent their eversion into the auricles during contraction. (The auriculo-ventricular apertures are of very large size, in order that the blood may be discharged from the auricles into the ventricles with as little delay as possible. This rapidity of action is gained at the expense of strength.)

The musculi papillares contract simultaneously with the ventricular wall to prevent relaxation of the chordæ tendineæ.

Con. 1. Long axis of the heart is not diminished.

2. Musculi papillares do not contract at the same time as the rest of the ventricular wall.

New Theories.—A. They contract before the ventricle, act obliquely, draw margins of contiguous valves together, and hence bring the valves into place (*Moens*).

If this be true, the systole of the mammalian heart begins in the sinus venosus, spreads over the auricles, is interrupted by the fibrous plate, starts again at the musculi papillares, spreads downwards to the apex and upwards to the base.

Pro. The electric variation of the whole mammalian heart is diphasic (*Reid* and *Waller*). This indicates a break in the contraction-wave; that it spreads from the veins to the auriculo-ventricular groove, and then from the apex to the groove. Anatomically the apex intervenes between the musculi papillares and the base.

B. It has been suggested that they are the last parts of the ventricle to contract.

Pro. The apex of the primary wave appears to be thrown above the top of the general ventricular curve, as if by such a sudden final effort.

Such action seems to be needed to expel the blood which must otherwise accumulate behind the auriculo-ventricular valves.

CARDIAC IMPULSE.

Felt in 5th interspace, midway between the mammillary and parasternal lines, when the subject stands upright.

Moves to left when subject lies on left side, to right when on the right side.

Higher in children, lower in old people.

Cause: Pressure of anterior surface of right ventricle (not the apex but spot about $\frac{3}{4}$ inch from apex), against chest wall due to:—

(1) Erection of heart.

(2) Recoil of heart from blood column.

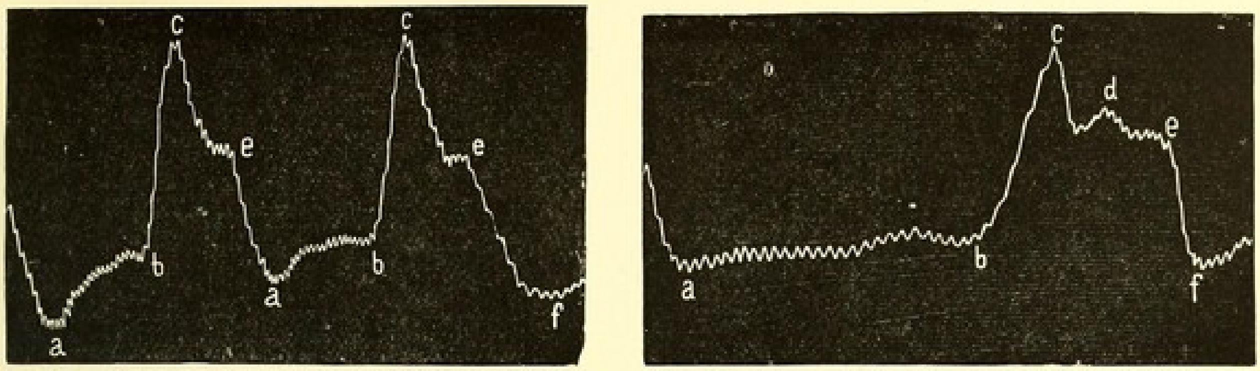
Cardiogram: tracing of impulse.

Burdon Sanderson and Page.—"Time Relations of the Excitatory Process in Ventricle of the Heart of the Frog," *Jour. of Phys.*, vol. ii. p. 384; vol. iv. p. 327.

Waller.—"Electromotive Changes Connected with the Beat of the Human Heart," *Phil. Trans.*, 1889, B., p. 169, and *Jour. of Phys.*, vol. viii. p. 229.

Bayliss and Starling.—"The Electromotive Phenomena of the Mammalian Heart," *Brit. Med. Jour.*, 1891, No. 1595, p. 186.

Fenwick and Overend.—"Report on the Contraction of the Papillary Muscles, and its Relation to the Production of Certain Abnormal Cardiac Sounds," *Brit. Med. Jour.* 1891, No. 1586, p. 1117.



FIGS. 8 and 9.—Cardiographic tracings of the impulse of the heart, recorded on a blackened plate borne on the end of a vibrating tuning-fork. *ab*, Systole of auricles ; *b–e*, systole of the ventricles ; *d*, closure of aortic, and *c*, of pulmonary valves *or*, *e*, closure of aortic and pulmonary valves.

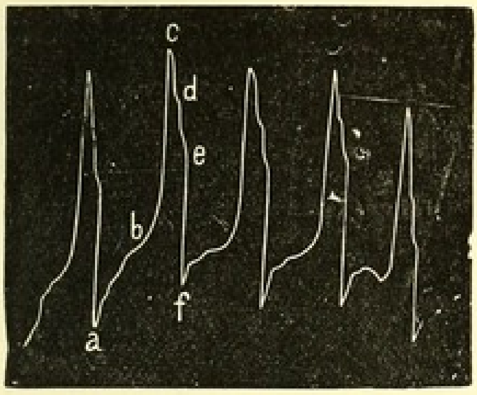


FIG. 10.—A normal impulse-tracing. *Lettering as in figs.* 8 *and* 9.

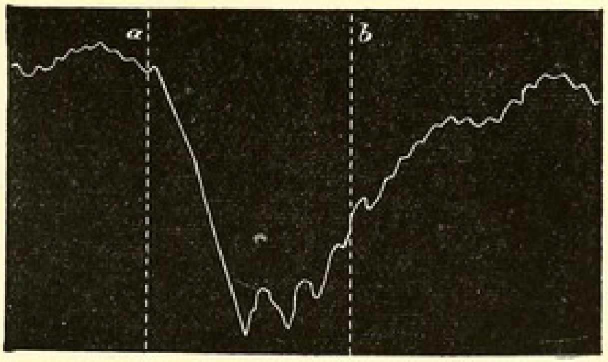


FIG. 11.—Effect upon the blood-pressure of stimulating the vagus nerve from *a–b*.

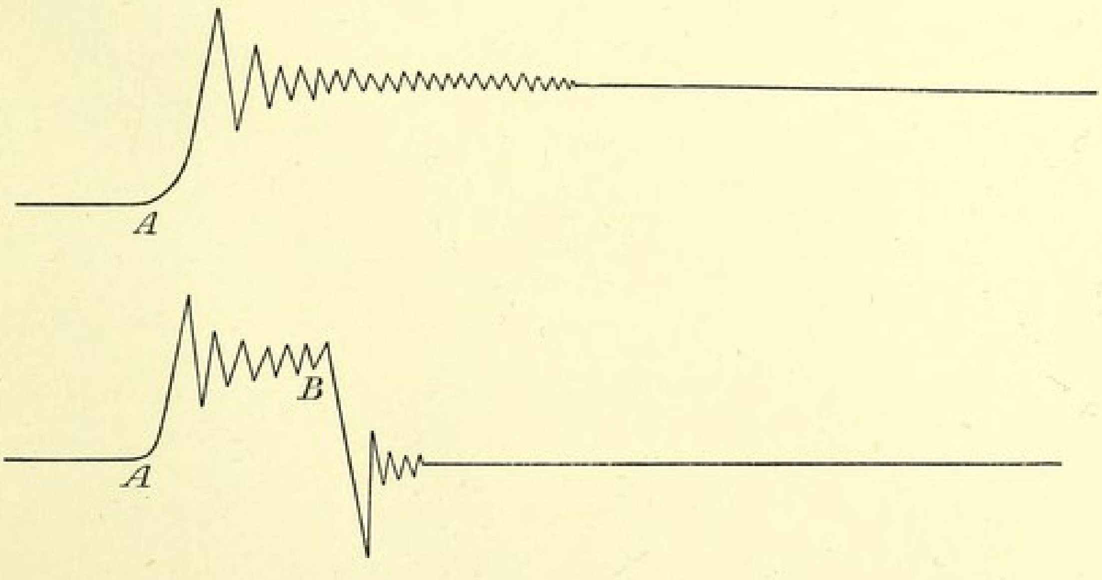
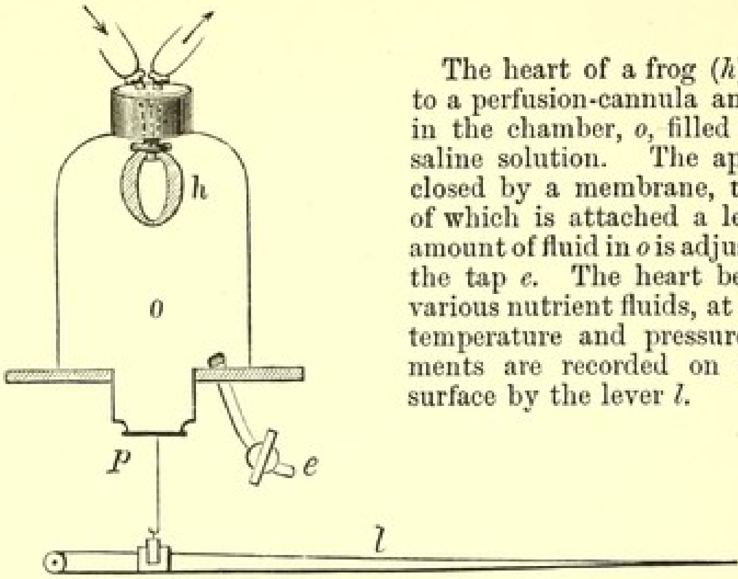


FIG. 12.—The primary and secondary waves produced by suddenly turning a stop-cock—on at A, off at B.

To face p. 22.]

PLATE V.



The heart of a frog (*h*) is attached to a perfusion-cannula and suspended in the chamber, *o*, filled with normal saline solution. The aperture, *p*, is closed by a membrane, to the centre of which is attached a lever, *l*. The amount of fluid in *o* is adjusted through the tap *e*. The heart being fed with various nutrient fluids, at any required temperature and pressure, its movements are recorded on a blackened surface by the lever *l*.

FIG. 13.—Roy's heart-tonometer.

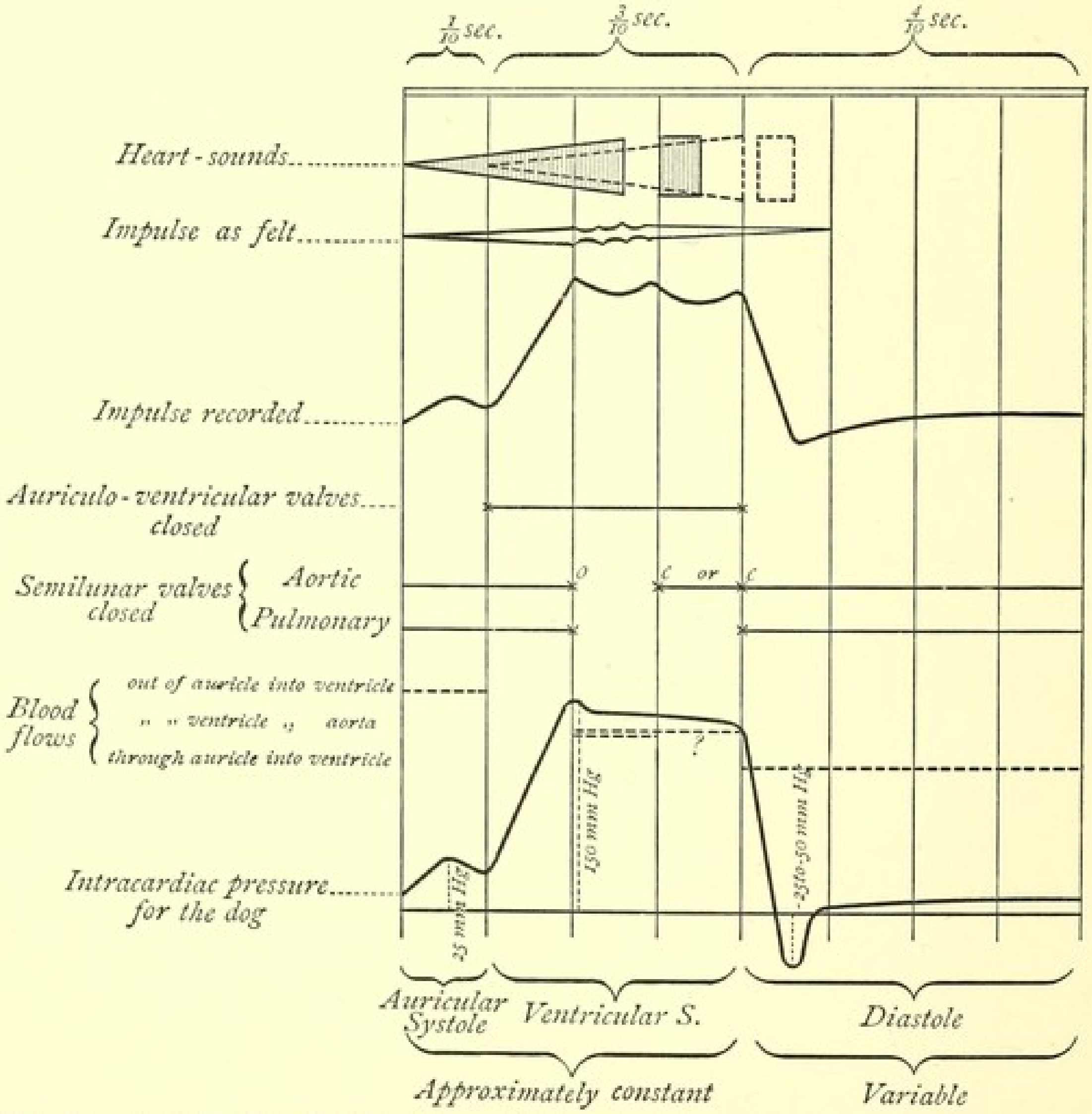


FIG. 14.—A table showing the time-relations of the events which occur during a complete cardiac cycle; the heart beating 75 times in a minute. The vertical lines mark tenths of a second, and the cycle is divided into eight parts.

The exact times at which the heart-sounds are heard and at which the aortic valves close, as well as the meaning of the three peaks on the cardiogram, are uncertain. *For the discussion of these questions see pp.* 23 *and* 24.

[*To face p.* 23.

Apparatus.—Cardiographs of various form, but all presenting a button to rest over the spot at which the impulse is felt; spring to depress the button, adjustable; tambour; tube communicating with a recording tambour.

The tracing shows—

A. That the heart is never still; each chamber begins to fill as soon as it is emptied.

B. Ventricular systole immediately follows auricular systole.

C. A pause intervenes between ventricular and succeeding auricular systole.

The length of this pause ∝ inversely as the rapidity of the beat. The total length of the systole is very little affected by rapidity of beat.

Details of the cardiac movements about which there is still some uncertainty.

The tracing (consult figs. 8, 9, 10, and 14) is divisible into—

A. Auricular systole.

Often showing smaller waves due to (?) asynchronism of the two auricles, or (?) of their several parts (mouths of venæ cavæ, appendages, atria proper).

B. Ventricular systole.

Showing (*c*, figs. 8, 9, 10) forcing of semilunar valves.

d and *e*. Closure of aortic and pulmonary valves respectively, the former closing first owing to blood pressure being higher in aorta than in pulmonary artery.

or (*d*) Closure of valves; (*e*) recoil of blood-column, followed by relaxation of ventricle.

or (*e*), or possibly even a later notch marks the closure of both sets of semilunar valves.

The question as yet under discussion is—How long is the blood in passing through the semilunar valves? It cannot begin to pass until the pressure in the ventricle exceeds the pressure in the aorta. It cannot continue to pass after the pressure in the ventricle falls beneath the pressure in the aorta.

Does the ventricle remain contracted after all its blood has left it?

The shortness of the pulse-wave in the vessels near the heart argues that it does.

C. Pause; ventricle filling.

It is very important to notice that the cardiac cycle is not a see-saw between auricles and ventricles, but blood flows from veins into auricles during ventricular systole, goes through auricles into ventricles during pause, out of auricles into ventricles during auricular systole. Auricles store blood during ventricular systole.

Sounds of Heart.—Lūbb dúp.

Tone.—First sound, a minor third lower than second; the two being respectively about G and B flat below the middle C, but the first sound being higher over the sternum, lower over the epigastrium. It is impossible to eliminate resonance-tones of chest, stethoscope, and ear.

Duration.—1st sound coincident with impulse (systole), lasts about $\frac{4}{10}$ of cycle; interval of $\frac{1}{10}$; short second sound; pause of $\frac{3 \text{ to } 4}{10}$.

Waller and Reid.—"The Action of the Excised Mammalian Heart," *Trans. Roy. Soc.*, 1887, p. 215.

M'William.—"The Rhythm of the Mammalian Heart," *Proc. Roy. Soc.*, 1889, pp. 206 and 287.

Haycraft.—"The Movement of the Heart within the Chest Cavity and the Cardiogram," *Jour. of Phys.*, vol. xii. p. 438.

Yeo and Barrett.—"Cause of the First Sound of the Heart," *Jour. of Phys.*, vol. vi. p. 145.

Haycraft.—"The Cause of the First Sound of the Heart," *Jour. of Phys.*, vol. xi. p. 486.

Causes.—1st sound has been assigned to—

A. Impact with chest wall.

Con. Heard after chest wall has been removed.

B. Rush of blood through heart.

Con. Not obliterated by clamping great veins.

C. Vibration of mitral and tricuspid valves.

Pro. Altered (obscured by murmurs) when either of these valves is diseased or hooked up by a wire.

Con. Is not completely absent in a dog's heart rapidly removed from the body and empty of blood.

D. Muscular sound.

Pro. Has somewhat the character of muscular sound.

Con. Contraction of heart is not a tetanus, *i.e.*, is not directly vibratile or sound-producing.

Note is much higher than that produced by voluntary muscle when contracting (192 vibrations as against 40 vibrations).

E. A combination of causes, of which C and D are the chief.

Pro. 1. *Wintrich* by resonators distinguishes the deeper longer muscular note from the higher sharper valvular note. (The muscular note, as understood by him, is chiefly made up of added resonance-tones of the ear, &c.).

2. *Haycraft* points out that the first sound heard in a bloodless heart is lower than that of a heart in which the valves are still acting.

Intracardiac Pressure.—Taken by passing a tube which ends in an india-rubber ampulla, through a vessel into the cavity, the pressure in which is to be determined. For the left ventricle the tube is passed down the carotid artery. The right ventricle is entered through the jugular vein. The right auricle in the same way, or a double tube carrying two ampullæ, is so placed that one ampulla is in the right auricle, the other in the right ventricle. The tubes communicate with tambours, which carry levers.

Pressure in right auricle of dog	– 12 mm.	to + 20 mm. Hg.
,, ,, ventricle of dog	– 17 mm.	to + 60 mm. Hg.
,, left ventricle of dog	– 52 (to – 20 mm.)	to + 140 mm. Hg.

Cause of negative pressure: elastic relaxation of forcibly contracted heart; like the return to its original form of a compressed sponge when the pressure is removed.

Pulse.

Definition.—The alteration in the shape and calibre of an artery, due to the sudden increase in blood-pressure, caused by the systole of the left ventricle.

In the radial artery the cross section becomes very slightly larger during the passage of the pulse-wave. The pulse, as felt by the finger or recorded by a sphygmograph, means more than this; between the waves the vessel is compressed by the pressure of the finger or by the spring of the sphygmograph; during the passage of the wave its cross section becomes round instead of oval; the finger or the button of the sphygmograph is raised by the pressure of the blood in the vessel.

Cause.—The lift given to the fluid-column by the contraction of the heart.

Gaskell.—"Tonicity of the Heart and Great Vessels," *Jour. of Phys.*, vol. iii. p. 48.

Rolleston.—"Observations on the Endocardial Pressure Curve," *Jour. of Phys.*, vol. viii. p. 235.

If the blood were enclosed in rigid vessels the "lift" would be felt simultaneously throughout the whole system (liquids are incompressible).

Since the blood is enclosed by extensible and elastic walls, the force of the heart's beat is resolved into two factors :—

1. Onward pressure.
2. Lateral pressure, consumed in overcoming the elasticity of the vessel-wall.

The wall recoils and the lateral pressure is added to the force which is being transmitted onwards.

The conditions are the same as they would be if a blow were given to one end of a solid rod of elastic material.

A delay of 1 sec. in every 10 metres is incurred in distending the vessel, *i.e.*, the rate at which the pulse-wave travels is 10 m. per sec., but clearly the rate depends upon the elasticity of the vessel-wall.

The length of the pulse-wave is about 5 m.

> If a pulse-tracing were recorded upon a blackened plate, travelling at the same rate as the pulse, a true reproduction of its form would be obtained. In all sphygmograms the wave is immensely fore-shortened.

The pulse is *not* the onward flow of the blood. Nor is it, on the other hand, a simple wave of percussion.

It is a sudden push given to an elastic column.

Physics :—

The height of the wave is gradually reduced by the "damping" effects of the comparatively inelastic tissues.

Its length $\propto$ time taken by the blood in passing the aortic valves :—

Its velocity depends upon B.-P., owing to the effect of pressure upon the vessel.

" " $\propto \sqrt{\text{elastic coefficient of the vessel.}}$

" " $\propto \sqrt{\text{thickness of the wall.}}$

" " $\propto \dfrac{1}{\sqrt{\text{specific gravity of the blood.}}}$

" " $\propto \dfrac{1}{\sqrt{\text{diameter of the artery.}}}$

Secondary Pulse-waves.

If an elastic tube is connected with a tap having a quickly acting stop-cock, the pressure in the tube rises suddenly when the cock is turned on. Owing to the inertia of the fluid, it exceeds at the first instant the ultimate mean pressure. The pressure reaches a level by a series of oscillations. When the cock is turned off, the column of fluid is carried onwards by its inertia, and, for an instant, the pressure at the cock falls below that of the atmosphere. It regains the atmospheric pressure by a series of oscillations.

The action of the heart resembles that of a stop-cock turned suddenly on and then suddenly off again (fig. 12).

The flat surfaces of the semilunar valves are more favourable than a stop-cock for the reflection of the blood after its recoil.

Further, the blood-stream is not merely cut off, but after it is cut off, owing to the elasticity of its enclosing walls, it travels backwards to shut-to the valves.

Broadbent.—"The Pulse," London, 1890.
Roy.—"The Form of the Pulse Wave as studied in the Carotid of the Rabbit," *Jour. of Phys.*, vol. ii. p. 66.
De Jäger.—"Hæmodynamics," *Jour. of Phys.*, vol. vii. p. 130.

∴ In addition to the primary wave which represents the sudden increase of pressure, caused by the expulsion of the contents of the left ventricle into the aorta, the pulse shows secondary waves of two kinds; those marking (*a*) the reception of the ventricular contents in the aorta; (*b*) the end of the column passing the semilunar valves.

Apparatus for recording the pulse.

The sphygmograph was invented by Marey. Various forms of sphygmograph are now in use, all consisting essentially of a button (*a*) which is pressed against the artery (the radial) where it lies between a bone and the skin by (*b*) a spring, the amount of pressure exerted by which can be (1) regulated, and (2) estimated; an arrangement (*c*) for transferring the movements of the button to a lever, (*d*) which can be so adjusted as to write, whatever the position of the button, upon a travelling surface (*e*).

A Sphygmogram shows a primary wave varied by a series of secondary waves. Of the latter, several waves which have characteristic forms in disease, have received names indicative of their position on the curve. The chief secondary wave in health is called :—

The Dicrotic Wave.—This is preceded by the dicrotic notch which separates it from the principal peak, or from an intervening peak called predicrotic.

Position.—It lies lower on the descending limb the farther the tracing is taken from the heart.

Favouring Conditions.—Sudden contraction; low tension.

Cause.—An artificial scheme shows waves of (1) oscillation due to the inertia of the fluid, (2) waves reflected from the periphery.

A. Is it a reflected wave?

Pro. In position it corresponds to a reflected wave, for it appears nearer the end of the pulse the nearer the tracing is taken to the periphery, *i.e.*, to the reflecting surfaces.

Con. 1. The conditions which increase it are unfavourable to reflection.

2. The arteries end (by breaking up into capillaries) in a way which makes reflection impossible.

B. Is it a wave of pure oscillation?

Con. 1. Although the largest it is not the first wave. The predicrotic is a smaller wave, whereas were these secondary waves due simply to the inertia of the fluid, they would diminish progressively in size.

C. Is it an oscillation reinforced by reflection from the semilunar valves?

Pro. When the blood is discharged into the aorta, one main and several oscillatory waves are set up. When the semilunar valves close under the influence of the elasticity of the aortic wall, the blood which falls back with the valves returns to the aorta as a fresh wave.

Drawback to all sphygmograms: waves are originated, or altered by inertia of the machine. These additions may be avoided by taking a hæmautograph, *i.e.*, by allowing blood to jet out of a cut artery on to a travelling paper.

The Pulse varies in rapidity, in rhythm, in force, in character (whether sustained or sudden), and in the relative prominence and sequence of its secondary waves.

The Pulse teaches us the rapidity, rhythm, force, and character of the heart's beat, the efficiency or otherwise of the cardiac valves, and also the condition of the walls of the arteries, whether they are extensible or rigid, elastic or inelastic.

Martin and Sedgwick.—"Pulse-waves in the Coronary Arteries," *Jour. of Phys.*, vol. iii. p. 165.

Roy.—"Elastic Properties of the Arterial Wall," *Jour. of Phys.*, vol. iii. p. 125.

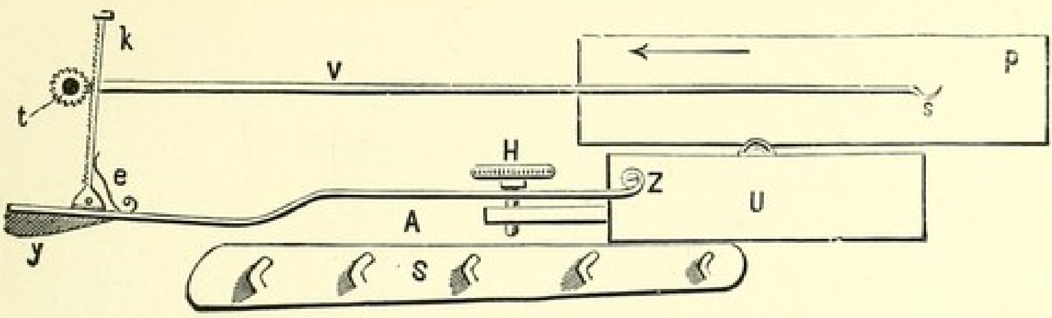


FIG. 15.—Diagram exhibiting the principles of construction of Marey's sphygmograph. S, the plate by which it is fixed to the wrist; *y*, an ivory button which rests upon the radial artery, carried by the spring, A, the amount of pressure exerted by which is adjusted by the thumb-screw H; *e*, a light spring which keeps the toothed rod, *k*, in contact with the cog-wheel, *t*; V, the style which writes upon a blackened plate, P, moved by clock-work contained in the box, U.

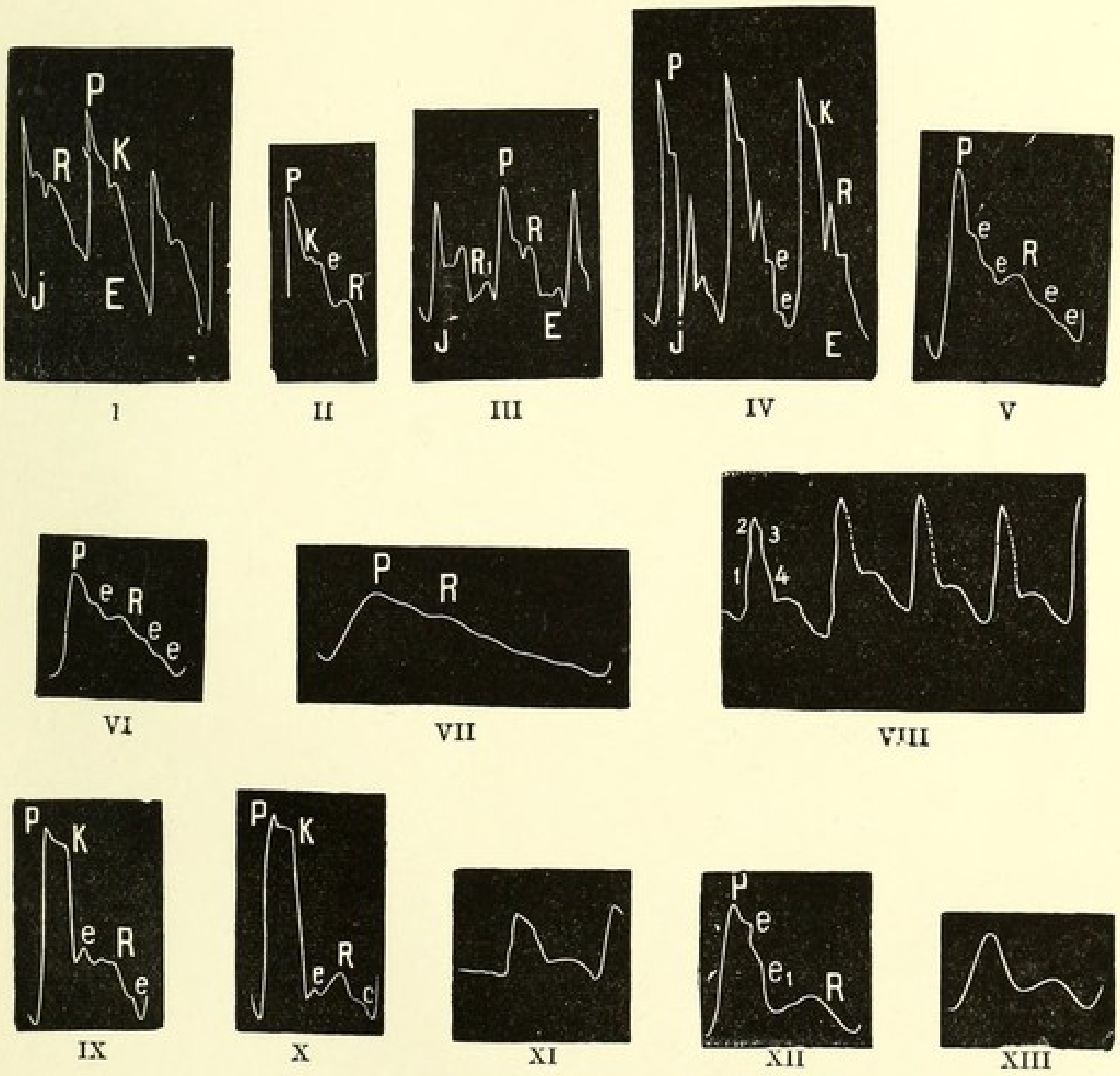
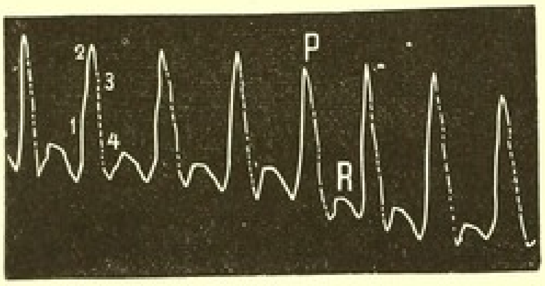
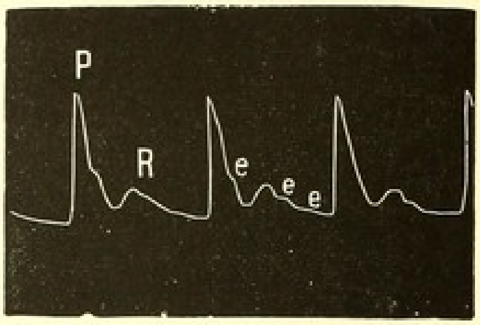


FIG. 16.—Sphygmograms. I, II, III, from the carotid artery—P, the primary wave or apex; K, the predicrotic wavelet; R, the dicrotic wavelet; *e*, *e*, oscillations due to the elasticity of the arterial wave; J, a pulse-wave on the inspiratory limb of the respiratory curve; E, on the expiratory limb. IV, Tracing from axillary artery; V to VIII, from the radial; IX and X, from the femoral; XI, from the posterior tibial; XII and XIII, from the dorsalis pedis.

To face p. 26.]



I



II

Fig. 17.—I, A markedly dicrotic sphygmogram from the radial artery, in fever. II, A healthy, but extreme low-tension radial pulse; contrast this with the high-tension pulse VI, and the pulse of a rigid artery VII.

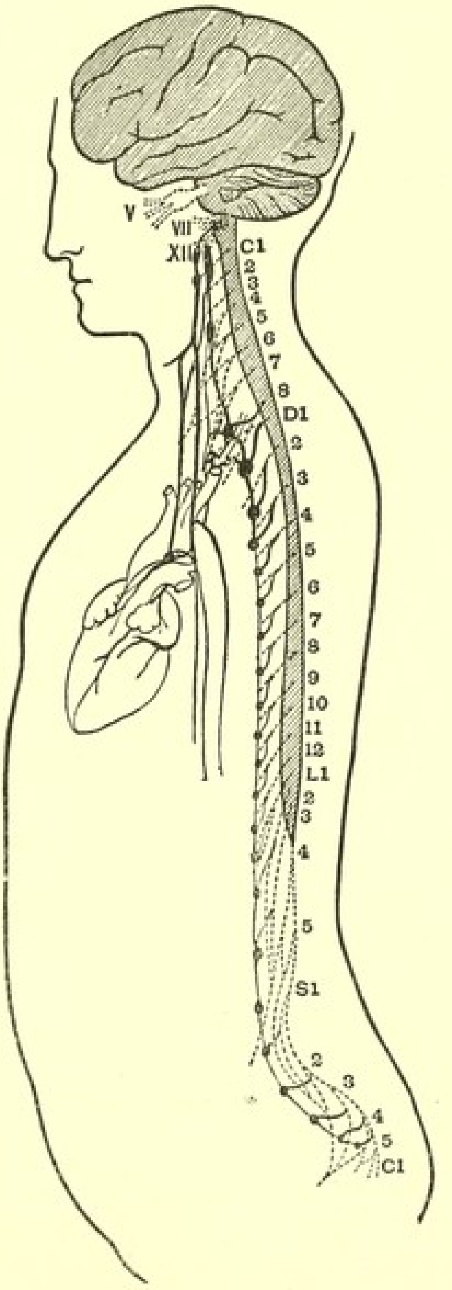


Fig. 18.

Fig. 18.—Diagram of the nerves of the heart, showing their relations to the cerebro-spinal axis and to the sympathetic chain.

The cranial nerves, V, VII, and XII, and all the spinal nerves, are indicated by dotted lines; the sympathetic chain by unbroken lines.

Below VII is seen the origin, from the medulla, of the vagus nerve. This nerve enlarges into the ganglia jugulare et cervicale. After giving off the superior laryngeal it supplies several nerves to the heart. The most important of those derived from the left vagus leave its recurrent laryngeal branch as it curves beneath the arch of the aorta to join the ganglion Wrisbergi. In front of the vagus trunk is seen the "superior cervical cardiac of the sympathetic" of human anatomy, which corresponds, probably, to the depressor nerve of the rabbit, cat, &c. Sympathetic branches from the middle and inferior cervical ganglia enter the posterior aortic plexus. They are derived from the upper dorsal rami communicantes through the ansa Vieussenii (which is represented as surrounding the inferior thyroid artery) and the ganglion stellatum.

The diagram is simplified by the omission of many intercommunicating branches.

[*To face p.* 27.

Difficulties in interpreting the Sphygmogram.—When the sphygmograph was first introduced, it was supposed that a tracing would give a permanent record of the condition of the vascular system, which could be easily compared with records taken from the same individual at different times, or with records from other persons. This expectation has not, as yet, been fulfilled, owing to the want of a canon for the interpretation of sphygmograms. The difficulties are of two kinds :—

1. Owing to the fact that so many causes act at the same time, it is impossible to estimate the part which each plays in producing the tracing. *E.g.*, Is the height of the curve due to the force with which the heart is beating or to the extensibility of the arterial wall ?

2. The form of the tracing depends upon the amount of pressure exerted by the spring of the sphygmograph upon the artery.

It is impossible to fix a standard pressure, for some features of the curve are only brought out when the pressure is high, others when the pressure low.

Classification of pulses of healthy people into two main groups.

A. High-tension pulses which indicate that each beat of the heart is forcible and well sustained ; that the valves are efficient ; that the blood is abundant in quantity ; that the arterial wall is elastic, and its muscular tissue (especially in the minute arteries) partially contracted ; that the capillary area is not abnormally open.

B. Low-tension pulses which indicate that one or more of these conditions is reversed.

The nearest approach to a definition of the features of the sphygmogram which indicate " tension," would be based upon the relation which the mean breadth of the tracing bears to its height : or, with various qualifications, upon the area circumscribed by the tracing.

HEART : NERVOUS MECHANISM.

Frog.—Right and left vagi only.

The two nerves enter the ganglionic ring at the junction of the sinus venosus and auricles. From these groups of ganglia (which collectively make up Remak's ganglia) the nerves pass respectively down the front and the back of the inter-auricular septum to two ganglia (Bidder's ganglia), which lie at the base of the auriculo-ventricular valves.

Function.—Stimulation of either vagus causes slowing or standstill of the heart. It therefore contains inhibitory fibres.

Effect sometimes ambiguous.

After injection of $\frac{1}{30}$ grain of nicotin, stimulation of vagus causes acceleration, the inhibitory fibres being paralysed (*Schmiedeberg*).

∴ The vagus also contains sympathetic accelerator fibres. They join the nerve immediately on its passing through the skull.

Reflex excitation of the vagus through the nervi mesenterici is obtained by tapping the exposed intestines.

Ineffective if the sympathetic chain has been divided opposite the junction of the two aortæ ; the cord divided below the medulla ; or the vagi cut.

Gaskell.—" Innervation of the Heart of the Tortoise," *Jour. of Phys.*, vol. iii. p. 369 ; vol. iv. p. 43 ; vol. v. p. 362.

∴ The route for reflex inhibition is in this experiment—mesenteric nerves—sympathetic ganglia at the level of the sixth vertebra—rami communicantes (at this level or higher)—spinal cord—medulla—vagi nerves.

Stannius' Experiment.

1. A ligature is drawn tightly round the junction of the sinus venosus and right auricle. The heart on the distal side of the ligature comes to a standstill. The sinus venosus continues to beat.

2. If the ventricle is severed from the auricles, by a second ligature, it at once begins to beat, while the auricles remain passive.

Several explanations of these results have been given.

A. That the first ligature stimulates an inhibitory mechanism, while the second removes the ventricle (with its automatic mechanism) from the influence of this inhibitory mechanism.

Con. Atropin does not prevent the first ligature from producing standstill.

B. That the motor mechanism for the whole heart lies in the sinus venosus.

1st section cuts off auricles and ventricle from the governing centre, and the severed portion of the heart does not contract in the absence of the commands by which it is usually governed.

2nd section sets free the ventricle which contains an automatic mechanism sufficiently powerful to work it when it is not looking to the sinus venosus for orders.

Con. More exact observations show that the movements of the ventricle which occur after the second ligature cannot properly be assigned to its rhythmic contraction, but the rapid irregular beats are due to the stimulus of the scissors or ligature.

C. The truth is that all the muscular tissue of the heart contains in itself a potentiality of rhythmic contraction. This tendency to contract at intervals is strongest in the sinus venosus, less strong in the auricles and least strong in the ventricle. A severed auricle and ventricle will after a time beat with regular sequence and rhythm, although more slowly than the whole heart. A severed ventricle beats irregularly.

The cause of the beat must be looked for in the heart itself.

Pro. (1) A strip from the ventricle of the tortoise' heart has been attached to a light lever by *Gaskell*, and seen to go on contracting for two days.

(2) The apex of the frog's heart, in which there are no nerves, will continue to beat if fitted with a perfusion-cannula which allows serum or other nutrient fluid to circulate through its cavity.

It appears that the muscular tissue takes nutrients from the circulating fluid, since it soon tires if supplied with salt-solution, but continues to beat if supplied with serum, or even with salt-solution containing albumen.

It appears also that the pressure of these fluids acts as a stimulus. If a ligature be drawn tightly round the ventricle *in situ*, and then removed, the ventricle does not recommence to beat although supplied with blood at a normal pressure (*Bernstein*).

With this apparatus the action of poisons on the heart-tissue can be investigated.

The rhythmic contraction of the whole heart is conducted from part to part by muscle.

Pro. A clamp which compresses the heart in the auriculo-ventricular groove, by preventing conduction of stimulus, destroys the synchronism of the auricles and ventricle, with the result that they beat at different rates.

Behaviour of frog's heart-muscle to stimuli, and comparison with skeletal muscle.

Unlike skeletal muscle, the muscle of the heart cannot be made to contract by stimulation of any nerve. It can be directly stimulated mechanically, chemically, thermally, or electrically.

The latent period is long (0·3 sec.), but variable. There is no proportion between the amount of the stimulus and the force of the beat. If the muscle reacts at all it gives a full (maximum) contraction.

If the stimulus falls during the "refractory period," *i.e.*, the early phase of contraction, it produces no effect at all.

It cannot be thrown into tetanus.

∴ The beat of the heart is a peristaltic wave of contraction which passes down from the sinus through the auricles and ventricle to the bulbus aortæ. It spreads from fibre to fibre. It is delayed at the junctions of the chambers, owing to some increased difficulty of conduction, so that it appears to be not a continuous wave but a sequence of contractions.

Conduction is by muscle, not by nerve.

Pro. Zigzag cuts do not prevent the spread of the contraction wave (*Engelmann*), which is conducted in any direction at the rate of 10 to 15 mm. per sec.

Although striated, both longitudinally and transversely, the muscular tissue of the heart differs in a marked degree from skeletal muscle. It is made up of single cells with large oval central nuclei, not of large multinucleated cells. The cells are destitute of sarcolemma; they branch, and the branches of neighbouring cells fuse. Impulses therefore spread from fibre to fibre, and do not need to be delivered separately to each fibre, as in the case of voluntary muscle.

What are the Functions of the Nerve-Cells?

We have no evidence of any function except the multiplication of nerve-fibres, and especially the division of a medullated fibre into a number of non-medullated fibres.

This holds good not only of the cells of the heart, but also of the cells of other ganglia, as the ganglia of the sympathetic chains, the submaxillary ganglion, ganglia of the intestines and elsewhere.

What are the functions of the nerves of the heart?

To regulate the tendency of the heart-muscle to contract in two different ways.

A. The "sympathetic" fibres are katabolic in action.
1. They accelerate the rhythm.
2. They augment the force of contraction.
3. They increase the conductivity of the muscle.
4. They diminish the distension of the heart.

B. The vagus is anabolic in action.
1. It retards the rhythm.
2. It reduces the force of contraction.
3. It depresses conductivity.
4. It increases the distension in diastole, and the quantity of blood which remains in the ventricle in systole.

∴ A and B are antagonistic. A increases the activity of the heart, and leads to its exhaustion by inducing it to put out more force than

Roy and Adami.—"Physiology and Pathology of Mammalian Heart," *Phil. Trans. Roy. Soc.*, vol. clxxxiii. (1892), B., pp. 199–298.

it is storing in contractile materials; B relieves the heart of work, and therefore of waste, to as great an extent as is compatible with the maintenance of the circulation. The readiness with which the vagus is called into activity by (1) increased blood pressure, and (2) increased intracranial pressure (cerebral congestion), show that it acts chiefly in the interests of the heart and the central nervous system.

The Mammalian heart is supplied by two sets of nerves, of which, at any rate, one contains both afferent and efferent fibres. The cardiac nerves in Man may be classified as follows (fig. 18) :—

A. "Sympathetic" fibres form a plexus in front and a plexus behind the aorta and pulmonary artery, and the fold of pericardium in which these two large vessels are contained. A richly ganglionated plexus is continued over the front and back of the heart, especially along the course of the two coronary arteries.

Roots of these plexuses.

a. Efferent branches from the inferior cervical ganglion and ganglion stellatum (first dorsal) which have left the spinal cord by the anterior roots of the upper dorsal rami communicantes as fine medullated nerves (2μ–3μ in diameter), having lost their medullary sheaths in the cells of the ganglia above-named, pass through the annulus Vieussenii (which surrounds the subclavian artery or one of its large branches) into the posterior plexus. When the cervical sympathetic chain bears a middle ganglion, a branch from this also goes into the posterior plexus.

b. A branch (the superior cardiac) which consists, in all probability, of afferent fibres only. It connects the posterior plexus with the superior cervical ganglion of the right side, and the anterior plexus with that of the left side. This is the "depressor" nerve. It contains numerous medullated fibres, of which the greater number leave the trunk before it reaches the sympathetic ganglion, and join the superior laryngeal branch of the vagus nerve. This nerve is, in reality, therefore a branch of the vagus. It seldom takes a direct course from its roots to the heart, but forms connections with the other cervical ganglia or their branches.

B. Vagus fibres.

Cardiac branches leave the vagus shortly below its cervical ganglion; others come off from the recurrent laryngeal. Those from the left vagus go into the anterior plexus, those from the right vagus into the posterior plexus.

The cerebro-spinal roots of the vagus cardiacs do not belong to the vagus properly so-called, but to the accessorius vagi. They can be easily distinguished by the small diameter of the fibres which they contain. The muscular fibres of the accessorius are about ten times as thick as its visceral fibres.

Influence of these nerves on the heart-beat.

A. The efferent sympathetic fibres are accelerator. They lose their medullary sheaths at a distance from the heart. They can be stimulated by an interrupted current; are much more effective when at a natural temperature than when allowed to get cold; have a long latent period, and a cumulative and long continued action.

Gaskell.—"Augmentor Nerves of the Heart," *Jour. of Phys.*, vol. v. p. 46.

Gaskell.—"Electric Changes in Quiescent Cardiac Muscle which accompany Stimulation of the Vagus Nerve," *Jour. of Phys.*, vol. vii. p. 451.

Gaskell.—"Action of Muscarin upon the Heart, and on the Electrical Changes in the Non-beating Heart, brought about by Stimulating of the Inhibitory and Augmentor Nerves," *Jour. of Phys.*, vol. viii. p. 404.

Sewall and Steiner.—"Depressor Nerve," *Jour. of Phys.*, vol. vi. p. 162.

M'William.—"Inhibition in the Mammalian Heart," *Jour. of Phys.*, vol. ix. p. 345.

B. The efferent vagus-fibres are inhibitory. They retain their medullary sheaths until they reach the heart.

They can be stimulated in various ways. Czermak was able to bring his own vagus into action, by pressing it against a vertebral exostosis.

Latent period is long (0·16 sec. in rabbit). Effect produced is greatest at first, and soon disappears even though the stimulation is continued.

The heart may be slowed (owing to the lengthening of diastole) or actually stopped.

Atropin renders the vagus absolutely ineffective.

As in the case of the frog's heart, the accelerator and vagus fibres seem to affect the nutrition of the heart-muscle, and, consequently, its tendency to contract on its own initiative, rather than to call it into action or to check it directly.

C. The depressor is an afferent nerve. Its stimulation causes a reflex dilation of the visceral blood-vessels with a consequent fall in B.P. Its function is to lower the blood pressure, whenever the heart cannot without injury continue to beat against it, owing either to the weakness of the heart or to the abnormal height of the B.P.

D. That other afferent fibres reach the central nervous system from the heart, is shown by the pain in angina pectoris, as well as by the pain, referred to the neck and shoulder, which results from valvular disease.

Both inhibitory and accelerator nerves may be stimulated in a reflex manner.

A. The vagus. The heart-beat is slowed through this nerve by emotions, such as terror or disgust. Fainting at the sight of blood is not exactly the consequence of a strong feeling, since it is often unaccompanied by any conscious emotion; it must be regarded as a tendency to self-protection; its usefulness, when the blood is flowing from the individual who faints, being obvious. The dependence of this protective tendency upon sex is also interesting.

When the brain is compressed, the vagus is stimulated. Venosity of the blood supplied to the medulla also acts as a stimulus.

Irritation of the viscera, *e.g.* by striking the intestine (Goltz' experiment), inhibits the heart.

Injury to any part of the body, if sufficiently severe, may stop the heart by vagus-inhibition. The great toe and the region about the anus are especially sensitive to this effect.

B. The accelerator nerves are thrown into action in a reflex manner by emotions, but it is difficult to distinguish between reflex stimulation of the accelerator fibres, and reflex removal of the normal inhibition of the vagus. Emotional quickening of the beat appears to be usually due to the latter cause.

Action of Poisons upon the Heart; complicated, because both stimulating and paralysing effects upon both muscular tissue and nervous mechanism have to be distinguished. The most noteworthy poisons may be arranged in two classes.

A. Those which paralyse the endings of the vagus, *e.g.*,

Atropin prevents inhibition by vagus-stimulation. The mechanism which it affects lies in the sinus.

Pro. If in the tortoise a knife be passed through the junction between the sinus and the auricle without cutting the coronary nerve

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Bayliss and Starling.—"On some Points in the Innervation of the Mammalian Heart," *Jour. of Phys.*, vol. xiii. No. 5, p. 407, 1892.

Stewart.—"The Influence of Temperature and of Endocardiac Pressure on the Heart, and particularly on the Action of the Vagus and Cradiac Sympathetic Nerves," *Jour. of Phys.*, vol. xiii. Nos. 1 and 2, p. 59, 1892.

Newell Martin.—"The Influence of Variations in Temperature upon the Rate of Beat of the Dog's Heart," *Trans. Roy. Soc.*, 1883, p. 663.

M'William.—"Fibrillar Contraction of the Heart," *Jour. of Phys.*, vol. viii. p. 296.

(continuation of the vagus from the sinus to the auricle and ventricle), and the vagus then stimulated, the beat of the auriculo-ventricular portion is slowed. If atropin is placed on the sinus, the stimulation of the vagus is rendered ineffective, although no atropin bathes the rest of the heart (*Gaskell*).[1]

Atropin also affects the cardiac tissue itself, or the ending of the nerves in this tissue (a fact which seems to militate against the preceding statement).

Pro. If a detached strip of the auricular wall (to which a lever is suspended) is beating, the beats stop on the application to the muscle of a weak interrupted current. Application of atropin to the strip prevents the interrupted current from inhibiting its action.

B. Poisons which paralyse the motor nerves.

Muscarin and pilocarpin bring the heart to a standstill in diastole.

Schmiedeberg attributed this to stimulation of the vagus-endings, but *Gaskell* shows (1) that when it is applied to the sinus of the quiescent heart, it does not cause the positive electrical variation which stimulation of the vagus produces; (2) that the heart may be stopped by muscarin, but vagus stimulation will still produce a + variation; (3) that the muscarin prevents stimulation of the accelerator nerves from developing the characteristic negative variation.

Nicotin and urari have the same action as atropin in paralysing the vagus, but, although no result follows from stimulating the vagus in the neck, stimulation of the sinus venosus still results in inhibition.

Nicotin paralyses the nerve-cells of the sympathetic, and prevents the passage of impulses through them; hence it prevents inhibition as the result of stimulating the vagus (the fibres of which join nerve-cells in the heart), but does not prevent acceleration as a result of stimulating the sympathetic fibres which have lost their medullary sheaths in the cells of the lateral ganglia.[2]

Muscarin applied to the heart still stops it after the application of nicotin.

Atropin puts an end to the standstill produced by muscarin. It is therefore an antidote to poisonous fungi.

VASOMOTOR SYSTEM: ARTERIES.

The muscular coat of the arteries is always more or less contracted, producing "tone."

Pro. Any influence which paralyses the muscular coat causes the vessel to dilate under blood-pressure.

The smaller the artery the greater is the amount of its muscle in proportion to its total cross section.

The function of the muscle is to regulate the amount of blood which passes through the vessel, therefore the smaller the artery the greater are the possible fluctuations in the amount of blood supplied to the area in which it is distributed.

The contraction of the muscle is induced by impulses passing down vaso-constrictor nerves.

A. Vaso-constrictor nerves: first discovered by *Claude Bernard* in the ear of the rabbit in 1852. Certain effects of their action had been described earlier, but no satisfactory explanation had been given.

Expt. 1. Cut sympathetic in neck. Ear blushes.

[1] *Jour. of Phys.*, vol. viii., 1887, p. 404.
[2] Langley and Dickinson, *loc. cit.* See p. 43.

∴ Either dilator fibres in the sympathetic are stimulated by the section ;
(*Con.* The effect lasts too long ;)
or tonic constrictor impulses are cut off.

2. Stimulate the cephalic end of the sympathetic (*Brown-Séquard*). The ear becomes pale.

∴ Sympathetic contains vaso-constrictor fibres.

This is true of all the nerves which supply cutaneous areas. It is also true of the splanchnic nerves which supply the alimentary canal and its appendages. The vessels of the skin and of the "splanchnic area" are chronically contracted. This contraction may be relaxed in a reflex manner by impulses starting from any particular area which (owing to injury or other cause) needs an increased blood-supply.

3. Stimulate the central end of the great or of the posterior auricular nerve. Ear-blushes ; this is an instance of reflex inhibition of tone.

4. After a time the vessels of the ear on the side on which the cervical sympathetic has been divided, return to their normal calibre.

∴ There exists a local mechanism which governs the vessels of the ear.

5. The local mechanism has a great tendency to rhythmic action ; the vessels may be seen to contract and dilate at regular intervals.

Course of Vaso-Constrictor Fibres (fig. 19).

They leave the cord as small medullated nerves (diam. about 2 μ), in company with the anterior roots of the spinal nerves. In the dog, their outflow is limited to the portion of the cord between the 2nd thoracic and 2nd lumbar nerves. They run in company with, or form a part of, the ramus visceralis to one of the "lateral" ganglia, where they enter distributive nerve-cells ; each medullated nerve which reaches the cell is represented by a bundle of non-medullated fibres which leaves it (*see* "sympathetic nerves," p. 41).

The de-medullated fibres stream along the sympathetic nerves which accompany the arteries ; those for the head and neck forming the, so-called, cervical sympathetic (wrongly supposed at one time to be the continuation upwards of the sympathetic chain).

The constrictor fibres for the heart itself (called "accelerator" nerves) run from the first thoracic ganglion, through the ansa Vieussenii which surrounds the subclavian artery or one of its branches, usually the inferior thyroid, to the posterior cardiac plexus.

The constrictor fibres for the abdominal vessels join the several abdominal plexuses.

The constrictor fibres for the vessels of the spinal column and for the meninges of the central nervous system turn back to the spinal nerves ("grey rami communicantes").

The vagus contains constrictor fibres for the lungs.

The constrictor fibres for the vessels of the upper limb pass from the upper thoracic ganglia to the brachial plexus. For the lower limb they travel from the lower splanchnic nerves to the lumbar and sacral plexuses *via* the lumbo-aortic plexus.

The efferent nerves to the skin are wholly or mainly constrictor, it being the predominant function of the skin to resist loss of heat by the body. The temperature of the body is lowered by the dilation of the cutaneous vessels and flushing of the skin.

Waters.—"Some Vaso-motor Functions of the Spinal Nerves in the Frog," *Jour. of Phys.*, vol. vi. p. 460.

Gaskell.—"Structure, Distribution, and Function of the Nerves which innervate the Visceral and Vascular Systems," *Jour. of Phys.*, vol. vii. p. 4.

Parts more deeply seated have not this function. Their activity is intermittent; increased activity demands an increased blood-supply, and hence the nervous mechanism by which they are governed provides in the main for vaso-dilation: it is not tonic, but acts when required.

B. Vaso-dilator nerves.

Expt. (1) Cut { (*a*) Muscular nerve.
(*b*) Glandular nerve (chorda tympani).
(*c*) Nervus erigens. }

Result: *a*, transient dilation; *b* and *c*, dilation, if present, scarcely visible.

(2) Stimulate *a*, *b*, *c* = dilation.

∴ Dilator nerves are not tonic.

Dilation can be brought into play reflexly, *e.g.*,

(3) Centripetal stimulation of the glosso-pharyngeal nerve results in the reflex dilation of the vessels of the submaxillary gland.

In many other cases dilation occurs in response to efferent stimuli, *e.g.*, (*a*) stimulation of the endings of the vagus nerve in the stomach produces a reflex flushing of its mucous membrane, (*b*) stimulation of the depressor nerve (fig. 18) leads to the dilation of the splanchnic area. In these cases, however, as in the case of a cutaneous area, the dilation is due to the removal of tonic constriction.

Course of Vaso-dilator Nerves (fig. 20).

They have been traced in certain cranial nerves, viz., the fifth (for the eye and nose), the seventh (for the submaxillary and sublingual glands), the ninth (for the parotid gland), the tenth which carries the cardio-inhibitory fibres.

The vaso-dilator fibres for the limbs either accompany the other nerves for the limbs along the roots of the brachial and lumbo-sacral plexus, or, leaving by the rami communicantes, join the roots of the plexus near their exit from the vertebral foramina.

Vaso-dilator fibres for the penis, &c., accompany the roots of the second, third, and fourth sacral nerves.

Vaso-dilator *v.* **Vaso-constrictor Fibres.**

Both leave the cord as small medullated nerves (about 2 μ in diameter), accompanying usually the anterior roots.

Dilator fibres take origin from all parts of the cerebro-spinal axis, pursue a direct course and retain their medullary sheaths for a long distance.

Constrictor fibres are limited in origin to the thoracic and upper lumbar region of the cord; they lose their medullary sheaths early, have an extensive course before joining mixed nerves, or remain always (as in the case of the cervical sympathetic) in contact with blood-vessels.

The two classes differ in mode of action: dilator fibres retain their vitality for a longer time after section, react better to a rhythmic than to a rapidly interrupted or constant current, are stimulated by successive snips, do not so quickly lose their irritability when cooled. The contrary behaviour of constrictor fibres depends apparently upon their not being protected so far by a medullary sheath.

C. Mixed nerves.

Expt. (1) Cut the sciatic nerve: the vessels of the leg and particularly of the foot dilate.

(2) Stimulate the peripheral end of the nerve soon after it has been cut: vessels contract.

Gaskell.—"Vaso-motor Nerves of Striated Muscle," *Jour. of Phys.*, vol. i. pp. 108, 262.

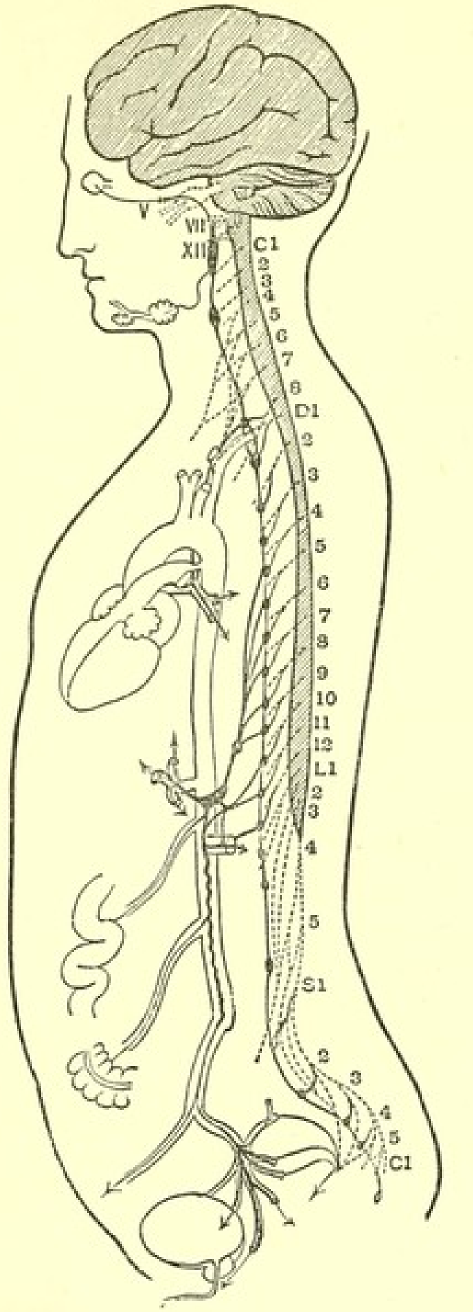


Fig. 19.—Diagram of the vaso-constrictor nerves.

The outflow of these nerves is limited to the dorsal region. They travel up the cervical sympathetic to the head. Those for the upper limbs, neck, and lungs pass through the first thoracic and last cervical ganglia. The great splanchnic conveys fibres to the stomach, liver, and spleen, *via* the semilunar ganglion. Fibres for the small intestine are derived from the semilunar ganglion and also from the lesser splanchnic nerve; fibres for the kidney from the least splanchnic. The splanchnic nerves contribute fibres to the aortico-lumbar plexus, from which are derived all the fibres for the pelvic viscera, the plexus which surrounds the femoral artery, and also for the great sciatic nerve.

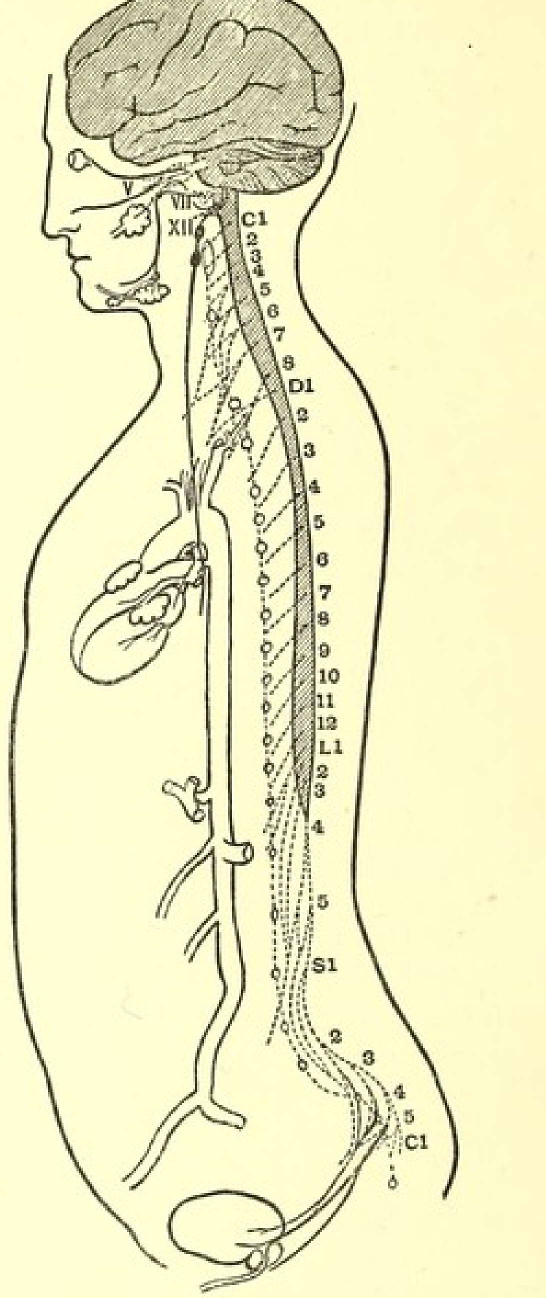


Fig. 20.—Diagram of the vaso-dilator nerves.

They accompany the ophthalmic division of V to the eye; the superior maxillary division of V to the nose; join the auriculo-temporal branch of V from IX; its lingual branch from VII. They accompany X to the thoracic viscera. The nerves for the pelvic viscera and external genital organs are derived from the rami communicantes of the sacral ganglia. Vaso-dilator fibres accompany the large nerve-trunks of the limbs. The course of the vaso-dilator fibres for the abdominal viscera is at present unknown.

[*To face p.* 35.

(3) Cool the nerve and then stimulate it, or stimulate it with a slowly interrupted current without cooling: vessels dilate.

(4) Stimulate the peripheral end of the nerve three or four days after it has been cut: vessels dilate.

∴ This great mixed nerve carries both dilator and constrictor fibres, although the latter predominate.

D. The tonic action of all the vaso-constrictor fibres of the body can be increased at the same time by reflex stimulation.

Expt. Connect the carotid artery of a curarised animal with a manometer; stimulate the central end of any cut sensory nerve—the general blood-pressure, as shown by the manometer, rises.

The chief agents in bringing about this rise in pressure are the splanchnic nerves. When the blood is not wanted for other purposes, it is to a large extent lodged in the organs of the digestive system. By constriction of the vessels of the abdominal viscera, the blood is returned to the general vascular system. However probable it may be that the splanchnic nerves contain dilator fibres (resembling the chorda tympani of the submaxillary gland) for each particular viscus, the predominant constricting action of these nerves has alone been witnessed.

The vessels of the splanchnic area can hold almost the whole blood of the body; hence the great fall of blood-pressure which results when the tonic action of the splanchnic nerves is inhibited by stimulation of the afferent (depressor) nerve of the heart.

Illustrations of Vaso-motor Action.

A. The metabolism which accompanies severe muscular work tends to raise the temperature of the body. This is counteracted by reflex inhibition of the vascular constriction of the skin, reflex activity of the sweat-glands, increased loss of heat from the lungs, &c. The presence in the blood of certain products of muscular metabolism (*e.g.*, sarcolactic acid) causes a dilation of blood-vessels by direct action upon their lining epithelium.

B. Active dilation of the blood-vessels of the brain interferes with digestion, by preventing the relaxation of the blood-vessels of the alimentary canal.

C. Dilation of the vessels of the digestive system is accompanied by reflex constriction of the vessels in other parts of the body. The surface of the body is cool during healthy active digestion.

In many cases the see-saw in the blood-allowance to more active and less active organs respectively seems to exceed the necessities of the case, *e.g.*,

D. The suction of a leech, which removes from half a drachm to a drachm from one spot, will cause a great constriction in a neighbouring congested area.

E. "Cupping" the skin of the loins depletes a congested kidney, and *vice versâ*:—

F. A cold bath before breakfast will sometimes produce such congestion of the kidneys as to result in slight albuminuria. This innocent appearance of albumen in the urine may be mistaken for disease. Blisters, setons, &c., by setting up inflammation in a healthy part, have a similar power of reducing the inflammation of a neighbouring diseased part; but in these cases the action is not purely vasomotor, but rather "trophic."

Junctions between afferent and efferent vaso-motor tracks.

The existence of a **dominant vaso-motor centre**, high up in the cerebro-spinal axis, was indicated by many experiments, *e.g.*,

1832, *Nasse* showed that the temperature of the limbs rises when the spinal cord is cut.

1852, *Brown-Séquard* showed that if the spinal cord is cut on one side the temperature of the opposite side of the body, below the section, rises.

The situation of the vaso-motor centre was located by *Ludwig* and *Owsjannikow* in the medulla oblongata, beneath the floor of the calamus scriptorius on either side of the middle line, but some little way from it, and nearer the ventral than the dorsal side of the medulla.

Pro. 1. Injury to the cerebro-spinal axis above the medulla (*a*) does not cause a marked fall of blood-pressure, (*b*) does not prevent reflex constriction of the blood-vessels, unless the injury is carried as far down the cerebro-spinal axis as the level just indicated.

2. Injury to the cerebro-spinal axis at any line below the "vaso-motor centre" does, *pro tanto*, cause dilation of blood-vessels.

The arteries are found to be empty after death. *Aristotle* inferred from this that they contain air; hence he applied to them the name used for the trachea, 'Αρτηρία, from ἀήρ, air, and τηρέω, I keep. Their emptiness is due to their contraction, continued after the heart has stopped.

Traube-Hering curves are produced by the rhythmic action of the dominant centre, which controls the general blood-pressure (figs. 5 and 7).

Subsidiary Vaso-motor Centres for local affairs.

A. In the spinal cord.

It is difficult to prove directly that the cerebro-spinal axis contains in each metamer junctions between afferent and efferent vaso-motor nerves, owing to the great disturbance which results when the dominant centre is cut off. There is, however, abundant evidence that such local centres exist :—

E.g., Reflex erection of the penis is possible after section of the dorso-lumbar cord.

B. Outside the spinal cord.

Pro. Local areas, such as the ear of the rabbit, recover not only their tone, but also their tendency to rhythmic contraction after severance of their vaso-constrictor nerves.

Do veins exhibit tone?

Evidence is at present insufficient, but the fact that blood accumulates in the veins of a frog in which the medulla and spinal cord are destroyed, to such an extent as to prevent any blood from reaching the heart, although the heart continues to beat in a normal manner, would seem to indicate that the veins, when cut off from the central nervous system, are abnormally dilated.

Langley.—"The Connection with Nerve Cells of the Vaso-motor Nerves for the Feet," *Jour. of Phys.*, vol. xii. p. 375.

MacWilliam.—"Graphic Records of the Action of Chloroform and Ether on the Vascular System," *Jour. of Phys.*, vol. xiii. p. 860, 1892.

Bowditch and Warren.—"Plethysmographic Experiments on the Vaso-motor Nerves of the Limbs," *Jour. of Phys.*, vol. vii. p. 416.

Sewell and Sandford.—"Plethysmographic Studies of the Human Vaso-motor Mechanism," *Jour. of Phys.*, vol. xi. 179.

Ellis.—"Plethysmographic and Vaso-motor Experiments with Frogs," *Jour. of Phys.*, vol. vi. p. 437.

Lauder Brunton.—"Rhythmic Contraction of the Capillaries in Man," *Jour. of Phys.*, vol. v. p. 14.

Campbell.—"Flushing and Morbid Blushing." London, 1891. R. Lewis.

SECTION III.

NERVES.

A motor nerve or nerve-fibre is the process of a cell which lies in the central nervous system. The nerves for unstriped muscle-fibres join cells in sympathetic ganglia, by which each single medullated fibre is replaced by a group of non-medullated fibres.

Sensory nerves are processes of cells in the root-ganglia (spinal ganglia); or, in some cases, of cells which lie nearer the periphery.

Fibres ascend and descend within the cerebro-spinal axis. The former have their cells of origin below, the latter above. Nerve-fibres branch both within and without the axis.

Classification of nerves.—The function of a nerve is to carry an impulse; nerves may be grouped (A) according to the character of the impulse which they are accustomed to carry—whether sensory, or motor, muscular, thermogenic, trophic, or secretory, augmentor or katabolic, inhibitory or anabolic; but there is no reason to think that the essential part of the nerve, the axis-cylinder, varies in structure according to the kind of impulse which it carries.

B. According to size. Sensory fibres and motor fibres for voluntary muscle have a diameter of from 8 μ to 16 μ. Fibres for involuntary muscle (sympathetic fibres) have, before they lose their myelin-sheaths, a diameter of from 1·8 μ to 3·6 μ. This difference in size makes it possible to trace the course of sympathetic fibres when within mixed nerves. Within the cerebro-spinal axis also the fibres differ in size, and may therefore be followed by attention to this character.

C. According to the nature of their wrappings:—1. Sensory nerves, the nerve-fibres which supply voluntary muscles, and the commencement of the nerves which supply groups of involuntary muscle-fibres, are protected and insulated by medullary sheaths; 2. the fibres which go to unstriated muscle are in the last part of their course destitute of myelin-sheath, as are also, perhaps, large numbers of other fibres, both within and without the cerebro-spinal axis.

Wrappings.—Isolated peripheral nerves are surrounded by a tubular lamina of connective tissue lined with epithelial cells (the sheath of Henle), which contains lymph. When the fibres are collected together into nerve-cords, the epithelium-lined connective tissue is termed endoneurium. Each funiculus is surrounded by perineurium, and the whole invested by epineurium. Excluding its connective tissue sheath, a medullated nerve-fibre consists of the following essential parts:—

A. The axis-cylinder, which is a process of a nerve-cell. This, in turn, is probably a bundle of fibrillæ lying in fluid or semi-fluid substance, invested by an elastic rind.

B. The medullary sheath, a row of hollow cylinders through which the axis-cylinder passes. Each segment is a cell, the value of which as an insulating and protecting sheath, depends upon the accumulation within it of a phosphorus-containing fat (myelin). The nucleus of the cell, surrounded by a little granular protoplasm, lies on the inner surface of the neurilemma. The ends of the myelin-cylinders (each of which is 1 to 2 mm. long) meet at the nodes of Ranvier.

Cement substance, which forms an albuminate with nitrate of silver, joins the cylinders together, and lymph, which, under certain circumstances, gives a similar reaction (producing the annular markings known as Frommann's cross-bands), occupies the space between the rind of the axis-cylinder and the inner surface of the medullary sheath.

Myelin is easily squeezed from one segment into another, showing that no septa divide the medullary sheath at the nodes.

The medullary sheath is divided by obliquely imbricated septa into Lantermann's cones. When it is stained with osmic acid, and its fatty contents are subsequently dissolved in absolute alcohol and oil of cloves, a reticulum is left behind. This reticulum may show that the myelin is supported by a neuro-keratin framework (*Kühne*), or it may be an artifact.

C. The primitive sheath, or sheath of Schwann, is a transparent homogeneous membrane which is not, so far as can be seen, interrupted at the nodes.

Neurons.—A nerve-unit or element consists (as was first pointed out by the writer[1]) of a nerve-cell with its protoplasmic processes and its axis-cylinder process or nerve-fibre, which runs from the cell to the periphery, or up or down in the cerebro-spinal axis. Eventually the fibre branches, whether in the end-plate of a muscle or in the grey matter of the cerebro-spinal axis, and its several divisions carry nuclei or "granules." *Waldeyer* proposes to call the nerve-unit a neuron.[2] The essential part of the nerve-fibre, its axis-cylinder, is therefore the unsegmented process of a nerve-cell, from which, as its nutrient centre (neuroblast of *His*), it grew out. The sheaths by which it is invested are formed from a great number of either mesoblastic or epiblastic cells (spongioblasts) which have accompanied the axis-cylinder out of the primitive neuro-epithelial tube.

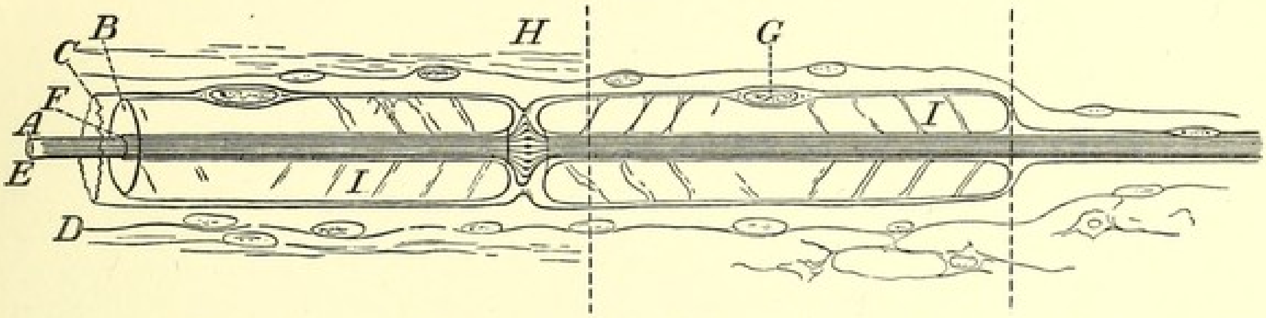
> *Matters at present in dispute:*—A. The methods of Golgi for impregnating the nervous tissue with chromate of silver or mercury, seem to have revealed the existence of slender branches which leave the axis-cylinder at right angles. These branches, named by *Ramón y Cajál* "collaterals," are found everywhere, but the precipitation or impregnation-method introduces obvious risks.
>
> B. Those who use Golgi's methods cannot see any anastomosis between the terminal branches of the nerves within the cerebro-spinal system. They are reduced, therefore, to regarding the exchange of impulses between the neurons, which is the essential function of the central nervous system, as an *actio in distans.*
>
> C. The protoplasmic (dendritic) processes of the nerve-cells have for long been regarded as constituting a network, through the strands of which an interchange of impulses takes place between the nerve-cells. The new method shows these processes running into neurogleial cells, and otherwise behaving in a manner which leads *Kölliker* and others to look upon them as not nervous at all, but only nutritive in function.

Although it is essential to the understanding of the central nervous system that it should be looked upon as a collection of neurons, the exact constitution of a neuron is at present uncertain.

2. Non-medullated fibres bear frequent nuclei. In some cases a sheath of Schwann can be distinctly recognised, in other cases it cannot be shown that the fibres have any sheaths except such as are derived from the connective tissues : it is difficult to account for the presence of the nuclei on the theory of the unin-

[1] Obersteiner and Hill.—"Central Nervous Organs," &c., pp. 32, 129, 169, 331, 358, &c.
[2] Hill.—"Current Nerve Anatomy and Physiology," *Brain*, Dec. 1891, p. 567.

Porter.—"The Presence of Ranvier's Constrictions in the Spinal Cord of Vertebrates," *Quart. Jour. Micr. Sci.*, vol. xxxi. p. 91, 1890.



Medullated fibre within a nerve-cord. | Isolated medullated fibre. | Non-medullated fibre.

FIG. 21.—Diagram exhibiting the relation of the several coats of a nerve to its essential element, the axis-cylinder. A, Axis-cylinder; B, medullary sheath; C, sheath of Schwann; D, connective-tissue sheath (endoneurium sheath of Henle) enclosing a lymph-space; E, axis-cylinder sheath, separated from the medullary sheath by F, the periaxial space; G, nucleus of Schwann's sheath and of the medullary segment, unless (?) this is deposited about (secreted by) the axis-cylinder; H, node of Ranvier; I, Lantermann's cones.

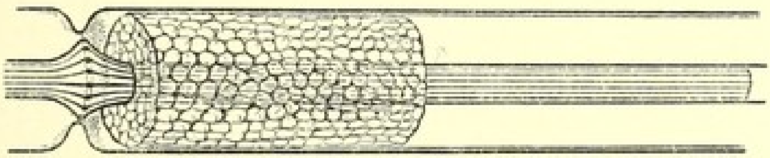


FIG. 22.—Diagram of a nerve at a node of Ranvier, showing the manner in which the axis-cylinder is dilated into a plate at the node, its primitive fibrillæ separated and thickened. The frame-work (neurokeratin reticulum of Kühne) by which the medullary sheath appears to be supported is also seen.

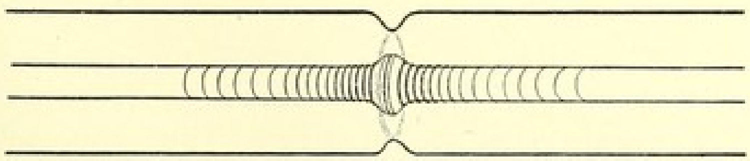


FIG. 23.—Frommann's annular markings.

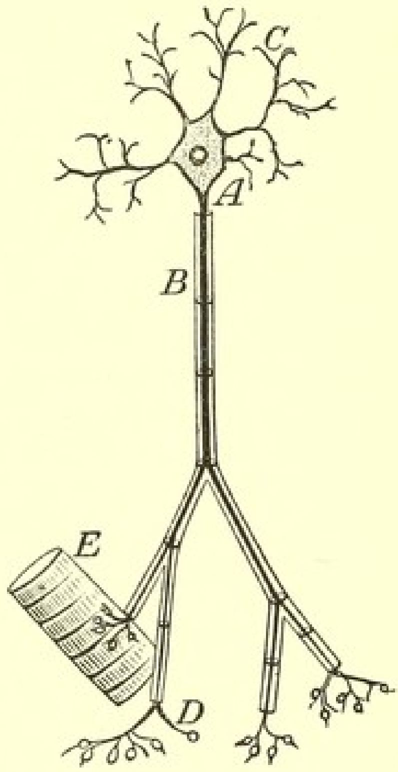


FIG. 24.—A neuron. A, The nerve-cell; B, its axis-cylinder process; C, its dendritic (protoplasmic) processes; D, the termination of one of its branches in a bunch of nucleus-bearing fibrils, *i.e.*, by connection with "granules;" E, a muscle-fibre.

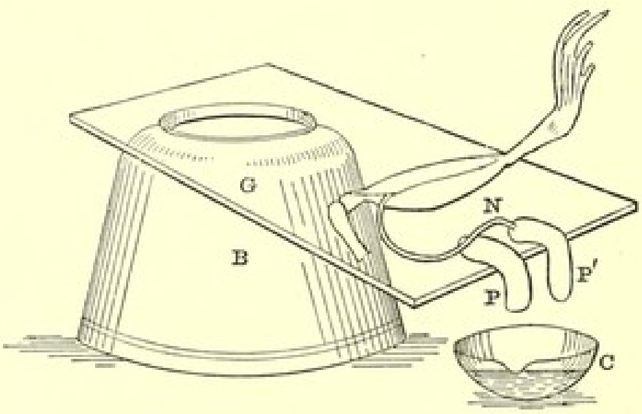


FIG. 25.—Diagram showing the way in which a nerve-muscle preparation may be stimulated by the demarcation-current of its own nerve. The leg of a frog is placed on a glass plate with its sciatic nerve resting upon two rolls of modeller's clay in such a way that its surface touches P, and its cut end touches P′. The bowl, C, contains normal salt-solution; when this is raised until P and P′ dip into it, the circuit is completed, and the difference in potential between the parts of the nerve which touch the two electrodes respectively, sets up a current which acts as a stimulus to the nerve-muscle preparation. A second stimulus is generated by the removal of the bowl, C.

[*To face p.* 39.

terrupted continuity of the axis-cylinder in the latter class of cases, unless these fibres possess an investing sheath which is overlooked.[1]

Stimulation.—Nerves may be stimulated at any part of their course by (*a*) variations in pressure, pinching, cutting, &c.; (*b*) by variations in temperature; (*c*) by chemical agents, acids, alkalies, or solutions of metallic salts; (*d*) by passage through a portion of their length of an electric current.

a, *b*, and *c* give rise, as a rule, to impulses repeated at irregular intervals.

Impulses generated in sense-organs appear also to be repeated (or vibratory). Voluntary impulses are intermittent, following one another with a rapidity of about 10 to the second (see p. 52).

It appears that the impulses discharged into an electric organ are more rapid —as frequent as 200 per sec.

Electric stimuli, if instantaneous, give rise to a single impulse; the application of a constant current, to an impulse at making (closing the key and so completing the circuit through the nerve), and at breaking (opening the key, and therefore interrupting the circuit through the nerve); rapidly repeated shocks, whether direct or induced, to impulses repeated with corresponding rapidity.

Impulses travel through the nerve in both directions with a rapidity, in motor nerves of the frog, of 27 *metres per sec.*; of mammals, 35 *metres per sec.* There are reasons for thinking that the conduction in sensory nerves is somewhat more rapid than this.

The transmission of nerve-impulses is very slow as compared with the rate of transmission of electricity and other forms of force.

It is doubtful whether there is any advantage in rate and ease of conduction, in favour of impulses travelling in the direction in which the nerve conducts during life.

> The shorter the piece of sensory nerve between the electrodes, the greater the effect upon the sensorium; the longer the piece of motor nerve, the greater the movement of its attached muscle.
>
> In unipolar excitation, when one electrode is placed on or over the nerve, and the other on some distant part of the body, it is found that the negative pole gives rise to the greater pain, the positive pole to the greater movement.

Electric Changes which Accompany the Passage of an Impulse.

A piece of isolated nerve at rest shows, like muscle (see p. 47), demarcation-currents.

These are best exhibited by placing the nerve upon nonpolarisable electrodes. The current at one end of a cut nerve may have an electro-motive force of ·02 of a Daniell's cell.

When an impulse, however produced, is generated in a nerve, its transit is marked by a negative variation which travels at the same rate as the impulse. Its duration at any given point is not more than ·0005 sec., its wave-length 18 mm.

[1] For fuller discussion of the histological meaning of nerves, see Obersteiner and Hill, "Central Nervous Organs," pp. 107–118; or Schäfer, "Quain's Anatomy," 10th edition, vol. i. part ii. pp. 307–315.

Griffiths.—"Rhythm of Muscular Response to Volitional Impulses in Man," *Jour. of Phys.*, vol. ix. p. 39.

Haycraft.—"Voluntary and Reflex Muscular Contraction," *Jour. of Phys.*, vol. xi. p. 352.

Warren.—"Some of the Influences which affect the Power of Voluntary Muscular Contractions," *Jour. of Phys.*, vol. xiii. Nos. 1 and 2, p. 1, 1892.

Hering.—"On Nerve-excitation by the Nerve-current," *Foreign Biol. Mem. Oxford*, 1887, p. 127.

Edes.—"On the Method of Transmission of the Impulse in Medullated Fibres," *Jour. of Phys.*, vol. xiii. No. 5, p. 431, 1892.

Rolleston.—"On the Conditions of Temperature in Nerves," *Jour. of Phys.*, vol. xi. p. 208.

Stewart.—"Heat Production in Mammalian Nerves during Excitation," *Jour. of Phys.*, vol. xii. p. 409.

It is measured by passing a shock into a nerve, and connecting the other end of the nerve with a galvanometer at a known interval of time after passing the shock. If the interval is too short, the impulse will not have travelled down the nerve, and therefore the galvanometer will show an unaltered negative variation. If the interval is too long, the negative variation will have again returned to its original condition. The negative variation cannot exceed the demarcation-current in intensity.

It is really necessary in this investigation to pass into a nerve a succession of shocks, because a single negative variation would be insufficient to overcome the inertia of the galvanometer-needle, but the deflection observed is equal to the deflection which each shock would produce but for this want of sensitiveness in the apparatus.

When a constant current is passed into a nerve, a remarkable condition of polarisation is set up. This condition is known as electrotonus. A current, which may be even twenty-five times as strong as the demarcation-current, appears in the direction of the polarising current.

The current of rest, current of action, and electrotonic current, were first described by Du Bois Reymond in 1843.

Does the setting up of the electrotonic current depend upon the physical structure of the nerve only, or would it be impossible but for the vital properties of the nerve?

> That it is not simply physical is indicated by the fact, that it cannot be established in dead nerve or nerve coagulated by heat, nor is it transmitted beyond a ligature (*Du Bois Reymond*).
>
> On the other hand, *Matteucci* showed, in 1863, that if the nerve is replaced by an overspun metallic wire, the sheath of which is moistened with a conducting liquid, electrical phenomena very similar to those of electrotonus are observed. *Hermann* used, instead of the overspun wire, an artificial nerve, made by immersing a wire in a long glass tube filled with liquid. The glass tube was fitted with a number of side tubes into which electrodes could be inserted. Provided that the contents of the tube are capable of polarisation, *e.g.*, if the core be a platinum wire and the liquid a solution of sulphate of zinc, extra-polar currents similar to those of electrotonus, and followed by several reversed after-currents, are set up.
>
> *Hermann* and *Samways* have also shown that after making or breaking a polarising current, the extra-polar effect is transmitted along the artificial nerve as a wave, resembling in form the "current of action" or "negative variation" which accompanies an impulse. It travels slowly like the negative variation; in a tube with wire-core, at the rate of 20–65 metres per sec.; in an overspun wire, at the rate of 28·3 metres per sec.

It is clear, therefore, that the electric phenomena which mark the passage of an impulse, depend for their production upon the physical as well as the physiological properties of the nerve.

The polarisation effect grows weaker as it travels along the artificial nerve. The negative variation is conducted along a nerve with no loss of force.

The Physiological Changes which result from the establishment of electrotonus:—
The irritability and conductivity of the nerve are diminished in the region of

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Hering.—"On the Positive After-variation of the Nerve-current consequent on Electrical Stimulation," *For. Biol. Mem. Oxford*, 1887, p. 255.

Tigerstedt.—"On the Internal Polarisation of Nerves," *For. Biol. Mem. Oxford*, 1887, p. 77.

Sewall.—"Polar Effects upon Nerves of Weak Induction Currents," *Jour. of Phys.*, vol. iii. p. 175.

Stewart.—"The Effect of Stimulation on the Polarisation of Nerve," *Jour. of Phys.*, vol. ix. pp. 26, 199; vol. x. p. 458.

the anode (where a condition of anelectrotonus is said to exist), increased at the region of the kathode (katelectrotonic region).

There is a neutral point between the anode and kathode where irritability is unchanged. This "indifferent point" is nearer the anode when the current is weak, nearer the kathode when it is strong.

No satisfactory explanation has yet been given of the increased tendency to explosion which exists at the kathode, and the diminished tendency to explosion which surrounds the anode.

Relation of Electrotonus to the Liberation of Impulses.

The generation of impulses by an electric current depends upon (*a*) the increased tendency to molecular disturbance (katelectrotonus) set up at the kathode when the current begins to pass, and (*b*) the return from diminished to normal irritability at the anode when the current is cut off.

Pro. 1. If a strip of muscle of the tortoise-heart is placed upon the electrodes, the wave of contraction can be seen to start at *k* when the current is made, at *a* when the current is broken.

2. In the same way, if the sartorius of a curarised frog is suspended with electrodes on either side of its upper end, it swings towards *k* when the circuit is made, towards *a* when the current is cut off, *i.e.*, the kathodic side contracts first on making, the anodic on breaking (fig. 32).

3. If a current which has been passing for some time through a considerable length of nerve is cut off, tetanus is produced (Ritter's opening tetanus). If the nerve is cut in what was the intra-polar region, the tetanus at once ceases, provided the anelectrotonic area is cut off; if the anode lies on the side toward the muscle, it is not affected by the section. This shows that the impulses producing the tetanus originate at the anode.

The two kinds of electrotonus are not equally effective in generating impulses.

If the current is of moderate strength, a contraction follows the making and breaking of either ascending or descending currents.

If it is weak, a contraction only follows the making of the current, *i.e.*, the rise of electrotonus.

If it is very strong, only breaking an ascending or making a descending current produces an impulse, as if the electrotonic condition prevented conduction.

SYMPATHETIC SYSTEM OF NERVES.

The ganglionated cord in the thorax and abdomen was termed by the ancients the intercostal nerve or great sympathetic, the vagus was termed middle sympathetic, and the facial small sympathetic, because these three nerves were supposed to be concerned in expressing the emotions and passions. The term "sympathetic" was eventually restricted to the great sympathetic nerve of the neck, thorax, and abdomen. *Bichat* regarded it as quite independent of the cerebro-spinal system. *Waller* and *Budge* proved that the fibres which enter the sympathetic are derived from the cerebro-spinal system. Various functions have been assigned to the

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Samways.—"Electrical Actions in Nerves and Allied Physical Phenomena," *Cambridge*, 1884.

Tigerstedt.—"Change of Excitability produced in Nerves by a constant Current," *For. Biol. Mem. Oxford*, 1887, p. 5.

Grützner.—"The Nature of the Electrical Break-contraction," *For. Biol. Mem. Oxford*, 1887, p. 93.

Tigerstedt.—"Contribution to the Theory of the Break-contraction," *For. Biol. Mem. Oxford*, 1887, p. 49.

Beevor.—"On some Points in the Action of Muscles," *Brain*, vol. xiv. 1, p. 51.

Cheaveau.—"On the Sensori-motor Nerve-Circuit of Muscles," *Brain*, pts. liv. and lv. p. 145, 1891.

ganglia. They have even been regarded as the results of disease, or (in the case of the spinal ganglia) as cushions for the protection of the nerves where they would otherwise be in contact with the bone. *Monro*[1] looked upon the ganglia as "sources of nervous matter and energy."

To give an historical account of the views held as to the anatomical connections and functions of the sympathetic system would occupy a large space to no purpose, for this system was not in the least understood until the publication of Gaskell's paper in 1885.[2]

Although we still use the term "sympathetic nerve," restricting it to the ganglionated cord and its branches, the expression has no longer any definite meaning, since all nerve-fibres are derived from the cerebro-spinal system, and only a portion of the visceral and vascular fibres are connected with this cord ; others take their course towards the periphery in the pars intermedia of the seventh, the vagus, glosso-pharyngeal, and the roots of the brachial and lumbo-sacral plexuses.

The ganglia are divisible into two great groups :—A. **the lateral ganglia,** found close to the vertebral column, and B. **the collateral ganglia,** which lie on the great branches of the aorta. The lateral ganglia are connected by commissural fibres.

The sympathetic in the neck is not a part of the lateral chain, but of the collateral chain of nerves and ganglia which lie on the blood-vessels (in this case on the carotid artery).

The ganglia are connected with the cerebro-spinal system by medullated nerves, easily distinguished by their small size ; about 2 μ as compared with 20 μ, the diameter of skeletal fibres. The so-called "grey rami communicantes" are fibres from the ganglia to the vessels of the cerebro-spinal system, and of its investing membranes, as well as vaso-constrictor fibres which accompany the intercostal nerves. The ganglia are not centres of reflex action, but simply collections of cells in which nerve-fibres are demedullated, each single medullated fibre which reaches a cell being broken up into a number of naked fibres.

A. Only a part of the fibres are demedullated in the lateral chain ; they differ in function from those which carry their medullary sheaths to the collateral ganglia, being—

Vaso-constrictor.
Motor.
Katabolic, or provokers of metabolism.

B. The fibres which pass on to the collateral ganglia without interruption in the lateral chain are—

Vaso-dilator.
Inhibitory.
Anabolic, or restrainers of metabolism.

These two kinds of nerves do not come in equal proportion from all parts of the cerebro-spinal axis.

A. Katabolic fibres have their chief outflow in the thoracic and upper lumbar regions.

B. Anabolic fibres take exit from the medulla, the upper lumbar, and the sacral regions.

The peculiar cells which constitute Clarke's column are found in the cerebro-spinal axis in the regions from which the anabolic fibres arise. They are rounded cells, placed with their long axes vertically ; since they give off few if any protoplasmic processes they are closely packed together, and not surrounded by the ordinary

[1] Monro.—"Observations on the Nervous System," p. 55.
[2] Gaskell, *loc. cit.*, see p. 33 of Note-Book.

Fox.—The Influence of the Sympathetic on Disease," Lond. 1885.

grey matter which receives the protoplasmic processes of many-branched cells. No peculiar cells can with certainty be associated with katabolic fibres.

Langley and *Dickinson* have discovered that nicotin poisons the cells of sympathetic ganglia, but does not affect the nerves which pass through the ganglia without cell-connections. It is possible, therefore, to determine in the case of any sympathetic nerve, the ganglion in which its fibres are demedullated.

The terms **Anabolism** and **Katabolism** are used to denote the opposite effects which chemical changes (metabolism) may have upon the cell in which they occur—its enrichment or impoverishment. In any attempt to express this idea after the manner of a balance-sheet, it must be borne in mind that the cell consists of (*a*) a protoplasmic framework—this is its machinery, which may be increased or diminished in amount; (*b*) within the meshwork of protoplasm accumulate the products characteristic of the cell's activity; (*c*) secreting cells extrude their metabolites at intervals—the amount to be seen in a cell at any moment is not therefore necessarily a test of the cell's specific activity. Bearing these facts in mind, balance-sheets showing the income and expenditure of a cell on "capital" and "current" accounts may be struck.

It is very difficult to distinguish between the nerves which provoke the formation of metabolites and the nerves which determine their extrusion; but there are reasons for thinking that certain tissues are under the influence of opposing nerves, and that the action of the anabolic and katabolic fibres is marked by electrical changes of opposite sign.

E.g., The heart is supplied by (*a*) the vagus nerve, which restrains its activity and improves its nutrition; its stimulation gives rise to a positive electrical variation. (*b*) It is also supplied by sympathetic fibres, *viâ* the ganglion stellatum, which increase its activity and wear out its tissue; their stimulation when the heart is quiescent gives rise to a negative variation.

In the same way the submaxillary gland is supplied by the chorda tympani and by the sympathetic filaments which accompany the facial artery. Stimulation of the former gives rise to an abundant flow of saliva, accompanied by a negative variation; stimulation of the latter induces a scanty flow of viscid saliva accompanied by a positive variation. This indicates that the same kind of antagonism exists, but the problem in the case of all gland-nerves is complicated by their effect upon the extrusion as well as upon the formation of secernable products. The anabolic fibres of the salivary glands are only present in the sympathetic nerves, their katabolic fibres in both cerebral and sympathetic nerves.[1]

[1] Bradford.—*Jour. of Phys.*, vol. ix. p. 315.

Langley and Dickinson.—"Pituri and Nicotin," *Jour. of Phys.*, vol. xi. p. 265.

Langley and Dickinson.—"Action of Various Poisons upon Nerve-fibres and Peripheral Nerve-cells," *Jour. of Phys.*, vol. xi. p. 509.

Langley.—Secretory Fibres supplying the Sweat-glands of the Feet of the Cat," *Jour. of Phys.*, vol. xii. p. 347.

Langley and Anderson.—"The Action of Nicotin on the Ciliary Ganglion and on the Endings of the Third Cranial Nerve," *Jour of Phys.*, vol. xiii. No. 5, p. 460, 1892.

Langley.—"On the Larger Medullated Fibres of the Sympathetic System," *Jour. of Phys.*, vol. xiii., Suppl. No., p. 786, 1892.

Miss Greenwood.—"The Action of Nicotin upon Certain Invertebrates," *Jour. of Phys.*, vol. xi. p. 573.

Bayliss and Bradford.—"Electrical Phenomena accompanying Secretion of the Skin," *Jour. of Phys.*, vol. vii. p. 217.

Bradford.—"Electric Phenomena accompanying the Excitation of so-called Secretory and Trophic Nerve-fibres in the Salivary Glands," *Jour. of Phys.*, vol. viii. p. 86.

Bradford.—"Some Points in the Physiology of Gland-nerves," *Jour. of Phys.*, vol. ix. p. 287.

SECTION IV.

MUSCLE.

Contractile, irritable.

Normally receives its stimuli from the end-plates of nerves, but can be stimulated directly after these are dead or paralysed by curare.

Pro. Ligature round the whole of one leg of a frog, excluding the sciatic nerve. Injection of curare into the frog's body. Upper part of the nerve is supplied with curarised blood, but yet conveys stimuli to the unpoisoned end-plates of the excluded limb. The muscles of the rest of the body cannot be stimulated through their nerves, but contract on the direct application of the electric current, blows, heat, acids, &c.

Is there any advantage in favour of the nerve-ending?

Pro. Pass the ligature round the leg of a frog, as in the above experiment, or vary the experiment by ligaturing one sciatic artery, and injecting curare into the dorsal lymph-sac. The curare cannot reach the muscles of the leg in which the artery is ligatured. Arrange a commutator in the course of an electric circuit in such a way as to divide the current into two halves. Lead one half (A) to the sciatic nerve of the poisoned limb, and the other half (B) to the sciatic nerve of the blood-free limb: B contracts, A does not. Lead one half direct to (A) the gastrocnemius muscle of the poisoned limb, and the other half to (B) the gastrocnemius muscle of the excluded limb: B will contract with a weaker current than A.

Structure of Voluntary Muscle.—Each fibre is a group of cells which have not separated. It is surrounded by a common cell-membrane (homogeneous, composed of elastin, or a similar highly resistant albuminoid), continuous, with imperfect septa, which divide the fibres into discs. The dark bands or "Dobie's lines" may be considered, from the way in which they tie-in the fibre, to be the appearances produced by septa, which are joined peripherally with the sarcolemma. Each compartment contains semi-fluid protoplasm, which appears in the centre of the compartment dim, at either end bright; hence the alternation of dark, bright, dim, bright, dark stripes. The dim protoplasm also exhibits, in most invertebrates, and all vertebrates, a longitudinal striation. There are many nuclei for each fibre. In the water-beetle they form a string in the core of the fibre (about 2 nuclei to every 3 discs); in the red muscles of mammals they lie in the protoplasm, but near the sarcolemma. In the most highly specialised (white) muscles they are brought close up to the internal surface of the sarcolemma. In insects the chromatin of the nucleus is disposed as a spiral band.

The dim bands are doubly refracting (anisotropous), the bright bands singly

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Tillie.—"A Contribution to the Pharmacology of Curare and its Alkaloids," *Jour. of Anat. and Phys.*, vol. xxiv. pp. 379 and 509, 1890; and vol. xxv. p. 41, 1891.

Bowman.—Several Papers upon the Structure of Muscle, in the collected works of Sir W. Bowman, London, 1892.

Rutherford.—"On the Structure and Contraction of Striped Muscular Fibre of the Crab and Lobster," *Proc. Roy. Soc. Edin.*, vol. xvii. p. 146.

refracting (isotropous). The substance of which the bright band is composed resembles, therefore, a fluid or a crystal of the cubical system in constitution, while the particles which make up the dim band are arranged along unequal axes.

During full contraction the bright bands disappear, but by contrast the whole dim band then looks brighter. The total amount of the singly refracting substance rapidly diminishes as the fibre contracts.

The descriptions given of the structure of muscle go into fuller detail than this, but as soon as matters of easy observation are passed, views as to structure must be expressed with full knowledge of the possibility of error due to three sources—(*a*) internal reflection and refraction within the cylindrical fibre, producing optical illusions; (*b*) post-mortem changes; (*c*) action of reagents.

Appearances of doubtful meaning.

Each bright band is crossed by an accessory dim stripe. This is easily resolved into a row of lozenge-shaped dots. In other positions of the microscope the two rows of dots fuse into one in the situation of Dobie's line (Krause's membrane). This appearance may be due to plates of granules, or may be the appearance produced by a reticulum, of which the dots are the nodes.

The dim band is crossed by a brighter median band—Hensen's median disc.

This stripe is observed in muscles fixed in a condition of extension by hardening reagents, and may be due to rupture of certain of the elements of the fibre.

Observed under polarised light during contraction, the total amount of singly refractile material collected on either side of Krause's membrane diminishes. The isotropous stripe grows thinner therefore; the anisotropous stripe increases in width without a corresponding diminution in thickness.

Theories of the Construction of Muscle-Fibre, and explanations of its contractility.

A. The simplest view is that of *Melland* and others, that muscle-fibres differ from non-contractile cells in having their protoplasm arranged in a strong rectangular network, not in an irregular network. The contractile metaplasm (muscle-columns) occupies the meshes of this network.

B. *Carnoy's* view is similar, but he considers the network, not the intervening substance, to be the contractile portion of the fibre.

C. Until recently *Schäfer* regarded the dots which lie in the bright stripes as the knobs on the ends of short rods.

None of these views satisfactorily explain either (1) the difference in molecular arrangement of the substance of the dim bands and bright bands, which are doubly and singly refracting respectively; (2) the disappearance of the bright bands at the height of contraction; or (3) the broadening of the dim band without proportionate diminution in its thickness during contraction.

Any theory of the constitution of muscle-fibre must account for 1, 2, and 3, and also for (4) the tendency of the fibre to split longitudinally into fibrils, and (5) transversely into (Bowman's) discs; and (6) the appearance in transverse section of Cohnheim's areas, *i.e.*, spaces separated by a network, or fibrils separated by intervening substance.

D. Recently *Schäfer* has, up to a certain point, adopted the reticular view, but regards the longitudinal striæ as the appearance, not of filaments, but of septa or

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Melland.—"A Simplified View of the Histology of the Striped Muscle-Fibre," *Quart. Jour. Micr. Sci.*, vol. xxv. p. 371, 1885.

cases of sarcoplasm which invest rods of hyaline contractile substance (sarcostyles). At the same time he gets over the difficulties with regard to refraction by supposing that the cases are thick-walled in the dim band, and very thin-walled in the bright band, so that the dim band resembles a piece of honeycomb, the bottoms of the cells of which touch one another at Hensen's stripe. He thinks that the rims of the honeycomb-cells are thickened, appearing in optical section as dots (the two rows of dots which lie on either side of Krause's membrane = the "accessory discs" of some writers). The contraction of the muscle is due to the withdrawal of the hyaline substance into the cells of the honeycomb; relaxation, to its return towards Krause's membrane.

In the wing-muscles of insects, the sarcoplasm is collected into thick septa which surround bundles of sarcostyles.

Schäfer considers the dots to be accumulations of sarcoplasm.

Melland and others look upon the dots as the optical appearance of longitudinal filaments crossing a complete or reticular membrane. In certain positions of the microscope they are seen as a single row, in other positions (out of focus?) as a double row.

During contraction the distinction between the bright and dim substance is lost for a time (confusion of substance), and then at the height of contraction they seem to have changed places. This may be due merely to the disappearance of the bright band and contrast of the dim band with the dark one, making the former appear bright; or it may be due to a removal of the sarcoplasm from Hensen's disc to Krause's membrane.[1]

NERVE-ENDINGS IN MUSCLE.

Striated Muscle.

Some invertebrates:—Simple fusion of axis-cylinder with muscle-substance.

Vertebrates:—Branching of axis-cylinder in a bed of granular protoplasm (Doyère's eminence) in mammals and reptiles; without such protoplasm in amphibians.

The protoplasm contains clear vesicular nucleolated nuclei, oval in shape —these are muscle-nuclei.

The arborescence of the nerve carries granular solid nuclei. They lie close on the branches of the axis-cylinder, but whether they belong to fusiform cells with which the branches come into connection (like the cells borne by similar branches in the central nervous system) is not clear.

The primitive sheath is said to fuse with the sarcolemma.

On the other hand, the flattened nuclei which rest on its deep surface appear to show that it is the sheath of Henle.

The medullary sheath either ends abruptly at the muscle-fibre, or is continued a short way along the chief branches of the nerve.

It is the rule for every striated muscle-fibre to have a nerve-ending: there may be exceptions to this rule.

The fibres of muscular nerves branch at Ranvier's nodes. One nerve-fibre supplies 40 muscular fibres in the leg. In the case of the eye muscle-nerves, 3 nerve-fibres supply 7 muscular fibres.

[1] For a full account of *Schäfer's* views, as well as for the history of the subject, see *Quain's Anatomy*, tenth edition, vol. 1, part 2, pp. 285 *et seq.*

Haycraft.—"On the Cause of the Striation of Voluntary Muscular Tissue," *Quart. Jour. Micr. Sci.*, vol. xxi. p. 307, 1881.

Haycraft.—"Minute Structure of Striped Muscle," *Proc. Roy. Soc.*, 1891, p. 287.

Haswell.—"A Comparative Study of Striated Muscle," *Quart. Jour. Micr. Sci.*, vol. xxx. p. 31, 1889.

Marshall.—"Further Observations on the Histology of Striped Muscle," *Quart. Jour. Micr. Sci.*, vol. xxxi. p. 65, 1890.

Stirling.—"Red and Pale Muscles in Fishes," *Studies from the Owens Coll.*, 1891, p. 1.

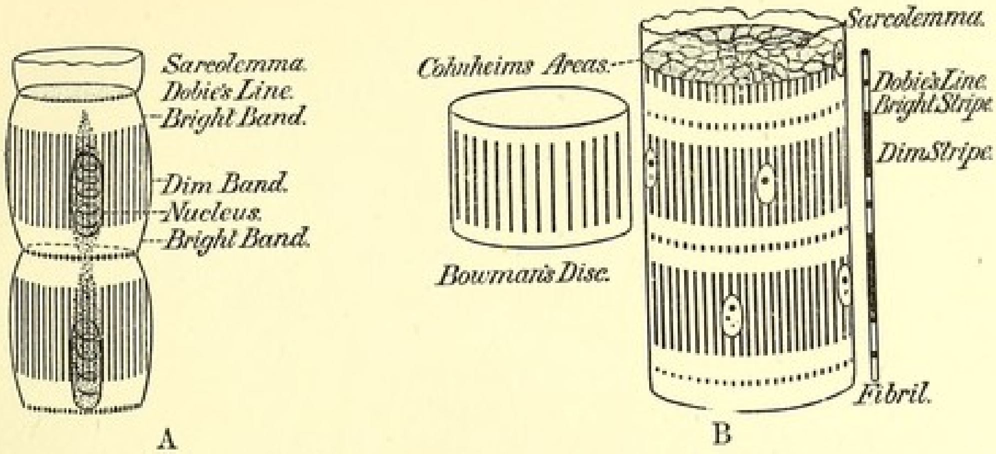

FIG. 26.—A, a muscle-fibre of an insect; B, a mammalian muscle-fibre. The diagram shows the way in which it splits into discs and into fibrils.

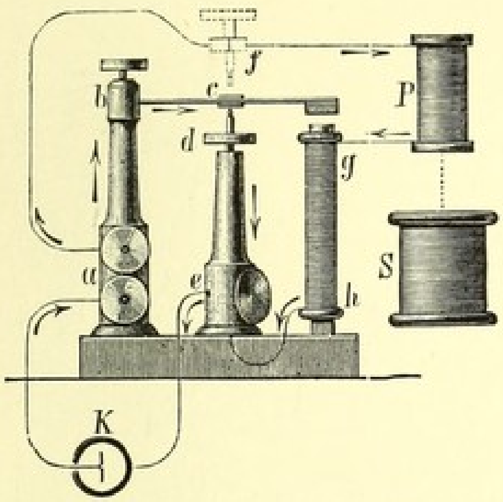

FIG. 27.—Diagram of the magnetic interrupter (Neef's hammer) with a primary coil, P, in the course of its long wire, in order that induced currents may be led off from a secondary coil, S. This apparatus, in various modifications, is used for tetanising muscle, either with direct or with induced shocks, rapidly repeated.

K, the battery, from which the current flows through *a*, *b*, *c*, *f*, P, *g*, *h*, *e*, back to the battery. As it flows through the wire coiled round the iron pillar, *gh*, this becomes a magnet which draws down the spring, *bc* (as in the figure), short-circuiting the current which then flows through *a*, *b*, *c*, *d*, *e*, back to the battery, unmaking the magnet, *gh*, and thus allowing the spring to fly back again to its original position. Between *a* and *f* is shown the side-wire which, keeping up a weak current through P, equalises the making and breaking currents.

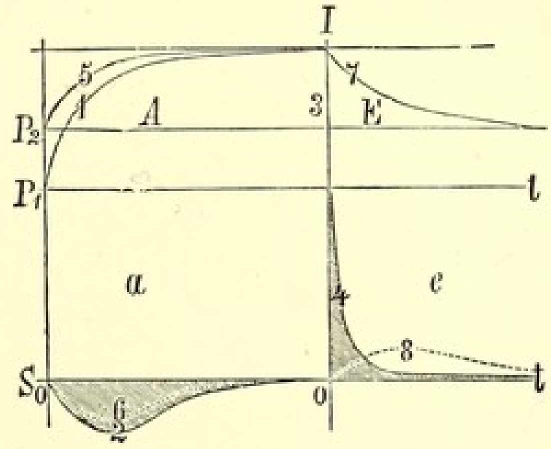

FIG. 28.—Diagram to show the effect of the "side wire" in equalising the making and breaking currents. 1 and 7, the primary making and breaking currents without, 5 and 7 with, the side wire; 2 and 4, the induced making and breaking currents without, 6 and 8 with, the side wire in the primary circuit.

To face p. 46.]

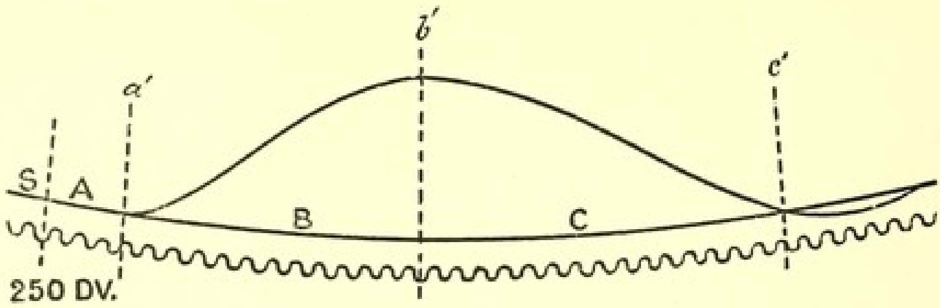

FIG. 29.—A tracing made by the contracting gastrocnemius of a frog upon the plate of a pendulum-myograph. SABC, the base-line scratched by the passive muscle. Beneath the base-line, the tracing made by a tuning-fork, vibrating 250 times to the second (double vibrations). S, The point at which the nerve was stimulated ; A, the latent period ; B, the contraction ; C, the relaxation.

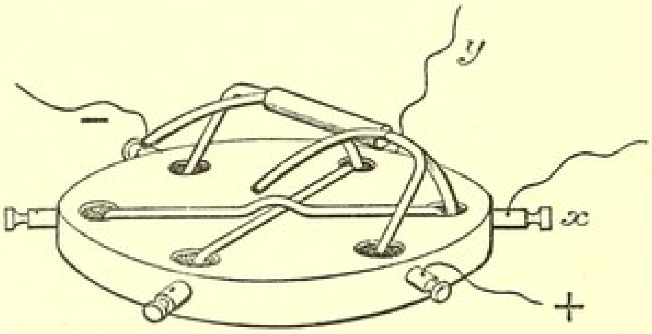

FIG. 30.—Pohl's commutator for reversing the direction of an electric current. When the ebonite arm is raised the current is interrupted ; when it is depressed the current is made ; when it is depressed on the opposite side the current is reversed.

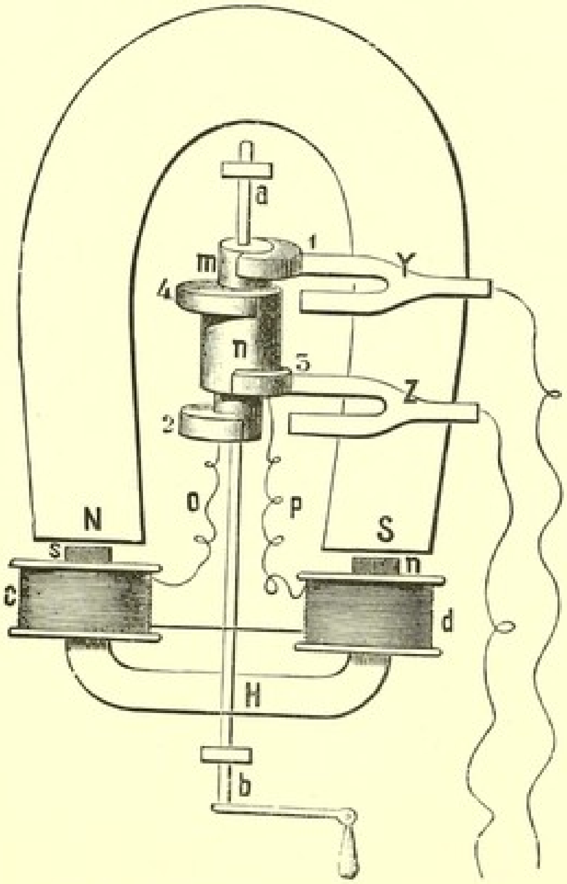

FIG. 31.—Stöhrer's commutator. *For description see p. 49.*

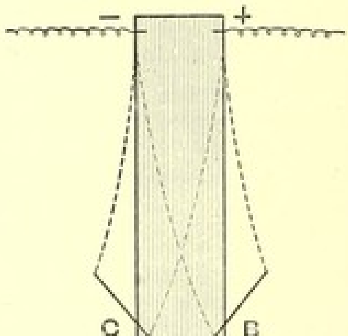

FIG. 32. — Diagram illustrating Engelmann's method of demonstrating that the contraction commences at the kathode on making, at the anode on breaking. R, the curarised sartorius of a frog is suspended between two electrodes. On closing (making) the circuit R assumes the position C, *i.e.*, swings towards the kathode (—) ; on opening (breaking) the circuit it assumes the position B, on the kathodic side (+).

ELECTRIC PHENOMENA OF PASSIVE-MUSCLE.

Current of Rest or Natural Nerve Current.—When an isolated piece of muscle is placed in circuit with a galvanometer, it is found that the muscle is a battery which generates a current passing from its cut ends to the equator. In other words, the cut end is negative to the middle point of the piece of muscle. A current passes from the middle point of the muscle through the galvanometer to the cut end.

The "natural" or demarcation current may have, in the frog, an electro-motive force of ·05 to ·08 of a Daniell's element.

Apparatus needed for its investigation.

Nonpolarisable electrodes, *i.e.*, electrodes which could not generate a current if placed in contact with dead muscle. It is necessary to bring into contact with the muscle a "normal" solution, which does not affect it chemically; the end of the electrode consists therefore of clay or blotting-paper moistened with 0·6 % solution of sodic chloride. The connection with the wire leading to the galvanometer must be made by a solution which cannot act chemically upon the wire, *i.e.*, a saturated solution of a salt of the metal of which the wire is made. The current is measured by compensation, *i.e.*, by passing in the opposite direction through the galvanometer an accurately graduated current. The neutralisation of the current in the galvanometer is obtained. The capillary electrometer is the simplest for the purposes of this observation.

Is the demarcation-current natural?

Con. 1. It is not to be observed in an uninjured muscle *in situ*.

2. It is a phenomenon common to all animal and even vegetable tissues. The dying or dead tissue is negative to the part of the tissue which is still alive.

3. The heart of the frog is iso-electric, but if it is cut the injured portion is found to be negative to the healthy portion. The difference in potential soon disappears, but can be renewed by making a fresh cut.

4. Depressing the vitality of any portion of a muscle, as by contact with potash salts, renders it negative to the vigorous portion.

5. If the muscle is cut by an apparatus, which, at the time at which it is cutting it, makes connection with the galvanometer (the falling rheotome), no current is observed.

The meaning of the muscle-current was at one time much discussed, but *Hermann* first in 1867 began to collect data, which have at length proved beyond doubt (*contra Du Bois Reymond et al.*) that the current is artificial.

The demarcation-current of one preparation may be used as the stimulus for another preparation, or even for itself (fig. 25). "Contraction without metals" may easily be obtained by "rheoscopic preparations."

When the end of the nerve of a nerve-muscle preparation is made to fall on the cut surface of the muscle, the nerve, by completing the circuit, allows a current

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Cagney.—"A Problem in the Electrical Reactions of Muscles," *Lancet*, 1891, vol. i. 24, p. 1306.

Du Bois Reymond.—"On Secondary Electro-motive Phenomena in Muscles, Nerves, and Electrical Organs," *Foreign Biol. Mem. Oxford*, 1887, p. 163.

Hering.—"On Du Bois Reymond's Researches on Secondary Electro-motive Phenomena of Muscle," *For. Biol. Mem. Oxford*, 1887, p. 229.

Hermann.—"On So-called Secondary Electro-motive Phenomena in Muscle and Nerve," *For. Biol. Mem. Oxford*, 1887, p. 277.

Biedermann.—"On the Phenomena of Inhibition produced by the Electrical Excitation of Striated Muscles, and on Positive Cathodic Polarisation," *For. Biol. Mem. Oxford*, 1887, p. 331.

to pass which stimulates itself. If a thread is tied round the nerve, the muscle does not contract.

Current of Action.—When a muscle is tetanised either directly or through its nerve, a current is developed in the opposite direction to that of the demarcation-current. This negative variation may reduce the demarcation-current almost to zero. If the muscle is uninjured, it does not show a current of action.

When a muscle is made to give a single contraction, the wave of contraction travels down the muscle at the rate of 3 metres per sec. The wave of contraction is preceded by a wave of negative variation, which travels at the same rate, but lasts at any given point only ·003 sec. It occurs in the latent period of the muscular contraction, *i.e.*, before the muscular contraction has developed, or at any rate before it is visible as a change of form.

Apparatus needed for the study of the nerve-muscle preparation.

A moist chamber in which the muscle can be suspended. An electric battery for stimulating the nerve: the Daniell's cell is a convenient form.

A magnetic interrupter by which the current may be frequently broken. It consists of an upright column which bears a steel spring. The spring is in contact with a milled-head screw, through which the current is led back to a second metal column connected with the negative plate of the battery. The second column is formed of a soft iron core, surrounded by the wire which leads the current back from the milled-head screw; it becomes a magnet, therefore, every time that the current is "made." But as soon as it is a magnet, it attracts a steel plate on the end of the spring, and, drawing the spring down, breaks the current and undoes its own magnetisation, thereby allowing the spring to fly back to the milled-head screw, remaking the current. The spring, therefore, vibrates between the screw and the magnet, and the current is in consequence alternately made and broken.

Accessory to the magnetic interrupter is a second pillar with a pointed top, which keeps the steel plate from touching the magnet, to which it would cling for a short time after the current was broken (fig. 27).

(P) A primary coil in the course of the wire which connects the milled-head screw with the magnet; this is of no use by itself, but it induces a current (opposite in direction) in S, a secondary coil. The current, which is made by closing the key and completing the circuit, is called the making or closing current, and—*mutatis mutando.* The making (closing) and breaking (opening) currents in the secondary coil are more sudden than those drawn straight from the magnetic interrupter, and therefore better stimuli for the nerve-muscle preparation. The current in the primary coil is constant in direction; that in the secondary coil is opposite to the primary on making, in the same direction as the primary on breaking. Of the two the "breaking" induced current is more sudden, and therefore more effective than the "making" induced current. This is because each loop of the wire in the coil acts as a primary coil to the loop of wire next to it, and its current consequently induces in the adjoining loop a current of opposite direction, which has to be overcome as the main current passes on. The primary current is therefore weakened when thrown into a coiled wire, and consequently the current induced in the secondary coil is not so strong as it would be were there no induction in the primary coil. No similar action occurs on breaking the primary current; the induced current in the secondary coil represents its whole strength.

If a weak induced current is used, only the breaking shocks induce contraction of the muscle.

The two kinds of shock may be equalised by using the contrivance (*af*)—a side wire which keeps up a constant weak current in the primary coil. This current resists the current which is induced in the secondary coil on breaking, and therefore diminishes its intensity. When Helmholtz's side wire is in use, the milled-head screw is screwed up far enough from the spring to prevent it from touching it.

It is often desirable to select only making-shocks, or only breaking-shocks, excluding the other kind. This can be done by using Stöhrer's commutator. The bent bar of soft iron (fig. 31 H) is rotated in front of the horse-shoe magnet, N S. Each time that its ends come opposite to the ends of the magnet, it also is magnetised. Its magnetisation induces a current in the wire coiled around it (magneto-induction). The magnetisation of the bar is made and unmade every time its ends approach and leave the horse-shoe; consequently, currents opposite in direction are induced twice in each revolution. 1 and 2, 3 and 4 are metal plates carried on a non-conducting ebonite core. 1 and 2 are connected with one end of the coiled wire, 3 and 4 with the other end. The current generated in the coiled wire is led off by the conductors Y and Z. 1–2 and 3–4 can easily be so placed as to touch Y and Z only as the ends of H approach the ends of N S, or only as they leave them. In the former case they lead off the induced "making" current, in the latter case they lead off the induced "breaking" current.

To make and break with immense rapidity, *Kronecker* and *Stirling* used a vibrating steel bar, surrounded at one end by a primary, at the other end by a secondary coil (tone-inductorium). It can be used to produce as many as 24,000 alternating currents per second. The rapidity of its vibration is estimated by the pitch of the sound given out.

Keys and commutators of various kinds are used. The simplest and at the same time the most generally useful commutator is Pohl's. Figure 30 explains itself. The end screws – and + are connected with the battery; the side screws *x* and *y* with the nerve or muscle. If the handle is moved across so that the free wires rest in the mercury cups on the opposite side of the disc, the current is reversed.[1]

A record of a single spasm shows—

A. A latent period or interval after stimulation before any visible change occurs. In an ordinary nerve-muscle preparation this includes (*a*) the time taken by the impulse in travelling along the nerve, and (*b*) the true latent period of about ·01 sec. before contraction occurs.

This interval may be still further diminished (to ·004 sec.) by using the best methods for registering the first change in the muscle. It is so short that it is possible that it is entirely consumed in overcoming the inertia of the muscle.

B. Contraction period = about ·04 sec.

C. Relaxation period = about ·05 sec.

[1] The pieces of apparatus named above are the most generally useful. For other forms of apparatus, see *M'Kendrick*, pp. 363 *et seq.*, or *Landois and Stirling*, 4th edit., pp. 668–710; M'Gregor-Robertson, *Physiological Physics*, London, 1884.

Kronecker and Stirling.—"The Genesis of Tetanus," *Jour. of Phys.*, vol. i. p. 384.

Sewell.—"Effect of Two Succeeding Stimuli upon Muscular Contraction," *Jour. of Phys.*, vol. ii. p. 164.

Sewell.—"The Cause of the Failure of very Rapid Electrical Stimulation to Produce Tetanus," *Jour. of Phys.*, vol. ix. p. 92.

Starr and Young.—"Responses to the Alternating Current in Normal and Degenerate Muscles," *The Amer. Jour. of the Med. Sci.*, Oct. 1891, p. 301.

Yeo and Cash.—"Relation between the Active Phases of Contraction and the Latent Period of Skeletal Muscle," *Jour. of Phys.*, vol. iv. p. 198.

Yeo.—"The Normal Duration and Significance of the 'Latent Period of Excitation,'" *Jour. of Phys.*, vol. ix. p. 396; vol. x. p. 149.

Graphic Record.

Meaning:—A tracing made by a body in movement, upon paper, blackened glass, or other suitable surface.

Advantages:—The transient movement makes a permanent record, the several phases of which can be studied at leisure.

In making a graphic record of a muscular contraction, it is necessary to mark (1) a base line, from which the amount of contraction is measured, (2) the time at which the stimulation is effected, (3) minute intervals of time, such as may be traced by a vibrating tuning-fork.

Myographs are made in many different forms, the object in every case being to provide a moving surface which can be conveniently kept in apposition with the point of a lever, moved by the muscle, and with the point of the time-marker. The commoner forms of apparatus consist either of a blackened revolving drum, or of a continuous roll of paper, or of a blackened glass plate attached to a long pendulum.[1] The duration of the contraction as a whole depends upon the kind of muscle. It is long in "red" and fœtal muscle. It is also increased by cold and by fatigue.

Mechanics of Muscle.

In extreme contraction it shortens by from $\frac{1}{2}$ to $\frac{2}{3}$ of its length.

Its power $\propto$ its cross-section.

The maximum lift of human muscle is 7000 to 10,000 grammes for each □ cm. of its cross-section. For frog's muscle 3000 grammes. By its attachment to levers, and by the arrangement of its fibres (in many cases obliquely to the tendons in which they are inserted), a great range of movement is obtained at the expense of strength.

1. Thus the biceps and brachialis anticus are inserted into a lever of the third order. The point of action of the power is about $\frac{1}{10}$ as far from the fulcrum as is a weight carried in the hand. If the cross-section of the united muscles were 16 □ cm., their power would be 112 kilos (7000 grammes × 16); they could, therefore, hold out a weight of 11 kilos (25 lbs.) in the hand. The muscles can shorten (*i.e.*, lift their points of insertion) 60 mm. (2 inches); by so doing they raise the weight in the hand 0·6 metre (20 inches).[2]

Examples of each order of lever are found in the body, but the third is commonest; the second, the least common. The triceps, the occipito-vertebral muscles, the gastrocnemius, *et al.*, act upon levers of the first order. The gastrocnemius when raising the heel from the ground, the glutei in hopping, *et al.*, upon levers of the second order.

If the greatest amount of work is to be obtained from a nerve-muscle preparation, it must be taken out of the body quickly and without injury, and suspended in a moist chamber at a suitable temperature.

How can it be arranged so as to obtain the maximum work from (A) a single spasm?

1. The right weight must be selected by experiment, because the contraction is a function of the resistance, *i.e.*, it does not follow that of several weights a given muscle will lift the lightest to the greatest height.

[1] *M'Kendrick*, p. 408 *et seq.*

[2] This is an estimate for a man of average height and strength. For additional cases and more exact measurements, see *Macalister's Anatomy*, pp. 45 and 67.

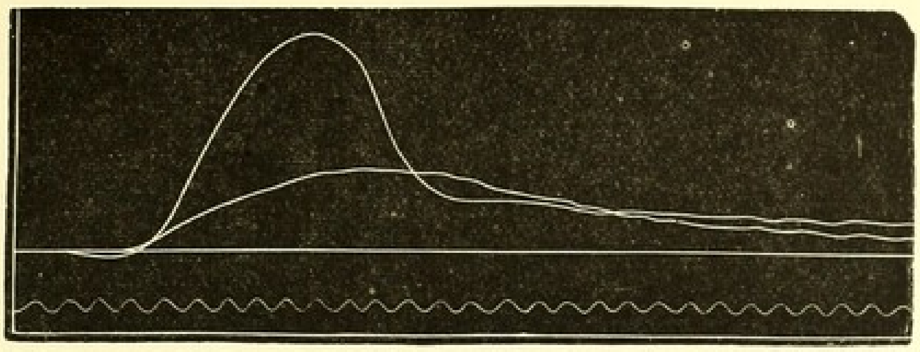

FIG. 33.—Curves obtained from a fresh muscle and from a fatigued muscle compared.

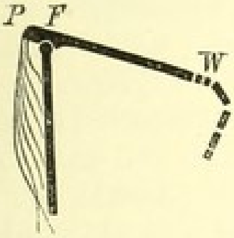

FIG. 34.—The triceps muscle acting on a lever of the first order.

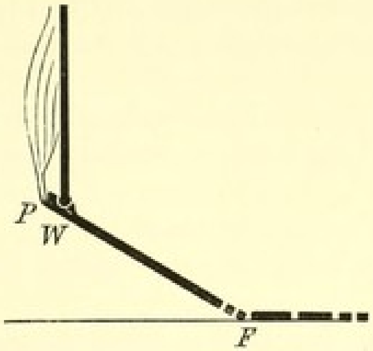

FIG. 35.—The triceps muscle acting on a lever of the second order.

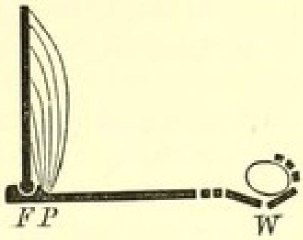

FIG. 36.—The biceps muscle acting on a lever of the third order.

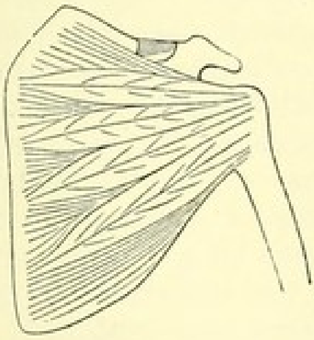

FIG. 37.—A bipenniform muscle; the subscapularis. By the oblique attachment of the fibres of compound muscles to their tendinous septa, the range and rapidity of movement is increased, the force diminished.

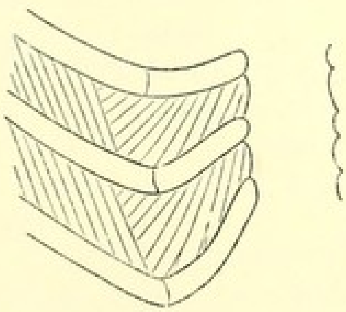

FIG. 38.—A portion of two external intercostal muscles and the intercartilaginous parts of two internal intercostals, showing the cross-lacing of their fibres.

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Weber's table for the gastrocnemius of the frog:—

Weight lifted, in Grammes.	Height in Millimetres	Work done in Gramme-millimetres.
5	27·6	138
15	25·1	376
25	11·45	286
30	7·3	219

The greatest amount of work is done against a moderate load.

2. The muscle must be "after-loaded;" it is not so powerful when stretched as when partially contracted.

3. The load must diminish progressively towards the end of contraction; a strongly contracted muscle is weaker than a partially contracted one.

All these requirements are provided for in the animal body, as shown in fig. 36. The work done when the biceps begins to contract is very small; it throws the weight forwards. Work reaches its maximum rather above half contraction. From this it diminishes again as the hand approaches the shoulder.

4. The stimulus must have an intensity considerably greater than its liminal value.

Physical Difference between contracted and uncontracted muscle.

A. **Form.**—The contracted muscle is shorter, broader, harder, and (?) less translucent than the uncontracted muscle.

B. **Optical Properties.**—The microscope shows that the bright bands at either side of Dobie's line diminish in size even to disappearance. Dobie's line becomes broader and darker.

This diminution of the bright band is not progressive, but early in contraction the dim and bright bands become fused together.

When fully contracted, the dark band, which occupies the place of Dobie's line, contrasts strongly with the dim band, which now looks brighter by contrast. In a sense, therefore, there is a "reversal of the stripe."

The changes are best observed in a muscle-fibre which is "fixed" by osmic acid or other reagent when only part of it is contracted. Examined under polarised light, no distinction can be made between the singly refracting bright bands and the dark line; both appear dark. During contraction this dark area becomes progressively narrower. The dim band remains doubly refracting, and becomes but little thinner, although much wider, as measured from side to side.

The contracted muscle-fibre is pinched in at Dobie's lines.

C. **Elasticity.**—Each additional unit of weight added to a piece of india-rubber or steel-spring gives rise, up to certain limits, to an equal increment of length. Equal weights added to muscle cause progressively diminishing increments of length. The curve of extension is an hyperbola. The muscle does not regain its original length after weighting by even a moderate weight.

Contracted muscle has less elasticity (power of resisting extension) than passive muscle. It returns more nearly to its original length when the weight is removed, *i.e.*, its elasticity although less is more perfect.

Weber's paradox. It results from the diminution of elasticity during contraction, that if a passive muscle is overloaded, and its nerve then stimulated, it lengthens instead of shortening.

Pettigrew.—"Animal Locomotion," *Inter. Sci. Series.*
Marey.—"Animal Mechanism," *Inter. Sci. Series.*

This has been regarded as indicating a transverse contraction, which is only recognisable when longitudinal contraction is prevented (*Lauder Brunton*).

Fatigue and defective nutrition (*Roy*) also diminish elasticity.

D. **Contraction** is accompanied by the evolution of heat.

After two or three minutes of tetanus, the temperature of frog's muscle is raised 0·14° to 0·18° C.

The single contraction of a gramme of muscle results in the evolution of about ·001 to ·005 calorie.

The muscles are the chief source of the heat of the body. In contraction $\frac{4}{5}$ of the energy set free takes, as a rule, the form of heat, to $\frac{1}{5}$ accounted for by external work. The proportion between heat and work varies, however. It is possible that the muscles may be stimulated to produce heat without undergoing change in form. Shivering is an irregular "fibrillar" contraction, which results from the demand for increased heat-production by the muscles.

E. When a stretched muscle is tetanised it produces a sound the note of which equals the note given out by (*i.e.*, the number of vibrations of) the interrupter.

When a stethoscope is applied to muscle contracting under the influence of the Will, a note having 39 vibrations per sec. is heard; but this is simply the proper note of the ear (see p. 131), and cannot be regarded as proving that the muscle is contracting 39 times per sec., or 19·5 per sec., as used to be supposed.

F. **Chemical Changes.**

Muscle when resting is alkaline, after prolonged work acid; after death it is acid. It yields on analysis[1]:—

Fat, gelatin, &c., derived from the connective tissue by which the fibres are surrounded.

The fibres themselves consist of: water, 75 %; proteids and albuminoids, 21 %; fats, extractives, salts, 4 %. They yield—

1. From the sarcolemma, elastin, or a closely allied substance.
2. From the semi-fluid contents of the fibre:—

Clot	α. Para-myosinogen, a globulin, precip. by NaCl, coag. at 47° C.	
	β. Myosinogen, ,, ,, ,, 56° C.	
Serum	γ. Myoglobulin, ,, ,, ,, 63° C.	
	δ. Albumin, not a globulin, not precip. by NaCl, coag. at 73° C.	
	ε. Myoproteose, ,, ,, ,, not coag. by heat.	

β is the essential precursor of myosin; α is found in small quantity; ε is the muscle ferment.

3. Pigments, of which myohæmatin is a type. They serve to hold the oxygen received from hæmoglobin until wanted by the muscle (*M'Munn*).
4. Extractives, which may be divided into—

(*a*) Nutrients (in which class would fall some of the above-named proteids). Fats, glycogen, inosite, fermentable sugar (derived from glycogen, and found after activity, but not in resting muscle).

(*b*) Products of action—

α. Nitrogenous—

Creatin, creatinin, xanthin, hypoxanthin, carnin, uric acid, urea, taurin, inosinic acid.

β. Non-nitrogenous—

Lactic acids (sarco-lactic and ethene lactic acid).

5. Salts—

Potassium and phosphoric acid are predominant.

[1] Halliburton, *Physiological Chemistry*, p. 405 *et seq.*

Herroun and Yeo.—"Sound Accompanying the Single Contraction of Skeletal Muscle," *Jour. of Phys.*, vol. vi. p. 287.
Halliburton.—"Muscle-plasma," *Jour. of Phys.*, vol. viii. p. 133.

Coagulation of Muscle-Plasma.

1864, *Kühne* obtained muscle-plasma from frog's muscle (out of which the blood had been washed by passing a stream of salt-solution through the vessel) by freezing it, pounding the frozen muscle in a cooled mortar, and pressing at the temperature of the air. It is a syrupy liquid, faintly alkaline.

It coagulates (most quickly at 40° C.), and the coagulum contracts, squeezing out muscle-serum. The coagulum consists of myosin. Myosin is a globulin containing 1·26 % of sulphur. It is soluble in 5–10 % NaCl and other neutral salts, precipitated by saturation. The serum is acid. A neutral solution of myosin in 5 % NaCl, if diluted with water, coagulates a second time, with separation of more sarcolactic acid.

Comparison of the Coagulation of Muscle-Plasma with that of Blood-Plasma.

1. Myosin does not contract to so great an extent as fibrin.
2. A second globulin is separated out in the formation of fibrin (*Hammarsten*). No second globulin appears in myosin-formation.
3. Sarcolactic acid is set free during the coagulation of muscle-plasma. No acid is formed during coagulation of blood.
4. Myosin is much more easily soluble in saline solutions than is fibrin, and when dissolved behaves as myosinogen, being capable of clotting a second time. Fibrin cannot be reconverted into fibrinogen.

Chemical Changes which constitute muscular metabolism.

During rest metabolic events similar to those which mark contraction, although less in degree, occur in muscle.

Pro. When the nerve-endings are poisoned with curare, or when the nerves going to muscle are cut, less carbonic acid is evolved; more glycogen accumulates in the muscle.

During activity.

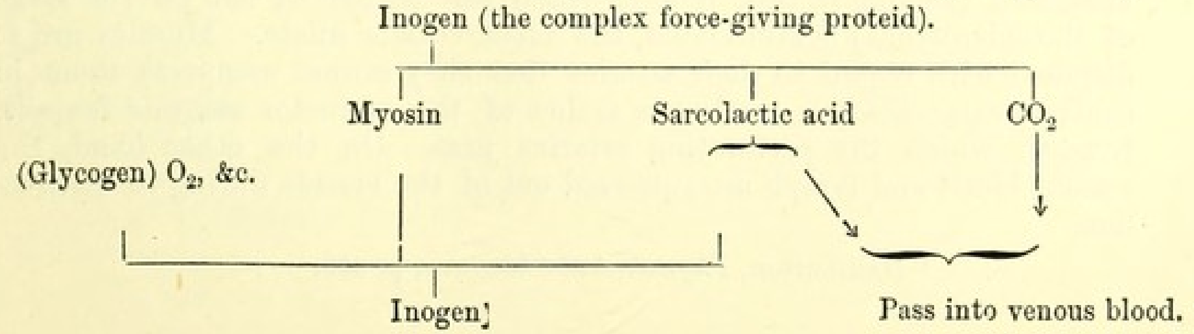
1. Proteids are not destroyed. They may be modified, and then built up again; but they are not so far consumed as to need elimination from the muscle-fibre.

   Pro. There is no considerable increase in the amount of N_3 eliminated from the body during muscular work.
2. The muscle becomes acid to test-paper. The amount of lactic acid developed $\propto$ as the number of times the muscle is made to contract.
3. The total amount of extractives soluble in water and not in alcohol is diminished. The quantity of extractives soluble in alcohol is increased. This indicates the disappearance of glycogen.
4. The amount of CO_2 given off is increased.

Chemical Theory of Muscular Contraction.

Contraction is not due to oxidation, for no free oxygen can be obtained from muscle; nor is it due to destruction of proteid. The only substances which leave the muscle are lactic acid and carbonic acid.

Hermann formulated the theory that resting-muscle contains a complex proteid which splits into myosin, sarcolactic acid, and carbonic acid. The formation of myosin not being completed (as in rigor mortis); but the myosin-antecedent being reunited with the lactic acid or with glycogen to re-form the complex proteid, thus—



Bernstein's theory is an effort to explain the electrical change and change of form which result from the chemical changes.[1]

Rigor Mortis.—Soon after death (in Man from 10 minutes to 7 hours) the muscles become rigid. This condition lasts for a period varying from 1 to 6 days. The sooner it commences the shorter the time for which it endures. It is accompanied by evolution of a considerable amount of CO_2 and an elevation of temperature. It commences quickly, and is soon over in exhausting disease, after great muscular exertion, and after administration of, or poisoning by, certain drugs (*i.e.*, veratrin, prussic acid, quinine, chloroform, ether, &c.).

Death of the muscle is preceded by nerve-death. The power of stimulating it through its nerve is lost before it enters into a condition of rigor.

The muscles of the head and neck are the first to become rigid.

If the blood-vessels are tied, the muscles which they supply pass into rigor slowly. Two stages may then be distinguished.

1. The muscles are stiff but excitable, and recover quickly on re-establishing the circulation.
2. The muscles are stiff, inexcitable, and cannot be restored.

In complete rigor the muscle is hard, dense, turbid, opaque, hardly extensible, and with no power of recovering its shape. Its reaction is acid. Its myosin is coagulated. Muscle-serum exudes from the surface when it is cut.

Is rigor mortis muscular contraction carried to an extreme?

Pro. 1. Duration $\propto \frac{1}{\text{amount of}}$ contraction before death.

2. Rapidity of onset $\propto$ amount of contraction before death.

3. Heat and CO_2 evolved $\propto \frac{1}{\text{amount evolved}}$ by the muscle before death.

Con. 1. It is not proved that myosin is formed in muscle when it contracts.

2. Contracted muscle is more extensible, but its elasticity is more perfect than that of resting muscle. In rigor mortis the muscle is almost inextensible, and has no elasticity.

What causes the rigidity to disappear?

Putrefaction?

Pro. In fishes rigidity lasts if the entrance of bacteria is prevented by using weak $Hg\ Cl_2$ (*Cossar Ewart*).

Con. It often disappears before putrefaction commences, or persists after it is well developed.

Self-digestion?

Pro. Muscle contains pepsin. If muscle is kept at the temperature of the body rigidity soon passes off, and the muscle is then found to contain proteoses and peptone in abundance (*Halliburton*).

Physiological Changes which accompany muscular action.

A. The blood-supply is increased.

In 1877 *Gaskell* showed that when the motor nerve of the mylohyoid muscle of the frog (a thin muscle which can be spread out on the stage of the microscope) is stimulated, the blood-vessels dilate. Muscles are so disposed with regard to their arteries that they cannot compress them in contracting: *vide* the tendinous arches of the adductor magnus femoris, beneath which the perforating arteries pass. On the other hand, the venous blood and lymph are squeezed out of the muscle during its contraction.

[1] Halliburton, *Physiological Chemistry*, p. 435.

B. The nutrition of the muscle is improved, and its growth in consequence favoured.

Development of muscle is obtained by exercise. Deformities of the figure are corrected, not by resting the weak parts, but by specially using them, as is provided for in the Swedish system of gymnastics—growth $\propto$ functional activity.

C. Fatigue results.

Causes of fatigue; are they (*a*) local?

a. Due to consumption of force-giving substance?

Con. The "fatigue curve" is almost a straight line. If the loss of power depended upon the consumption of force-giving substance, the fall would be rapid at first and afterwards slow.

β. Due to accumulation of products of action?

This is the more probable explanation:

Pro. 1. When frog's muscle is contracting with difficulty, the circulation through its blood-vessels of a normal salt-solution, which removes products of action without bringing nutrients, renews its activity.

In the same way, the stiffness and pain in overworked muscle is removed by quickening the circulation by a hot bath or by massage.

2. The injection into the circulation of lactic acid accelerates and immensely increases fatigue.

b. Are the causes of fatigue of central origin?

The nervous elements in connection with the muscle must be regarded as forming a part of the contractile apparatus. Does fatigue commence in the nerve-cells?

Pro. However tired the muscles, unusual impulses, due to fright or other strong emotion, cause them to contract vigorously, in a way which would appear impossible for a clogged machine.

Con. 1. We know nothing with regard to the relative force of the impulses in the two cases, and therefore we cannot say how much greater may be the explosion provoked by the impulse when reinforced by emotion.

2. It is impossible to tire nerve-fibres.

If, while interrupted impulses are being sent through a nerve, its nerve-endings are paralysed with curare, contraction of the muscle ceases, to be resumed as the effects of the curare pass off. (*Bowditch.*)

We do not know whether the same result would be obtained if the impulses were sent through a reflex arc in the central nervous-system, or whether the nerve-cells and other constituents of the grey matter are capable of being tired.

Fatigue curve; as the muscle tires:—

a. The latent period is lengthened.

b. The duration of the phase of contraction is hardly, if at all, lengthened, but the height of the contraction is diminished.

c. The time taken up in relaxing is greatly increased (fig. 33).

Brinck.—"Experiments on Nutrition of Muscle," *Brit. Med. Jour.*, 1891, No. 1595, p. 181.

ELECTRIC ORGANS.

About fifty different species of fish are provided with organs capable of delivering an electric shock of greater or less intensity. The shock given by a gymnotus or a malapterurus is sufficiently strong to knock down a man who steps upon it with his naked foot. The shock from a torpedo paralyses its prey at some little distance, notwithstanding the rapid dissipation of electricity by sea water. The organ in the skate can hardly prove offensive to animals larger than the parasites which try to settle on its back.

The electric organ of malapterurus is made from transformed gland-cells, and innervated by the branches of a single giant-fibre which originates in a single giant-cell on each side of the body. In most other fishes the organ is muscle so transformed as to serve not for contraction, but only for electric discharge, and supplied by fibres from numerous characteristic nerve-cells. The discharge is from the nerve-disc through the modified muscle. The living organ presents a constant current in this direction. It also conducts more freely in this than in the opposite direction ("irreciprocal conduction").

In the common skate (Raia batis) a firm structure 6 or 7 inches long, by half an inch to an inch thick, is embedded in muscle on either side of the tail. It consists of discs 1·5 mm. wide by 1 mm. thick, surrounded by fibrous connective tissue (fig. 40).

In its early development each disc contains an embryonic muscle-fibre. The nerve is applied to the anterior end of the fibre. This end grows in breadth and becomes cupped, while the other constitutes the narrow handle of the club. In the adult organ the handle can still be found, but the essential part of the disc, the anterior end of the fibre, is greatly increased in breadth. A medullated nerve breaks up dichotomously into a large number of non-medullated nucleus-bearing branches, which spread out on the membrane covering the front of the disc. Behind the membrane lies the muscle, its coarse (transverse) striations contorted in all directions. This is covered by a homogeneous nucleated layer, which projects as papillæ into the mucilaginous connective tissue which constitutes rather more than half of each disc.

Gymnotus electricus: the organ is somewhat similar, but the nerves are applied to long papillæ on the posterior surface of the modified muscle. It therefore discharges from tail to head.

Torpedo galvani: certain gill-muscles are modified into electric organs, which form a large mass on either side of the head. Each organ contains about 800 prisms. Each prism is divided by horizontal septa into some 615 superposed plates, resembling the discs of a voltaic pile. Each plate is a multi-nucleated cell, divided into three layers, with its nerve-ending on the ventral aspect. It discharges from belly to back. Its muscular origin is no longer recognisable.

Du Bois Reymond.—"Observations and Experiments on Malapterurus," *For. Biol. Mem. Oxford*, 1887, p. 369.

Du Bois Reymond.—"Living Torpedos at Berlin," *For. Biol. Mem. Oxford*, 1887, pp. 417 and 479.

Gotch.—"Electromotive Properties of the Electrical Organ of Torpedo Marmorata," *Phil. Trans.*, 1888, p. 329.

Ewart.—"The Electric Organ of the Skate," *Phil. Trans.*, 1888, B., pp. 399 and 539, and 1892, B., p. 389.

Fritsch.—"The Origin of the Electric Nerves in the Torpedo, Gymnotus, Mormyrus, and Malapterurus," *Nature*, Jan. 19, 1893.

Marshall.—"Observations on the Structure and Distribution of Striped and Unstriped Muscle in the Animal Kingdom and a Theory of Muscular Contraction," *Quart. Jour. Micr. Sci.*, vol. xxviii. p. 75, 1887.

CARDIAC MUSCLE-FIBRES.

Nerve-endings ; uncertain, probably the nerve-filament becomes confluent with the muscle substance.

Contraction: owing to the absence of sarcolemma, branching of fibres and union of their branches, the impulse spreads as in nonstriated muscle from fibre to fibre. The latent period is long, the contraction sustained. This kind of muscle shows extreme tendency to rhythmic action, and therefore the effect of stimulation depends upon the phase of metabolism, *i.e.*, the part of a muscular cycle in which it falls. Immediately after contraction, the heart-muscle is hardly susceptible to stimulation ; "refractory period." (See Heart, p. 29.)

PLAIN MUSCLE.

Plain muscle differs widely in structure from striated muscle. Its cells are small (100 μ by 7 to 10 μ), devoid of sarcolemma, united into bands or sheets by "cement substance." An oval nucleus surrounded by a little granular protoplasm lies in the centre of each fibre ; the rest of the cell-substance is somewhat refractive, firm, homogeneous, or marked by longitudinal striæ. Plain muscle is supplied by non-medullated nerves. Knob-like endings have been described, and the enormous number of nerve-cells and fibres in the intestines (Auerbach's and Meissner's plexuses) seem to show that here at any rate each cell receives a fibre. The middle of the ureter, on the other hand, is said to be destitute of nerves.

Chemistry.—Albumin, globulins, myosinogen, creatin, glycogen, are found in plain muscle, and there is no reason to think that the chemistry of its contraction differs from that of striated muscle.

Stimuli.—Mechanical, chemical, or making and breaking of constant currents.

Latent period very long, contraction lasts several seconds ; spreads as a wave (1 cm. long, and travelling 20 to 30 mm. in a second) from fibre to fibre. Irritability is very dependent upon temperature, being lost at 19° C.

When severed from the nervous system, plain muscle contracts at intervals under the influence of natural local stimuli.

CILIARY MOVEMENT.

Cilia line the inferior meatus of the nose, the trachea and bronchi ; the ducts opening into the pharynx ; fallopian tubes, uterus, vasa efferentia, and coni vasculosi of the epididymis ; central canal of the spinal cord and ventricles of the brain (in early life if not always). They vary in size, those in the epididymis being the largest.

Nature of the Movement.—A sudden bending down on one side with slow recovery, repeated 10 to 20 times a second. The cilia contract successively, sending a series of ripples over the field. The tail of a spermatozoon undulates like that of a tadpole.

Origin of the Movement.—In many invertebrates it is controlled by the nervous system. In mammals it is continuous. Does the cell-protoplasm shake the cilia?

Pro. 1. The superficial layer of the epithelial cells is hyaline and striated as if made up of the handles of the cilia fitted into a mosaic ; a vertical striation of the subjacent protoplasm is often visible.

Cooke.—"Action of Various Stimuli on Nonstriped Muscle," *Jour. of Anat. and Phys.*, vol. xxiv. p. 195, 1890.

2. It is difficult otherwise to explain the control (in invertebrates) of the nervous system.

Con. The sudden doubling down of surface-cilia, and the wriggling of the tails of spermatozoa, seem to be movements which could not be conducted by the cell-body.

Engelmann states that cilia are doubly refracting, and supposes that they consist of a contractile and an elastic filament united together.

Chemistry of Ciliary Action.—The same as that of muscle. Chloroform, ether, carbonic acid, stop it; oxygen favours it. It is retarded by cold, accelerated by warmth up to 40° C., a little above which temperature proteids are coagulated. When it is becoming fatigued, its vigour is renewed by application of dilute alkali (1 part KHO in 1000 of water); this indicates that, as in muscle, fatigue is due to accumulation of sarcolactic acid.

Engelmann.—"Physiology of Protoplasmic Movement," *Quart. Jour. Micr. Sci.*, vol. xxiv. p. 370, 1884.

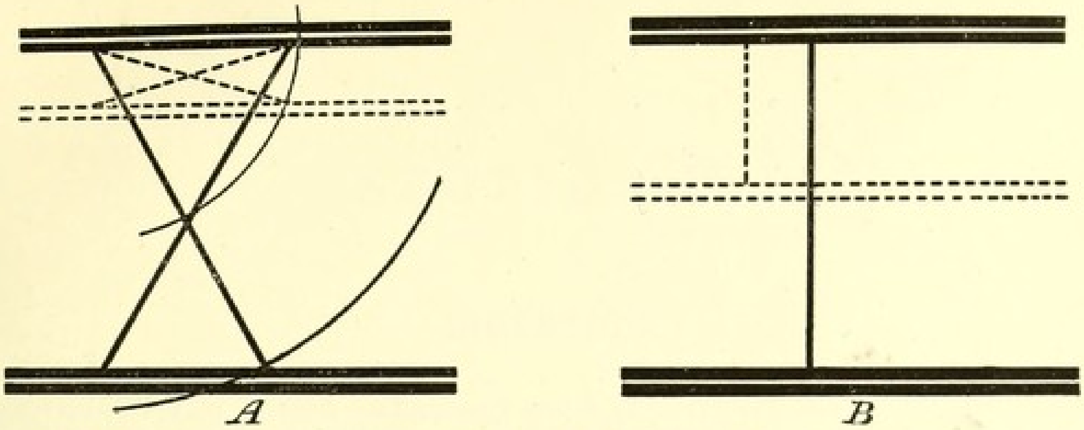


FIG. 39.—Diagrams showing the extent to which two rigid bars can be approximated by muscles placed, A, obliquely and, B, vertically respectively.

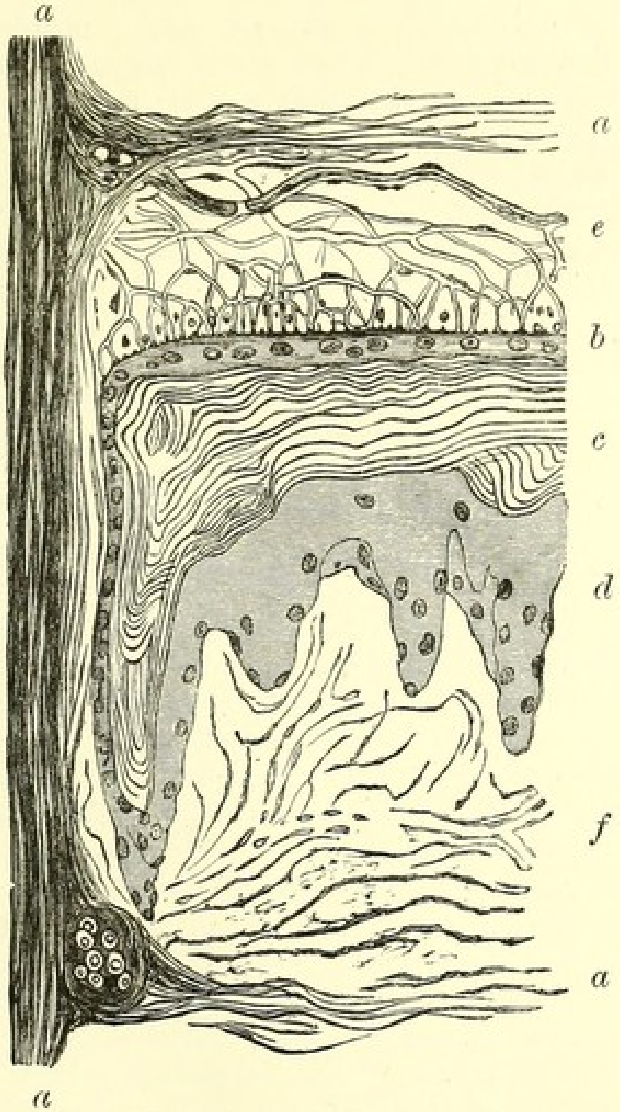


FIG. 40.—About ⅓ of a disc of an electric organ of the skate. Antero-posterior section. *a*, The fibrous capsule of the disc; *b*, *c*, *d*, the modified muscle-fibre—*b*, its nucleated layer; *c*, its striated portion (the striæ are too distinct in the figure); *d*, the posterior lamina of the homogeneous nucleated portion of the muscle-fibre prolonged into papillæ, which project from the margin of alveoli; *e*, the nerve-ending (near the fibrous septum of the capsule the nerve-fibres are surrounded by irregular fragments of medullary sheath; they divide dichotomously as they approach the muscle-fibre, losing their medullary sheath, but still invested by a homogeneous, nucleated sheath of Schwann); *f*, loose muco-gelatinous connective tissue which occupies the posterior half of each disc.

To face p. 58.]

SECTION V.

DIGESTION.

Apparatus.—The human alimentary canal is divisible into the mouth, which is not a part of the primitive alimentary canal of the embryo, but an involution of the epiblast (the stomodæum). The fauces are guarded by folds, of which the anterior (anterior pillar) passes to the tongue, the posterior pillar to the pharynx. The tonsils occupy the hollows between the pillars. The roof of the pharynx belongs to the stomodæum. The pharynx is 4½ inches long and widest from side to side. The trachea opens out of its anterior wall beneath the hyoid (2nd post-oral) arch; its aperture, the rima glottidis, is guarded by the elastic epiglottis, which, attached by its base to the hyoid bone, is depressed over the rima glottidis during swallowing. The œsophagus is 9 to 10 inches long. Its inferior aperture is the cardiac orifice of the stomach. The adult male stomach has a capacity when distended of about 3½ litres. At its pyloric end it is slightly constricted into a small second chamber, the antrum pylori. It is separated from the duodenum by a powerful constrictor muscle, the pyloric valve. The duodenum, 12 finger-breadths (9 inches) long, is curved like a horse-shoe. Its first part is, like the stomach, freely movable; its second and third parts are fixed to the body-wall behind the peritoneum. The common bile-duct and the pancreatic duct open into it, on the median side of its second (vertical) portion by a single orifice. Its cavity is constricted by valvulæ conniventes, which are most prominent just below this orifice. The remainder of the small intestine is about 20 feet in length. It is supported by a double fold of peritoneum, the mesentery, which, about 4½ inches long where it is attached obliquely to the posterior wall of the abdomen (from the left side of the 2nd lumbar vertebra to the right sacro-iliac synchondrosis), is at its intestinal margin folded repeatedly upon itself. Its upper two-fifths are termed jejunum, its lower three-fifths ileum. There is no line of demarcation between these two regions. Valvulæ conniventes become less prominent as the small intestine is descended, and are absent from its lower fourth. Villi also are more prominent in its upper than in its lower portion. Lymph-follicles are scattered about the small intestines, and are very numerous in the vermiform appendix of the large intestine; in the ileum they are collected into about thirty patches, "Peyer's Patches" (1–3 cm. long, by 1–2 cm. wide), which occupy the side of the intestine farthest from the mesentery. The colon is about 4 feet long. It commences at the ileo-colic valve which, as two shelf-like folds projecting into the colon, guards the narrow horizontal inferior orifice of the small intestine. The large intestine is constricted by three longitudinal bands of muscle, the tæniæ coli. The wall between the tæniæ is sacculated, being raised into transverse plicæ sigmoideæ which bound the pouches or haustra. The commencement of the colon is bulged out below the ileo-colic valve into the so-called cæcum, but the real cæcum, the homologue, that is to say, of the cæcum of lower animals, does not grow in post-embryonal life, but remains as the small vermiform appendix. The ascending colon is fixed to the body-wall, the transverse colon is freely movable; the first part of the descending colon is fixed, but the second part, the "sigmoid flexure," is very freely movable. The rectum is about 8 inches long. It is curved from left to right, and also from before backwards into an inverted S. The lower part of the rectum is not a part of the primitive gut of the embryo, but an involution of the epiblast; a depression of the skin-surface, that is to say, the proctodæum, which meets and joins the hind gut. When, as occasionally happens, it fails to meet the gut, the anus is imperforate.

Glands which secrete digestive fluids are outgrowths of the epithelium of the canal, and therefore formed from the hypoblast of the embryo, with the exception of the salivary glands which belong to the stomodæum (mouth-involution), and are therefore epiblastic. The outgrowths are hollow tubes, except in the case of the liver, which consists in the first instance of solid rods of epithelial cells.

Gland-cells present varying appearances, according to the distance of the cells from the opening of the duct. The ramified tubes are divisible into ducts, intermediate portions, and acini.

The gland-cells are supported within lymph-sinuses or spaces, from the fluid contained in which they obtain the raw materials for their secretions. The connective tissue by which they are supported is reduced to a minimum. It may constitute a "basement-membrane," or may be a mere basket-work, allowing the naked bases of the cells to project into the lymph, as in the salivary glands. Plates of connective tissue surround the lymph-spaces. Blood-vessels and lymph-vessels ramify in these plates, but do not come into contact with the cells. (The appearance presented by hardened preparations in which the tissues have shrunk-together are deceptive in this respect.) Nerves are found in the connective tissue, but their mode of ending in gland-cells has not been satisfactorily determined.

The presence of nerve-cells, from which processes pass amongst the gland-cells, and fuse with their body-substance (or perhaps with the nucleus), has been described by *Pflüger*, *Kupffer*, and *Macallum*, but these observations need confirmation, owing to the uncertainty of the methods used. (In attempts to stain the terminations of nerves with gold-chloride, the precipitation of oxide of gold is apt to produce delusive effects.)

[In describing glands it is well to take these several structures in order, mentioning first the general form of the gland, whether simple or compound; tubular or acinous. A compound acinous gland is described as racemose. Then describe the character of the epithelium in the different parts of the gland-system, the basement-membrane, other connective tissue, blood-vessels, lymphatics, nerves.]

The characteristic tubular glands of the alimentary canal are first found at the cardiac aperture of the stomach (in carnivora and omnivora), where the stratified epithelium of the œsophagus gives place abruptly to the glandular mucous membrane of the stomach. From this spot almost down to the anus the mucous membrane is honeycombed with tubular glands. Near the cardiac orifice the glands are long, and placed close together, so that in sections it is seldom possible to recognise the tubular form of the glands; they do not in hardened preparations show any distinct lumen; they contain two kinds of cell, (*a*) oxyntic, parietal or border cells, lying in contact with the basement-membrane, large, ovoid or angular, somewhat yellow in tint, with granular cloudy protoplasm and central spherical nucleus—they secrete acid; (*b*) peptic, central or principal cells, bordering the lumen of the tube, cubical, colourless, clear or granular, with nuclei which are displaced towards the basement-membrane when the cell is charged. Towards the pylorus

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Mummery.—"Some Points in the Structure and Development of Dentine," *Phil. Trans.*, 1891, B., p. 527.

Robertson.—"The Relation of Nerves to Odontoblasts and on the Growth of Dentine," *Trans. of the Roy. Soc. of Edinburgh*, vol. xxxvi., 1892.

Greenwood.—"Gastric Glands of the Pig," *Jour. of Phys.*, vol. v. p. 195.

the tubes are shorter than at the fundus, and two or three open together into a wide mouth; they contain peptic cells only. At the pylorus they begin to pierce the muscularis mucosæ, and for about the upper half of the duodenum a certain number of the tubes branch in the submucous tissue, and the ends of the tubes dilating into acini—constitute Brunner's glands. The tubes which do not branch are known as crypts of Lieberkühn. In the large intestine the tubes are relatively much wider than in the small intestine, and exhibit a distinct lumen. The mucous membrane of the colon is very easily distinguished from that of the stomach by this character. The mucous membrane of the small intestine is raised into villi, of which there are 10 to 18 in a *sq. mm.* in the duodenum, fewer in the ileum. The alimentary canal is supplied with a great abundance of lymphatic vessels and nerves. Lymph-vessels form a plexus around the tubular glands, and are continued as club-shaped vessels (lacteals) into the villi; they unite into a fine network above, and a coarse network beneath the muscularis mucosæ; valved vessels perforate the circular muscular coat to join another plexus between this and the longitudinal coat; effluents pass in the serous coat to the mesentery, which conveys them to the receptaculum chyli. Lymph-follicles are frequent in the submucous tissue; they are rare in the stomach, and limited to its pyloric end; more numerous in the small intestine, and still more numerous in the colon. Between the pillars of the fauces they are collected into a group, the tonsils; another group constitutes the pharyngeal tonsil; the regular groups in the ileum constitute, as already said, Peyer's Patches.

The nerves of the intestine form two plexuses, of which the inner one is the finer meshed; both bearing immense numbers of oval or round ganglion-cells, with large, clear vesicular nuclei. The outer plexus, Auerbach's, lies between the longitudinal and circular coat, the inner, Meissner's, in the submucosa.

The gland-cell consists of nucleus and cell-body. The nucleus is concerned with cell-multiplication, and appears, therefore, in a resting condition in cells which are loaded with products ready for excretion, while it is larger and presents other signs of activity in young cells and cells empty of secretion. The cell-body presents within itself an elaborate structure first recognised about ten years ago, and described by *Strassburger*, *Flemming*, *et al.* The protoplasm (or kytoplasma) is economised by its disposition in a network or *reticulum*, the meshes of which are filled by *enchylema.* The enchylema contains (*a*) the food-stuffs not yet metabolised; (*b*) the fully-formed metabolites; and probably also (*c*) a substance concerned in the work of metabolism. Each cell is therefore a little factory, in which the physiologist can recognise machinery, raw material, and manufactured products; he can determine the effect of nervous action or changed conditions, not only by analysing the secretion poured out by the gland, but also by observing the microscopic changes which occur within the cell-substance. The specific secernable products appear in the form of granules, which stain with osmic acid. If the granules consist of mucigen they swell up on the addition of water and other reagents, giving to the cell a turgid, glassy appearance, which causes sections of "mucous" glands to assume a characteristic appearance. In hardened preparations of mucous glands (*e.g.*, the submaxillary or sublingual glands of the cat or dog; parts of these two glands in Man), the young protoplasmic cells which are growing up to take the place of worn-out mucous cells are packed together in groups near the basement-membrane, and known as the "demilunes of Gianuzzi."

Are such groups of young cells restricted to mucous glands? This question is difficult to answer, since it is only when the adult cells are loaded with mucigen that they contrast strongly with the darkly staining

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Gibbes.—"On some Points in the Minute Structure of the Pancreas," *Quart. Jour. Micr. Sci.*, vol. xxiv. p. 183, 1884.

young cells. Perhaps, however, the secretion of mucus leads to unusually rapid destruction of secreting cells.

For the sake of making a distinction between mucus-secreting glands and those which do not secrete mucus, the latter are spoken of as "serous" or "albuminous."

Loaded *v.* Exhausted Cells.—When full of their specific products the gland-cells are larger, their outlines less distinct than when they are empty; their nuclei are irregular in outline, and placed nearer to the basement-membrane; their secernable products are seen as granules, or, owing to the deliquescence of mucigenous granules in water, as clear mucus contained in an open network.

When emptied the cells are smaller, their outlines distinct; nuclei large and round, near the centre of the cell; granules, or mucus, have either disappeared or are collected on the side of the cell next the lumen.

It is important that the cells should be examined under similar conditions. The salivary glands and glands of the stomach need to be examined fresh. The granules in the pancreas are not destroyed by alcohol.

Specific Differences between Glands.

It is very difficult to associate differences of function with structural peculiarities of gland-cells. Many cells present a zone in which their cell-substance is marked by striæ vertical to the surface. In the intestines the side towards the lumen is striated; in salivary ducts and in the tubuli contorti of the kidney the striated side is next the basement-membrane; it is possible that such a structure is favourable to considerable and rapid absorption.

The cells of the mammary gland contain during activity droplets of fat. The cells of sebaceous glands undergo almost complete fatty degeneration, lose their power of extruding the fat, and are disintegrated as a whole. In other gland-cells the secernable products accumulate as granules, *e.g.*, in the salivary glands, chief cells of stomach, pancreas, &c. The border or oxyntic cells in the stomach increase in size when loaded, and shrink in emptying, but no change in structure has been noted. In the liver, rounded masses of glycogen accumulate. The cells of the testis produce spermatozoa by cell-division.

What evidence is there that the granules are secernable products?

1. Their number is reduced by secretion.
2. In digesting fibrin stained in carmine, the amount of colouring agent liberated into the fluid varies as the amount of fibrin digested (Grützner's colorimetric test). The colour which the fluid assumes in a given time, when a given weight of carmine-fibrin is digested with a given amount of gastric mucous membrane or pancreas, varies as the quantity of granules in the gland-cells.

   On the other hand, the pancreas-cells of a starving animal contain granules, but yield no zymogen to glycerin. Perhaps the granules are only zymogen-carriers?

Are the granules the pure ferment?

No; they consist of or contain the ferment in combination = zymogen.

Pro. A glycerin-extract of the fresh stomach or pancreas is inert when freshly diluted. The diluted extract becomes active on standing, or more

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J. N. Langley.—"Physiology of Salivary Secretion," *Jour. of Phys.*, vol. i. pp. 68, 96, 339.

J. N. Langley.—"On the Changes in Serous Glands during Secretion," *Jour. of Phys.*, vol. ii. pp. 261, 281; vol. iii. 269.

J. N. Langley.—"Physiology of the Salivary Secretion," *Jour. of Phys.*, vol. vi. p. 71; vol. ix. p. 55; vol. x. p. 291; vol. xi. p. 123.

J. N. Langley.—"The Histology of the Mucous Salivary Glands, and the behaviour of their Mucous Contents, *Jour. of Phys.*, vol. x. p. 433.

quickly if mixed with weak mineral acid, or subjected to a stream of carbonic acid.

What is the chemical nature of the "Cloak"?

This question cannot at present be satisfactorily answered. Zymogen is not a compound of a ferment and a cloak in loose combination, but an antecedent of the ferment which differs from it in chemical properties. When carbonic acid gas is passed through a solution of pepsinogen, a globulin is thrown down, and the digestive capabilities of the solution destroyed; but it is not the globulin which possesses digestive power. If the pepsin is first set free from its "cloak" (by warming with dilute acetic acid), the carbonic acid does not diminish its digestive power.[1]

Ferments.—Defined as bodies which induce change in other substances without change in themselves. The change is usually of the nature of hydrolysis.

In some cases the effect is due to a vital action, *e.g.*, the alcoholic fermentation of sugar by yeast. Even from dead yeast (killed by ether), a ferment can be extracted which converts cane-sugar into inverted sugar (a mixture of dextrose and lævulose in equal parts), but no alcohol-making ferment.

The non-living ferments, like living ferments, are remarkably dependent upon temperature—acting best at a certain fixed temperature (usually about 40° C.)—being destroyed by a high temperature and thrown out of action, but not permanently destroyed, by a low temperature. Their activity is hampered by the accumulation of the products of action. It does not appear that they are destroyed or their activity in any way diminished by use.

Classification of ferments according to their nature (*Hoppe-Seyler*):—

A. Organised.

(Yeast), torula urinæ, bacteria of many kinds found in the alimentary canal.

B. Organic ferments or emzymes (of Kühne):—salivary; ptyalin. Gastric; pepsin, rennin, lactic acid ferment.

Pancreatic; amylopsin, trypsin, steapsin, milk-curdling.

Intestinal; changing maltose into glucose, invertin, (?) proteolytic and milk-curdling.

In muscle and urine; pepsin. In most tissues diastatic ferments.

Blood; fibrin ferment.

C. Inorganic ferments or bodies which, like platinum-black or sulphuric acid in the process of "continuous etherification," produce results very like those of fermentation.

Classification of ferments according to the nature of the substances upon which they act:—

Proteolytic, amylolytic, steatolytic, inversive, milk-curdling, &c.

The digestive secretions contain certain hydrolytic ferments or enzymes in solution in water, with inorganic salts. The ferments never occur alone, but they are accompanied by allies without which their action is imperfect. By-processes aiding digestion are carried on by accessory substances. The secretion as collected usually contains also products of the action of its enzymes.

[1] Langley and Edkins, *Jour. of Phys.*, vol. vii. p. 371.

Haycraft and Miss Southhall.—"Note on an Amylolytic Ferment found in the Gastric Mucous Membrane of the Pig," *Jour. of Anat. and Phys.*, vol. xxiii. p. 452, 1889.

Fraser.—"Action of Infused Beverages on Peptic Digestion," *Jour. of Anat. and Phys.*, vol. xx. p. 361; vol. xxi. pp. 337 and 413.

Yeo and Herroun.—"Composition of Human Bile," *Jour. of Phys.*, vol. v. p. 116.

Copeman and Winston.—"Human Bile," *Jour. of Phys.*, vol. x. p. 213.

Paton and Balfour.—"On the Composition, Flow, and Physiological Action of the Bile in Man," *Rep. Lab. Roy. Coll. Phys. Edin.*, vol. iii. p. 191.

Sidney Martin.—"Influence of Bile on Pancreatic Digestion," *Proc. Roy. Soc.*, 1889, p. 358; 1890, p. 160.

Rachford.—"The Influence of Bile on the Fat-Splitting Properties of Pancreatic Juice," *Jour. of Phys.*, vol. xii. p. 72.

Comparison of the several digestive secretions :—

	Saliva.	Gastric Juice.	Bile.	Pancreatic Juice.	Succus Entericus.
Amount per diem	1–2 litres (2–5 pints).	7 litres (15 pints).	500 c.cm. (?) 16 oz.	150 c.cm. (?) 5 oz.	
Specific gravity .	1004 – 1010.	1002.	1030 (?)	High.	1011.
Percentage of solids	0·5	0·5	14	8 (in Carnivora) less in Man (?)	2·5.
Ferments . .	Ptyalin.	Pepsin. Milk-curdling ferment (rennin).		Amylopsin. Trypsin. Steapsin. Milk-curdling.	Ferments which invert cane-sugar, milk-sugar, and maltose.
Ferments' ally .	$Na_2 CO_3$.	HCl 0·2 %.		$Na_2 CO_3$.	$Na_2 CO_3$.
Accessory bodies .	Salivary corpuscles. Mucin.	Mucin.	Bile salts 9 %. Sodic glycocholate. Sodic taurocholate.	Globulins (coagulable). Casein.	Albumin. Mucin.
Accidental bodies .	Epithelium. Bacteria. Leptothrix buccalis, &c.		Mucus, Pigments } 3 %. Fats and soaps 1 %. Cholesterin 0·2 %.		
Products of action .		Lactic acid from fermentation of carbohydrates.		(Peptones : Leucin and Tyrosin).	
Salts . . .	KCNS (potassic sulphocyanate, antiseptic).	$Ca Cl_2$. $Ca_3 (PO_4)_2$. Na Cl. &c.	0·6 – 1 %. Na Cl. KCl. $Ca_3 (PO_4)_2$, $Mg_3 (PO_4)_2$. Iron, manganese, silica.	Chiefly Na Cl.	

Notes on the Secretions.

A. Saliva has three functions, of which the two first are chief :—

1. The watery parotid saliva poured out at the root of the second molar tooth in the upper jaw moistens the food and aids attrition by the teeth.

2. The mucous submaxillary and sublingual saliva poured on to the frænum linguæ aids the formation of the masticated food into a bolus.

3. It converts boiled starch through erythro-dextrin (which still gives a red colour with iodine) and achroo-dextrin into dextrose.

B. Gastric juice, the only acid secretion, provides for the minute subdivision (chymification) of the food and its preparation for further digestion in the intestine, chiefly owing to its power of digesting gelatin, and hence removing connective tissue—dissolving the envelopes of fat-cells, and splitting muscle-fibre into discs.

1. It peptonises gelatin.

2. Converts albumins and globulins into peptones and antecedents of peptones.

3. Curdles milk.

4. (When it contains mucin), converts cane-sugar into dextrose.

C. Bile has no specific digesting power. It is accessory to digestion.

1. It precipitates peptones and parapeptones, causing the chyme to form a sticky deposit on the valvulæ conniventes, and thus delaying its progress.

2. It emulsifies fat, and enables it to pass through membrane without digestive alteration.

3. It stimulates the muscular wall of the intestine.

4. It is antiseptic.

D. Pancreatic juice is by far the most active of the digestive secretions. It finishes digestion, rendering the chyme thin and alkaline.

1. It is a far more vigorous proteolytic ferment than pepsin. It can digest nuclein and mucin, which are unaffected by gastric juice.

2. It converts raw as well as cooked starch into maltose.

3. It splits fats into their fatty acids and glycerin.

E. The digestive action of succus entericus is problematical. It can certainly "invert" the saccharoses, turning cane-sugar into a mixture of dextrose and lævulose, milk-sugar into dextrose and galactose, maltose into glucose.

F. It is not known whether digestive ferments do or do not occur in the large intestine.

Organised (living) ferments are found throughout the whole of the alimentary canal, but their presence, although unavoidable, must be looked upon as abnormal. The healthier the organism, and the more exactly the quantity of food is adjusted to its needs, the fewer will be these commensalists, or parasites sharing their host's food.

Examples of fermentations brought about by living organisms within the alimentary canal :—

A. In the stomach.

1. Decomposition of milk-sugar and other carbohydrates by the bacterium lactis:—

Sugar. *Lactic Acid.*

$$C_6H_{12}O_6 = 2C_3H_6O_3$$

Harris and Tooth.—"The Relations of Micro-Organisms to Pancreatic Digestion," *Jour. of Phys.*, vol. ix. p. 213.

Harris and Gow.—"Ferment Actions of the Pancreas in different Animals," *Jour. of Phys.*, vol. xiii. No. 6, p. 469, 1892.

Macfadyen.—"The Behaviour of Bacteria in the Digestive Tract," *Jour. of Anat. and Phys.*, vol. xxi. p. 227, 1887.

Macfadyen, Nencki, and Sieber.—"Research into the Chemical Processes in the Small Intestine of Man," *Jour. of Anat. and Phys.*, vol. xxv. p. 390, 1891.

2. The further conversion of lactic into butyric acid.

Lactic Acid. *Butyric Acid.*

$2C_3H_6O_3 = C_4H_8O_2 + 2CO_2 + 2H_2$[1].

B. In the intestines.

3. *Calcic Acetate.* *Marsh gas.*

$Ca2(C_2H_3O_2) + H_2O = CaCO_3 + CO_2 + 2CH_4$.

4. *Cellulose.* *Marsh gas.*

$n(C_6H_{10}O_5) + n(H_2O) = n(3CO_2) + n(3CH_4)$.

5. Glycerin yields butyric, butyro-acetic, and succinic acids.

6. Proteids and their digested products are broken up by bacteric ferments into alkaloids (indol, skatol), amines, amido-acids (leucin, tyrosin, &c.), fatty acids, ammonia, carbonic acid.

Methods of Collecting Digestive Secretions.

A. Saliva ; by taking ether into the mouth, or simply by chewing india-rubber, a flow of saliva is promoted.

The separate salivas may be obtained by placing cannulæ in the ducts of the several glands.

B. Gastric juice.

1785, *Spallanzani* obtained the juice by making birds swallow pieces of sponge which he could withdraw from the stomach by a string.

1822, *Dr Beaumont* collected it through a gastric fistula made by a musket bullet in the abdominal wall of a young Canadian, Alexis St Martin. The wound healed with a flap, by moving which the interior of the stomach was easily inspected. Beaumont carried on a long series of observations upon digestion, both within and without the body.

Schwann made an artificial juice by digesting the mucous membrane with 0·2 °/₀ hydrochloric acid.

v. Wittich showed that ferments can be extracted by glycerin. The extract must be made from the stomach of an animal which has been dead for 24 hours, or else the stomach must be washed with dilute hydrochloric or acetic acid. The glycerin extract can be used after addition of hydrochloric acid, or the pepsin may be precipitated from it by alcohol, collected and dried.

C. Pancreatic juice can be obtained by placing a cannula in the duct of the gland in the dog, and bringing the tube out through the wound in the abdomen.

Artificial juice is made by mincing up a pancreas which has stood for 24 hours (to allow of the conversion of the zymogen into enzymes), and extracting with glycerin ; 1 °/₀ of sodium carbonate is added.

D. Bile can be taken from the gall-bladder, or collected through a biliary fistula (in Man), or by means of a cannula in the bile-duct of an animal.

E. Succus entericus is obtained from a loop of the small intestine isolated from the rest of the alimentary canal and stitched to the body-wall.

Chemistry of the digestion of the several constituents of the foods.

A. Sugars. The three principally taken in food are :—

1. Milk-sugar—by gastric juice, is converted into galactose (*i.e.*, the sucrose is changed into a glucose, both dextro-rotary).

Lactose. *Galactose.*

$$C_{12}H_{22}O_{11} + H_2O = 2C_6H_{12}O_6.$$

[1] Although easy to remember, this equation does not fully represent the reaction ; water is taken up and less hydrogen is evolved, than represented by the equation.

In the intestines by inversive ferments it is converted into a mixture of dextrose and galactose.

2. Cane-sugar is changed by gastric juice into dextrose.

$$\underset{\textit{Saccharose.}}{C_{12}H_{22}O_{11}} + H_2O = \underset{\textit{Dextrose.}}{2C_6H_{12}O_6}.$$

In the intestines it is changed into a mixture of dextrose and lævulose (lævorotary).

3. Fruit-sugar (dextrose) needs no change. To these three must be added the sugar (maltose) made within the alimentary canal by the digestion of starch.

4. In the intestines the maltose is changed into dextrose.

It appears, therefore, that all sugars are absorbed in the form of glucoses, *i.e.*, sugars with the formula $C_6H_{12}O_6$.

B. Starch is changed by saliva or by pancreatic juice into maltose—a sugar identical with that formed by diastase in malting. Intermediate by-products can also be recognised thus :—

Mix some boiled starch with saliva, and warm to 35° C. Test every half-minute, by allowing a drop to fall into iodine-water on a white slab. Colour, at first blue (starch); then violet; then reddish brown (erythro-dextrin); then colourless. At this stage add excess of alcohol ; a white precipitate falls (achroo-dextrin). Maltose is present by this time. After long digestion only maltose is found. It is to be noted, however, that sugar is present as soon as dextrin. ∴ Although there is a single end-product it is reached by several lines.

$$\underset{\textit{Starch.}}{10(C_6H_{10}O_5)n} + 4(H_2O)n = \underset{\textit{Maltose.}}{4(C_{12}H_{22}O_{11})n} + \underset{\textit{Achroo-dextrin.}}{(C_6H_{10}O_5)n} + \underset{\textit{Erythro-dextrin.}}{(C_6H_{10}O_5)n}.$$

Notice that the molecular weights of starch and dextrin are unknown.

C. Proteids are digested partly in the stomach and partly in the upper part of the small intestine under the action of pancreatic juice.

The products of action of pepsin and trypsin are similar, although there are marked differences in intermediate stages and in intensity of action.

Pepsin.	*Trypsin.*
Requires acid medium.	Requires alkaline medium.
Acts slowly.	Acts rapidly.
Causes fibrin to deliquesce.	Erodes fibrin.
Acid albumin is formed.	Alkali-albumin is formed.
Digests gelatin.	?
Cannot digest—	Digests—
Nuclein.	Nuclein.
Mucin.	Mucin.
Elastin.	Elastin.
Does not decompose hemipeptone.	Breaks up hemipeptone into leucin, tyrosin, &c.

1836, *Schwann* discovered pepsin, and named the product of its action albuminose.

1850, *Lehmann* termed the product peptone ; he recognised that it is not coagulated by heat as albumin is.

Meissner and *Schmidt-Mülheim* recognised intermediate products, parapeptone, &c.

Our present knowledge of the digestion of proteids is due to *Kühne* and his pupils.

Lea.—"A Comparative Study of Artificial and Natural Digestions," *Jour. of Phys.*, vol. xi. p. 226.

Halliburton.—"Chemical Physiology," &c., p. 627.

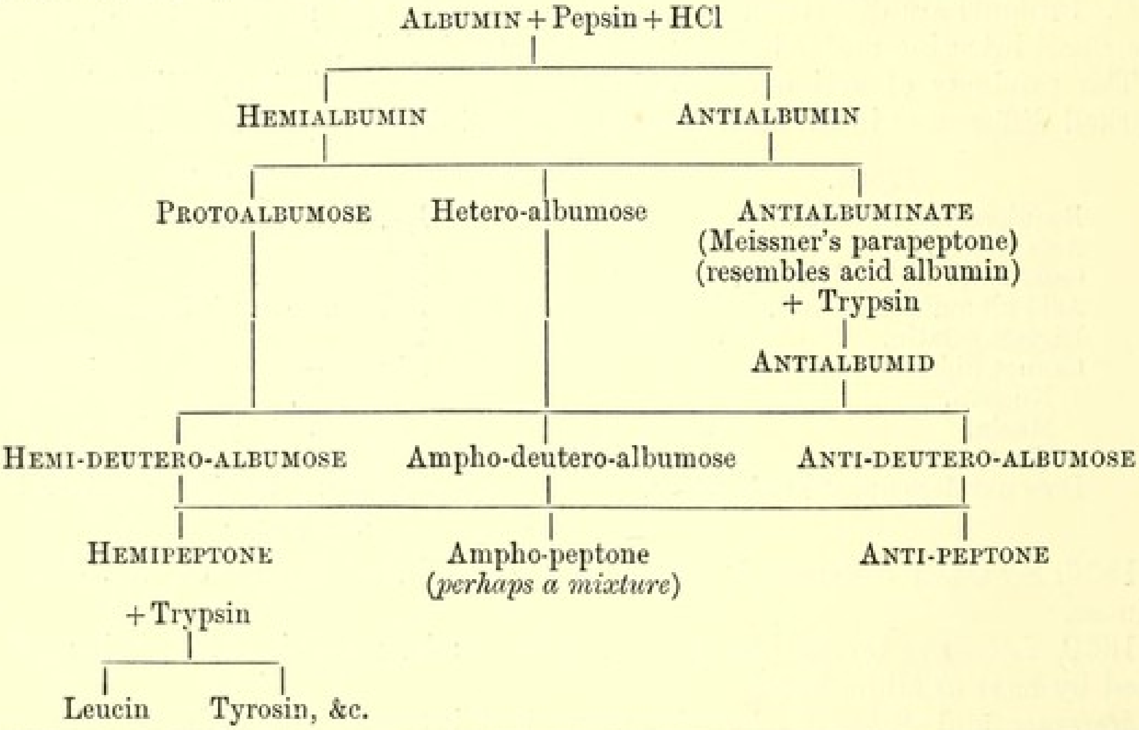
Kühne has shown that proteids have a complicated composition, and that (*A*) the first effect of digestion is to split them into two bodies, which differ in their resistance to digestion, in the character of the intermediate products and in the power of the final product to resist decomposition. The end-product of the one line—antipeptone—is not destroyed by pancreatic juice, while hemipeptone may be decomposed by pancreatic juice into leucin, tyrosin, asparaginic acid, ammonia, &c.

B. The end-products, anti- and hemi-peptone, are not reached at once, but by several intermediate stages. Anti-albumin may either go through an acid-albumin stage, which further complicates the intermediate products since pepsin cannot change it into peptone, or it may reach amphopeptone without taking this by-path.

The character of the intermediate products depends upon the nature of the particular proteid from which digestion starts; whether an albumin, globulin, gelatin, or other species of proteid or albuminoid. Albumins and globulins are not diffusible, and are coagulated by heat; they give a violet colour with $CuSO_4$ and KHO. Peptone can pass through animal membranes, and is not coagulated by heat; it gives a rose colour with $CuSO_4$ and KHO. The intermediate bodies (which used to be called collectively "parapeptone") are not coagulated by heat; they give the same rose-red (biuret) reaction as peptone, but cannot pass through an animal membrane, and are not ready therefore for absorption into the blood. They may be separated from peptone by the addition of $(NH_4)_2SO_4$ to saturation, which precipitates the proteoses but does not precipitate peptone. Deutero-albumose, which is nearest to peptone, is not precipitated by saturation with $MgSO_4$, as are hetero- and proto-albumose.

Hetero-albumose resembles a globulin in being insoluble in water which contains no salt, and partly precipitated, by heating, from its solution in 10 % NaCl.

What might therefore be called the longitudinal and transverse cleavage of albumin may be represented as follows:—



Chittenden and Smith.—"Digestion of Gluten-casein," *Jour. of Phys.*, vol. xi. p. 410.

Chittenden and Hartwell.—"The Relative Formation of Proteoses and Peptones in Gastric Digestion," *Jour. of Phys.*, vol. xii. p. 12.

Chittenden and Solley.—"The Primary Cleavage Products in the Digestion of Gelatin," *Jour. of Phys.*, vol. xii. p. 23.

Chittenden and Goodwin.—"Myosin-peptone," *Jour. of Phys.*, vol. xii. p. 34.

Edkins.—"The Changes Produced in Casein by the Action of Pancreatic and Rennet Extracts," *Jour. of Phys.*, vol. xii. p. 193.

C. Fat differs from the other chemical constituents of the food, inasmuch as it cannot be rendered soluble in water by any fermentative change.

a. The greater part is absorbed as fat by the cells lining the alimentary canal, which take it up in minute globules. Its subdivision into globules (emulsification) is favoured by various substances, introduced in food or secreted by the alimentary canal, which prevent the reunion of the fine particles into which it is divided by the churning-action of the musculature of the canal-wall.

Its absorption by living cells, and passage through membranes is aided by the bile, which diminishes its surface-tension or tendency to retain the globular form, and therefore causes it to spread into films or run into threads.

This action of bile may be illustrated in many ways; *e.g.*, if it is desired to apply oil-colours to glass, the surface of the glass is first sponged with a solution of ox-gall. The passage of oil through wet blotting-paper is facilitated by moistening the paper with a solution of bile-salts. The superiority of cod-liver oil over other fatty foods depends upon its low surface tension; the dietetic value of a specimen of this oil is tested by observing the extent to which a drop spreads out on the surface of a saucer full of a very weak solution of sodic carbonate; the thinness of the film is estimated by its iridescence.

b. Pancreatic juice contains a ferment capable of splitting fat into its acid and glycerin. (A similar decomposition is effected when fat is exposed to the action of super-heated steam.)

$$\underset{\textit{Palmitin.}}{C_3H_5\begin{cases}C_{15}H_{31}COO\\C_{15}H_{31}COO\\C_{15}H_{31}COO\end{cases}} + 3H_2O = \underset{\textit{Glycerin.}}{C_3H_5\begin{cases}OH\\OH\\OH\end{cases}} + \underset{\textit{Palmitic Acid.}}{\begin{matrix}C_{15}H_{31}COOH\\C_{15}H_{31}COOH\\C_{15}H_{31}COOH\end{matrix}}$$

This ferment is isolated by rubbing up fresh pancreas with powdered glass, glycerin, and 1 per cent. Na_2CO_3, and allowing the extract to stand for two or three days. If the extract is added to an emulsion of fat and gum tinged blue with litmus, at a temperature of 40° C., the liberation of the fatty acid is shown by its action on the litmus, which turns red.

Fatty acid may be absorbed as such.

c. Some fat is converted into soap (which is soluble) by the alkaline secretions of bile, pancreatic juice, and succus entericus, *e.g.*,

$$\underset{\textit{Stearic acid.}}{C_3H_5\begin{cases}C_{17}H_{35}COO\\C_{17}H_{35}COO\\C_{17}H_{35}COO\end{cases}} + 3\,NaHCO_3$$

$$= \underset{\textit{Glycerin.}}{C_3H_5\begin{cases}HO\\HO\\HO\end{cases}} + \underset{\textit{Soap.}}{3\,C_{17}H_{35}COONa} + 3\,CO_2.$$

Digestion of the Several Foods.

Vegetables consist of large quantities of starch, some proteids, a very little fat, important salts, and a great deal of water, enclosed in cellulose cell-walls. The cellulose is indigestible, but the digestive juices remove the nutritive substances from within its cells. Raw vegetables are digested but little until they come in contact with the pancreatic juice; they therefore need very fine division by the teeth, in order that they may pass the pyloric sphincter.

Meat consists of muscle supported by connective tissue and mixed with fat. In the stomach it is prepared for the complete peptonisation which occurs in the small intestine; gelatin being dissolved, the fibres fall apart, and are further split into discs or sarcous elements.

Fat consists of a slight framework of gelatinogenous connective tissue, with blood-vessels and lymph-vessels, enclosing in its meshes large fat-cells. The nucleus and protoplasm of the cell are pushed to one side by the drops of fat (a mixture of olein, stearin, and palmitin—fluid, at the body-temperature), which distends the vesicle. Gastric juice dissolves the connective tissue, setting the fat-cells free, and also dissolves the gelatinogenous envelope of the cell, liberating the fluid fat, which is churned up with the other contents of the stomach to form "chyme." In the duodenum (*a*) some fat is rendered capable of absorption by the bile, which favours its fine subdivision; (*b*) some is split into fatty acid and glycerin by one of the ferments of pancreatic juice; (*c*) some is saponified by the alkali ($Na_2\ CO_3$) of the secretions.

Milk is curdled by the rennin in the stomach, and its casein is peptonised by gastric juice and pancreatic juice. If without previous admixture with gastric juice it comes in contact with pancreatic juice, it is in the same way curdled before absorption. Its fat is digested in the manner already described. Milk-sugar (lactose) is absorbed as such from the stomach; in the intestines it is, before absorption, converted into dextrose and galactose.

Earthy Salts, the very important insoluble carbonates and phosphates which are contained in vegetables, particularly cereals, are dissolved by the acid of the gastric juice.

Changes in the Appearance of the Food.—The foods, broken into irregular fragments by the teeth, are by the solution of their gelatinogenous framework, and by the splitting of muscle-fibres, reduced to a state of fine division. The fat is set free by the solution of the envelopes of the fat-cells, and churned up with the finely divided food into a creamy emulsion, or chyme, which passes through the pylorus. The precipitation of peptone and parapeptones renders this sticky. After reaching the lower part of the duodenum it begins to become thinner, and the bright tawny colour given to it by the bile-pigments turns to green and grey. Water is absorbed by the wall of the colon, and it becomes again thicker and browner.

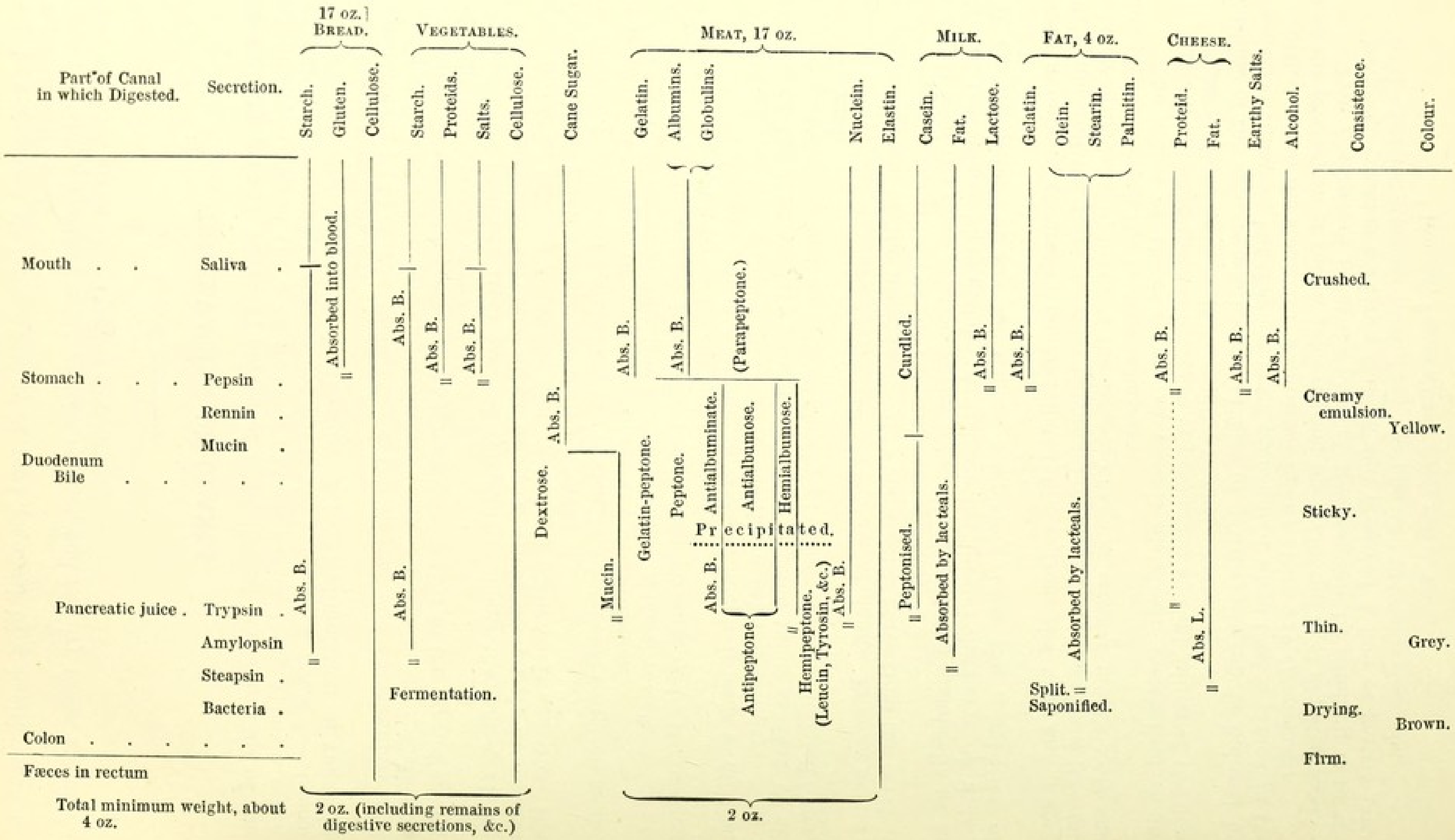
The fæces contain all that was insoluble in the food, together with such constituents of the secretions as have not been absorbed—oxidised, and inspissated. On a mixed diet the fæces weigh one-seventh to one-eighth as much as the food.

1. The indigestible constituents of the food are chiefly cellulose, keratin, mucin (which largely escapes digestion by pancreatic juice), chlorophyll, gums, resins, cholesterin, to which must be added much uncooked starch, tendon, elastic fibres, nuclein, and insoluble salts.
2. Products of decomposition of food, such as insoluble soaps, fatty acids, products of the decomposition of hæmoglobin.
3. Bile residues: mucin, cholesterin, lecithin, sterco-bilin, and choletelin.
4. Bacteria of many kinds, and *débris* from the intestinal wall.
5. Undigested food which may, when the diet is excessive, be present in large amount, greatly swelling the weight of fæces.

Meconium: the dark green fæces of the new-born infant consists of concentrated bile, with the addition of leucocytes, broken down columnar cells, &c. Bilirubin, biliverdin, and other pigments are present; stercobilin is absent.

The following table exhibits the changes by which a typical day's diet is prepared for absorption. In estimating the amounts it is supposed that all the carbohydrate required (say 240 grammes) is obtained from bread. The proteid which the bread contains (about 30 grms.) is deducted from the meat. Sufficient meat is taken, therefore, to yield 70 grammes of dry proteids. The weights of the vegetables, sugar, milk, and cheese which enter into the diet are not estimated. To make a balance-sheet it is necessary to analyse these articles of diet, and diminish the weight of meat, bread, and fat by the amount of their chief constituents which have been supplied in these other foods.

A DAY'S FOOD.


Part of Canal in which Digested.
Secretion.
17 oz. Bread.
Starch.
Gluten.
Cellulose.
Vegetables.
Starch.
Proteids.
Salts.
Cellulose.
Cane Sugar.
Meat, 17 oz.
Gelatin.
Albumins.
Globulins.
Nuclein.
Elastin.
Milk.
Casein.
Fat.
Lactose.
Fat, 4 oz.
Gelatin.
Olein.
Stearin.
Palmitin.
Cheese.
Proteid.
Fat.
Earthy Salts.
Alcohol.
Consistence.
Colour.
Mouth . . . Saliva .
Stomach . . . . Pepsin .
Rennin .
Mucin .
Duodenum
Bile . . . . . .
Pancreatic juice . Trypsin .
Amylopsin
Steapsin .
Bacteria .
Colon . . . .
Fæces in rectum
Total minimum weight, about 4 oz.
Absorbed into blood.
Abs. B.
Fermentation.
2 oz. (including remains of digestive secretions, &c.)
Dextrose.
Mucin.
Gelatin-peptone.
Peptone.
Antialbuminate.
Antialbumose.
Hemialbumose.
(Parapeptone.)
Precipitated.
Antipeptone
Hemipeptone.
(Leucin, Tyrosin, &c.)
2 oz.
Curdled.
Peptonised.
Absorbed by lacteals.
Split. = Saponified.
Abs. L.
Crushed.
Creamy emulsion.
Yellow.
Sticky.
Thin.
Grey.
Drying.
Brown.
Firm.

It will be understood that the quantity of food required by a healthy man is very variously estimated.

To give the table a practical value, articles of diet, and not dry foods, are used, and their weight is given after English standards.

INNERVATION OF GLANDS.

Submaxillary gland: afferent; nerves of taste, lingual (sides and tip of the tongue), glossopharyngeal (back of tongue). These nerves bring about a reflex flow of saliva in response to stimuli applied to the tongue. A reflex flow is also induced in many other ways, *e.g.*, by thought of food; stimulation of vagus in stomach (before vomiting), &c.

Efferent nerves; (A) chorda tympani, *via* the lingual and submaxillary ganglion; stimulation of this nerve, either directly or in a reflex manner, induces a copious watery flow under a pressure which may exceed that in the carotid artery. It dilates the blood-vessels of the gland.

B. Sympathetic branches from cervical sympathetic along the course of the facial artery; stimulation of these fibres causes a viscid flow, rich in organic materials, including salivary corpuscles and amorphous matter. It constricts the blood-vessels of the gland—is not affected by atropin.

Vaso-dilation *v.* increased metabolism of gland-cells. Increased secretion might be the mechanical result of increased blood-pressure, *i.e.*, filtration.

Con. 1. Pressure in duct may exceed pressure in blood-vessels.

2. Submaxillary gland secretes at some pressure under stimulation of chorda when arteries are cut and empty.

3. Atropin causes secretion to cease, although it leads to dilation of blood-vessels. Hence belladonna makes the mouth hot and dry.

Function of the submaxillary ganglion; apparently the same as that of all other ganglia—to replace each medullated fibre by a number of nonmedullated fibres.

Parotid gland.

Afferent nerves; same as for submaxillary and sublingual glands. Efferent nerves: A. Auriculo-temporal of the trigeminal. B. Sympathetic fibres from the cervical sympathetic along the sheath of the external carotid artery.

A. and B. bear the same relation to the blood-vessels and the gland-cells as in the case of the submaxillary gland. A. induces the greater discharge of water, but B. (in the parotid at any rate) more completely clears the gland-cells of granules.[1]

Nerve supply of stomach; nonmedullated fibres from the vagi, and fibres, chiefly nonmedullated, from the solar plexus. The fibres form one plexus (bearing abundance of nerve-cells) between the longitudinal and circular muscle-coats and another plexus beneath the mucous membrane.

The action of these nerves as regards gland-cell metabolism is unknown, although there is evidence of production and inhibition of the flow of gastric juice by stimuli descending from the brain.

Blushing of the mucous membrane and flow of gastric juice can be induced by mechanical stimulation, but they are more pronounced when food is placed in the stomach than when the stomach is stimulated in any other way (*Beaumont*).

Does the production of gastric juice depend upon absorption of digested food?

Pro. Heidenhain isolated a piece of the stomach by stitching it to the body-wall (making a Thiry's fistula), and observed a flow of gastric juice in the isolated stomach when food was put into the main stomach.

[1] Langley, Papers already cited, *vide* p. 62.

Are certain foods better generators of gastric juice than others, *i.e.*, peptogenic foods, as *Schiff* termed them?

Pro. It is customary, and probably beneficial, to commence a meal with soup, extracts of meat, bread well chewed, &c.

Schiff attempted to prove that this custom is based upon physiological principles, by killing two dogs which had fasted for a similar period; one dog (A) having been kept altogether without food, the other (B) having had "peptogens" administered to it four hours before death. He found that an extract of B's stomach was then more actively proteolytic. His method of comparison is, however, open to objection.[1]

Nerve-Supply of Pancreas; from the solar plexus. The gland is thrown into activity by stimulation of the medulla or spinal cord, even after section of the vagi.

Secretion is inhibited by stimulation of the efferent vagus, *i.e.*, in a reflex manner.

The pressure in the duct is inconsiderable. The flow of pancreatic juice is almost continuous, but shows a great increase soon after food is taken, and again 5 to 7 hours after a meal (in the dog).

Nerve-Supply of Liver; through the solar plexus, from the splanchnic nerves, and also from the termination of the vagi.

The mode of action of these nerves is unknown; stimulation of the medulla does not, as in the case of the pancreas, cause a flow of bile, but, on the contrary, arrests the flow by constricting the visceral blood-vessels.

The pressure in the duct is low, but higher than that in the portal veins.

The amount of bile produced fluctuates with the taking of food, very much in the same way as the amount of pancreatic juice. The flow is most rapid, however, about 6–8 hours after a meal (in the dog).

It depends upon the kind of food, being most abundant after the ingestion of meat, although its only directly digestive action is upon fats.

Emptying of the gall-bladder is induced by stimulating the orifice of the common bile-duct with acid, as by the passage into the duodenum of acid chyme.

MUSCULATURE OF THE ALIMENTARY CANAL.

A. **Longitudinal Fibres.**

Of the gullet, a band on either side, attached to the base of the skull, and divisible into the glossopharyngeal, stylopharyngeal, and salpingopharyngeal fasciculi; striated.

Of the œsophagus, stomach and small intestines, forming a continuous sheet.

Of the colon, divided into three longitudinal bands.

Of the rectum, forming a continuous sheet.

B. **Circular Muscles**, internal, forming continuous sheet:—

Those of the gullet are divided into three pieces attached in front to the supports of the three branchial arches—the inferior maxilla, the hyoid bone, and the thyroid cartilage respectively; behind they join in a raphé, the upper end of which depends from the pharyngeal spine of the occipital bone. These constrictores pharyngis consist of striated fibres.

Of the stomach; the truly circular fibres constitute the middle coat, the most internal are oblique, forming loops which radiate from the left side of the cardiac ring.

[1] *Vide* Langley, *Jour. of Phys.*, vol. iii. p. 291.

Macullum.—"Termination of Nerves in the Liver," *Quart. Jour. of Micr. Sci.*, 1887, p. 439.

MOVEMENTS OF THE ALIMENTARY CANAL.

Tongue; almost universal. The food is made into a bolus, which is passed backwards to the fauces by (1) the elevation of the sides of the tongue by the palato-glossi, and (2) a wavelike elevation of its dorsum.

Fauces; the mouth is separated from the gullet by the isthmus faucium, bounded by the soft palate, anterior pillars of the fauces, and dorsum of the tongue.

Pharynx is lifted up around the bolus by its longitudinal muscles. The longitudinal fibres then relax, and peristalsis begins with the superior constrictor.

Œsophagus; the wall being formed at the upper part of striped muscle, undergoes a rapid peristaltic contraction, the rest of the tube, being formed of plain muscle, contracts more slowly. Peristalsis is very strong; a ball pulling against a weight of 250 grammes is carried down the œsophagus in a dog (*Mosso*).

The rima glottidis is closed by the contraction of its muscles, and covered by the epiglottis, which is depressed by the pressure of the food, aided by the contraction of the aryteno-epiglottidean muscles; the glosso-epiglottic ligament being at the same time slackened owing to the drawing of the hyoid bone forward beneath the tongue.

Stomach; a combination of rotation and peristalsis. The hair-balls found in the stomachs of carnivora are rolled up by the movement first-mentioned. The peristalsis is in the turkey's gizzard sufficiently strong to crush a lead tube which will resist a weight of 40 kilograms.

Small and Large Intestines; peristalsis, a double movement, the contracted ring forming the *point d'appui* for the longitudinal muscle which dilates the region immediately in front of the peristaltic wave.

Rectum is first depressed by its longitudinal fibres, then emptied by peristalsis; lastly, the sphincter being relaxed, the lower end of the rectum is lifted up from about the fæces by the levator ani.

Innervation of the Muscles.

A. The longitudinal fibres are supplied by nerves which do not lose their medullary sheaths until they reach the ganglia of the collateral chain; or, in the case of the fibres for the levators of the pharynx, retain their sheaths to the end.

For the pharynx; the glossopharyngeal.

For the stomach; the vagus.

For the intestines; the splanchnics.

For the rectum; the 3rd and 4th sacral.

B. The circular fibres are supplied by nerves which are demedullated in the ganglia of the lateral chain; or in the case of the vagus-fibres in the cervical ganglion.

For the pharynx and œsophagus; pharyngeal branch, from the ganglion jugulare of the vagus; upper part of œsophagus, recurrent laryngeal; lower part, œsophageal plexus of vagus.

For the stomach and upper part of the intestines; the vagus.

For the lower intestines, including the rectum; the lower splanchnics (anterior roots of D 11 and 12, and L 1 and 2, in the dog).

Between the longitudinal and circular muscle-coats the nerves form a close plexus (Auerbach's), and another between the circular coat and the mucous

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Walton.—"The Function of the Epiglottis in Deglutition and Phonation," *Jour. of Phys.*, vol. i. p. 203.

Stuart and M'Cormick.—"The Position of the Epiglottis in Swallowing," *Jour. of Anat. and Phys.*, vol. xxvi. pt. 2, p. 231, 1892.

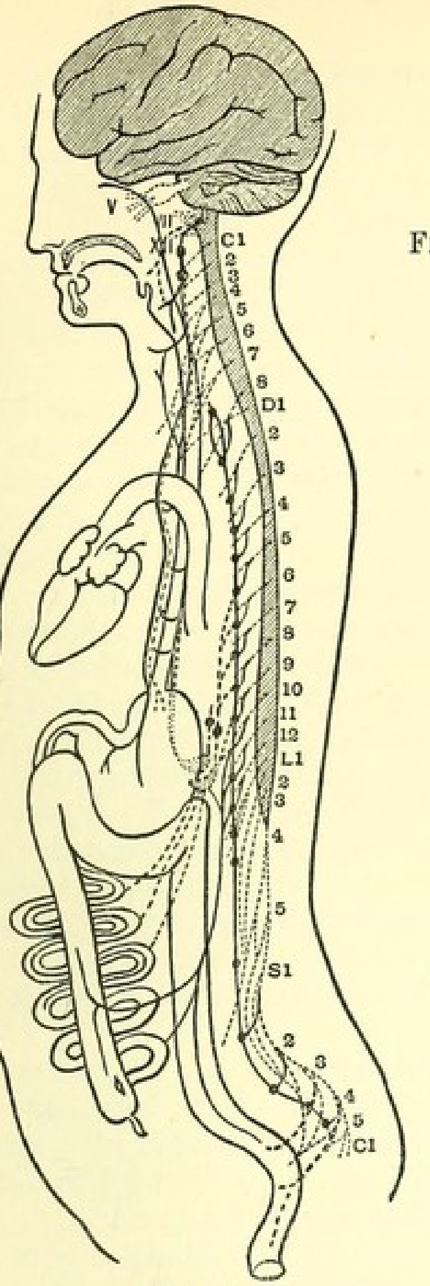

Fig. 41.

FIG. 41.—Diagram of the nerves of the alimentary canal.

The motor nerves of the longitudinal muscles (inhibitory to the circular fibres) are dotted. The motor nerves of the circular muscles (inhibitory to longitudinal fibres) are unbroken.

Belonging to the former class (A), the glosso-pharyngeal is shown crossing the figure XII; fibres for the œsophagus and the inhibitory fibres for the cardiac sphincter of the stomach accompany the vagus; fibres for the small intestines pass through the semilunar ganglion from the splanchnic nerves; fibres for the rectum come off from the third and fourth sacral nerves. Belonging to the latter class (B), the left vagus is shown passing in front of the arch of the aorta and giving off the recurrent laryngeal; it then unites with the right vagus to constitute the plexus gulæ; the vagi give constrictor fibres to the upper part of the small intestine; the lesser splanchnic supplies the lower part of the small intestine and the whole of the large intestine.

To the right of the stomach is seen the loop between the great splanchnic and right vagus nerves (ansa memorabilis Wrisbergi); it carries the right semilunar ganglion. Each splanchnic nerve carries a small ganglion (ganglion of Lobstein).

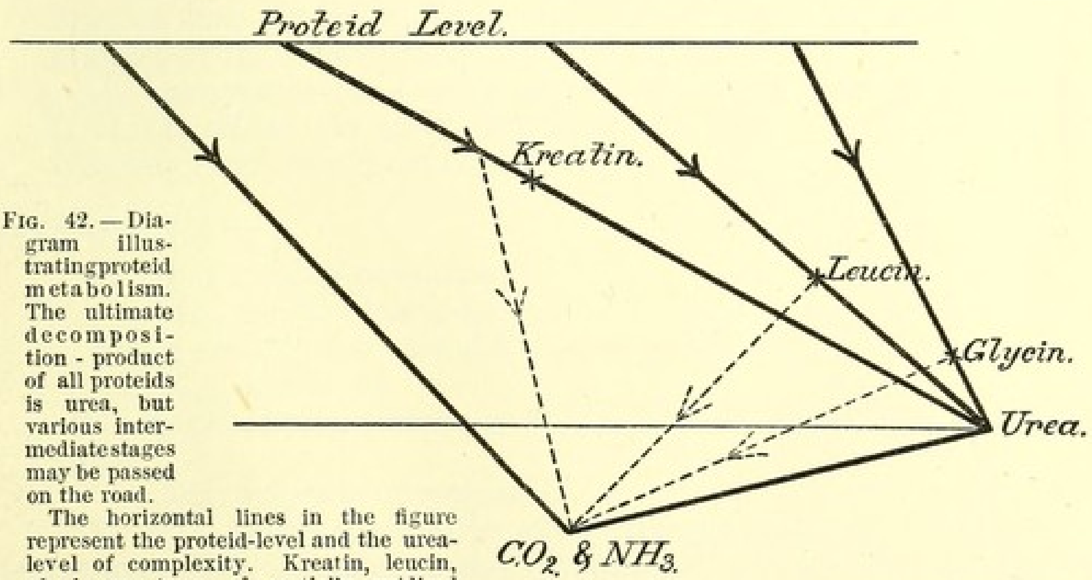

FIG. 42.—Diagram illustrating proteid metabolism. The ultimate decomposition - product of all proteids is urea, but various intermediate stages may be passed on the road.

The horizontal lines in the figure represent the proteid-level and the urea-level of complexity. Kreatin, leucin, glycin are types of partially oxidised nitrogenous substances found in the body. It is impossible to say whether they are successive stages in nitrogenous metabolism or whether they are stages on lines of chemical change, which diverging at the first decomposition of proteid do not meet again until urea is reached.

There are also indications that in some cases, if not in all, decomposition reaches a level lower than urea, and that urea is formed by a constructive process from carbamate or carbonate of ammonia.

To face p. 74.]

membrane (Meissner's), which run the whole length of the intestine. At the nodes of the plexus are groups of nerve-cells.

Can this plexus serve as a reflex mechanism?

Pro. 1. Distension of the intestine increases the vigour of its peristalsis.

2. Want of oxygen, as in asphyxia, or cessation of the circulation, gives rise to active peristalsis.

Con. It is unlikely that the plexus in the alimentary canal has a function which detached clumps of nerve-cells and fibres have been proved not to possess in so many other situations.

Vomiting is preceded by a sensation of nausea and reflex flow of saliva. A deep inspiration is taken, the glottis closed, and diaphragm fixed. Contraction of the abdominal wall then presses the stomach against the diaphragm; its cardiac sphincter relaxes, and its other musculature contracts. Reversed peristalsis of the œsophagus does the rest.

Carnivorous animals need to possess the ability to empty the stomach; herbivora do not run anything like the same risk of filling the stomach with indigestible matter. While the dog can probably vomit at Will, the horse cannot be made to vomit; the anatomical disposition of the stomach in the horse making no provision for this act. In the horse the cardiac and pyloric sphincters are near together; the former is strong, the latter weak. The stomach is not so placed as to make it possible for it to be compressed between the diaphragm and the abdominal wall.

Nervous Mechanism.

Afferent nerves; glossopharyngeal, vagus, &c. In certain cases the impulses proceed from nerves of special sense, such as the olfactory. In the vomiting, which is frequently a symptom of cerebral disease, the impulses originate in the brain.

Efferent nerves; to open the cardiac sphincter—the vagus; to cause contraction of the abdominal walls—various.

Centre; the chief junction between these nerves lies in the medulla.

Action of Emetics.

A. Local; on vagus-endings in the stomach, *e.g.*, mustard and water, zinc sulphate, &c.

B. Central, *i.e.*, acting independently of the nerve-endings in the stomach, *e.g.*, tartar emetic and apomorphia, which produce vomiting when injected into the blood, even after the stomach has been replaced by a bladder, or the vagus nerves have been divided.

C. Ipecacuanha (or emetia) appears to have a more complicated action. It chiefly affects the nerve-endings of the vagus, for it will not produce vomiting after division of this nerve.

Purgatives act:—

A. By increasing peristalsis.

E.g., nicotin, jalap, &c.

B. By exciting the wall of the canal to secretion.

E.g., croton oil.

C. By preventing osmosis of fluid out of the contents of the alimentary canal.

E.g., sulphate of magnesia.

D. By a combination of the effects above named.

Defæcation.—The contents of the intestine do not pass beyond the sigmoid flexure until just before defæcation. When they enter the rectum there occurs:— 1. Reflex inhibition of anal sphincter. 2. Peristalsis of rectum. 3. Elevation of levator ani.

Defæcation occurs normally in a dog in which the spinal cord has been divided between the dorsal and lumbar regions. Budge's centrum ano-spinale lies (in the dog) at the level of the fifth lumbar vertebra. After division of the cord, touching the anus causes energetic reflex contraction of the sphincters.

ABSORPTION.

How do the products of digestion get out of the alimentary canal? Three views have been held :—

1. That leucocytes are active agents in taking up nutrients. This is doubtless true, since they resemble amœbæ in their power of ingesting insoluble particles, and leucocytes in the neighbourhood of the alimentary tract are observed to contain fat-globules, glycogen, &c., but whether for their own use or the public service cannot be determined.

Per contra, the number of leucocytes present in the walls of the alimentary canal is insufficient to allow us to regard them as even important agents in absorption.

2. That absorption is intercellular.

Pro. Processes of connective tissue pass from the basement-membrane between the cells.

Con. The transmission of the nutrients from the connective tissue to the blood-vessels would remain inexplicable.

3. The cells lining the canal ingest the nutrients, both diffusible and non-diffusible, and excrete them into the tissue-spaces.

Pro. 1. Osmic acid staining shows the epithelial cells to be loaded with fat-granules after a meal. 2. Their free borders are striated in a manner which recalls the striation of secreting cells, on the side from which they absorb fluids, *i.e.*, the free border of the intestinal cells resembles the attached (outer) border of cells in the tubuli contorti of the kidney, the ducts of salivary glands, &c.

The cause of this striation has been much discussed.

α. Do the striæ represent pores?

β. Are they the optical appearances of contiguous rods or prisms?

Heidenhain regards the border as composed of vertical rods separated by homogeneous substance; either rods or hyaline substance may be withdrawn into the cell body.

γ. Do they indicate a structure which has been elaborated from the pseudopodia that project from the free borders of the lining cells of Distoma hepaticum, and certain other invertebrate animals?

Absorptive endoderm cells of Hydra have retractile flagella. *Miss Greenwood* has shown that the absorptive cells of the earthworm are ciliated during starvation, whereas after food the cilia are retracted and the border appears rodded.

Reid.—"Osmosis Experiments with Living and Dead Membranes," *Jour. of Phys.*, vol. xi. p. 312.

Reid.—"Report on Experiments upon Absorption without Osmosis," *Brit. Med. Jour.*, 1892, No. 1624, p. 323.

Edkins.—"The Absorption of Water in the Alimentary Canal," *Jour. of Phys.*, vol. xiii. No. 5, p. 445, 1892.

However absorbed the nutrients find themselves in the tissue spaces of the villus,[1] which they leave by two distinct routes.

A. The diffusible substances are absorbed by the blood.

B. Nondiffusible substances remain in the lymphatic system, passing on into the central lacteal. They are not discharged into the blood until the thoracic duct joins the left subclavian vein at the point of junction of this vessel with the jugular.

Absorption and transmission are aided by :—

A. The peristaltic contraction of the wall of the canal, which exerts a pressure upon its contents.

B. The pumping action of the villi in the parts of the canal in which they exist (small intestine).

> Fibres of the muscularis mucosæ pass into each villus ; some are placed longitudinally in its centre, others, near the surface, lie obliquely, and while contracting tend to keep the lacteal from being completely occluded, and to allow the contents of the tissue-spaces of the villus to be squeezed into it. During contraction the blood-vessels of the villus are emptied, and as they fill again, the villus becoming turgid erects itself.

The lymph in the lacteal system is distinguished as "chyle." Its further passage towards the thoracic duct is aided by the movements of the intestines, the contraction of the abdominal wall, and the descent of the diaphragm.

The valves in the submucous plexus prevent the regurgitation of chyle.

HISTORY OF THE FOOD during and after absorption.

A. **Carbohydrates** enter the blood as sugars ; the starch, which constitutes a large proportion of our food, having been changed by the amylolytic action of saliva and pancreatic juice into maltose, is partly absorbed in this form, partly converted by the action of succus entericus into glucose. Cane sugar is changed into dextrose (by gastric juice), or into a mixture of dextrose and lævulose (by succus entericus). Milk sugar is changed (by gastric juice) into galactose or (by succus entericus) into a mixture of dextrose and galactose. Fruit sugar (dextrose) needs no change. Small quantities of cane sugar and dextrin are absorbed without change. In the blood all the sugars assume the form of dextrose. In the general blood its amount is about 0·1 %. In the portal circulation after a meal rich in starch it reaches 0·2 to 0·3 %.[2]

Further history of dextrose.

1848, *Claude Bernard* showed that a considerable quantity of sugar (3–4 % or even more) can be extracted from the liver.

1857, He showed that if a proper method is adopted for making an infusion of

[1] It is most important that the physiologist should attempt to picture to himself the tissue-spaces as they exist during life. No matter what reagent is used for hardening tissue, lymph escapes from the spaces, the tissue-cells lose fluid by exosmosis, and the tissue shrinks to perhaps half its original bulk ; blood-vessels then appear to be in contact with gland-cells, instead of separated from them by a sponge-work of lymph-filled spaces. Henle's sheath clings to the nerve-fibres instead of investing them with a bath of lymph ; we are apt to think of the absorbed nutrients as passing straight from the epithelial cells into blood-vessels, instead of remembering that they can only enter blood-vessels by osmosis from lymph.

[2] Seegen obtains twice as much sugar from the blood in the hepatic vein as from the portal blood. If this is the normal and constant result independent of feeding and of operative disturbance, it follows that the liver manufactures sugar, and does not simply store it. This is not the theory upon which the following account is based.

Paton.—"Composition and Flow of Chyle from the Thoracic Duct in Man," *Jour. of Phys.*, vol. xi. p. 109.

Harley.—"The Behaviour of Saccharine Matter in the Blood," *Jour. of Phys.*, vol. xii. p. 391.

the liver before *post-mortem* fermentative changes have set in, not sugar but glycogen is extracted.

Glycogen, $n(C_6H_{10}O_5)$, a greyish white amorphous powder; gives opalescent solution in water; barely diffusible; dextro-rotary 211°; yields port-wine colour with iodine.

It seems to stand to the easily diffusible sugars in the same relation as the starches of the vegetable kingdom. *Claude Bernard*, therefore, compared the liver to the tuber in which the potato stores its carbohydrate. Preparation:—Kill animal quickly, throw the warm liver into a basin of boiling water, chop it up under the boiling water, which destroys the ferment and coagulates the liver-proteids. Purify the decoction by precipitating the glycogen with alcohol, boil the precipitate in an alcoholic solution of potash to destroy adherent proteids, wash in ether and then in alcohol; *or* precipitate the uncoagulated proteids in the decoction with hydrochloric acid and potassio-mercuric iodide.

Is the liver a reservoir of carbohydrate-foods?

Pro. Its cells are protoplasmic, spontaneously coagulable, capable of amœboid movement when isolated on the warm stage; they are in intimate relation with an immensely rich system of portal capillaries; there is every appearance of their being able, like amœbæ, to take up food-stuffs.

In favourable nutritive conditions they become loaded with granules of proteids, globules of fats, and glycogen in glancing masses. The latter accumulates around the nucleus in mammalian liver-cells, at the outer margins of the cells in livers which have, as in the frog, a lumen within the cell-column.

Is the accumulation of glycogen dependent upon feeding?

Carbohydrate-foods cause great accumulation of glycogen in the liver, even as much as 12 % in the fowl. Proteids cause slight accumulation. Gelatin also increases the amount of glycogen. Fats give rise to no accumulation. Glycogen almost disappears in fasting.

Does it vary with the consumption of force-producing substance?

Pro. The frog stores glycogen when its metabolism is diminished by cool weather.

Active exercise causes a rapid diminution of the hepatic glycogen.

Is it the very same sugar that is absorbed in the alimentary canal which accumulates as glycogen in the liver?

Pro. (1) Mannite (the normal hexatomic alcohol, $C_6H_8(OH)_6$ and inosite (muscle-sugar) do not lead to the accumulation of glycogen in the liver.

(2) Sugar injected slowly into the jugular vein, escapes from the body by the kidneys. Injected into the portal vein, it is stopped by the liver and no sugar appears in the urine.

Con. 1. Diabetic patients excrete large quantities of sugar on a proteid and fatty diet, and at the same time glycogen is to be found in the liver and in the tissues.

2. Phloridzin given to a starving animal causes a diabetic output of sugar, far in excess of the amount which could be derived from the drug, which happens to be a glucoside.

Caution.—The body has considerable power of adapting its metabolism

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Shore and Jones.—"The Structure of the Vertebrate Liver," *Jour. of Phys.*, vol. x. p. 408.
Shore.—"Notes on the Origin of the Liver," *Jour. of Anat. and Phys.*, vol. xxv. 2, p. 166.
Brunton and Delépine.—"On some of the Variations observed in the Rabbit's Liver under certain Physiological and Pathological circumstances," *Roy. Soc. Proc.*, vol. 303, p. 209.

to its circumstances. We can never distinguish between the substitution of one food-stuff for another (or covering of its metabolism), and the accumulation of the latter; *e.g.*, glycerin as food increases the glycogen of the liver, not by conversion into glycogen, but either by taking the place of glycogen which would otherwise be withdrawn for metabolism, or (as *Ransom* thinks) by preventing the formation of sugar within the liver cells.

Whether a food-stuff, sugar for example, loses its identity by entering the molecule of protoplasm, and other corresponding atoms of the protoplasm are anew segregated as sugar, or whether the identical atoms of sugar remain from first to last distinct, is of little consequence.

How is sugar set free from the liver?

Heating the liver kills a ferment which converts glycogen into sugar.

This ferment has never been isolated. It is not the ordinary amylolytic ferment of the body, for it converts glycogen into dextrose, not into maltose; it is found in muscle and other tissues in as large amount as in the liver.

Where does the ferment come from?

Perhaps the blood, since congestion and stasis of blood in the liver leads to the disappearance of glycogen.

What becomes of the carbohydrate?

Sugar is nearly constant in the blood; its estimation is very difficult, but it amounts to about 1 in 1000 parts.

Glycogen is found in muscles, particularly in the embryo; it forms a very large amount, even 40 *per cent.* of embryonic muscle. It also occurs in the placenta.

What use does the body make of it?

It forms the portion of the molecule of muscle-protoplasm which is destroyed in muscular contraction.

Pro. (1) It accumulates in muscle of which the nerve is cut.

(2) It diminishes in amount during tetanus.

(3) Active movement removes glycogen from the body much more completely than starvation.

Ultimate fate: it leaves the body as H_2O and CO_2.

Diabetes Mellitus is a condition of the body in which sugar appears in the urine to the amount of even 1 to 2 *lbs. per diem.* How produced?

1. It occurs as a disease.
2. Experimentally; by puncturing the floor of the fourth ventricle, at the nucleus of origin of the vagus nerve (*la piqûre de Claude Bernard*).
3. By administration of phloridzin, amyle-nitrite, morphia, urari, chloroform, ether, chloral, carbonic oxide gas, or strychnia.

Feature common to most of these methods: they produce a disturbance of the vascular system, perhaps stagnation of blood in the liver. (This is not true of strychnia poisoning.) Nervous route of impulse produced by *la piqûre*, unknown.

The liver receives its nerves from the solar plexus. This plexus is formed chiefly by the right vagus, and the splanchnic major and minor of both sides. Its vaso-constrictor fibres pass from the cord by the inferior

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Harley.—"Experimental Pathological Evidence proving the Existence of Pancreatic Diabetes," *Jour. of Anat. and Phys.*, vol. xxvi. pt. 2, p. 294, 1892.

Schnée.—"Diabetes: its Cause and Permanent Cure," Trans. from the German by R. L. Tafel, London, 1889.

Eves.—"Liver Ferment," *Jour. of Phys.*, vol. v. p. 342.

Ransom.—"Diabetes and Glycerine," *Jour. of Phys.*, vol. viii. p. 99.

Chittenden and Lambert.—"The *Post-mortem* Formation of Sugar in the Liver in the presence of Peptones," *Studies from Yale College*, 1885.

cervical ganglion, ansa Vieussenii, ganglion stellatum and splanchnics (*Cyon* and *Aladoff*).

Diabetes is not produced by cutting or stimulating any of the nerves above named. It is produced by stimulating the central end of the cut vagus.[1]

Section of the splanchnics often sets it aside, by reducing the blood-pressure in the abdominal vessels.

Where does the sugar come from?

The glycogen stored in the liver?

Pro. The greater the quantity of glycogen in the liver, the greater the output of sugar in the urine in experimental diabetes.

Does disease or pricking of the medulla lead to an increased production of glycogen (or sugar) by the liver?

Pro. (1) Diabetic patients excrete sugar when all carbohydrates are eliminated from the food.

(2) Administration of phloretin (or its glucoside, phloridzin) leads to excretion of sugar by starving animals.

Theory of diabetes. It is generally considered that the excretion of sugar is due to the inability of the liver cells to retain glycogen, and its consequent immediate hydration into sugar and escape into the blood. On this assumption the disease is treated by the constant administration of sugar in small quantities (the "grape" or "whey cures"), in order to make up for the inefficiency of the liver as a reservoir.

There is reason to think that less sugar is used up by the tissues in diabetes than when the supply in the blood is normal.

Pro. The output of CO_2 is diminished, of urea increased.

B. Absorption of Peptones.[2]

a. Do they remain in the lacteal?

Con. 1. Their presence in chyle has not been detected.

2. If the thoracic duct is opened and the chyle allowed to escape, or if it is ligatured and the chyle prevented from entering the blood-circulation, the amount of proteid absorbed and metabolised (as shown by the output of its end-product, urea) is unaffected.

b. Are they taken up by the blood-vessels?

Difficulty; as in the case of the chyle, analysis fails to reveal the presence in the portal blood of peptones.

Nor can they be found in the blood issuing from an isolated loop of intestine, when their disappearance from within the loop is easily demonstrated.

∴ They are reconverted into albumins or other non-diffusible proteids, as they pass the wall of the alimentary canal.

Pro. (1) They have, when injected into the blood, poisonous effects, causing a rise in temperature, fall in blood-pressure, and loss by the blood of its power of coagulating.

(2) The blood itself has (at any rate when out of the body) no power of changing peptones into albumin.

(3) Peptones injected into the blood are very rapidly excreted by the kidney.

It is most probable that the blood-vessels take up all or almost all the peptones which are absorbed.

[1] *Cf.* Lauder Brunton, *Brit. Med. Jour.*, 1874, p. 40; F. W. Pavy, Croonian Lecture on Diabetes, 1878.

[2] Spelt by some authors "peptone," but by most "peptones."

Shore.—"The Fate of Peptone in the Lymphatic System," *Jour. of Phys.*, vol. xi. p. 528.
Pollitzer.—Physiological Actions of Peptones and Albumoses," *Jour. of Phys.*, vol. vii. p. 283.

Further history of proteid foods.

Are they stored?

Pro. 1. Proteid granules accumulate in the livers of well-fed animals, but we have no information as to their origin or destination.

2. More proteids are taken up by the tissues than are actually required to repair their waste.

The amount of proteid used by the body can be measured by the amount of its end-product, urea, which is excreted. One part of urea contains about the same amount of nitrogen as three of proteid. Under normal circumstances there is no other channel by which nitrogen leaves the body.

When food is withheld from well-fed animals, the nitrogen excreted is at first very much higher than it is after a few days of starvation, indicating that more than the necessary minimum of proteid is habitually metabolised in the body.

Along what lines are proteids decomposed?

All roads lead to urea in Man and carnivorous mammals, amphibia and fishes; urea and hippuric acid in herbivora; uric acid in birds, reptiles, and many invertebrates. In the fœtus, urea is largely replaced by allantoin.

A. Any partially oxidised nitrogenous substance found in the body is therefore an antecedent of urea (fig. 41).

1. Kreatin is always present in muscle [it decomposes into sarcosine (methyl-glycin) and urea; $C_4H_9N_3O_2 + H_2O = C_3H_7NO_2 + CON_2H_4$]. Kreatinin is a constant constituent of urine, but does not occur in sufficient quantity to represent all the kreatin formed in muscle.

2. Glycin appears to be formed in the body; since uric acid may be a result of the synthesis, in the body, of glycin and uric acid [glycin = amido-acetic acid; heated in a closed tube with urea, it combines to form uric acid, $C_2H_5NO_2 + 3CON_2H_4 = C_5H_4N_4O_3 + 3NH_3 + 2H_2O$]; hippuric acid (glycin-benzoic acid) appears in the urine when benzoic acid is administered.

3. Leucin (amido-caproic acid) is perhaps formed in the body; since it replaces urea in the urine in acute yellow atrophy of the liver. It may be due in this case to special decompositions of the liver-proteids.

4. No representative of the group of amidated aromatic acids, into which proteid is decomposed in the laboratory, is to be found in the body; unless the glycin-benzoic acid of the hippuric acid secreted by herbivora arises in this way, and not from substances in the fodder.

Con. Herbivora do not secrete hippuric acid while at the breast.

B. Any partially oxidised proteid occurring in food, appears as urea in urine, *e.g.*, the leucin of pancreatic digestion.

Does oxidation overshoot the stage of urea, and is there a constructive metabolism?

Pro. 1. Ammonia-salts in food increase the urea in urine.

2. Traces of carbamic acid (NH_2COOH) are found in the blood and elsewhere. Urea has been produced by the electrolysis of ammonic carbamate ($NH_2COONH_4 = CO(NH_2)_2 + H_2O$).

Can the body construct its own proteids from simpler antecedents?

This is not impossible; (1.) since fats and carbohydrates can be made in the body from proteids, elaborate constructive processes do occur.

(2.) Beef tea, meat extracts, &c., have a beneficial effect, which may be due to their rapid absorption and easy metabolism, or may be due to their taking part in constructive processes.

Where is the end-product, urea (or uric acid), formed?

In the kidney?

Con. Urea accumulates in the blood when the kidney is diseased or removed.

In the liver?

Pro. 1. It contains urea in mammals, uric acid in birds.

2. Blood passed through the liver takes up urea.

3. Acute atrophy of the liver diminishes the output of urea in the urine.

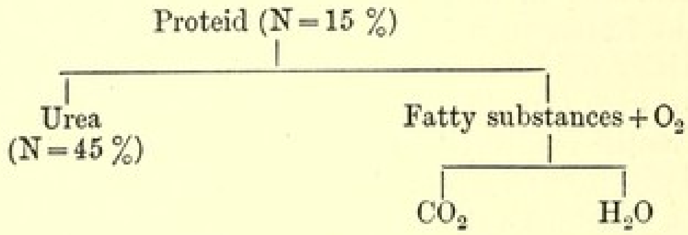
4. Removal of the liver puts a stop to the formation of uric acid in the goose.

Exclusion of the liver, by connecting the portal and jugular veins, puts a stop to the formation of urea (*Solnikoff*).

What uses does the body make of proteid foods?

Liebig divided our foods into (1) tissue-forming and work-producing foods (proteids), and (2) heat-producing foods (fats and carbohydrates).

On an exclusively meat diet the Guachos of the South American Pampas[1] keep in health and do severe work. In their case the proteid-molecule is probably split into a section containing all its nitrogen and a section of a fatty nature.



But on an ordinary diet the proteid is used to repair tissue rather than to yield force. On a vegetarian diet the force set free in muscular work is exclusively derived from the metabolism of non-nitrogenous food-stuffs.

Pro. 1. *Parkes* found that soldiers do not secrete more nitrogen when doing severe work (*e.g.*, carrying bricks for punishment) than when idling; that if they rest for two days and then do severe work, the amount of nitrogen is at first diminished by the exercise.[2]

2. *W. North* found that nitrogen often increased at the commencement of severe work, but he also showed that the body tends to economise its nitrogen when it is put to severe strain.[3]

3. *Fick* and *Wislicenus*, after abstaining from nitrogenous food for 17 hours, did a certain easily-estimated amount of work in climbing the Faulhorn, 1956 metres high. They then took a full nitrogenous meal. During the period of abstention from nitrogenous food, the hourly excretion of urea fell; it rose during the period of work; fell when they rested; rose considerably after the nitrogenous meal. If all the energy set free by the metabolism of proteid (as estimated from the output of urea) had been applied to muscular work, it would not have sufficed to carry them more than half way up the Faulhorn; *ergo*, the energy was set free by the consumption of other substances.

Proteid foods are partly used for purposes of current expenditure, but chiefly applied to the repair of the tissues. Ultimately they are reduced to urea, H_2O and CO_2, of which the former leaves the body in the urine.

"Nitrogenous equilibrium" means equality between the nitrogen ingested in food and that excreted in urine.

[1] Charles Darwin, *Voyage of the Beagle*, Murray's edition, 1889, p. 117.

[2] *A Manual of Practical Hygiene*, seventh edition, p. 360, &c. *Proc. Roy. Soc.*, No. 89 (1867) and No. 94 (1867).

[3] *Proc. Roy. Soc.*, vols. xxxvi. p. 11; xxxix. p. 443.

If more nitrogen is ingested than excreted, the body is laying on flesh, even though (as is desirable in "training") the body-weight remains constant, owing to the combustion of the fat of the body.

If more nitrogen is excreted than ingested, body-proteids are being consumed. It is possible for weight to increase at the same time, owing to the accumulation of the fatty portion of the proteid-molecule.

When equilibrium is maintained, the proteid elements of the tissues are not undergoing change—the frame-work of the body is repaired as it is worn out, but not increased.

C. History of Fat during and after absorption.

Fat is found after a meal in the lymphatic (lacteal) vessels, as was observed first by *Asellius* in 1627.

A section of a villus stained during digestion with osmic acid shows fat in the epithelial cells, the connective tissue spaces, and in the lacteal chamber.

Is any fat absorbed by the blood-vessels?

Pro. If the amount of fat collected by the lacteals, and delivered through the thoracic duct, is compared with the amount absorbed (*i.e.*, amount in food *minus* remainder in fæces), there is a deficit of about 50 %.

Con. The quantity of fat in the portal blood is not increased during digestion.

Further history of Fat in the Body.

It is carried by the thoracic duct into the blood, its presence in the general blood being demonstrable for some time after a meal.

By the action of leucocytes, or in some other way, the fats are carried to the tissues, where they are either stored as fat (in the connective tissues) or used for purposes of current expenditure.

Are the cells which constitute the fat-cells ordinary connective tissue cells?

Pro. Fat accumulates in tissues in which no other kind of cell is visible until deposition of fat commences.

Con. In certain situations, *e.g.*, beneath the skin of the eyelid and the penis, within the cranium and in the general tissue of the lungs, fat is never formed in health.

Is there a special form of fat-storing connective tissue cell?

Pro. The cells in which fat is stored in the embryo are distinguishable from the general connective tissue cells before deposition of fat begins, by their small size and protoplasmic appearance.

Is the fat stored in "plasma-cells"?

Pro. Very granular protoplasmic cells are found pressed up against the sheaths of nerve-fibres and elsewhere.

Con. They seem also to occur in large quantities in certain situations, in the interstitial tissue of the testis in many animals, for example, without leading to the accumulation of fat; but these cells may perhaps be of a different kind.

Is the fat which is stored in the body only such fat as has been absorbed from the food?

Con. (1) The composition of the fat of the body does not vary with the composition of the fat of the food.

Dogs fed on palm-oil or even on spermaceti lay-on fat of the usual composition.

(2) With a suitable diet, animals put-on more fat than is actually contained in the food.

Liebig showed that a cow gives more fat in its milk than is contained in the grass on which it feeds.

In an experiment made by *Lawes* and *Gilbert*, it was found that a pig accumulated in its body 472 parts of fat for every 100 parts contained in its food.

It may be doubted whether any of the fat poured by the thoracic duct into the blood is fixed in tissue-cells.

There is very great difficulty in understanding how the fat can leave the blood-vessels, and still greater difficulty in following this non-diffusible substance into the tissue-cells.

The invariable chemical composition of the fat of the particular animal throws doubt upon the ability of the cells to take up fat from the blood *via* the lymph.

On the other hand, there is no reason to think that oxidation of fat occurs in the blood.

To what use is the fat of the body put?

1. It forms in many places—the tips of the fingers and toes and the heel, for example—elastic cushions.

2. The subcutaneous fat serves as a heat-insulating covering for the body.

3. It is stored around the kidneys and elsewhere as a reserve of potential energy.

This is notably the case in bears, dormice, and other animals about to hibernate.

It yields when oxidised more energy than either of the other classes of food-stuffs, viz., 9000 calories per gramme, against 4500 for proteid and 4000 for starch.

Is this energy applied indifferently to doing external work and to producing heat?

In cold climates people eat fat; there does not seem to be the same need for fat to supply force for muscular action; rather are carbohydrates and proteids preferred by men who have to do severe work.

Ultimate fate of Fat.

It leaves the body as CO_2 and H_2O.

The Value to the Body of Food.

A. Out of it the body is constructed, and by it the body is kept in repair.

The proportional weights of the several tissues are as follows:—

Skeleton,	15·9
Muscles,	41·8
Thoracic viscera,	1·7
Abdominal viscera,	7·2
Fat,	18·2
Skin,	6·9
Brain,	1·9
Other constituents,	6·4
	100·0

Fat is a reserve of energy. Available foods are also stored in the liver and elsewhere.

If deprived of food, the body lives on its own tissues, which, in a certain cat starved for 13 days were reduced in weight to the following extents respectively:—

Fat, was reduced by	97· %
Spleen,	63·1 ,,
Liver,	56·6 ,,
Muscles,	30·2 ,,
Blood,	17·6 ,,
Brain and spinal cord *nil*.	

Normal Diet.

Ranke found that his own weight (75 *kilos.*) was maintained (the nitrogen of the body remaining stationary) on a diet containing the following substances :—

Dry proteid	100	grammes, yielding	450,000	calories of energy.
,, fat..................	100	,, ,,	900,000	,, ,,
,, carbohydrates...	240	,, ,,	960,000	,, ,,
Salts....................	25			
Water..................	2600			

This diet, which was chosen without regard to cost, as an agreeable and customary diet, could be made up by meat 17 oz. (dry proteid 15 %), butter 4 oz., bread 17 oz. (dry proteid—glutin 6 %, starch 51 %).

Moleschott's dietary: proteid 120 grammes, fats 90 grammes, carbohydrates 330 grammes, salts 30 grammes.

The dietary may be immensely varied, but there are limits beyond which the assimilation of the amount of food necessary to maintain the body-weight entails unnecessary labour, *e.g.*, 1000 to 1300 grammes of wheaten bread would yield 120 grammes of proteid, with much more than the necessary (800 grammes) of carbohydrate; 566 grammes of beef would yield the proteid, but not nearly sufficient carbohydrate.

An animal living entirely on meat (without fat) requires $\frac{1}{25}$ of its body-weight *per diem.* Any man whose digestion would allow him to adopt a similar diet, would consume and eliminate three times as much nitrogen as could be fixed by the tissues.

A day's income in energy.

A day's food (*Ranke's* normal diet) yields 2,310,000 calories of heat in its oxidation to urea, carbonic acid, and water.

This is determined by burning the food in a calorimeter, and measuring the amount of heat to which its combustion gives rise. The unit of heat is the calorie or amount of heat sufficient to raise 1 gramme (1 c.cm.) of water 1° C.

This amount of heat completely transformed into external work would a little less than suffice to raise one million kilogrammes one metre high.

A good day's work equals 150,000 kilogramme-metres (*Foster*).

This may be estimated in various ways.

A. By finding out how much work (in climbing, for example) can be done in the day without loss of weight or disturbance of nitrogenous equilibrium.

B. By observing the amount of work done habitually by a gang of men *e.g.*, pile-drivers or stevedores.

What use is made of the remaining 850,000 kilogramme-metres of energy?

It is needed to keep up the body-temperature. The work done by the heart equals about 75,000 kilogramme-metres, but this is all dissipated in heat, since the force set free by the heart is entirely devoted to overcoming friction between the blood and its enclosing walls.

Dietetics.

Selection of food is guided chiefly by three considerations:—1. price; 2. digestibility; 3. suitability for providing the force required under stated conditions of climate; 4. its influence upon metabolism.

1. The foods given in public dietaries contain more carbohydrate and less proteid

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Edward Smith.—"Foods," *Inter. Scien. Series.*

W. North.—"Effects of Starvation, with and without Severe Labour, on the Elimination of Urea," *Jour. of Phys.*, vol. i. p. 171.

than is likely to be consumed by a man who chooses his diet without considering its cost.

They must supply at a minimum enough carbon to yield about 900 grammes of CO_2, *i.e.*, 245 grammes.

They must contain sufficient proteid to replace the tissue-proteids daily worn out in the body. This amount is not easily calculated, but probably cannot fall below 45 grammes (resulting in formation of 15 grms. of urea), since this seems to be about the amount secreted by a starving man. As a matter of fact, most men find, by personal experience, that the body works best with a daily consumption of about 100 grammes of proteids (33 grammes urea).

2. Digestibility depends chiefly upon (*a*) the form in which the food is presented to the digestive juices, thus:—

Pie-crust, hot buttered toast, &c., are indigestible, because the fat, which will not be digested until it reaches the small intestine is melted into the other substances, protecting them from the gastric juice.

On the other hand, cream and butter by themselves are easily emulsified.

Pork, because it contains large quantities of easily melted fat, with which, in cooking, every muscle-fibre becomes coated.

Radishes, cucumber, &c., owing to the large quantity of indigestible cellulose by which the digestible contents of each cell are enveloped.

Chicken, boiled fish, &c., are easily digested because they present a fat-free fibre for the gastric juice to act upon.

Sweet-bread consists of small cells supported by loose connective tissue; the latter is digested by gastric juice, and the cells, falling apart, are quickly dissolved.

This list can be easily amplified.

(*b*) Upon the suitability of the food to provoke the flow of digestive secretions without irritating the alimentary canal.

"Rich" food and aromatic substances are apt to inhibit secretion.

Many things, wholesome in themselves, are unwholesome when mixed. This is true of meat *plus* much sugar, perhaps owing to the secretion of mucus which cane-sugar provokes from the stomach.

3. Power of yielding force. Omnivorous Man can obtain force from any food. The body adapts itself to its food, and but few rules can therefore be laid down.

Proteids, the most luxurious of foods, provoke the body to extravagance.

If a person, whose weight and nitrogenous equilibrium is maintained on a mixed diet, take more proteid, the body-weight may fall, owing to a general increase in metabolism.

If other foods are replaced by proteids, the fats of the body are burnt up to supply their place (*Banting*).

Fats are chosen by people in cold climates; they are avoided by people in warm climates.

4. The work thrown by the foods upon the organs of digestion and excretion.

The data for guidance in this matter are scanty. Meat-extracts, grape-sugar, alcohol, are probably absorbed without change.

Meat would appear to make a heavier demand upon digestion than starch. The metabolism and elimination of proteids throws more work upon the liver and kidneys than does the elaboration of carbohydrates and fat.

The composition of foods; the results of analysis are differently stated, according to the meaning put upon the terms proteid, albuminoid, &c.—much nitrogen-containing substance is indigestible. The following averages are useful as data for calculating diet-tables:—

Clean uncooked meat, fish, egg, contain, weight for weight, almost the same amount of digestible nitrogenous substances, differently estimated according to the quality of the article and the method of analysis (20 % to 12 %), the highest per-

centage being in the flesh of chickens, the lowest in eggs; say 15 % for purposes of calculation. Dry peas and biscuits contain as much or more proteids than meat, weight for weight.

Wheat, barley, rye, oats, contain about equal amounts of proteid, say 12 %; maize, 10 %; rice, 5 %. In the amount of fat which they contain, oats and maize head the list with 5–6 %; wheat contains 2 %; rice, 0·8 %.

Of the cereals, oatmeal is the most nutritious, but its proteids are not, like the gluten of wheat, sufficiently tenacious to allow it to be made into bread.

THERMOTAXIS.

Temperature of the body; animals may be divided into two classes.

A. Homoio-thermal; including Man and other mammals (when not hibernating); the body temperature is constant and independent of the temperature of the element in which the animal lives.

Mean temp. in Man, 98·6° F., 37° C., as taken in the axilla, in the blood about 2° F. higher. Varying not more than ½° in an individual who travels from the equator to the pole.

Diurnal variation about 1 %. Highest from 3–5 o'clock P.M. Lowest from 3–5 o'clock A.M.

The temperature is increased by feeding and by muscular work.

It is higher in youth than in age.

The amount of heat produced by the body in half an hour would, if none were lost, raise its temperature 1°.

B. Poikilo-thermal animals; in these the temperature varies with, but does not necessarily equal, the temperature of the surrounding medium.

How is the temperature maintained in equilibrium in homoio-thermal animals? By variations both in heat-production and heat-loss.

Production: CO_2 and $H_2O \propto \frac{1}{\text{temperature.}}$

Loss: Evaporation of sweat and loss of heat by radiation $\propto$ temperature of the air.

Where is heat produced in the body?

A. The respiration of every living tissue results in the production of heat.

B. The glands when active produce a great deal of heat. When the submaxillary gland is thrown into extreme activity by stimulation of the chorda tympani, the saliva in Wharton's duct may be 1·5° hotter than the blood in the carotid artery.

The blood in the hepatic vein is sometimes 2° hotter than the blood in the inferior vena cava.

The activity of the brain is accompanied by heat;[1] there is a marked difference between the amount of heat produced by the brain during unconsciousness (whether in sleep or produced by anæsthetics), and the heat-production during the maintenance of consciousness.

C. The muscles constitute nearly one-half of the body-weight, and their metabolism results in the production of heat as well as movement.

In the most successful experiments made with detached muscle, the energy set free in work does not exceed one-quarter of the energy liberated in heat; within the body they doubtless work more effectively, but their

[1] Mosso's Croonian Lecture, 1892, reported in *Nature*, May 5, 1892.

activity must result in the production of the greater part of the heat set free in the organism.

Do chemical changes occur in muscle for the purpose of heat-production without work-production?

Pro. (1) The adaptation of heat-production to heat-loss seems to exact the existence in the body of a tissue which can produce more or less heat as circumstances require.

(2) When the nerve-endings in muscle are paralysed by curare, the animal loses its power of maintaining a stationary temperature. That the temperature is not kept up by muscular *movements* is evident in sleep.

(3) Shivering would appear to depend upon the reflexion through the central nervous system of impulses so strong that they do more than merely increase passive metabolism, they excite the fibres to such chemical activity as results in their contraction.

Polypnœa: a dog gets rid of heat from the tongue and respiratory passages by rapid, shallow, panting breathing. The small bronchi are at the time contracted, and the air therefore only enters the larger passages.

The regulation of temperature depends upon the integrity of the nervous system.

Are there in homoiothermal animals "specific calorific" or thermotaxic nerves?

Pro. 1. Section between the medulla and spinal cord, or administration of urari (which paralyses the nerve-endings in the muscles), destroys the animal's power of maintaining its normal temperature.

2. Experimental injury to the brain, especially to the parts about the internal capsule, upsets the regulating mechanism.

Are there two interacting mechanisms—(1) thermogenic, (2) thermolytic?

Pro. 1. Sudden cooling of the skin often raises the body-temperature, *i.e.*, increases by reflex action the production of heat in the passive muscles = thermogeny.

2. Muscular activity causes the blood-vessels of the skin to dilate and the sweat to flow = thermolysis.

Are there dominant thermogenic and thermolytic centres?

Pro. Section below the medulla leads to a fall in temperature owing to vascular dilation. Section above the medulla, on the other hand, to a rise in temperature, as if thermo-inhibitory fibres were cut through. Injury about the basal ganglia causes a rise in temperature.

Limit of action of the thermotaxic mechanism; prolonged exposure to cold or heat wears out the regulating mechanism, and the body-temperature falls or rises.

In Man, if it fall by 4° or 5°, or rise to 45° C., death inevitably results. The temperature of many adult animals may be lowered considerably more than this (rabbits to 18° C.).

A child's temperature falls sooner and farther without fatal result. A puppy or kitten may be cooled to 4° or 5° C. and yet recover.

Hibernating animals; the regulating mechanism ceases to act when a certain temperature is reached; after this the animal becomes poikilo-thermal, *i.e.*, its temperature falls and rises with that of the surrounding air. As long as it is below this critical point the animal is dormant unless it is lowered as far as 0° C., when, in some cases at any rate, the animal wakes up and attempts to restore its body-temperature by movement.

Metabolism is extremely depressed. Respiratory movements are shallow and infrequent. In some cases, indeed, it would appear that the pressure upon the lung

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Stewart.—"Loss of Heat by Radiation from the Body," *Studies from the Owens College*, 1891, p. 100.

exerted by the beating heart alone changes the air in the lungs, and yet the blood is bright-coloured, less O_2 being excreted than absorbed. No urine or fæces are formed.

Balance-Sheet of Energy in Units of Heat.

Dr.		Calories.	Cr.		Calories.
By Ranke's normal diet—			Transformed into external work		350,000
Approximately produced as follows :—	per cent.		Expense in keeping the body warm, divided as follows:—	per cent.	
By metabolism in muscles	85		Warming the food . .	3	
Glands and brain . .	10		Warming and rendering moist, inspired air .	20	
Other tissues . .	5		Providing for radiation and evaporation from the skin . . .	77	
	100				1,960,000
		2,310,000		100	2,310,000

Fever is due to derangement of the thermotaxic mechanism.

Does it depend upon diminished loss ("*Traube's* retention theory").

Pro. Skin, although hot, is dry.

Con. 1. CO_2 and urea produced may exceed the normal by 50 %.

2. Direct calorimetric observations upon children prove a greatly increased heat-production.

Is increased production due to

(1) Paralysis of the nervous mechanism, which inhibits katabolism? Or,

(2) To stimulation of a nervous thermogenic mechanism by poisons?

Pro. Rapid rise of temperature after injection of the products of bacteric action upon proteids. Or,

(3) To direct stimulation of the tissues to exaggerated metabolism?

Pro. Changes in the blood are recognisable in rheumatic fever, but whether as the cause of the increased tissue-change or as their result cannot be determined.

Influence of nervous system upon nutrition.

Trophic nerves: The impulses which reach the muscle determine (1) the amount of heat produced by muscular katabolism, (2) the amount of work done.

Is there a third kind of influence which regulates the repair of the muscle-fabric, and in the same way, in the case of other tissues, insures their integrity and growth?

Pro. 1. Abundant evidence that disease or division of nerves leads to atrophy of tissue.

2. Herpes and other cutaneous diseases are the result of nerve-lesions (see p. 157).

3. Section of the Vth nerve leads to ulceration of the cornea.

4. Bed-sores are more likely to follow continued pressure when the spinal cord is diseased than when it is intact.

Difficulty: in (1) there is absence of functional activity, in (3) and (4) disturbance of the vaso-motor system and abolition of the sensations which lead us to change position, and otherwise to protect the part.

LACTATION.

Quantity of milk secreted in 24 hours about 700 to 800 c.cm. (see p. 187).

Sp. gravity, 1·028 to 1·034. Reaction slightly alkaline when quite fresh, acid on standing.

Milk is a perfect food for the infant, containing all three classes of food stuffs. Its composition, doubtless, indicates the proportions in which they may best be blended in the diet of the adult, although water is largely in excess of the amount needed by the adult, who would require to take about 5 litres (11 pints) of milk per diem to obtain the quantity of food prescribed by Ranke's normal diet. It must not be forgotten, however, that herbivorous animals obtain a much larger proportion of proteid and fat when at the breast than their fodder affords them subsequently.

Composition of milk—

	Human.	Cow.
Proteids	2	4
Fats	2·75	4
Sugar	5	4·4
Salts	·25	·6
	10	13
Water	90	87
	100	100

The proteids are casein, a form of alkali-albumin, and therefore not coagulated by heat; precip. by saturation with neutral salts, by acetic acid, or by acetic acid and a stream of CO_2.

Lactalbumin, coagulated by heat (although not when mixed with the other constituents of milk).

Fats are palmitin, stearin, olein, and other lighter glycerides of caproic, caprylic, capric, butyric, and other fatty acids.

The sugar is lactose, a very insoluble sugar (requiring 6 times its weight of cold water for solution), crystallising in rhombic prisms, usually agglomerated. Dextro-rotation 59·3°. Very easily fermented into lactic acid.

Curdling of milk by rennin—

Casein + rennin.

Tyrein[1] a proteose.

The tyrein is not prp. in the absence of calcic phosphate. Curdling may also be described as a conversion of caseinogen into casein (*Halliburton*), the formation of any proteose being doubtful.

The clot of human milk falls in much lighter flocculi than that of cow's milk, unless the latter has been first boiled or mixed with lime-water.

When milk becomes sour the casein is precipitated, but this is not comparable to the clotting by rennin.

When boiled a "skin" forms, due partly to the coagulation of lactalbumin, but partly the result of the action of air upon caseinogen.

[1] Foster's *Physiology*, 5th ed., pp. 374 and 781.

Halliburton.—"The Proteids of Milk," *Jour. of Phys.*, vol. xi. p. 448.
Sebelien.—"The Proteids in Milk," *Jour. of Phys.*, vol. xii. p. 95.
Ringer.—"The Action of Lime Salts on Casein and on Milk," *Jour. of Phys.*, vol. xi. p. 464.
Ringer.—"The Behaviour of Caseinogen," *Jour. of Phys.*, vol. xi. p. 473; vol. xii. p. 164.
Hewlett.—"On Lacto-globulin," *Jour. of Phys.*, vol. xiii., Suppl. No., p. 798, 1892.

Secretion of Milk.

The mammary gland presents the same phenomena of rest and activity as do other glands, but they are spread over a much longer period.

Active at birth in both boys and girls (witch's milk), it does not again begin to form milk until the end of pregnancy.

The resting gland, before pregnancy, is smaller, the tubes shorter and less ramified, the alveoli fewer than in the active gland. The alveoli are small, and packed with polygonal cells of clear protoplasm destitute of fat.

The secretion first discharged ("colostrum") is loaded with granular fat-containing epithelial cells, which have been discharged bodily from the secreting tubes. Hence it is rich in globulins and albumins. Secretion at this period resembles the formation of sebum. In later stages the fat-globules are extruded without disintegration of secreting cells.

Nervous Mechanism of Secretion.—Stimulation of the nipple leads to its erection, to contraction of the galactophorous ducts and their ampullæ; it also quickens the secretion of milk. Erection of the nipple cannot occur after section of the intercostal nerves, but secretion continues.

SECTION VI.

THE SKIN.

Functions.

A. Protection.

It is formed of many layers of cells, most numerous on the heel, sole of foot, palm of hand, and the back about the upper dorsal vertebræ and over the scapulæ.

It limits the exudation of the body-juices.

The deepest part of the stratum corneum is the most impervious layer; lymph poured out amongst the cells of the Malpighian layer in inflammation (forming a blister) does not enter the stratum lucidum of the corneous layer.

It prevents absorption of fluid.

In Man it is smeared with the secretion of the sebaceous and ceruminous glands.

In the porpoise and other aquatic mammals the cells of the corneous layers of the skin contain large oil-globules. Numerous oil-globules are found in the cells of the hoof of horses, &c.

In special situations it is developed into nails, claws, and other organs of similar nature; in other situations into hair.

Hairs diminish immensely the loss of heat by radiation; they also prevent the skin from becoming wet; *vide* the arrangement of the hairs in Man (by whom they are not needed for warmth), sloping downwards in all situations except the back of the fore-arm—most numerous on extensor surfaces.

B. It allows of some absorption of gases (a dog can be poisoned by enclosing its body in a bag of SH_2), of water, and perhaps salts (after excessive sweating a man's weight goes up very slightly in a warm bath), and of unguents.

C. A very small amount of respiration occurs through the skin, certainly not more than 1 % of the whole. In the frog cutaneous respiration is a much more important factor.

D. The sweat-glands eliminate the same waste-products as the kidneys in very small quantities, not more than 0·3 °/$_\circ$ of the urea leaves the body in sweat.

It seems possible, however, that the excretion by the skin of certain auto-toxic substances is necessary, since the gilded cupid of a Roman festival, or an animal even partially shaved and varnished or covered with gelatin, dies in pyrexia. The body-temperature falls rapidly owing to increased loss of heat by radiation; even if this is prevented, death still results, with febrile symptoms.

Sweat.

Sweat-glands are present in all parts of the body except the glans penis and inner surface of the prepuce.

Palm of hand and sole of foot, 2736 to square inch; between the shoulders, 400 to square inch.

Perspiration which is evaporated as soon as excreted, is termed "insensible. When it accumulates in drops, "sensible."

Amount in 24 hours, about 2 lbs.

Sp. gr., 1·005. Percentage of solids, 1·2.

Reaction, (?) alkaline if free from sebaceous matter; *Hoppe-Seyler* says that it is always acid, owing to the presence of acid phosphate of sodium.

Composition:[1]—

Water,		98·88
Solids,		1·12
Salts,		·57
Sodic chloride,	·39	
Alkaline sulphates,	·18	
,, phosphates,		
,, lactates,		
Potassic chloride,		
Urea,		·08
(Quickly converted into ammonic carbonate.)		
Fats, fatty acids, and cholesterin,		·30
(From the sebaceous glands.)		
Epithelium,		·17
(Keratin, containing sulphur.)		

Mechanism of Perspiration.

Claude Bernard saw profuse sweating on the side of the head and neck on which the sympathetic nerve was cut.

Is this an indirect effect of vascular dilation?

Con. (1) *Luchsinger* found that if the sciatic of one leg in the cat is cut and the animal placed in a hot chamber, it sweats through the balls of the other three feet, but not on the foot the nerve to which is cut.

∴ Sweating is produced by nervous action.

(2) The sweating of the hands and feet is prevented by bathing them with a solution of atropin, which increases vascular dilation.

(3) In certain nervous conditions (as in asphyxia, &c.) a "cold" sweat breaks, for sweating can be induced in a reflex manner.

Central stimulation of the nerve of one leg leads to a sweating of the opposite one.

The centre for the hind limbs lies in the lower dorsal, for the fore limbs in the middle cervical region.

The centres of the cord are governed by a dominant centre in the medulla, which is thrown into action by fear; by muscular exertion; by stimulating of the nerves of the tongue with mustard; by the direct (?) action of many drugs, such as pilocarpin, physostigmin, muscarin, strychnin, picrotoxin, nicotin; by carbonic acid in the blood.

Are the kidney and the sweat-glands concerned in a common function? Is the one organ vicarious to the other?

Pro. (1) The amount of water secreted by the kidney varies inversely as that discharged by the skin.

(2) Sweat is, in a sense, very dilute urine.

(3) Free perspiration affords great relief in renal disease, but unfortunately—

(4) Prolonged inflammation and hardening of the kidney is accompanied by similar changes in the skin. This last observation tends to establish the intimate relation between the two.

[1] Charles' *Physiological Chemistry*, p. 349.

APPENDAGES OF THE SKIN.

A great variety of appendages, protective, offensive, and tactile, are developed from the skin by the modification in form and chemical composition of the cells of its corneous layer.

The roots of hairs (except tactile bristles) lie obliquely in the corium unless erected under the influence of emotions; or, in Man, by cold (*cutis anserina*). A few bundles of plain muscular fibre pass obliquely downwards from the superficial layers of the corium to the sides of the hair-follicle. Owing to their insertion into the follicle beneath the sebaceous glands, and their oblique position, they squeeze-out the sebum at the same time that they cause erection of the hair.

Sensory Nerves of Hairs:—The tactile hairs on the cheek of carnivora, rodents, and other animals are supplied by medullated fibres from N.V. They join the hairs just beneath the ducts of the sebaceous glands, and, losing their myelin, break into fibrils which encircle the hair and further give rise to deeper fibrils which run up and down on the surface of the hair, to end in flat expansions.

Pilo-motor Nerves.—The distribution of nerves to the muscle by which the hairs of the monkey and cat and the quills of the hedge-hog are erected has been investigated by Langley and Sherrington, who find that the nerves, which issue from the spinal chord, are distributed through the sympathetic system.

In the monkey, pilo-motor nerves for the face and head accompany the anterior roots of D 3 and 4, and are connected with nerve-cells in the superior cervical ganglion. Cutting the cervical sympathetic on one side completely prevents the elevation, under emotion, of the hairs of that side. Fibres for the buttock, thigh, and tail leave the spinal cord with D 12, L 1, 2, and 3, and descend the lumbo-sacral sympathetic chain.

In the cat, D 3 to 7 supply pilo-motor nerves, which ascend in the cervical sympathetic; D 7 to L 3 supply pilo-motor nerves for the back and tail. The areas supplied by the several dorsal nerves overlap. Leaving the spinal cord by the "white" rami communicantes, the fibres are demedullated in the lateral ganglia, each small-fibred root being conveyed along the sympathetic chain to 4 or 5 ganglia, from which as "grey" rami communicantes non-medullated fibres pass to the same number of spinal nerves. The tail is supplied by L 2 and 3, the fibres being connected with nerve-cells chiefly in the first coccygeal ganglion.

The hair turns grey when some of the hairs recently formed are deficient in pigment. Its silveriness is due to the appearance of innumerable air clefts within the hair.

Langley and Sherrington.—"On Pilo-motor Nerves," *Jour. of Phys.*, xii. p. 278. *Proc. Roy. Soc.*, 1893.

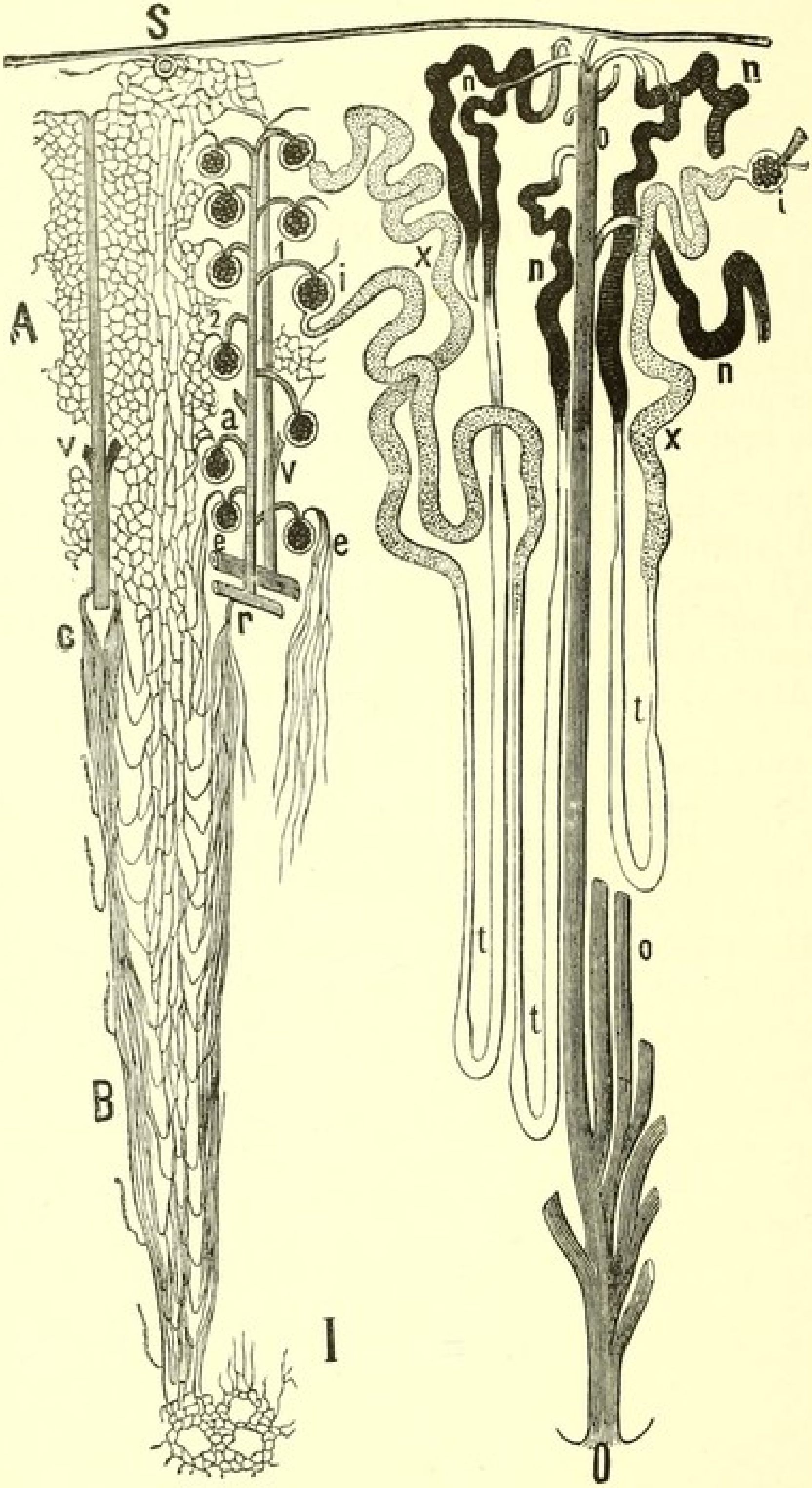

FIG. 43.—Diagram of the secreting apparatus of the kidney, and the vessels by which its several portions are supplied with blood. *a*, Interlobular artery giving off short wide vasa afferentia to *i*, the glomeruli ; *v*, interlobular vein communicating with S, vena stellata, and also receiving branches from the cortical plexus ; 2, vas efferens or venule formed by the union of capillary vessels of a glomerular tuft, and breaking up into a second set of capillary vessels, which surround and supply *x*, the first contorted and spiral tubules, and *n*, the irregular, second contorted and junctional tubules ; *r*, vas rectum verum breaking up into long narrow capillaries which supply *t*, the loops of Henle, and *o*, the collecting tubules.

[*To face p.* 95.

SECTION VII.

THE KIDNEY.

Urine.—*Amount* about 50 oz. (1·4 to 1·6 litres).

Sp. gr., 1·015 to 1·025, with considerable variations depending upon the amount of water absorbed.

Reaction to test-paper ; acid, owing not to a free acid but to acid sodium-phosphate.

Pro. (1) Sodium-hyposulphite gives no precipitate as it would do were uric acid present uncombined with alkali.

(2) Congo red is not changed to violet, as it would be did urine contain 1 part of hippuric acid free in even 50,000 parts of water.

The urine becomes less acid or even alkaline :—

(A.) After a full meal, when much acid is being secreted in the stomach.

(B.) After free perspiration.

(C.) When the food contains large quantities of alkaline salts (*e.g.*, oatmeal) or of vegetable acids (*e.g.*, rhubarb).

(D.) By fermentation with torula ureæ within the bladder (owing to vesical catarrh), or after standing.

This alkalinity is due to ammonia, as may be recognised by the disappearance of the blue colour on warming the test-paper.

Composition of urine passed in 24 hours : [1]—

Solids = 1½ oz. (50 grammes).

A. Nitrogenous waste products.

Urea,	33·18 grammes.
Kreatinin,	0·91 ,,
Uric acid,	0·55 ,,
Hippuric acid,	0·40 ,,

B. Non-nitrogenous waste products.

Oxalic acid.

Lactic acid.

C. Inoxidisable bodies present in the food, or produced in the alimentary canal.

Indol, phenol, kresol, pyrocatechin, indoxyl, skatoxyl (substances due to bacteric fermentation, and occurring in the urine as potassic sulphates. *E.g.*, *Indol.* C_8H_6N,K,SO_4).

The elimination of bodies of this class is of the greatest consequence to the economy ; they are relatives of the exceedingly poisonous "alkaloids," which comprise the ptomaines and leucomaines and other bodies formed by the bacteric fermentation of proteids. Hence the relief of uncomfortable sensations and other nervous symptoms which follows defæcation and diuresis.

D. Ferments ; pepsin and amylopsin.

E. Pigments.

The nature of urine-pigment has been much disputed. It may be termed urochrome (*Thudichum*), or, following *M'Munn*,[2] it may be regarded as urobilin (which other observers find only in febrile urine).

[1] *Cf.* Halliburton, *Text-book of Chemical Physiology and Pathology*, p. 709 *et seq.*

[2] M'Munn, *Clinical Chemistry of Urine*, pp. 104–112.

Urobilin resembles hydrobilirubin (which may be obtained from bilirubin by the action of nascent hydrogen set free by sodium-amalgam).

It resembles stercobilin, which occurs in the fæces.

It also resembles choletelin.

All the bodies above named are products of bile-pigment.

Urobilin may also be made from hæmatin by the action of tin and hydrochloric acid. Whatever, therefore, may be its exact relation to blood-pigment and bile-pigment, it is clear that blood-pigment is the ultimate source of the other two.

F. Salts.

Sodic chloride, 15 grammes. This salt appears to be essential to the processes of osmosis, which occur within the body.

Phosphates and sulphate of potassium, calcium and magnesium.

G. Gases. CO_2 (with a very little O_2 and N_3) 15 vols %.

Urine may vary in health in—

The amount of water, and therefore in specific gravity and colour.

The urea varies as the amount of proteid in the food.

Uric acid makes its appearance in considerable quantity under very many circumstances, producing a cloud of "lithates," which are dissolved when the urine is boiled.

The relative amounts of the salts, and hence the reaction of the urine, vary with diet.

The presence of indoxyl-sulphate of potassium (called by mistake indican) depends upon bacteric fermentations in the small intestine. Its amount varies, therefore, with the length of time during whch the food remains in the intestine and other circumstances. It is not found in the urine of young babies.

Mechanism of the Kidney.

The kidney is a compound tubular gland.

The end of each tube is dilated into (1) a glomerulus, the head of which is pushed in by a tuft of blood-vessels. By a narrow neck the glomerulus is connected with (2) a contorted tube, this becomes less irregular as it approaches the medullary ray, and is termed (3) the spiral tube, which leads into (4) the descending limb of Henle's loop, this turns up again and dilates into (5) the ascending limb, which becomes (6) the irregular tube, (7) the second contorted tube, (8) the collecting tube, (9) the discharging tube or ductule.

Henle's looping tubes lie in the intermediate or boundary zone of the kidney. The other parts of the tubes, except the ductules, lie in its cortex.

The epithelium of each part is characteristic, and the several kinds of epithelium may be grouped into three distinct classes. 1. The glomerulus is lined by flattened scales, and similar scales invest the tuft of blood-vessels.

2. The cells of the contorted, spiral and irregular tubes are turgid, cloudy, indistinctly separated from one another. They project irregularly into the lumen. Their outer portions are rodded (indicating a power of imbibing fluid), their inner portions granular (p. 96).

3. The very narrow descending limbs of Henle's loops are lined by a flattened epithelium, the nuclei of which project slightly towards the lumen.

Bowman (1842) inferred from its structure that the mechanism of the kidney is divisible into two parts.

A. The glomeruli, through which the water filters.

B. The proper secretory apparatus.

Ludwig (1844) thought that the water would carry with it the soluble constituents of the urine, and that the very dilute urine filtered through the glomeruli would be concentrated by reabsorption.

Smith.—"The ammoniacal decomposition of urine," *Quart. Jour. Micr. Sci.*, vol. xxvii. p. 371, 1887.

Noël Paton.—"The relationship of urea formation to bile-secretion: an experimental research," *Jour. of Anat. and Phys.*, vol. xx. pp. 114, 267, 520, and 662, 1885.

M'Munn.—"Colouring matters of bile and urine," *Jour. of Phys.*, vol. vi. p. 92.

Bowman's view, rather than *Ludwig's*, is borne out by experiment.

Pro. 1. In the ichthyopsida the contorted tubules are not supplied by capillaries from the glomerular veins, but by a separate (renal-portal) system of capillaries derived from the femoral veins.

Nussbaum tied the renal artery in the frog and found that sugar, peptones, egg-albumen were no longer excreted by the kidney.

Therefore they leave the blood through the filtering apparatus (the glomerulus).

Urea is excreted by the kidney with the renal artery tied.

From this it may be concluded that it is excreted by the tubules, together with much of the water.

2. *Heidenhain* found that indigo-carmine (sulphindigotate of soda) is excreted by the epithelium of the tubules; this can be seen in sections of the kidney made after its injection into the blood (provided blood-pressure has been lowered by section of the spinal cord below the medulla, otherwise the flow of water carries away the coloured particles).

The ascending limbs contain nearly cubical cells.

The collecting tubes and ducts are lined by the usual columnar cells.

In the same way the blood-supply of the kidney, which is unlike that of any other organ, shows that the three parts are under entirely different hydrostatic conditions (fig. 43).

1. The glomeruli are supplied by short and comparatively wide lateral branches of the vasa recta.

Their pressure must be high but quickly and widely varied by vaso-motor action.

2. The contorted, spiral, and irregular tubes are supplied by the capillaries into which the veins from the glomeruli break up.

Their pressure must be always low but constant.

3. The loops of Henle and the ducts are supplied by long arterial capillaries.

Their pressure is lower and more uniform than that of the glomeruli.

Anatomical considerations seem to demand a division of the mechanism into three parts, as stated above, and there is reason to think that a rigid distinction into two only, viz., the glomeruli and tubes, cannot be maintained.

Adami, working with *Heidenhain*, finds that—

(1.) If the renal arteries of the frog are tied, a collateral circulation, capable of carrying carmine, in suspension, or hæmoglobin into the glomeruli is soon established.

(2.) Water injected into the blood of the dog sets free hæmoglobin, which collects in the glomeruli; but if nitrate of soda is administered, the hæmoglobin is washed out of the glomeruli, *i.e.*, a diuretic which was supposed to affect only the tubules stimulates the glomeruli.

The fluctuations in amount of the blood in the kidney are very easily recorded by the oncograph.

A blood-pressure tracing from the kidney shows the heart's beats, respiratory

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Bowman.—"The Structure and Uses of the Malpighian Bodies in the Kidney," *Collected Works of Sir W. Bowman*, London, 1892.

Adami.—"Nature of the Glomerular Activity of the Kidney," *Jour. of Phys.*, vol. vi. p. 382.

Tillie.—"The Occurrence of Hæmoglobinuria in Blood-Pressure Experiments," *Jour. of Anat. and Phys.*, vol. xxv. p. 550, 1891.

Herringham, Davies, and Groves.—"The Excretion of Uric Acid, Urea, and Ammonia," *Jour. of Phys.*, vol. xii. pp. 475, 478.

Halliburton.—"The Proteids of Kidney and Liver Cells," *Jour. of Phys.*, vol. xiii., Suppl. No., p. 806, 1892.

undulations, and Traube-Hering curves. The curves last named are complementary to those seen in a tracing from the carotid artery, proving that the renal vessels are amongst those which produce the fluctuations in B.P., recorded in the Traube-Hering curves: indeed they are exceedingly amenable to the government of the vaso-constrictor centre in the medulla, *e.g.*, dyspnœic stimulation of the vaso-motor centre causes the kidney to shrink (fig. 5).

Nerves of the Kidney.

In Man, chiefly the least (3rd) splanchnic.

In the dog, fibres which leave the cord in the anterior roots of the dorsal and lumbar nerves, but particularly the 11th, 12th, and 13th dorsal.

They are both vaso-constrictor and vaso-dilator.

1. Section is followed by dilation of renal vessels.
2. Peripheral stimulation by constriction.
3. Slow rhythmic stimulation affects the vaso-dilator more than the vaso-constrictor fibres, and hence it is followed by dilation.

No secretory or trophic fibres have as yet been discovered. The problem is therefore less complicated than in the case of the salivary glands.

Atropin and pilocarpin have no effect upon secretion.

On the other hand, while the action of certain diuretics, such as nitrous ether, and perhaps digitalis, may be entirely due to their effect upon the blood-vessels, it is impossible to account for the diuretic action of urea, acetate of soda, caffeine and theobromine, &c., without supposing that they increase the secretory activity of the epithelium of the renal tubules.

The flow of urine is increased by any operation which causes dilation of the renal vessels without such dilation of other vessels as would lower the blood-pressure, *e.g.*,

A. Section of the renal nerves causes great increase.

With simultaneous central stimulation of a sensory nerve or peripheral stimulation of the splanchnics, still greater increase.

B. Section of splanchnic nerves; increase slight, owing to dilation of whole visceral area.

C. Section of the cord; diminution in secretion, owing to general fall in B.P.

Bradford.—" Innervation of the Renal Blood-Vessels," *Jour. of Phys.*, vol. x. p. 358. *Proc. Roy. Soc.*, 1889, p. 369.

SECTION VIII.

RESPIRATION.

Object.

Galen taught that the inspired air passes into the left ventricle, where it generates "vital spirits."

Down to and including the time of *Descartes* (1625), it was considered that the reason for the inhalation of air is the cooling of the blood.

1661, *Malpighi* described the blood-vessels of the lungs, and pointed out that they form a closed system—known for a long time as the rete mirabile Malpighii. There is, therefore, no mixing of air and blood, as was supposed up to that time.

1768, *Spallanzani* observed that "fixed air" (CO_2) is produced by worms enclosed in a vessel full of nitrogen.

1772, *Priestley* proved that breathing and burning have the same effect on air, and made the discovery that air vitiated by animals is again rendered respirable by plants.

1775, *Lavoisier*, by accurate analysis, proved that the change in air produced by breathing or by combustion depends upon the removal of oxygen, and its replacement by CO_2.

He was of opinion that the lungs are the "furnace (foyer) of the body," but he added that "combination of oxygen with carbon may also occur in the blood." Two theories were for a long time before physiologists.

A. The "combustion theory," *i.e.*, that oxidation occurs in the lungs.

Pro. Free oxygen could not be found in the blood.

Con. 1. The lungs would be burnt up (*Lagrange*, 1791).

2. The blood of the left side of the heart is not noticeably hotter than that of the right (*Claude Bernard*).

B. "Secretion theory," *i.e.*, that carbonic acid is thrown off by the lungs, although not produced there.

1836, *Magnus* obtained CO_2 from the blood by means of the air-pump. He concluded that O_2 and CO_2 are dissolved in the blood.

Con. 1. If this were the case, variations in pressure would produce great disturbance of the system. *Whymper* found no difficulty in breathing under a pressure of 14 inches, on the top of Chimborazo (20,500 ft.). *Dr Glaisher* rose in a balloon from a pressure of 29·6 inches to a pressure of 14·8 inches in half an hour without discomfort.

2. The amount of gas removed from blood by the air-pump is not proportional to the diminution in pressure. It does not, that is to say, obey *Dalton's* law for absorption of gases by liquids.

Explanation. Gases are bodies the molecules of which repel one another. The tension or total pressure exerted by a gas will therefore depend upon the number of molecules of the gas compressed within a given area. The molecules of one gas fit in amongst the molecules of other gases, and to a certain extent, varying according to the nature of both gas and liquid, amongst the molecules of liquids. The amount of any given gas absorbed by a liquid depends upon the tension of that gas, and is not affected by the tension of other gases with which it may be mixed.

3. Blood absorbs much more oxygen than water would do, *i.e.*, 20 vols °/₀ as against 2 vols °/₀, at the body-temperature.

Serum will give up 30 vols °/₀ of CO_2 to the air-pump, and 6 vols more on addition of an acid. Defibrinated blood will give up 40 vols °/₀.

Stokes discovered that the colouring-matter of blood exists in two forms of different colour, containing different proportions of oxygen.

Reduced hæmoglobin can take oxygen from air at any pressure above (about) 300 mm. mercury.

∴ The object of respiration is to give the hæmoglobin of the blood the opportunity of combining with oxygen, and so replacing the oxygen which it has lost in its circuit of the body, and to allow the carbonic acid, which is partly dissolved in blood and partly in loose chemical combination with its salts, to escape into the air.

Mechanism.—The term respiration is used indifferently to denote the union of oxygen with carbon in the tissues, the liberation of carbonic acid by the tissue-cells within which it is formed, the escape of carbonic acid from the blood, and the entrance of oxygen into the blood in the capillaries of the lungs.

The lungs are two bags enclosed within the air-tight thorax, the movements of which they follow owing to the elasticity of their walls. The lungs are always stretched; if the thorax is opened even in expiration, they collapse (exerting a pressure of 6 or 7 mm. Hg.); in a deep inspiration the pressure reaches 30 mm. Hg.

The first inspirations are made against considerable resistance; enlargement of the chest sucks blood into the pulmonary artery, lowers the pressure in the right ventricle, and favours the closure of the foramen ovale by the membranous flap which hangs on its left side.

Muscles of Ordinary Inspiration.

The tendinous centre of the diaphragm is almost stationary beneath the heart. Its sides are depressed 2 to 2·5 cm. with rectification of their curves.

The ribs are elevated and slightly rotated by the external intercostals, levatores costarum, and serrati postici superiores. The scaleni fix the first two ribs.

Ordinary expiration is due to elastic recoil, aided perhaps by the internal intercostals and serrati postici inferiores, although the latter have a more important function in fixing the lower ribs, and, therefore, the diaphragm in forced inspiration.

The external intercostals are undoubtedly inspiratory; the same seems to hold good of the intercartilaginous part of the internal intercostals, but the function of the rest of the internal intercostals is open to debate.

Are they expiratory?

Pro. 1. Two horizontal bars jointed to a vertical bar (*Bernouilli's* model adopted by *Hamberger*, 1727) are raised by elastic bands attached in the manner of the external intercostals, depressed by bands representing the internal intercostals.

2. *Martin* and *Hartwell* observed that the internal intercostals, when two ribs and their muscles are isolated, contract alternately with the diaphragm in the dog and cat, although in the latter animal they only come into action in forced respiration. This indicates that they are expiratory.

Champneys.—"Experimental Researches in Artificial Respiration in Stillborn Children, &c., London, 1887.

Martin and Hartwell.—"Respiratory Function of the Internal Intercostal Muscles," *Jour. of Phys.*, vol. ii. p. 24.

Sewall and Pollard.—"Relations of Diaphragmatic and Costal Respiration, with Particular Reference to Phonation," *Jour. of Phys.*, vol. xi. p. 159.

Con. 1. It must be remembered that the cross-laced muscles acting *together* would approximate the ribs, and the object of the crossing may be to increase the possible range of approximation ; the crossing of the fibres also strengthens the thoracic wall, and this is probably its chief advantage.

2. The descent of the diaphragm sucking air into the chest, tends to pull the intercostal spaces inwards. The intercostal muscles serve to prevent this.

Diaphragmatic *v.* Costal Respiration.

In the female, diaphragmatic respiration does not predominate to the same extent as in the male, owing to the need for protecting the gravid uterus from displacement by abdominal viscera.

Measurements in Respiration.

Descent of the diaphragm chiefly produces distension of the flanks ; the umbilicus moves about 10 mm. forwards.

The diameters of the chest are measured by a stethometer or rigid frame with points to rest against the chest-wall ; its movements, by placing a tambour beneath one of the points.

In ordinary respiration, movement is very slight. The upper sternal diameter varies 1 mm., the lower sternal diameter 1·5 mm., the transverse costal diameter 2 mm.[1]

In forced inspiration the movements are much more considerable.

The average circumference, measured beneath the mammæ, is 900 mm. when the chest is distended ; about 820 mm. at the end of expiration.

Capacity of the chest (after *Hutchinson*) :—

	Cubic Inches.[2]	
Residual air	100	Left behind after deepest expiration.
Supplemental	100	"Vital capacity" or maximum quantity which can be breathed into a receiver (fig. 44).
Tidal	30	
Complemental	100	

Vital capacity $\propto$ (approximately) as the height of the person.

An inch of height adds about 8 inches capacity. It is less in women than in men of the same height. Number of respirations per minute : in middle life, 17 ; at birth, 44. Force of respirations : in calm breathing, air is sucked in and blown out with a force of 2 or 3 mm. To determine the force exerted by the inspiratory muscles it is necessary to add to this the elasticity of the thoracic wall and of the lungs which they have to overcome.

When the air-passage is closed, and the greatest possible inspiratory effort made, the pressure in the chest is reduced by 100 mm. Hg. With the most violent expiratory effort it is raised by 120 mm. Hg.[1]

Rhythm of respiration varies very greatly under different circumstances.

In calm breathing, expiration is longer than inspiration in the ratio of 6 : 5 ; a slight pause separates expiration from inspiration. Tracings taken with any of the various forms of pneumatographs or stethographs, or by a manometer inserted in one nostril while the other nostril is open, show that muscular effort is most

[1] Burdon-Sanderson, *Handbook of the Physiological Laboratory*, p. 292.

[2] All measurements might be given according to the same system, but in some cases the numbers happen to be easier to remember when the English system is used, in other cases when the continental system is followed.

Wood and Cerna.—"The effects of Drugs and other Agencies upon the Respiratory Movements," *Jour. of Phys.*, vol. xiii., Suppl. No., p. 870, 1892.

noticeable at the commencement of inspiration, while the expiratory limb of the curve indicates that elastic recoil is the principal factor in expelling air from the chest.

During hibernation the movements of the heart help to change the air in the lungs (p. 88).

Changes in Air produced by Respiration.

	Inspired air.	Air expired in quiet respiration.	After the breath has been held as long as possible.
O_2	21	16	12
N	79	79	79
CO_2	·04	4	8

Water-vapour to saturation. Organic matter, temperature raised to 30°—38° C.

It must be particularly remembered that an inspiratory effort draws the air into the trachea and large bronchi only, the amount of tidal air being about $\frac{1}{6}$ that of the air left behind in the lungs after ordinary expiration. This fresh air mixes with the air in the ultimate air-passages by diffusion. Of the 30 inches of air expired, 10 inches may be looked upon as pure air just introduced by inspiration. When the breath is held for some time, CO_2 is uniformly distributed throughout all the air in the lungs; at the same time, holding the breath allows the blood to become more than usually venous, and therefore the percentage of CO_2 in the air of the alveoli probably exceeds the normal.

Air contaminated with carbonic acid by breathing to the extent of 1 % is quite unfit for respiration; indeed the presence of ·08 % of carbonic acid shows an insanitary want of ventilation. A considerably larger quantity of pure CO_2 would do no harm; and its determination is of value, therefore, not for itself, but as a means of estimating the amount of other unknown and more deleterious impurities.

Carbonic acid excreted per diem . . . . = 900 grammes.

Oxygen needed to produce the above—

$$C(12) + O_2(32)\ \frac{900 \times 32}{44} = 655 \quad ,,$$

Oxygen retained for the oxidation of nitrogenous and other substances secreted by the kidney . . . = 45 ,,

Total amount of oxygen consumed per diem . . . = 700 ,,

The lungs as apparatus for exchanging the gases of the blood with the air; for allowing of the exit of carbonic anhydride and entrance of oxygen.

Principles of construction: capillary vessels are brought as near to the surface as possible, being separated from the air by thin epithelial scales only; air is not allowed to come in contact with these vessels until after it has been rendered warm and moist. The fresh air is not drawn up into contact with the capillaries, but after its passage through the nose, upper part of pharynx, trachea, and large

Haycraft and Edie.—"The Cardio-Pneumatic Movements," *Jour. of Phys.*, vol. xii. p. 426.

Hodsdon.—"An Experimental Inquiry into the Influence of the Pulmonary Blood-pressure upon the Collapsed Lung," *The Lancet*, 1891, No. 3525, p. 649.

Semon.—"Position of the Vocal Cords in Quiet Respiration in Man," *Proc. Roy. Soc.*, 1890, pp. 156 and 403.

Fred Smith.—"The Chemistry of Respiration in the Horse," *Jour. of Phys.*, vol. xi. p. 65.

Marcet.—"A Chemical Enquiry into the Phenomena of Human Respiration," *Phil. Trans.*, 1890, vol. 181, p. 1.

Marcet.—"Chemical Phenomena of Human Respiration while Air is being Re-breathed in a Closed Vessel," *Proc. Roy. Soc.*, 1890, p. 340, and 1891, p. 103.

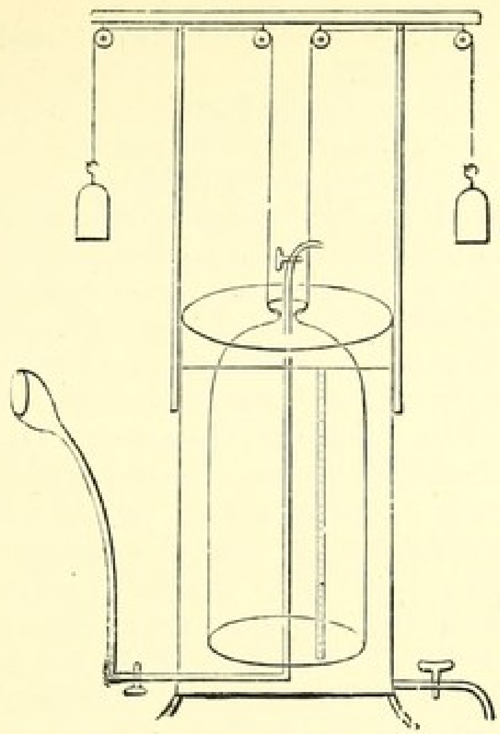

FIG. 44.—Plan of Hutchinson's spirometer. A graduated cylinder filled with water is suspended by counterpoised cords in a vessel of water. A deep breath having been taken, the air from the chest is breathed into the spirometer, and the vital capacity of the person who makes the experiment is indicated by the height to which the cylinder is raised.

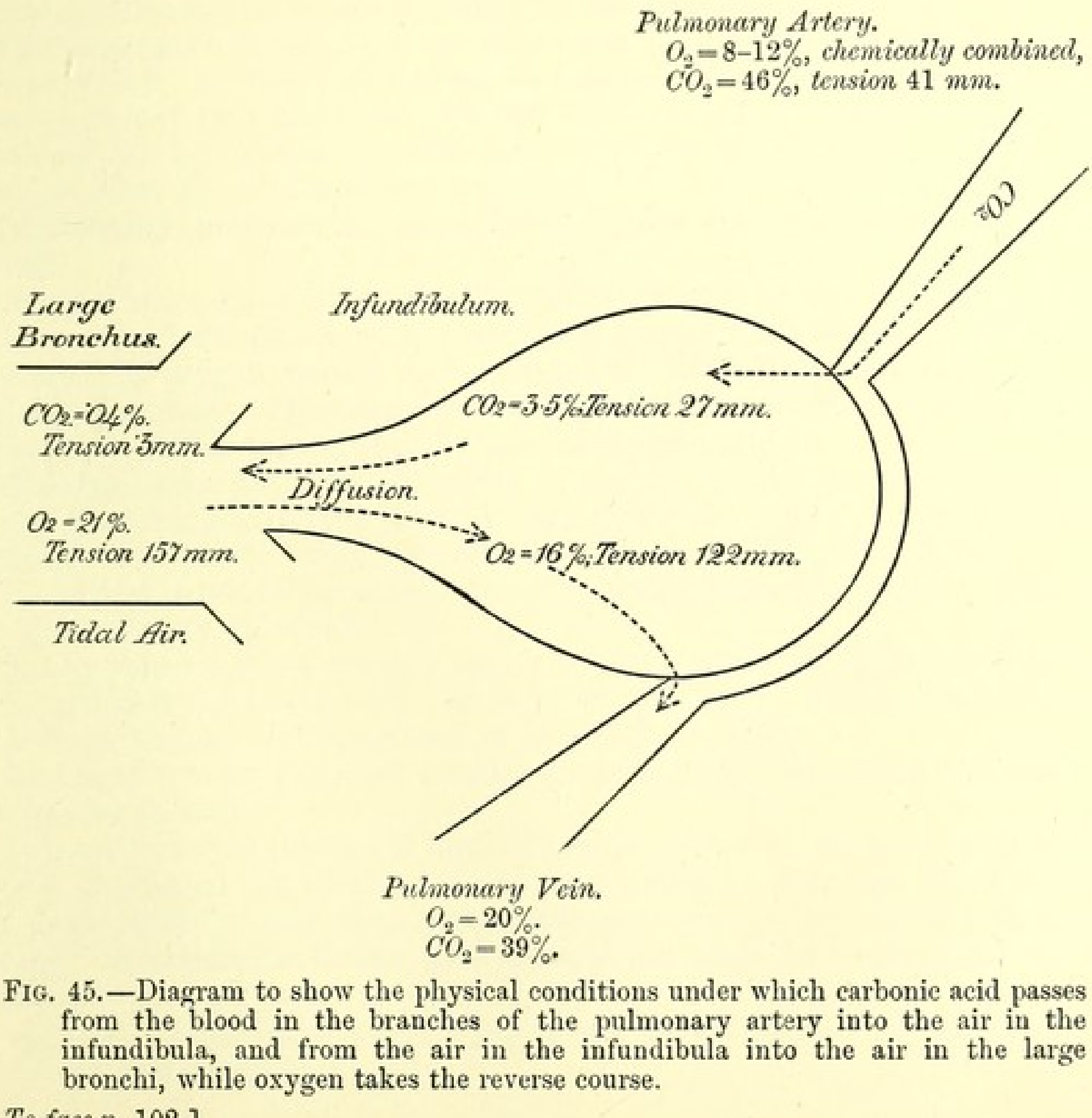

FIG. 45.—Diagram to show the physical conditions under which carbonic acid passes from the blood in the branches of the pulmonary artery into the air in the infundibula, and from the air in the infundibula into the air in the large bronchi, while oxygen takes the reverse course.

To face p. 102.]

bronchi, it reaches the chambers in which the smallest bronchioles end, by diffusion. The ultimate chambers or alveoli of the lung in which the exchange of gases occurs, are nearly hemispherical cups, 250 μ ($\frac{1}{100}$ inch) across. Their walls are formed of almost structureless membrane (an expansion of connective tissue-cells) encircled by elastic fibres, the ends of which frequently bifurcate. The membrane supports a network of capillary-vessels derived from minute arteries which (although the arrangement is far from regular) tend to encircle the rim of the cup, while the vein in which they unite generally leaves the bottom of the cup. In Man the tissue is very delicate; and instead of each alveolus having its own set of capillaries, these vessels project sometimes on one side of the membrane, sometimes on the other, so that they are exposed now in this alveolus, now in the adjoining one. The alveoli are lined by large flat nucleated cells or "squames" (about 40 μ in diameter) the thin transparent expansion of which alone separates the epithelial wall of the capillary from the air in the alveoli. Numerous granular cells lie in the angles between the squames, capable of proliferation, and ready apparently to take their place as the squames fall off. The blood is therefore separated from the air by (1) the epithelial cells which form the wall of the capillary vessel containing it, and (2) the lining cell, of the alveolus. Between the connective tissue wall of the alveolus and its epithelial lining lies a copious lymphatic network. Numerous leucocytes wander out of the blood-vessels into the lymph-spaces, and through the epithelial lining of the alveolus on to its free surface, pushing their way back into the lymphatic vessels between the squames, usually at the angle where three squames join (pseudo-stomata). *Débris* of every kind and foreign particles, such as soot, are removed from the alveoli by these scavengers. In inflammation enormous numbers of leucocytes emigrate, filling up the alveoli.

The capillaries of the lung are short and narrow, but the total length of the minute vessels in which the blood is exposed to aëration is very great. It has been estimated that there are 725,000,000 [1] alveoli, exposing a superficial area of about 90 sq. metres (or 100 times the area of the skin). Each alveolus supports some 40 or 50 capillary vessels.

Interchange between the gases of the blood and the air in the pulmonary alveoli.

Oxygen is not dissolved in the blood, but chemically combined with its hæmoglobin. Oxyhæmoglobin is not dissociated until the air-pressure falls to about 300 mm. (its oxygen tension being 64 mm.). Therefore, even at the top of the highest mountain which has yet been climbed, the tension of oxygen in air is sufficient to enable hæmoglobin to become oxyhæmoglobin.

Carbonic acid is partly dissolved in serum, partly combined with its salts. Under the air-pump, serum gives up very nearly as much carbonic acid as can be obtained from blood, but it is present in the serum in three conditions.

1. At first it leaves the serum according to the law of pressures. This part of the gas is simply dissolved.

2. On pressure being lowered almost to *zero*, a gush of CO_2 occurs, showing that this portion is combined with the salts of the serum, forming an acid carbonate of sodium, and an acid compound of Na_2HPO_4 and CO_2.

3. About 6 vols. per cent. remains in combination *in vacuo*, and can only be set free by an acid.

It must be added (4) that if hæmoglobin is present in the serum, this last 6 vols. comes off without the addition of an acid; therefore, although blood cannot take up more carbonic acid than serum, the presence of hæmoglobin facilitates its escape. *Hoppe-Seyler* thinks that hæmoglobin must be decomposed by the air-pump into acid products.

[1] Estimates differ widely: 355,000,000 is the number adopted by Macalister (*Text-book of Human Anatomy*, p. 341).

In the case of oxygen the tension in alveolar air is always so great as to cause it to pass readily into the blood.

In the case of carbonic acid, experiments in holding the breath seemed to show that its tension in the alveolar air might exceed its tension in the blood, necessitating the existence of an excretory mechanism. When, however, the air is drawn off from one lobe only of the lung (by a Wolffberg's catheter) while air is entering and leaving the rest of the lung in a normal manner, it is found that no such difficulty exists.

Gases contained in blood measured at 0° C. and pressure of 760 mm. Hg. :—

	Oxygen.	Carbonic anhydride.	Nitrogen.
In 100 volumes of arterial blood, .	20	39	1–2
,, ,, venous, ,, .	8–12	46	1–2

1672, the presence of gas in blood first recognised by *Mayow.*

1799, oxygen obtained from blood by *Sir Humphrey Davy.*

1836, the mercurial air-pump invented by *Magnus*, and gases extracted in considerable quantity. He still made the mistake, however, of supposing that they were simply dissolved, although *Berzelius* at the end of the last century had shown that blood will absorb more oxygen than either water or serum.

Exact results, which make it quite clear that the gases are not dissolved, are due to the combined labours of many workers (*Ludwig*, *Schmidt*, *Bert*, *Pflüger*, *et. al.*).

Method.—The mercurial pump (fig. 84) consists of a column of mercury of more than 760 mm. length. A long flexible tube connects the bottom of the rigid tube with a receiver (A). The rigid tube carries a receiver (B) at its summit. When A is lowered, the mercury runs out of the rigid tube, and gas is drawn out of C into B; by now closing the stopcock towards C, opening it towards the measuring tube, and then raising A, the action of the pump is reversed, and the gas which had been collected in A is driven into a measuring-glass. Before the chamber which contains the blood is connected with the pump, the pump is exhausted of air; after this, each depression of A sucks gas out of the blood, each elevation of A drives the gas into the measuring tube. A drying-tube is placed between the pump and the blood to collect the water which evaporates from the blood. There are several modifications of this pump, known by their inventors' names (Ludwig's, Pflüger's, Alvergniat's, &c.).

Respiratory quotient $\frac{CO_2 \text{ exhaled}}{O_2 \text{ absorbed}} = 0{\cdot}87$ for Man.

$= 0{\cdot}9$ to 1 for herbivora.

This indicates that a greater proportion of the oxidised waste-products leaves the body in urine when the diet is rich in nitrogenous foods than when it is poor in these substances.

Intensity of respiration, as shown by the amount of oxygen consumed in 24 hours, per kilo of body-weight:—

Small singing birds	11·360 grammes.
Hen	1·3 ,,
Cat	1·0 ,,
Man	0·4 ,,
Frog	0·08 ,,

HÆMOGLOBIN AND ITS DERIVATIVES.

Berzelius showed that blood will absorb much more oxygen than water or serum.

1853, *Funke* crystallised out the colouring-matter of blood. *Reichert* had already (1849) observed the crystals in the uterus of a pregnant guinea-pig; and *Leydig* had, in the same year, seen them in the contents of the stomach of a leech.

1862, *Hoppe-Seyler* described its spectrum.

1864, *Stokes* showed that, "like indigo, it is capable of existing in two states of oxidation, distinguishable by a difference of colour." He termed it cruorin, but *Hoppe-Seyler's* name, hæmoglobin, is generally adopted.

It alone holds oxygen in the blood, since in its crystalline condition it is united with as much oxygen as would be taken up by the amount of blood which contains the same weight of hæmoglobin.

Hæmoglobin forms about 14 % of blood.

The whole blood can hold about 4 grammes of oxygen at one time.

1 gramme of hæmoglobin, in solution, can take up (if it be at the time fully reduced) 1·59 c.cm. of oxygen at 0° C. and 760 mm. Bar.P.

When it passes from the oxidised to the reduced condition its colour, as analysed by the spectrum, changes as shown in the diagrams (fig. 46). The centre of the band α is due to the absorption of the rays of (yellow) light, which have a wave-length of 578 millionths of a millimetre. The centre of band β blots out yellowish-green rays, with wave-length 539 millionths of a millimetre (0·539 μ).

Preparation of Hæmoglobin.—The blood of some animals crystallises with great facility. Allow a drachm of rat's blood to coagulate, put a few drops of water upon a clean slide, take up the freshly coagulated blood and dip it repeatedly in the water, in a few minutes crystals of hæmoglobin will appear on the slide.

If it be blood which crystallises with difficulty (*e.g.*, human blood), it is necessary to defibrinate it, to expose it freely to air so that all the hæmoglobin may be oxidised, to freeze and thaw so as to liberate the hæmoglobin from the stroma of the corpuscles, to crystallise at a low temperature, and perhaps to add ¼ of its volume of cold alcohol in order to diminish the solubility of the oxy-hæmoglobin.[1]

Crystalline form: Man, rhombic prisms; guinea-pig, tetrahedra; squirrel, hexagonal plates; hamster, rhombohedra or hexagons.

Upon what does the peculiar crystalline form depend?

Upon the medium from which the hæmoglobin crystallises?

Con. The hæmoglobin of one animal crystallised from the blood of another animal, retains its crystalline form.

Upon the water of crystallisation?

Pro. 1. It varies considerably in amount in different specimens of hæmoglobin.

2. The hæmoglobin of the squirrel can be obtained in rhombic prisms by repeated crystallisation.

3. The spectroscopic properties, the compounds which they form, and the products of decomposition, are the same for all forms of hæmoglobin: ∴ the essential part of the salt is identical in all cases.

Do the different forms of crystal differ in crystallographic type, or only in "habit"?

[1] For detailed methods, see *Handbook of the Physiological Laboratory*, p. 180; or Halliburton's *Chemical Physiology*, p. 268.

> They belong to different systems. The hexagon of the squirrel is not a rhomb with its angles truncated, but a true hexagon, since it is singly refracting, while crystals of the rhombic system are doubly refracting.

The (pseudo) polymorphism of oxyhæmoglobin, and its power of giving up oxygen from its molecule, depend probably upon the extreme complexity of its molecule, which is perhaps heavier than that of any other crystalline body.[1]

Methæmoglobin has a brown colour and characteristic spectrum. It is made by treating hæmoglobin with such oxidising agents as nitrite of amyle. It contains the same amount of oxygen as oxyhæmoglobin but in closer union.

Hæmoglobin combines with carbonic oxide (CO), with nitric oxide (NO), and perhaps with other gases in the same way as with oxygen (O_2). In each case one molecule of hæmoglobin (probably) is combined with one molecule of the gas. The compounds are isomorphous, but differ in their spectra and in the permanence of their union; carbonic-oxide-hæmoglobin, *e.g.*, being much more stable than hæmoglobin, hence the poisonous nature of these gases.

Decompositions.

$Hb^{n.}$ + acid or alkali.

Hæmatin 4–5 °/ₒ. Globin (a proteid) 95–96 °/ₒ.

Hæmatin is insoluble in water, alcohol, and ether; soluble in caustic alkalies and in acid alcohol.

Its formula is $C_{34}H_{35}N_4FeO_5$.

2 (Alkaline) Hæmatin + $(NH_4)_2S$.

Hæmochromogen. O_2.

Hæmochromogen (not hæmatin) is probably the ferro-compound in hæmoglobin.

Oxyhæmochromogen (which contains more oxygen than the hæmatin from which the hæmochromogen was obtained) is probably a ferri-compound forming part of oxyhæmoglobin. The hæmochromogen is therefore apparently the atomic group upon which the respiratory value of hæmoglobin (*i.e.*, its power of combining with oxygen) depends. The proteid plays no part in absorbing gases.

Hæmin = hæmatin + 2HCl. As a medico-legal test, it can be prepared from old blood-stains by boiling a piece of the stained cloth with glacial acetic acid and a small crystal of common salt.

Hæmatin + $2H_2SO_4 + O_2$ = Hæmato-porphyrin + $2FeSO_4$. This pigment occurs in the integument of earthworms, slugs, &c.

When the blood stands in old hæmorrhages, in aneurisms or in corpora lutea, its iron is absorbed and **hæmatoidin** left behind. Its spectrum shows no bands. Hæmatoidin = bilirubin. It has the same crystalline form, and gives the same play of colours with Gmelin's test (fuming HNO_3).

When blood is effused beneath the skin, a similar play of colours is observed during the process of its absorption, the colour of the bruise changing from reddish purple to blue, green, and eventually yellow.

[1] The analysis of hæmoglobin is of little consequence, since it is a combination of hæmatin with a proteid, forming a complex body of unknown formula. Its percentage composition (in the dog) is C.53·85; H.7·32; N.16·17; O.21·84; S.0·39; Fe.0·43, with water of crystallisation.

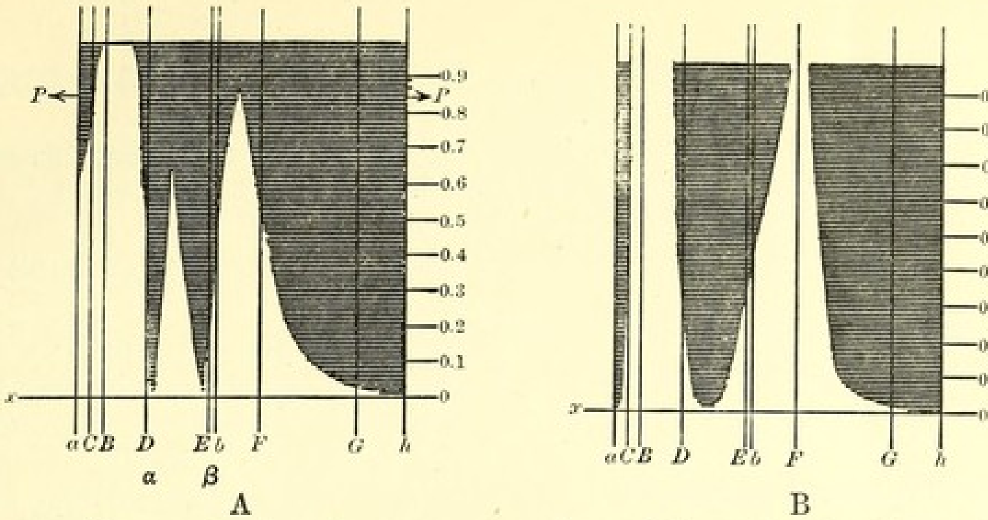

Fig. 46.—Diagram showing the spectra of oxyhæmoglobin and reduced hæmoglobin in solutions of varying strength. A, Spectrum of oxyhæmoglobin. In a certain thickness of solution containing 0·8 %, HbO_2, no bands were visible; two bands made their appearance when the solution was diluted to 0·6 %. The centre of the band α, which lies close to Frauenhofer's line D, corresponds to a wave-length of 579 λ (0·579 μ), the centre of the band β, which lies near E, would have a wave-length of 553·8 λ. [The wave-length of D is 589 λ, of E 526 λ.] B, Spectrum of reduced hæmoglobin. The centre of the single band corresponds to a wave-length of 550 λ.

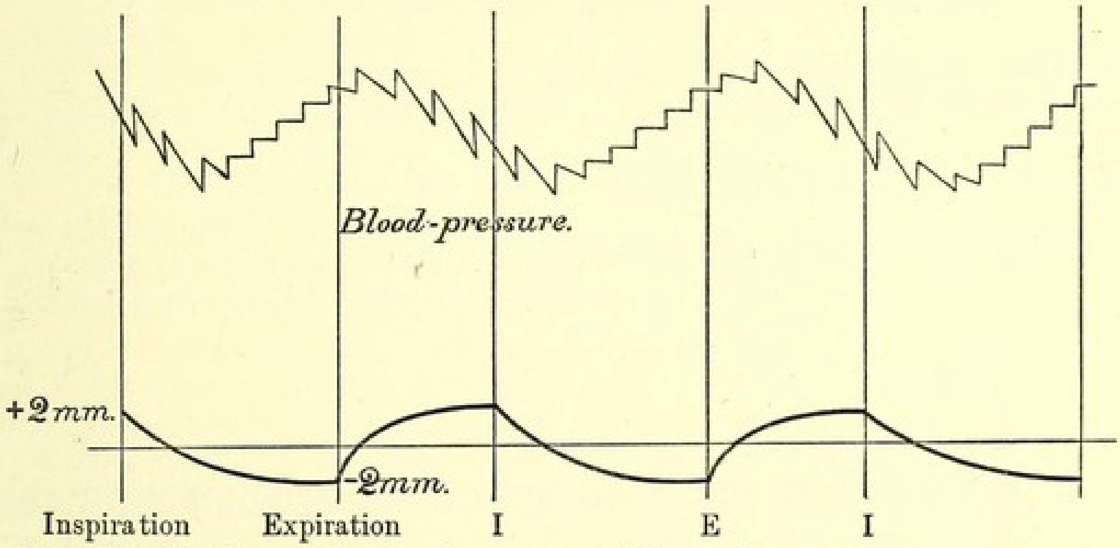

Fig. 47.—Tracings of the blood-pressure and the respiratory pressure compared.

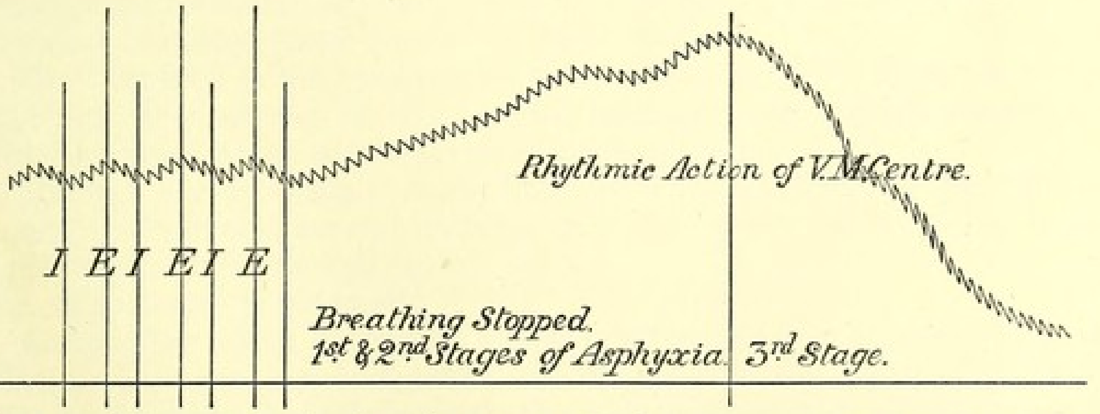

Fig. 48.—Diagram showing the effect upon a blood-pressure tracing of the cessation of respiration. I, Inspiration; E, expiration. Respiration is stopped at the end of expiration, after which the pressure rises steadily. In the second stage of asphyxia the pressure shows rhythmic variations. In the third stage it falls rapidly.

[To face p. 106.

INTERCHANGE BETWEEN THE BLOOD AND THE TISSUES.

Spallanzani showed that worms confined in an atmosphere of nitrogen exhale carbonic acid. He considered, however, that the CO_2 was formed in the stomach by digestion.

1823, *W. Edwards* pointed out that the amount of CO_2 is too great for such a source.

1850, *Liebig* showed that muscle removed from the body takes oxygen from, and gives carbonic acid to the air by which it is surrounded during contraction.

O_2 passes from air → blood → lymph → cells.
CO_2 passes to „ ← „ ← „ ← „

The physics of the interchange of CO_2 between the tissues, the lymph, and the blood is difficult to express in figures. Such investigations as have been carried out give a lower tension for carbonic acid in lymph (35 *mm.*) than in venous blood (41 *mm.*). The tension of the carbonic acid in the lymph in the interstices of the tissues must however be higher than that in the blood of the capillaries; probably 45 mm.

Do the tissues excrete partially oxidised substances, which, in the lymph or in the blood, are further oxidised to carbonic acid, &c.?

Con. 1. Muscle free from blood gives off CO_2.

2. The fluids surrounding the tissues, like the fluid secretions, contain hardly any free oxygen.

3. Metabolism is carried on for some time in a frog in which all the blood is replaced by salt solution : ∴ its oxygen must be stored in the tissues.

4. The blood has very little oxidative power; *e.g.*, it does not oxidise grape-sugar or pyrogallic acid.

(On the other hand, lactate of soda is oxidised within circulating blood).

∴ Oxidations (respiration) occur in the tissues.

NERVOUS MECHANISM WHICH GOVERNS RESPIRATION.

Flourens discovered that injury to the floor of the fourth ventricle near the point of the calamus scriptorius puts an end to respiration, and therefore to life. Hence he named the respiratory centre "le nœud vital."

The "centre" is the junction between a large number of motor nerves supplying the muscles of the nostrils, larynx, chest, and diaphragm, and afferent nerves which accelerate or retard respiration.

If all afferent nerves which reach the centre be cut (except the afferent fibres running in the motor nerves) and the medulla be severed from the higher brain, respiratory movements still occur.

∴ Respiratory centre is automatic.

Automatism often stands in physiology for reflex action, of which the afferent impulses are unknown. In the case of the respiratory centre, afferent impulses doubtless reach the centre along the mixed nerves by

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Marckwald.—"The Movements of Respiration and their Innervation in the Rabbit," &c. Transl. by Thomas Arthur Haig. London, 1888.

which its motor action is exhibited; originate in the cut ends of nerves, and also in the central nervous system itself.

The centre is rhythmic in action.

Pro. If the spinal cord be severed from the medulla, so that chest-respiration is prevented, the nostrils and larynx still contract rhythmically for a time.

It is bilateral.

Pro. Divide the medulla by median section, and then cut one vagus; respiration is rendered slower on the side of the body on which the vagus is cut; inflation of the chest is thus made impossible, and the animal dies.

Its irritability is greatly affected by alterations in the character of the blood by which it is nourished.

Pro. 1. Venosity of the blood causes dyspnœic movement.

2. If the blood of the centre only is venous, dyspnœa results. This can be produced by compressing the carotid arteries = "garotting." If the compression, by a hand grasping the neck from behind, is very sudden, the brain is rendered anæmic for the moment, and the subject of the experiment faints.

3. If the blood going up the carotid arteries is warmed, the activity of the centre is increased.

4. Strychnin increases the excitability of the centre.

The centre is controlled by afferent impulses ascending various nerves, of which the chief are :—

A. The vagus which accelerates.

1. Cut the vagus, and respiration is slowed.

2. Stimulate the cut central end, it is quickened to the normal rhythm, or beyond the normal rhythm. In certain cases it may even be brought to an end owing to tetanus of the diaphragm.

B. The superior laryngeal branch of the vagus (the sensory nerve of the larynx) retards respiration.

1. Cut this nerve; no result.

2. Stimulate its central end, respiration is slowed even to standstill of the diaphragm.

∴ While respiration is habitually advanced by impulses ascending the vagus-trunk, the sensory nerve of the larynx gives warning of sensations (irritant gases, &c.) which call for holding the breath.

C. The glossopharyngeal.

1. Cut; no result.

2. Stimulate central end; respiration is stopped for a time equal to that occupied by the three previous respirations.

∴ This nerve, when its end-twigs in the fauces are stimulated by food or drink, inhibits respiration until the food is swallowed.

Where do the accelerator impulses normally originate, and what produces them?

Does the venosity of the blood in the lungs stimulate the endings of the vagus?

Con. If the chest is distended with nitrogen an expiratory movement is induced although the blood has not been aërated.

Is the stimulus the result of the movement of the chest?

Pro. In artificial respiration the nostrils dilate as the chest is inflated, so long as the vagus is intact; when the vagus is cut, the

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Head.—"Regulation of Respiration," *Jour. of Phys.*, vol. x. pp. 1 and 279.

movements of the nostrils cease to be synchronous with those of the chest.

Is the stimulus to the respiratory centre produced by expansion or by contraction of the chest?

By both.

Expansion or distension causes an expiratory effort, and inhibits inspiration.

Contraction or emptying causes an inspiratory effort, and inhibits expiration.

There are many other proofs of the double nature of the centre.

Although it is much easier to provoke an inspiratory effort than to provoke an expiratory effort, there are circumstances under which a stimulus results in an inspiration with inhibition of expiration, and others which call forth an expiration with inhibition of inspiration.

E.g., 1. A slap to the buttock of a new-born baby is found by the midwife to be a valuable adjuvant to the impulses which induce the first inspiration.

2. Cold water, especially when applied to the back of the head (as in shampooing), causes a long inspiration, with inhibition of expiration.

3. Stimulation of the splanchnic nerves causes an expiratory movement with inhibition of inspiration. A violent blow in the epigastrium produces this effect in a marked degree.

4. By applying electrodes to the medulla oblongata, it is possible to provoke either an inspiratory or an expiratory movement, according to the phase of respiration during which the impulse is applied and the intensity of the stimulus. Inspiratory movements are provoked with a weaker stimulus than is required for expiratory stimulation (*Marckwald*).

Subsidiary centres above the medulla.

1. Stimulation of the optic nerve by bright light provokes very many people to sneeze.

2. Stimulation of the fifth nerve in the nostril causes sneezing.

3. Monotonous stimulation of the auditory nerve induces many persons to yawn.

Sneezing and yawning are modified respiratory movements; the reflex centres by which they are carried out probably lie near the nuclei for the IInd, Vth, and VIIIth nerves respectively.

4. Direct stimulation of a certain spot in the wall of the third ventricle deepens respiration (*Christiani*); stimulation near the upper part of the pons provokes inspiration (*Martin* and *Booker*). The stimulus in these cases is applied in the course of the reflex arcs for sneezing and yawning respectively.

Subsidiary centres below the medulla.

The movements made by a young animal when its skin is pinched, after division of the lower part of its medulla, were supposed to depend upon respiratory centres in the spinal cord. *Marckwald* has shown that they are not respiratory, but merely irregular spasms.

Apnœa.—When respiration has been abnormally active for a time (a number of

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Martin and Booker.—"Effect of Stimulation of the Mid-brain upon the Respiratory Rhythm," *Jour. of Phys.*, vol. i. p. 370.

Spencer.—"On the Changes evoked in the Circulation and Respiration by Electrical Excitation of the Floor of the Fourth Ventricle," *Proc. Roy. Soc.*, vol. l. p. 142.

deep breaths are taken before diving), there follows a period of quiescence, generally regarded as due to saturation of the blood with oxygen.

Con. 1. Forcible repeated inflation of the lungs by hydrogen induces apnœa.

2. Division of the vagus renders it almost impossible to produce apnœa by artificial respiration.

Excessive vagus-stimulation causes apnœa, no matter what may be the condition of the blood.

Stimulation of the vagus in a chloralised animal usually produces inhibition of respiration.

Dyspnœa is the forcible respiration which results from inadequate aëration of the blood. Additional muscles are used to aid the respiratory act, particularly the scaleni, serrati postici, and sterno-mastoidei. Its phenomena can be accounted for by the increased irritability of the respiratory centre.

Asphyxia.—If the trachea is occluded, death results in Man in about 7 minutes, or in 4 minutes if the lungs are full of water. The disturbance to the system may be divided into three stages :—

1st minute: dyspnœa, spasms spreading from the muscles of forced respiration, particularly those of inspiration, to all the flexor muscles of the body.

2nd minute: convulsions cease, expiratory efforts alone are made.

3rd and 4th minutes : consciousness is abolished, expiratory efforts cease, and convulsive inspirations, often spreading into spasms of all the extensor muscles, alone are visible. These "stretching convulsions" become less and less frequent, and cease in about 5 minutes ; but the heart may beat (making recovery possible) for about two minutes more.

After death, the venous system and right side of the heart are gorged with dark blood, while the arterial system is almost empty, owing to the resistance which is opposed to the passage of venous blood through the capillaries of the lungs.

Summary of the nervous mechanism of respiration.

The respiratory centre on each side of the medulla is double, consisting of an inspiratory and an expiratory portion. It has acquired a rhythmic automatism, which carries it on in the absence of any (known) afferent impulses. Its activity is exceedingly dependent upon nutrition. The centre is controlled by impulses which descend from above, as well as by impulses which ascend from below. The varying effects of these impulses depend upon the fact that they may either (*a*) increase or decrease the activity of the double centre, or (*b*) increase the activity of its inspiratory half with inhibition of expiration, or (*c*) increase the activity of its expiratory portion with inhibition of inspiration.

Cheyne-Stokes' respiration; a pathological condition in which breathing is periodic, a pause of $\frac{1}{2}$ to $\frac{3}{4}$ of a minute being followed by an ascending and descending "staircase" of respirations.

A somewhat similar form of respiration can be produced in animals by dividing the medulla transversely. Division of the vagi removes the periodicity, irregular spasms taking its place. Hibernating animals take a deep breath, followed by shallow breaths and then a pause. It appears likely, therefore, that *Cheyne-Stokes'* respiration depends upon the absence of controlling impulses which normally descend from above. The experiments upon animals throw no light upon the ascending staircase.

Sherrington.—"Note on Cheyne-Stokes' Breathing in the Frog," *Jour. of Phys.*, vol. xii. p. 278.

Mann.—"A Contribution to the Study of Cheyne-Stokes' Breathing," *Brain*, vol. xiii. p. 178, 1890.

Problems in respiration can be solved if three things are borne in mind :—

1. Fresh air contains 21 °/ₒ of O_2, although about 6 or 7 °/ₒ is sufficient to allow of respiration. On the other hand, if CO_2 accumulates in alveolar air to the amount of about 8 °/ₒ, its further exit from the blood becomes impossible. In a confined space, therefore, even though it contain nothing but oxygen to start with, death occurs from accumulation of CO_2.

2. Carbonic acid is a narcotic poison. Hence the violent convulsions produced by deficiency of oxygen are not seen when the blood is saturated with carbonic acid. This is the condition in fatal pulmonary disease.

A. In a small space an animal dies in convulsions because all the oxygen in its blood is used up.

B. In a large space full of air it suffers narcosis.

C. In a chamber full of nitrogen it dies in convulsions.

D. In a chamber full of oxygen it dies in narcosis.

E. Under diminished pressure, although the circulation is affected, respiratory interchange of gases occurs with the usual facility until the tension of oxygen is less than half the normal. Eventually the animal dies in convulsions.

F. Increased pressure up to 15 atmospheres produces sleepiness, above this pressure the animal dies in convulsions owing to cessation of its tissue-oxidation.

3. Although the above are the effects of disturbance of oxygen and carbonic acid pressures, it must be remembered that the noxiousness of impure air depends not upon the respective amounts of these gases which it contains, but upon the presence of organic impurities, of which certain volatile bodies (of amide nature) cause headache, drowsiness, &c., while disease-germs escape oxidation in a foul moist atmosphere. Insufficient ventilation, therefore, favours the spread of consumption and other diseases.

Influence of Respiration upon the Circulation.

Facts.—A blood-pressure tracing shows variations in pressure equal in number to, although not synchronous with, the respiratory movements.

The "respiratory" undulations of the B.P. tracing are later than the respirations themselves (see fig. 46). Allowing for this difference in time,—

During Inspiration :
- The blood-pressure rises.
- The heart beats faster ; each beat is shallower.

During Expiration :
- The blood-pressure falls.
- The heart's beats are slower, deeper, more dicrotic.

Explanations.—Probably no single or simple explanation can be found ; many conditions, mechanical and physiological, work together.

A. Are the undulations due to sympathetic activity of the vaso-motor centre ?

Con. (1) Cardiac inhibition is most active when the B.P. is falling. Some cause therefore (perhaps the increasing venosity of the blood towards the end of expiration) stimulates the cardio-inhibitory centre during the phase when the vaso-constrictor mechanism is least active.

(2) Section of the vagi equalises the beats on the two sides of the respiratory curves, but does not affect the rhythmic alterations in B.P.

B. Or are the undulations due to mechanical causes ?

a. To alterations in pressure on the heart and great vessels? These must be very complicated in their effect:—

(*α*) On the intrathoracic vessels and the cavities of the heart.

Inspiration, lowering of pressure (to, from -2 mm. to -30 mm. Hg. according to its force) enlarges the great veins and sucks blood into the heart, causing stronger beat, greater output, and eventually a rise in arterial pressure, but not until the blood has traversed the lungs,—*say* 15 seconds after inspiration.

Inspiration also distends the aorta (to a very small extent owing to the thickness of its wall), and so lowers B.P.

(*β*) On the abdominal vessels the pressure caused by descent of the diaphragm is the reverse in many respects of the pressure on the intrathoracic vessels. The effect of the pressure on the abdominal vessels would be to head-up the blood in the aorta, raising B.P. immediately, and also to drive venous blood into the right heart, and consequently to raise the arterial pressure after an interval of, *say*, 15 seconds.

Pro. (1) Pressing on the abdomen raises B.P.

(2) Section of phrenic nerves and opening abdomen abolishes respiratory curves (*Stirling*).

Con. It has not been shown that the undulations in the femoral artery reverse those in the carotid.

b. To alterations in the pressure on the pulmonary vessels.

The capillaries of the lung must be distended during inspiration. Hence they, first, hold more blood and lower B.P., and, afterwards, transmit more blood and raise B.P.

Pro. The variations in time of occurrence and depth of the undulations, with more rapid and deeper inspirations, favour this explanation.

Con. In artificial respiration the pressures are exactly reversed, but it has not been shown that the curves are reversed.

C. Are the undulations due to the stretching and consequent narrowing of the pulmonary capillaries which occurs when the alveoli are dilated either by negative or positive pressure?

Such an explanation would do away with the difficulty in explaining the similarity of the curves in natural and in artificial respiration. It would not, without many qualifications, explain the different forms of tracing obtained in more and less forcible distension of the chest.

Valsalva's experiment (1740).

Take a deep breath, close the glottis, and make the greatest expiratory effort possible; the circulation is arrested, for reasons easily deduced from the foregoing discussion.

J. Müller's experiment (1838).

Empty the chest of air, close the glottis, and make the most forcible inspiratory effort possible; the pulse ceases, owing to the engorgement of the pulmonary vessels and the consequent emptiness of the left ventricle.

With regard to the cause of the respiratory undulations, note that this is at present an academic question, since none of the explanations advanced can be considered as final. If it could be shown that the curves are reversed by substituting artificial for natural respiration, it would be proved that the cause is purely

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Bowditch and Garland.—"Effect of the Respiratory Movements on the Pulmonary Circulation," *Jour. of Phys.*, vol. ii. p. 91.

mechanical; if it could be further shown that the curve obtained during artificial respiration is not affected by opening the thorax, it would be clear that the variations in arterial pressure are produced by the dilation and diminution of the small pulmonary vessels.

In Asphyxia.

Blood-pressure rises (fig. 48).

Heart's beats are slower and deeper (even when the vagi are cut and the animal is under curare). These changes continue to become more pronounced as long as efforts to respire are made by the animal.

If the animal is curarised and artificial respiration stopped, long curves due to the rhythmic action of the vaso-constrictor mechanism appear (Traube-Hering curves fig. 5).

In the third stage of asphyxia B.P. falls, Traube-Hering curves disappear, the heart's beats become shallow and irregular.

Owing to the great resistance to the passage of blood through the lungs, the right side of the heart is gorged with blood, the left side almost empty. Hence the pulse is lost at the wrist long before the heart ceases to beat, and therefore long before recovery has ceased to be possible, if the chest be inflated with air, and the block in the pulmonary capillaries thereby removed.

Effect upon circulation of cessation of respiration.

During first and second stages of asphyxia the blood-pressure rises rapidly, owing to a general stimulation (by the venous blood) of the vaso-constrictor mechanism. Pressure rises when the spinal cord is separated from the oblongata, but in less degree than when the oblongata is in connection; ∴ the latter is the chief agent. It occurs when the vagi are divided; ∴ it is the venous blood which stimulates the "centre" in the medulla oblongata. When the pressure is near its maximum the overstimulated centre takes on a rhythmic action.

> The rhythmic rise and fall may be a return to the rhythmic action (Traube-Hering curves) of the vaso-motor mechanism, sometimes seen under perfectly normal conditions in B.P. tracings, obtained with the kymograph, but better seen in plethysmographic tracings, *e.g.*, of the kidney or a limb ; or they may be illustrations of the almost universal rule that an over-stimulated nervous mechanism takes on rhythmic activity; *e.g.*, a brick can be held in the hand steadily for a time, but as the arm tires it begins to sway up and down. If the latter view is adopted, they should not be called *Traube-Hering* curves.

Relation of muscular work to respiration and circulation.—The only great fluctuations in consumption of oxygen and production of carbonic acid depend upon the muscles. Increased activity renders the blood rapidly venous. Venous blood, however produced, increases the excitability of the respiratory mechanism. It is generally thought, however, that the alteration in venosity of the blood is insufficient to account for the increased respiration, *e.g.*, the panting produced by running, unless some special product of muscular metabolism (presumably sarco-lactic acid) is the immediate stimulant to the medulla oblongata.

Muscular activity is accompanied by dilation of the vessels by which the muscle is nourished (again sarco-lactic acid is perhaps the agent which acts upon the wall of the vessels); this tends to lower B.P., the heart in consequence beats more quickly and forcibly. The rapid action of the heart is attributed to the removal of the inhibitory influence of the vagus.

> *Marey's* law that, "the rate of the beat is in inverse ratio to the arterial pressure," only holds good when the vagi are intact.

SECTION IX.

THE SENSES.

VISION.

The eye resembles a photographic camera filled with water. It is bounded in front by the convex cornea. The iris is the diaphragm by means of which the quantity of light entering the eye is regulated. It contains a biconvex lens, the focal length of which can be altered to suit the distance of the objects looked at. The retina is the sensitive plate which receives the image.

If it were a "simple collecting system," presenting but one spherical surface, bounding a medium of uniform refractive index, the course within it of a pencil of rays could easily be determined as follows :—

Given the radius of curvature of the anterior surface S, and the distance behind the anterior surface at which rays parallel with one of its radii are brought to a focus, F, the principal focus :—

(It is convenient to determine the position of this focus with regard to a line which coincides in part of its course with one of the radii. In the case of a simple collecting system limited by a spherical surface, this line is of course chosen arbitrarily, but the principal focus is marked on this line which is called the optic axis OCF.)

Draw a ray ACA_1 which passes through the centre of curvature, and therefore falls upon the bounding surface in a radial direction ; it will not be bent out of its course by refraction.

Any ray parallel with OCF will be so bent as to pass in the denser medium through F. Prolong it until it cuts the unrefracted ray. The point at which it cuts it, is the point at which all rays from A are brought to a focus.

In the same manner, the position at which all rays from B, or from any point intermediate between A and B, is brought to a focus, may be determined, and in this way the image B_1 A_1 of AB is constructed.

Two data only need therefore be borne in mind, (1) that all rays parallel with the optic axis pass through the principal focus ; (2) that rays which coincide with a radius of curvature (*i.e.*, fall upon the surface vertically) are not refracted.

The eye is not, however, a simple collecting system with one surface and one refracting medium, but a centred system of media of different refractive indices; of the several media, cornea and aqueous and vitreous humours have almost identical refractive indices (=to that of water), while the lens has a higher index ; nevertheless, for purposes of calculation, the mean curvature and mean refractive index have been calculated, and a diagram (*Listing's* reduced eye fig. 50) constructed upon these two means.

Bernstein.—"The Five Senses of Man," *Intern. Science Series.*

Le Conte.—"Sight : an Exposition of the Principles of Monocular and Binocular Vision," 2nd ed., *Intern. Science Series.*

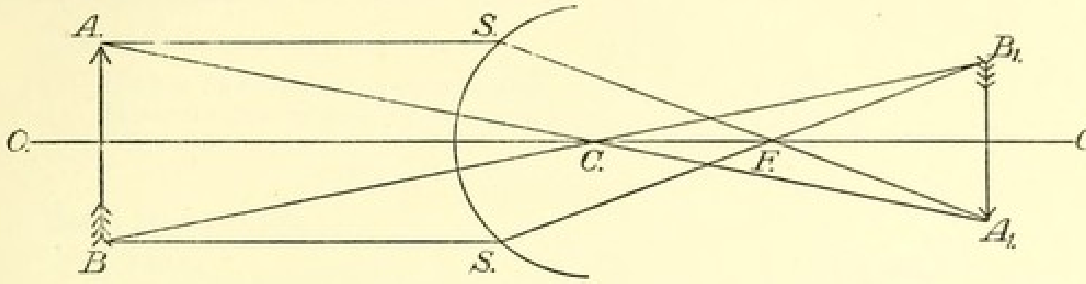

FIG. 49.—The formation of an image by a simple collecting system. *For explanation see the opposite page.*

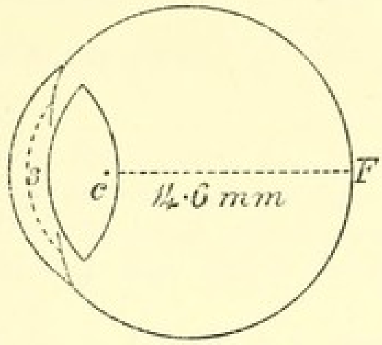

FIG. 50.—Listing's reduced eye. *s*, The single (ideal) anterior surface (2·3448 *mm.* behind the anterior surface of the cornea, with radius of curvature of 5·1248 *mm.*) ; *c*, the common centre (nodal point) ; F the principal focus.

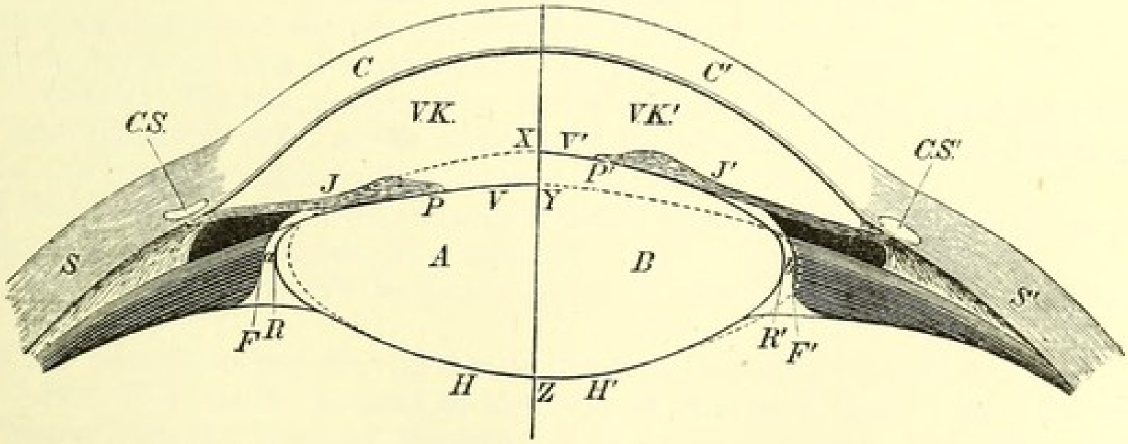

FIG. 51.—A section through the cornea, lens and ciliary region of the eye, showing the changes which take place in the lens during accommodation for distance. V′P′, the anterior surface of the lens when accommodated for the near point ; VP, the anterior surface of the lens when accommodated for parallel rays ; C, cornea ; CS, canal of Schlemm ; S, sclerotic ; VK, anterior chamber ; J, iris ; R, margin of lens ; F, margin of ciliary processes ; *a*, canal of Petit ; H, posterior surface of lens (on to which is continued the membrana hyaloidea) ; YZ, optic axis.

To face p. 114.]

The combined nodal point or common centre of curvature is just in front of the posterior surface of the lens. The common principal focus is 14·6 mm. behind the back of the lens. This is the position of the fovea centralis in distant vision.

Optical measurements for the human eye.

Refractive indices; air = 1.

Cornea and aqueous humour, each	1·337
Mean for the several layers of the lens	1·454
Vitreous humour	1·336

Water = 1·336.

Radii of curvatures.

Cornea	7·7 mm.
Lens anterior surface when focussed for ∞	10·3 ,,
,, ,, when focussed for the near point	6·0 ,,
,, posterior surface	6·1 ,,

Distances.

Front of cornea to front of lens	3·4 mm.
Thickness of lens	4·0 ,,
,, vitreous humour	14·6 ,,
Total length of axis	22·0

Accommodation for distance.

The eye when at rest is focussed for infinity, *i.e.*, for parallel rays.

When attention is directed to objects near at hand, the focus of the eye is altered by a muscular effort. That the focus is thus accommodated to the distance of the object from the eye is shown very clearly by an experiment designed by *Scheiner* in 1619.

Two pin-holes are made in a card at a distance apart less than the diameter of the pupil. With one eye shut the pin is viewed by the other eye through the two holes at once. If the eye is accommodated for the pin a single image is seen, if the image is focussed in front of or behind the retina two blurred images are formed on the retina. It is impossible for a person with a normal eye to focus the pin at a less distance than 5 inches (the normal "near point") A myopic person can focus it when nearer than this, but cannot focus it if it be held beyond his "far point."

By what mechanism is the eye adjusted for distance?

A. It was supposed that the curvature of the cornea is altered.

Con. (1) We can accommodate under water. Water has practically the same refractive index as the cornea, and therefore a change in the curvature of the latter would not affect accommodation.

B. Is the position of the retina changed, as the sensitive plate is racked nearer to or farther away from the lens in a camera?

Con. This could only be accomplished by altering the shape of the globe of the eye.

C. It has been definitely proved that the lens undergoes a change in shape.

Pro. If a candle is held to the side of the head three images are reflected from the front of the eye. 1 is erect and clear. 2 larger, erect, slightly less distinct. 3 small, inverted, indistinct. 1 is reflected from the front of the cornea, 2 from the front of the lens, 3 from the back of the lens.

Landolt.—"The Refraction and Accommodation of the Eye and their Anomalies," Trans. by C. M. Culver, Edinburgh, 1886.

Barrett.—"Velocity of Accommodation," *Jour. of Phys.*, vol. vi. p. 46.

As the eye is directed from a distant to a near object, 2 grows smaller, until it is about the same size or even smaller than 1 : ∴ the anterior surface of the lens becomes more convex. Its radius of curvature for distant vision is 10 *mm.*; for near vision, 6 *mm.* When focussed for distance it diminishes the size of the reflected image less than does the more convex cornea; when focussed for the nearest point it diminishes it slightly more than does the cornea.

By what mechanism is accommodation for distance effected?

Accommodation for near objects is accompanied by a sense of effort. It occurs less quickly than the return to distant vision. It is accomplished by the ciliary muscle.

The ciliary muscle consists of two parts:—1. the radiating fibres are attached to the outer coat of the eye at the junction of the cornea and the sclerotic, from which line they spread out into the ciliary processes, and farther back into the choroid—the tensor choroideæ, or Brücke's muscle. 2. A bundle of circular fibres on the inner side of the radiating fibres; this is the compressor lentis, or Müller's muscle.

The lens is composed of epithelial fibres, which, starting from a triradiate attachment in front, hoop round to a triradiate attachment at the back; each fibre is bent like a piece of a carriage-spring. When the eye is at rest (*i.e.*, accommodated for infinity), the lens is pressed against a transparent membrane (the suspensory ligament of the lens), with which its capsule has fused. In this position this ligament is more nearly flat (its radius of curvature is increased to 10 *mm.*) than it is when the eye is accommodated for a near object (when its radius of curvature is 6 *mm.*); the change in its shape is effected by the contraction of the ciliary muscle, the compressor lentis diminishing the size of the ring to which its margin is attached, while the tensor choroideæ increases the pressure in the posterior chamber of the eye, and so helps to make the lens bulge forward. Even without such pressure the elasticity of the lens causes it to assume a more spherical form, as is seen when it is removed from the eye.

Inefficient accommodation.

In old people the lens loses its elasticity; they cannot, therefore, accommodate for a near object without the aid of convex glasses = presbyopia.

In many persons the eyeball is either too long or too short, and therefore, although the mechanism of accommodation is normal, persons with the former defect can see objects very near to them (their near point is less than 5 inches), but cannot see distant objects, *i.e.*, they are short-sighted or myopic; persons with the eyeball too short cannot see objects near at hand, but their eyes when at rest are accommodated for converging rays = hypermetropia.

These two defects can be compensated for by spectacles. If a person is myopic, the reason for which he wears spectacles is that his far point (the greatest distance at which he can see distinctly) may be moved from x inches to infinity. Suppose that in a given case tne far point is 12 inches, it is as if the patient had in his eye an unnecessary biconvex lens of 12-inch focus, which brings the eye when at rest into focus for an object 12 inches distant, when it should be focussed for parallel rays If, therefore,

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Donders.—"Anomalies of Accommodation and Refraction of the Eye," Trans. by Moore, London, 1864. (*New Syd. Soc.*)

Longmore.—*The Optical Manual, or Handbook of Instructions for dealing with Optical Defects*, London, 1885.

he wear a pair of spectacles with *concave* glasses and focal length of 12 inches, his defect is corrected.

In England lenses are numbered according to their focal length in inches. The lens required in the case just quoted is therefore "concave 12," or simply "$\frac{1}{12}$."

It is becoming common to use Donders' "standard dioptric," or lens of one metre focal length, as the unit; $+x$ means, therefore, a lens of x dioptrics, or x times as strong as the standard. Thus $+ 4{\cdot}0$ means a convex lens of $\frac{1}{4}$ metre focal length; $- 4{\cdot}0$ a concave lens of $\frac{1}{4}$ metre focal length. It is in this form that the order is usually sent to the optician.

It happens that the refractive index of glass (of the kind most used) is 1·5, and therefore if the lens is *bi*concave or *bi*convex its focal length is the same as its radius of curvature, so that in the case just quoted the radius of curvature must be 12 inches.

The proper (convex) lenses for hypermetropic eyes can only be determined by trial. The end to be accomplished is the same, *viz.*, to bring objects on the horizon into distinct view when the eye is perfectly at rest.

In all cases it is taken for granted that the accommodating mechanism is normal; the defect lies in the length of the axis of the eyeball.

Nervous mechanism of accommodation for distance.

Centre; extreme anterior part of the floor of the aqueduct of Sylvius.

Efferent nerves; anterior roots of III, radix brevis of ciliary ganglion, short ciliary nerves to ciliary muscle.

The act is voluntary, although the effort is not as a rule consciously an effort to accommodate the eye, but the attempt to make out the details of a near object.

Relaxation (accommodation for infinity) is much quicker than contraction (accommodation for a near object), owing to the elastic rebound of the compressed lens; it is not accompanied with the sense of effort which marks contraction of the ciliary muscle.

Accommodation for amount of light is effected by the movements of the iris. The black pigment (uvea) on the back of the iris cuts off all rays which do not pass through the pupil. Diminution of the pupil is due to contraction of the circular fibres, enlargement to the elastic rebound which occurs when the circular fibres relax, aided by contraction of the radiating fibres of the iris.

The pupil is contracted :—

1. For strong light.
2. When near objects are viewed (second function of the iris). Reason: to cut off divergent rays which would not be focussed; although less light is reflected from near objects than for those which are far away.
3. When the eyes are turned inwards; since this position is associated with near vision.
4. In the early stages of chloroform-poisoning (after a stage of excitement, accompanied by dilation), and when the eye is acted upon by morphia, nicotin, or physostigmin.

The pupil dilates when 1, 2, or 3 are reversed, and

4. Under the influence of atropin and allied drugs. In the last stage of chloroform-poisoning (an evidence that the administration of chloroform has been pushed too far).

Langley and Anderson.—"On the Mechanism of the Movements of the Iris," *Jour. of Phys.*, vol. xiii., No. 6, p. 554, 1892.

5. In dyspnœa.
6. When a sensory nerve is strongly stimulated.

Is diminution of the pupil entirely muscular, or partly also the result of turgescence of the vessels of the iris?

The action of vascular repletion and depletion is shown by the oscillations of the iris, synchronous with the beat of the heart, which are seen in cases of aortic regurgitation. This is a secondary cause in accommodation for amount of light, however, since the iris works with a bloodless eye.

Nervous mechanism of the iris (fig. 52).

A. 1. Cut II or III; no effect upon the size of the pupil, but either section prevents it from reacting to light.

2. Stimulate II centrally or III peripherally, and the pupil contracts.

∴ The iris is governed by a reflex mechanism which causes it to contract.

Route taken by constrictor impulses: afferent, the optic nerve (II), efferent, the anterior rootlets of the third nerve (III)—radix brevis of the ciliary ganglion—short ciliary nerves.

Centre; the floor of the aqueduct of Sylvius, beneath the anterior corpora quadrigemina.

The exact manner in which the two limbs of the reflex arc are united within the brain is not quite clear. Within the brain the optic nerve has a double distribution—(*a*) its connection with the optic thalamus and the back of cerebrum, which provides for vision; and (*b*) its connection with the mid-brain, in which all the reflexes by which the eye is brought into position and adjusted take place. In Man and other animals with stereoscopic vision a large proportion of the optic fibres do not decussate in the optic chiasm, and it appears that the afferent fibres for contraction of the pupil are amongst these, since median section of the mid-brain does not abolish the reflex. Nor do the fibres go directly to the lateral geniculate and anterior quadrigeminal bodies, since removal of these structures does not interfere with the reflex. Physiologists look, therefore, for a communication between the optic *nerve* and the nucleus of the third nerve on the same side, by fibres which do not pass along the whole length of the optic *tract;* such a route might be found amongst the many groups of fibres which have been described,[1] but the difficulty is by no means cleared up, since the pupillary reflex is equally well developed in the frog and other animals in which all the fibres of one optic nerve go into the opposite optic tract.

That the mechanisms of the two sides are associated can be shown by making a pin-hole in a card, and looking through it at a bright surface, *e.g.*, the globe of a lamp, while the other eye is alternately opened and closed. Every time that light is admitted into the unprotected eye the disc of light seen through the pin-hole contracts; when the unprotected eye is closed the disc enlarges.

B. (1) Cut the sympathetic nerve in the neck.

The pupil contracts.

(2) Stimulate its peripheral end (*i.e.*, towards the head).

The pupil dilates.

∴ The iris is governed by a tonic dilator mechanism.

(3) This dilator action can be augmented reflexly by fear, &c.

Centre for dilation of the pupil: in the floor of the aqueduct of *Sylvius*, to the outer side of the constrictor centre. *Route taken by dilator impulse:* down the crura cerebri, medulla oblongata, and spinal cord to the level of the 2nd cervical nerve, the ramus communicans to the ganglion stellatum, up the sympathetic in

[1] Obersteiner and Hill.—"Central Nervous Organ," p. 279 *et seq.*, particularly p. 283.

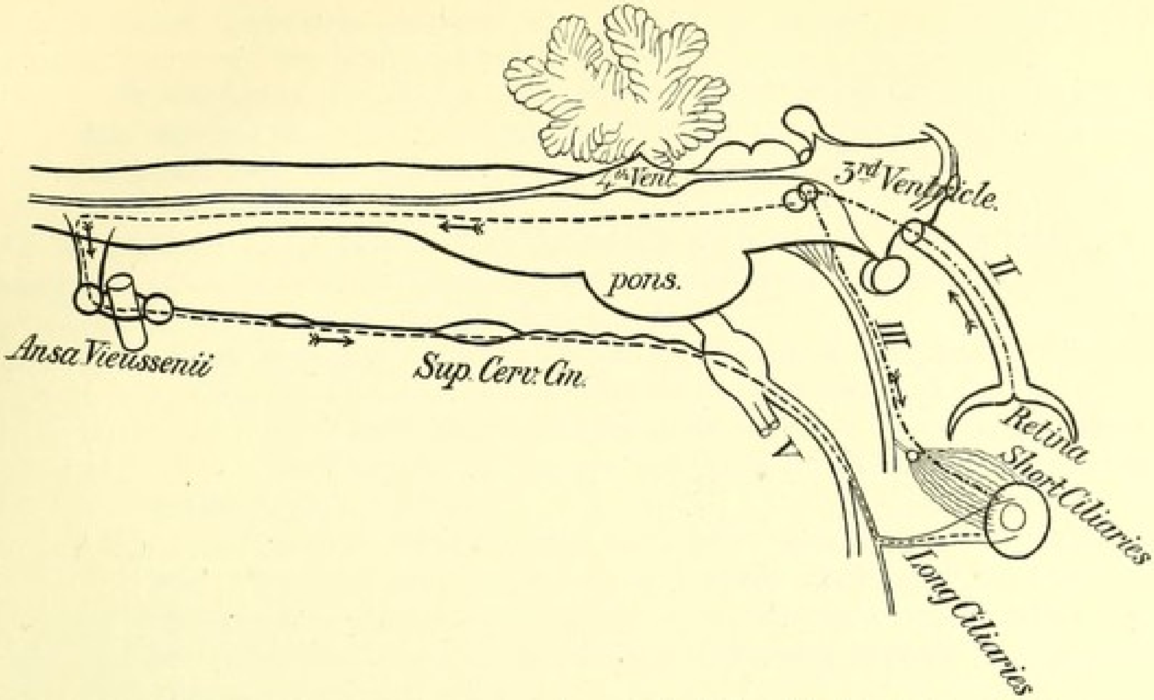

FIG. 52.—Diagram showing the connection of the iris with the brain. Reflex arc for constriction of the pupil, - · - · - · - · - · - ; path of tonic dilator impulses, - - - - - - - - - - - - - -.

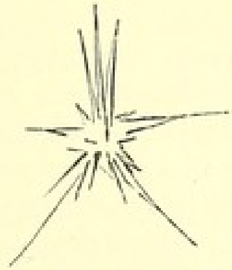

FIG. 53.—The appearance presented by a star when seen with the right eye. A distant point of light always appears as a stellar figure, owing to the irregular astigmatism produced by the puckering of the lens when compressed by the suspensory ligament. The shape of the star depends upon the arrangement of the fibres of the lens. With the eyelids partly closed a different kind of irregular astigmatism is produced by the waves in the lachrymal secretion.

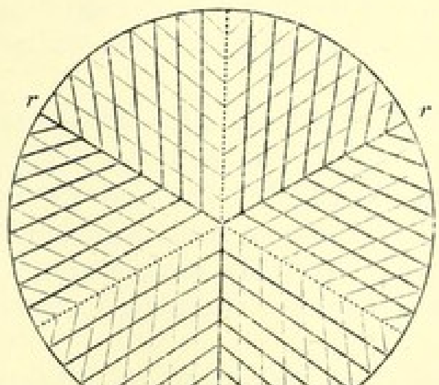

FIG. 54.—Diagram illustrating the arrangement of the fibres of the crystalline lens about three axes, *r*, on the anterior surface diverging at an angle of 120°, and three axes (dotted lines) on the posterior surface bisecting these angles.

To face p. 118.]

the neck to the Gasserian ganglion of V, along its ophthalmic division, through the nasal nerve and the long ciliaries to the iris.

It was found by *Budge* that irritation of the spinal cord between the 6th cervical and 3rd dorsal nerves causes the pupil to dilate; hence he imagined that this region contains a centre for dilation of the pupil, the centrum cilio-spinale inferius.

C. When B or A are respectively producing their utmost results, atropin (belladonna) still causes dilation; physostigmin (Calabar bean) contraction.

∴ There must be a local mechanism or centre.

Is the ciliary ganglion a centre for movement of the pupil?

Con. 1. The dilator impulses do not pass through it.

2. These drugs produce their effect on an excised eyeball.

3. The iris of the eye (of the eel) floated out in salt solution reacts to light (*Arnold*).

∴ The iris reacts directly with great sensitiveness to certain drugs and other stimuli; its action is further controlled by two nervous mechanisms, the one causing it to contract in a purely reflex manner, the other exerting a tonic dilating influence, capable of augmentation through its reflex centre.

During sleep the pupil is contracted.

At death the pupil dilates, but retains its power of contracting in response to light for several hours; especially in the cat.

Is dilation of the pupil due to the contraction of radiating muscle-fibre?

Con. (1) Although in the bird, the otter, and some other animals, radiating fibres are found in abundance on the deeper layers of the iris, their presence is very doubtful in other animals, including Man.

(2) In its extreme susceptibility to drugs the iris resembles the heart, in which a greater and less tendency to contract are induced by the action of antagonistic nerves, the vagus (inhibitory) and the sympathetic (accelerator) respectively. *Gaskell* suggests that the circular iris fibres are under the influence of similar antagonistic nerves, the short and long ciliaries respectively.

(3) A strip of the iris, when stimulated by the interrupted current, elongates instead of contracting.

(4) Warmth dilates, cold contracts the pupil of the extirpated eye.

∴ It is possible that both sets of ciliary nerves act upon the same muscle. This suggests a search for relaxor, inhibitory, or anabolic nerve-fibres, in addition to the motor or katabolic fibres, in the case of all muscles.

The field of vision is the section of the outer world which can be seen at any time without movement of the eye or eyes.

For each eye it subtends an angle of 145° in the horizontal plane.

For the two eyes together it subtends an angle of 180°; in this case, however, all objects in the field of vision are not seen by both eyes; only the central part of the field (subtending an angle of about 90°) is the field of binocular or stereoscopic vision.

This is easily proved by gazing at an object with both eyes, and then shutting first one eye and then the other; the amount of the field which

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Neilson.—"The Observation of the Pupil as a Guide in the Administration of Chloroform," *Jour. of Anat. and Phys.*, vol. xxii. p. 154, 1888.

disappears on either side depends upon the extent to which the bridge of the nose projects.

In monkeys alone is stereoscopic vision so complete as in Man. In other animals the fields of the two eyes overlap but little or not at all.

In binocular vision, all the objects in the field of vision the images of which upon the retinæ are to be felt at any given moment by the brain—to give rise to a sensation, that is to say—must be focussed upon "identical" or "corresponding points" on the two retinæ.

Only those images which are formed within the fovea centralis are clearly perceived. Those formed on the peripheral portions of the retina are seen indistinctly. Vision with the fovea centralis is termed "direct" vision; with the rest of the retina "indirect" vision. The brain neglects imperfectly focussed images and images which do not fall upon corresponding points, and pays attention only to those rays which are clearly focussed upon corresponding points.

The plane in the outer world upon which lie all objects, which we can see with both eyes at once, is termed the "horopter."

The form of the horopter may be very simple; in the "primary position," *i.e.*, with the head erect and vertical, and both eyes directed to a point at a great distance, *e.g.*, a ship upon the horizon, lying in the extension of the median vertical plane of the head, it is a plane extending from the feet of the observer to the distant point at which he looks; in the "secondary position," with the visual axes converging, the horopter for objects which lie in the plane of the visual axes is a circle of which the line joining the nodal points of the two eyes is a chord; or the form of the horopter may be very complex.[1]

Movements of the eyeballs may be classified in two groups.

A. Movements executed voluntarily for the purpose of directing vision to a particular object. The eyeball in all voluntary movements rotates about an axis which passes through its centre of rotation, *i.e.*, a spot on the visual axis,[2] a very little behind the geometric centre of the eyeball. Further, all axes of rotation lie in one and the same (frontal) plane, which cuts the visual axis at right angles.

Thus we can at Will direct the eyes up and down, from side to side, or obliquely, but we cannot by an effort of Will combine the movement with rotation of the eyeball about its longitudinal axis—"swivel-movements," because, if we could do this, we should bring the images of the object we are trying to see on to non-corresponding points on the two retinæ, and see it double. For this reason we cannot, by an effort of Will, make the eyes diverge, or make the visual axis of one eye slope above or below the visual axis of the other; and yet if, owing to a prism being placed in front of one eye, it is impossible for objects to be focussed upon corresponding points

[1] The optics of binocular vision is provided with a distinct terminology. For fuller information upon this and other points in the physiology of the eye, see *Landois and Stirling's Physiology*; *Hermann's Physiology*, translated by Gamgee; the article "Stereoscope," by M'Kendrick, in *Encyclopædia Britannica*, 9th ed.; *Bowman's Collected Papers*, Lond., 1892.

[2] "Optic axis" is the line upon which the several refractive media are centred; "visual axis," the line connecting the centre of rotation of the eyeball with the point of regard, or, which comes to the same thing, the fovea centralis with the point in the visual field which is at any moment most clearly seen. There is some doubt as to whether the optic axis of the eyeball coincides exactly with the visual axis, but practically the two expressions are identical with one another and with "longitudinal axis."

Stuart.—"New Mode of Demonstrating the Relation of the Two Sides of the Retina to the Outer World," *Jour. of Anat. and Phys.*, vol. xxv. p. 298, 1891.

Hickson.—"The Eye and Optic Tract of Insects," *Quart. Jour. Micr. Sci.*, vol. xxv. p. 215, 1885.

without such an irregular position of the eyeballs, they assume such positions without our being conscious of its unusual nature. When, in the absence of a prism, one eyeball is pushed out of position by the finger, or when the associating mechanism is paralysed by alcohol, double vision results.

B. "Circular" rotation (swivel-movement) of the eyeballs—which cannot be executed voluntarily—comes into play in binocular vision to keep on corresponding points, when the head is rotated, the images formed on the two retinæ of the object at which we are looking.

As the head is depressed toward the shoulder each eye swings like a compass supported within gimbals. A certain amount of circular rotation is necessary in many movements of the eyes, even though the head remains stationary, as for instance when the eyes are directed from a distant to a near object.

MUSCLES OF THE EYEBALL.

Movements of class A and the muscles by which they are carried out.

Direction.	*Position of axis of rotation.*	*Muscle.*
To nasal side.	Vertical.	Internal rectus.
To temporal side.	,,	External rectus.
Upwards.	Horizontal.	Superior rectus and inferior oblique.
Downwards.	,,	Inferior rectus, corrected by superior oblique.

The tendon of Zinn, from which the recti muscles take origin, is attached around the optic foramen on the inner side of the visual axis. The line of muscular action is inclined to the visual axis at an angle of 20°. Acting alone, therefore, the superior rectus pulls the eyeball over and inwards at the same time that it elevates it, and in the movement vertically upwards this circular rotation needs to be corrected by the inferior oblique.

Movements of class B; in certain cases, as already stated, by the superior and inferior recti, but more particularly by the oblique muscles.

The two oblique muscles together almost form a girdle for the eyeball, being attached near one another on the temporal side of its posterior hemisphere. Their line of action does not, however, cross the visual axis at right angles, but cuts it at an angle of 60°. When they act by themselves, therefore, they do not merely produce circular rotation, but circular rotation combined with outward movement.

Nervous mechanism for movements of the eyeball.

The superior oblique muscle supplied by IV (N. trochlearis).
The external rectus muscle ,, VI (N. abducens).
The rest of the muscles ,, III (N. oculomotorius).
The connections of these three nerves with the brain are dissimilar.

III has two distinct groups of cells of origin in the tegmental region of the mid-brain.

(*a*) A well-defined cylindrical nucleus consisting of very large cells. This nucleus lies near the median plane of the mid-brain.

(*b*) Several ill-defined groups of smaller cells which lie laterally and ventrally to the chief nucleus.

The nerve-fibres mainly issue on the same side as the nucleus. The most anterior fibres are smaller than those of the posterior roots. They come apparently from the smaller cells, and are destined for the muscle fibres of the iris and the ciliary muscle.

Fibres (of the VIIth nerve) which supply the orbicularis palpebrarum take origin in the back of the oculo-motor nucleus.

IV originates from a nucleus which lies beneath the front of the posterior tubercle of the corpora quadrigemina, and is not clearly separated from the oculo-motor nucleus. The nerve-fibres which arise in these (large) cells differ from all other cranial nerve-roots, in taking exit on the dorsal side of the brain, after an almost, if not quite, complete decussation.

VI. The nucleus of this nerve lies some way farther back than the other eye-muscle nuclei. Its fibres take exit from the side of the brain on which the nucleus lies.

The several nuclei of the mid- and hind-brain, including the nuclei of III, IV, and VI, are connected together by a longitudinal commissure (the posterior longitudinal bundle).

It seems probable that the reflexion of afferent visual impulses into the nerves of the ocular muscles occurs in the anterior tubercles of the corpora quadrigemina, since stimulation of one of these bodies leads to conjugate lateral deviation to the opposite side. A similar movement is obtained by stimulating the cortex of the occipital lobe of the brain.

Probably, therefore, there is a distribution of the impulses generated in the retina, so that part pass to the occipital cortex where they are perceived, while the remainder go to the mid-brain (anterior tubercles of the corpora quadrigemina), and produce, by reflex action, appropriate movements of the eyeball, and movements of accommodation for distance and for amount of light. The movements of the eyeball are further under the control of the cerebral cortex.

Serial position of the centres for the nerves of the ocular muscles.

Hensen and *Völckers* have shown that the centres for movement and accommodation of the eyeball form a natural series from behind forwards.

1st. The centre for impulses distributed to the greater number of ocular muscles, by which the field of vision is searched and the eye brought into position.

2nd. The centres for the internal recti, by which the eyes are converged upon the object when found.

3rd. The centre for the iris.

4th. The centre for accommodation.

The position of the nucleus for the external rectus behind all the centres above-named would seem to indicate that its chief function is to bring the eyes to a position of rest after convergence.

OPTICAL DEFECTS OF THE NORMAL EYE. In considering the optics of the eye, it is customary to compare it with combinations of metal and glass: the living tissues of which it is composed present imperfections which are usually corrected in optical apparatus.

A. The refracting media are not truly centred.

B. **Spherical aberration** is not completely corrected.

If the surface of a lens is part of a sphere, the rays which enter near its margin are brought to a focus sooner than those which pass through its centre. A lens should therefore be made flatter at the margin than at the centre, *i.e*, paraboloid.[1]

Spherical aberration is partially corrected in the eye (1) by the cornea,

[1] For information concerning the optics of combinations of lenses, see Carpenter's *Microscope*, edited by Dr. Dallinger, 1892.

Maddox.—"Investigations into the Relation between Convergence and Accommodation of the Eyes," *Jour. of Anat. and Phys.*, vol. xx. pp. 475 and 565, 1886.

PLATE XXI.

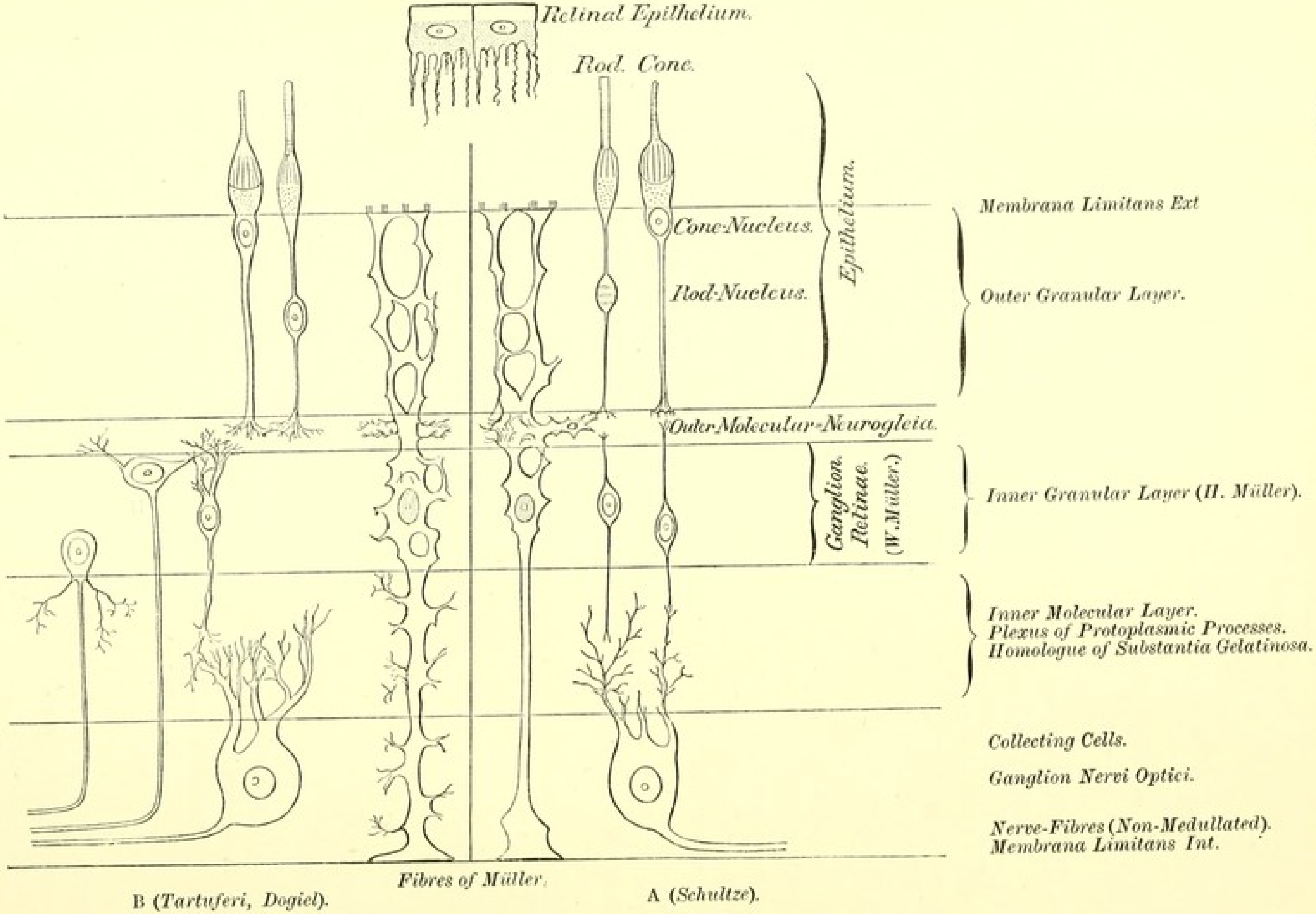

FIG. 55.—Diagrams illustrating the two chief views regarding the plan of structure of the retina. According to the older view (A), the fusiform cells of the inner granular layer are in continuity, through the outer molecular layer, with the bases of the epithelial cells. The inner processes of these fusiform cells (granules) give rise to a plexus (in the inner molecular layer), from which the large nerve-cells of the retina alone collect processes. The fusiform cells are considered as the homologues of the cells of the spinal ganglia, the inner molecular layer as corresponding to the substantia gelatinosa Rolandi (*Hill**). B, In a retina containing cones only, *e.g.*, the turkey's, it is obvious that the inner granular layer contains more than one nucleus (between three and four) to each cone. *Dogiel* and others consider that this layer contains three kinds of cell, and that the axis-cylinder processes of two kinds out of the three pass directly into the nerve-fibre layer.

* Hunterian Lectures, rep. in *Brit. Med. Jour.*, April 1886.

[*To face p.* 123.

which is ellipsoidal; (2) by the lens, which increases in density, although irregularly, from the margin to the centre.

C. **Irregular astigmatism.**

When the lens is flattened up against the suspensory ligament, the puckering due to the arrangement of its fibres about three axes which meet at angles of 120° upon its anterior surface, and three axes upon the posterior surface which bisect these angles, produces a "starred" figure. This is seen when a star or a distant gas-lamp is looked at (figs. 53 and 54).

D. **Chromatic aberration.**

In a window of stained glass, the blue appears to be more distant than the red. This is partly the result of an association of ideas, but it depends also upon the fact that the violet end of the spectrum is brought to a focus at a shorter distance from the lens than is the red end.

If a distant light is looked at through violet (purple) glass, which absorbs the middle of the spectrum, it appears either with a red centre and a blue fringe, or with a blue centre and a red fringe, according as the eye is accommodated for red or blue rays, since it cannot be accommodated for both at once.

E. **The yellow spot** is so called because all the elements of the retina, except the rods and cones and outer nuclei, in this the region of direct vision, contain a yellowish-brown pigment.

This pigment absorbs blue-green rays; hence we regard as pure white light which contains an undue proportion of blue-green.

Clerk-Maxwell's experiment. Look at a white cloud through a solution of chrome-alum. This solution transmits only the blue-green and red rays. The former are absorbed in the region of the yellow spot, which is therefore marked out as an oval reddish-purple patch upon a blue-green field. The patch soon disappears: the brain overlooks this, as it does other imperfections, in the eye.

F. The yellow-coloured elements of the yellow spot are slightly **doubly-refractive.**

Hence if a white cloud is looked at through a *Nicol's* prism which polarises the light, *Haidinger's* brushes appear at the point of fixation when the prism is suddenly rotated. This shows that a doubly refracting substance is placed between the prism and the central part of the sensitive nerve-curtain.

Common abnormal optical defects of the eye.

A. **Imperfect accommodation,** already referred to (p. 116).

B. **Regular astigmatism,** and also irregular astigmatism other than the form just described as universal.

In most cases the cornea (or the lens) is more convex in its vertical than in its horizontal diameter, as if its shape were altered by the pressure of the lids.

If two pin-holes be made in a card at a less distance apart than the diameter of the pupil, and a needle be focussed through both holes at once, held close to the eye (as in *Scheiner's* experiment), a single image can still be obtained; when the holes are vertical and the needle horizontal, at a smaller distance from the eye than is necessary, when the needle is vertical and the holes horizontal; because the focus for the vertical meridian is nearer the lens than is the focus for the horizontal meridian. In other words, the near point for the vertical meridian is nearer the eye than that for the horizontal meridian.

There is no common focus (stigma) for the eye. If a vertical linear object is looked at it produces two images, which cannot both be in focus at the same time, for the rays which enter the eye through its vertical meridian are focussed in front of those which enter through its horizontal meridian. The brain has a choice, and it chooses those rays which enter through the horizontal meridian and neglects the others, since the former give the clearer darker image.

An image is most distinct when the axis of the linear object coincides with the least curved meridian of the cornea: ∴ when two equally strong lines cross one another vertically the horizontal line always appears thicker than the vertical line if the vertical meridian of the cornea is the more curved. This is the common test. *Correction*:—Place a cylindrical lens (*i.e.*, a lens curved in one meridian only) in front of the eye with its long axis at right angles to the astigmatic meridian.

C. **Opacities in one of the refracting media**—"muscæ volitantes"—so called because the effort to see them distinctly results in their flying away. The shadow which the opaque speck produces falls upon some part of the retina other than the fovea centralis; when the eye is moved with a view to bringing the shadow (supposed to be the image of an object in the outer world) into the line of direct vision, the speck is, of course, moved with the eye.

THE RETINA AS A SENSITIVE SCREEN.

Histology.—Unlike all other sense-organs, the retina is formed entirely from an outgrowth of the brain. This outgrowth from the fore-brain, the optic vesicle, is pitted-in as the optic cup. The central (concave) wall of the cup becomes the retina, its peripheral (convex) wall the retinal (choroidal) epithelium. The whole retina is therefore a part of the brain, and contains tissues which in other cases are found only within the cerebro-spinal axis.

In the eyes of vertebrates the sensitive part of the retina (the bacillary layer) is directed outwards; the nerve-fibres are collected on the inner (concave) surface.

The elements of which the retina is composed are some of them nervous and others supporting (neurogleial). Of the latter class, the fibres of *Müller* are the most conspicuous. With their outer extremities they constitute the outer limiting membrane; by the apposition of their inner ends, the internal limiting membrane.

The neuro-epithelial elements are arranged in three strata:—

1. The rods and cones with their basal processes, which pass through the outer limiting membrane, and bear on its inner side the nuclei of these (epithelial) cells; the outer nuclei. The outer limbs of the rods consist of superimposed discs of a non-staining, probably fatty material; they are pink in colour, and measure $30\,\mu \times 2\,\mu$. The inner limb is protoplasmic, stains with carmine, granular in its inner, striated in its outer portion.

The outer limbs of the cones are not coloured; they are only $10\,\mu$ in length, except in the macula lutea, where they measure $60\,\mu$.

The basal processes of the cones bear, just beneath the outer limiting membrane, clear vesicular nuclei. The nuclei of the rods lie deeper in the layer, and are often transversely striped.

2. The second stratum consists of larger vesicular nuclei, surrounded by scanty protoplasm, giving off branches which end in a network both on their outer and inner sides. The networks, with their supporting neurogleia-cells, form the narrow outer and broad inner molecular layers.

3. The ganglion-cells are large, and give off branching processes into the inner molecular layer; unbranched (axis-cylinder) processes into the layer of nerve-fibres. These fibres are not invested by myelin-sheaths until they reach the lamina cribrosa.

There are two views with regard to the connections of these elements (fig. 55):—

A. The view of those (*Schultze*, *Schwalbe*, *et al.*) who regard the inner nuclei as belonging to small bipolar cells, the delicate processes of which are connected with the basal processes of the rods and cones (in the outer molecular layer) and the branched processes of the ganglion-cells in the inner molecular layer. Those who hold this view look upon the outer molecular layer as mainly neurogleial.

B. The view of *Tartuferi, et al.*, who consider that the cells of the inner nuclear layer are of three distinct kinds :—

(*a*) Bipolar cells, which branch in both molecular layers.

(*b*) Flattened cells, which branch in the outer molecular layer and give off an axis-cylinder process on the inner side.

(*c*) So-called unipolar cells, which branch in the inner molecular layer only, and also contribute an axis-cylinder process to the nerve fibre layer.

The retinal epithelium consists of cubical cells, loaded on their retinal side with black pigment. Pigment-containing processes of the cells depend amongst the outer limbs of the rods and cones. They are withdrawn in the dark, extended in bright light.

Variations in structure in different parts of the retina.

A. Where the optic nerve enters, fibres alone are present. The optic disc is therefore insensitive, and termed the "blind spot." It has a diameter of 1·8 mm., subtending an angle of 6°.

B. The visual axis cuts the retina at the yellow spot (macula lutea). The centre of the macula lutea is depressed (fovea centralis) by the removal from the retina of all its elements except the cones, which are variously estimated at from 2000 to 7000 in number. The nuclei and the rest of the elements other than the cones are accumulated around the margin of the spot, raising the retina into a thickened ring. The fovea centralis is colourless, but a good deal of brownish-yellow pigment is found in all the elements, except the rods and cones and their nuclei, which make up the ring.

The macula lutea is oval, its long axis 2 mm.

The fovea centralis has a diameter of 0·2 to 0·3 mm. and subtends an angle of 0·3°. It lies 4 mm. to the outer side of the optic disc.

C. Near the yellow spot the retina contains 1 cone to 4 rods.

Midway to the ora serrata, 1 cone to 24 rods.

At the ora serrata, rods only.

Variations in sensitiveness in different parts of the retina.

A. **The optic disc**—absolutely insensitive (fig. 56).

Make a small cross upon a piece of white paper, and about 4 inches to one side of the cross a large black blot. Shutting one eye, hold the paper 12 to 16 inches away from the other with the blot on the outer (temporal) side and slightly below the horizontal line. When the cross is looked at, the blot disappears from the field of vision. By shifting the paper until the blot is again visible, the area cut out of the field of vision by the optic disc can be mapped out.

B. **The fovea centralis** is the region of direct vision, and the only part of the retina capable of receiving stimuli sufficiently discrete for reading. Two stars or other points can be recognised as separate if they subtend an angle of 1′ (60″) with the fovea; *i.e.*, when their images on the retina are 4 μ apart.

At the margin of the macula lutea there is a rapid fall of sensitiveness, and from thence to the periphery of the retina a more gradual decline.

C. **Near the ora serrata**, to form discrete sensations, luminous points must subtend an angle of 4°, forming images on the retina more than 1 mm. apart. This region is therefore 250 times less sensitive than the fovea. There is no corresponding anatomical difference between the two regions.

Kühne and Sewall.—"Physiology of the Retinal Epithelium," *Jour. of Phys.*, vol. iii. p. 48.
Boden and Sprawson.—"The Pigment-Cells of the Retina," *Quart. Jour. Micr. Sci.*, vol. xxxiii., part 3, p. 365, 1892.

D. All parts of the retina are not equally sensitive to colour.

The peripheral zone is completely colour-blind.

The middle zone is red-blind, *i.e.*, distinguishes blue and yellow only, not red or green.

Colour-vision is distinct only in the middle.

A perimetric chart of the field of vision is made by fixing the head and directing the gaze to a point (the fixation point) around which a curved arm carries an illuminated object. The illuminated object, whether white or coloured, is pushed along the arm until it disappears from the field of vision, and the point at which it disappears is marked on a chart.

Which of the layers of the retina is sensitive to light?

The outer layer of the rods and cones.

Pro. 1. 1819, *Purkinje* made a large number of subjective observations. Amongst other things he observed that the retinal vessels throw upon the sensitive layer of the retina, shadows, which can be perceived under suitable conditions. These shadows are not perceived under ordinary circumstances, but if they are made to fall in unusual places, by placing the source of light to the side instead of the front of the eye, we see them.

Look at a white surface while a bright light held to the side of the head enters the eye through the sclerotic; the pattern of the retinal blood-vessels is seen on the white surface.

The layer in which their shadows stimulate nerve-endings must be posterior to these vessels which lie on the front of the retina.

Move the source of light and the pattern appears to move in the same direction. (The shadows on the retina of course move in the opposite direction, but the brain interprets movement to the right on the retina as movement to the left in the field of vision.) Measure exactly the distance through which the light is moved and the distance through which the shadow appears to move, and the actual depth behind the vessels of the sensitive layer can be easily calculated.

It is found to equal the distance of the outer limbs of rods and cones from the blood-vessels.

2. If white lines are drawn so close together on a black ground that adjacent lines subtend an angle of 60″ with the eye, they appear not straight but irregular, as if the analytical apparatus formed such a mosaic as we know to be presented by the ends of the rods and cones.

Are the cones the anatomical units from which impulses start?

Pro. 1. In the fovea centralis only cones are found.

2. From the centre of one cone to the centre of the next is 3·6 μ. We can recognise as distinct images which fall about this distance apart.

Con. 1. Cones are absent altogether in sharks, in owls, and in nocturnal mammals.

2. Towards the margin of the retina there is no correspondence between "sensational units" and the distance apart of cones.

Can we distinguish in function between cones and rods?

Con. Cones alone are found in snakes, crocodiles, &c., and we have no reason to think that vision in these animals differs essentially from vision in animals with rods only or with rods and cones.

How are undulations of light converted into nervous impulses?

A. By vibration of the outer segments of the rods and cones in sympathy with the undulations of light?

Con. This is a physical impossibility. Undulations of light have a wave-length, according to the place they occupy in the spectrum, of from 0·4 μ (violet) to 0·8 μ (red); and rapidity of from 481 billions of

FIG. 56.—To prove the existence of a "blind spot," hold this diagram at a distance of 10 inches from the right eye, with the cross a very little higher than the black disc; look at the cross and the black disc vanishes.

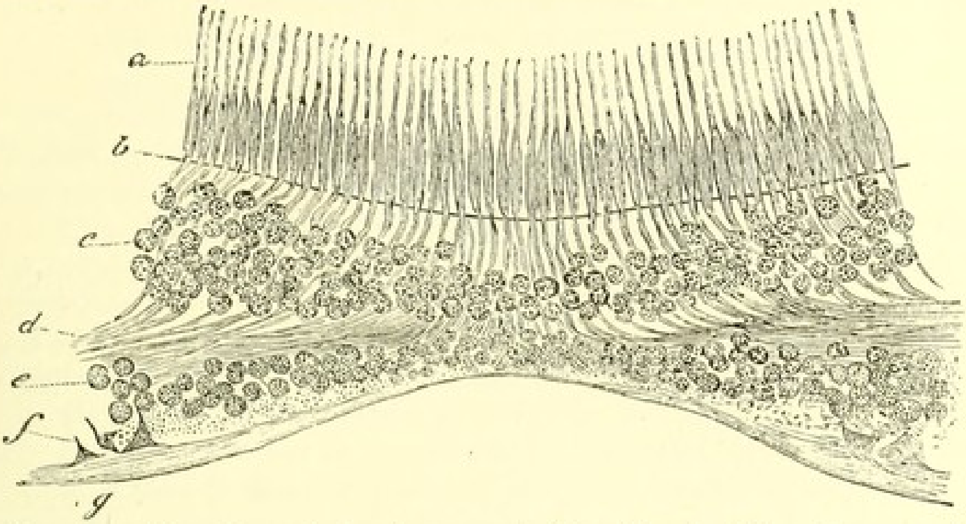

FIG. 57.—A section through the fovea centralis. The bacillary layer consists of cones only. The inner granules are for the most part displaced into the thickened ring which surrounds the fovea. Into this ring all the nerve-cells are also displaced. No nerve-fibres line the centre of the fovea. Yellowish-brown pigment is diffused throughout all the layers around the fovea, except the bacillary layer and the outer granules. Hence the name macula lutea applied to the fovea and its encircling thickened rim.

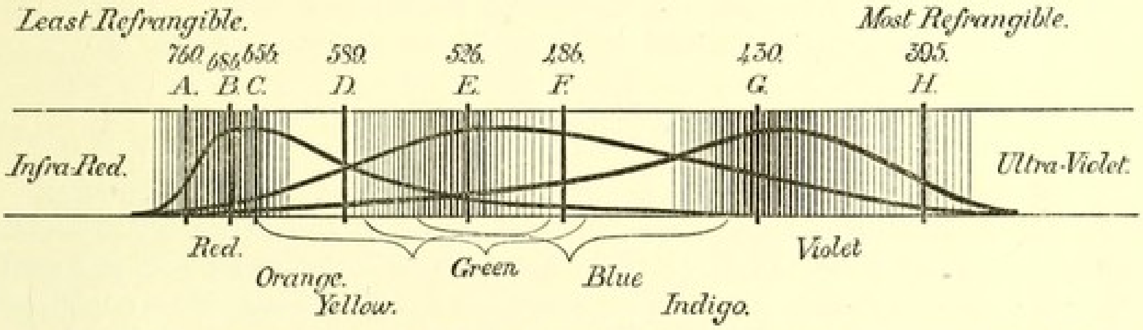

FIG. 58.—The analysis, by the retina, of coloured rays into three groups which give rise to three primary sensations of red, green, and violet.

The spectrum of sunlight is not continuous, but exhibits certain gaps (Frauenhofer's fixed lines), of which the chief are marked A to H, with the wave-length of the central missing rays in lambdas [$\lambda = {\cdot}000001\ mm. = {\cdot}001\ \mu$].

The spectrum affects vision from a little below A to a little beyond H. Heat rays are found chiefly at the red end and extend into infra-red. Chemical (photographic) effects are produced chiefly by the more refrangible rays, even those which lie far beyond the visible spectrum.

In the diagram the complementary colours (which together make white) are united by brackets. The red, green, and violet portions of the spectrum are shaded; orange and yellow, blue and indigo are not shaded. The extent to which each of the three primary colour-sensations is awakened by the several portions of the spectrum is indicated by the three curved lines. It is to be noticed that the primary colour-sensation of green, which is affected most acutely by rays a little to the violet side of E, is also affected by rays which lie on either side of "green"; the same statement holds good for the red and violet sensations. The yellow sensation provoked by rays of wave-length 589 λ (D) is due to the equal stimulation of the red and green analytical apparatus, with slight stimulation of the violet.

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vibrations per second (red) to 764 billions of vibrations per second (violet). The outer limbs of the cones are from 20 to 60 μ in length. They are inelastic and not homogeneous, but tend to cleave in discs.

B. By inducing chemical changes in pigment.

Pro. 1. The effect of light upon pigment is matter of common observation.

2. The simplest eyes in the lowest animals consist of a piece of transparent epidermis, at the back of which pigment is accumulated = a "pigment spot." The invariable presence of pigment indicates that this is the substance essential to the origin of a sensation of light.

The outer limbs of the rods are tinged with pigment—visual purple or rhodopsin. Is this the pigment which is chemically altered by light, giving rise to new compounds which act as nerve-stimuli?

Pro. 1876, *Boll* showed that if an animal is killed in the dark, or in a room lighted by yellow rays only, and its head then fixed in front of a window or skylight, the pattern of the window is bleached upon its retina. *Kühne* found that an ordinary mordant (4 °/$_{\circ}$ solution of alum) fixes the picture, which is therefore a photograph or "optogram" taken by the retina.

Con. Rhodopsin cannot be essential to vision, since—

1. There is none in the cones, *i.e.*, none in the region of distinct vision.
2. There is none in the eyes of bats, pigeons, or hens.

The sensitive pigment is to be found in the retinal epithelium.

Pro. These cells send pigmented processes down amongst the outer limbs of the rods and cones. When the eye is exposed to light, the pigmented processes extend nearer to the membrana limitans; in the dark they are withdrawn to the very apices of rods and cones. The rods are also said to lengthen under the influence of light.

Probably the visual purple of the rods is absorbed from these processes.

Pro. The peeled retina of the frog which has been bleached by light, recovers its colour when laid again upon the choroid.

COLOUR-VISION.

Light travels in undulatory vibrations of the æther. The intensity of the light varies as the amplitude of the vibrations, its colour depends upon the length (and therefore the rapidity) of the waves. White light is a mixture of vibrations of different wave-length. The colour of an object depends upon its power of reflecting certain rays, and absorbing the rest.

Limitations of vision. The eye is only able to respond to rays having a wave-length which lies between 0·4 μ (violet) and 0·8 μ (red). The infra-red rays cannot be perceived, the ultra-violet rays produce a grey glimmer, owing to the fluorescence of the media of the eye (*von Helmholtz*).

We can perceive and (except at the extreme ends) distinguish every part of the spectrum within the limits of vision, but we cannot discriminate superposed sensations; we regard a mixture of long and short rays as a group of rays of wave-length equal to the mean of the lengths of the two sets (their intensity being equal).

Two colours, far apart in the spectrum (complementary to one another), we interpret as white when mixed.

Nettleship.—"Visual Purple in the Human Eye," *Jour. of Phys.*, vol. ii. p. 38.
Kühne and Sewall.—Boden and Sprawson, *loc. cit.*, *ante*, p. 125.
Berry.—"Critical Remarks on the Theories of Fundamental Colour Sensations," *London Opth. Rep.*, vol. xiii. p. 1.

Any three colours when properly mixed produce the same sensation as white.

Every colour, if sufficiently intense, gives the sensation of white.

The above are the most important data to bear in mind when considering the question :—

How do we distinguish colour?

Thomas Young in 1807 formulated the theory that the retina contains three sets of apparatus *a*, *b*, *c*, for responding to stimulation by rays of light; (*a*) stimulated by red rays, (*b*) by green rays, (*c*) by violet rays, in the highest degree, but either of the three stimulated to a less extent by all rays within the range of colour-vision.

This theory is endorsed by *von Helmholtz.* It suffices to explain our power of discriminating all the colours to which the eye is sensitive. It accounts for the fact that a mixed colour originates the same sensation as a pure colour intermediate in position in the spectrum, since the stimulation by the intermediate pure colour would be distributed between the three kinds of apparatus in precisely the proportions in which the mixed colour is analysed by them.

Other arguments in its favour are :—

1. It fits in with the observation that defects of colour-vision consist, not in total blindness to certain parts of the spectrum, but in such colour-blindness as may be accounted for by the supposition that one set of sensitive elements is absent from the patient's retina.

The commonest defect is "Daltonism," due to omission of the apparatus most highly sensitive to red rays. It occurs in 1 person in every 35 (the proportion is much higher if only males are considered).

2. The non-coincidence of the perimeters for blue, red, and green light indicates structural differences in the retina; the apparatus sensitive to red light occupying a smaller area on the retina than that for blue.

3. The different relation between intensity of light and intensity of sensation in the case of the several colours.

Blue light of low intensity makes a greater impression upon the sensorium than does red light of low intensity : ∴ at mid-day the field of vision appears redder, in the evening it appears bluer; a winter landscape seen through red glass suggests summer, a summer landscape seen through blue glass appears wintry.

4. In santonin-poisoning the violet apparatus is first stimulated, and then paralysed, the patient seeing everything yellow.

5. Very rapidly intermitted white light appears green, owing to the sensitiveness (rapidity of reaction) of the apparatus for responding to green being greater than that of the other two kinds of apparatus.

6. Consecutive coloured images : after staring at a red object until the apparatus by which red is perceived is fatigued, the complementary colour is seen on looking at a white field.

Con. 1. It is quite certain that each individual cone is equally sensitive to all colours : ∴ the anatomical distinction between the three kinds of terminal apparatus (or nerve-fibres) has yet to be discovered.

2. This theory does not distinguish between darkness (retinal rest) and blackness. It admits no sensation of blackness.

7. If three photographs be taken without shifting the camera, (*a*) with all the rays but the red blocked by ruby glass, (*b*) with all but the green rays blocked, (*c*) with all but the violet rays blocked, three partial pictures are obtained, which, when superimposed by three lanterns upon a screen, reproduce the object photographed in its original colours, if red, green, and violet glasses respectively are placed between the slides and the screen.

8. For some little distance up each end of the spectrum, the shortening and lengthening of the waves does not produce an alteration in the tint of

the red and violet respectively, but only in their intensity : .·. each of these colours stimulates one of the three kinds of apparatus only.

Hering adapts to the explanation of colour-vision the theory that the retinal elements are stimulated by chemical changes in pigment. The conception of three kinds of apparatus is replaced by the conception of three kinds of pigment, (*a*) giving when katabolised red, when anabolised green ; (*b*) κ yellow, α blue ; (*c*) κ black, α white.

Con. 1. Black depends upon absence of reflected light : .·. the black-white pigment stands upon a different footing to the others.

2. Intense red or yellow, as well as intense green or blue, produces the sensation of white : .·. katabolism as well as anabolism of the pigments *a* and *b* produces the same stimulus as anabolism of the pigment *c*.

3. Three kinds of pigment have yet to be separated.

The two theories agree in explaining all phenomena of colour-vision as the analysis of an infinite number of waves of different lengths into three groups : in analysing the effects produced upon our consciousness by light-waves into mere "primary colour sensations," *Hering* has probably taken a step towards the truth in assigning the physical analysis to chemical changes in pigment ; but it is not yet proved that there are three separate pigments, or that the chemical changes produced in them by light are of the nature of "assimilation" and "dissimilation" respectively ; nor, on the other hand, is it quite necessary, even if each primary sensation is represented by a distinct retinal pigment, that both constructive and destructive alterations in the pigment should be capable of acting as a stimulus to nerve-endings in the retina.

HEARING.

The ear is the organ through which vibrations of sound stimulate the ends of the auditory nerve.

Vibrations of sound differ from vibrations of light, in that while the latter are undulatory (up and down), the former are pulsatile (forwards and backwards).

Pulsations, perceivable by the ear, have wave-lengths which vary as the force of the sound, and any rapidity between 40 and 40,000 per second.

The mechanisms for the analysis of vibrations, so fundamentally different in nature as those of light and sound, must differ widely in structure.

Mechanism for conducting sound-vibrations to the sense-organ.

A. The bones of head ; as when a vibrating body is placed in contact with the teeth or forehead, or when the head is under water. This is "direct" conduction, of which advantage is taken for testing whether or not the external or middle ear is diseased. Sound can still be conducted to the internal ear when the external or middle ear is diseased, by the use of a kind of fan which, held between the teeth, collects and transmits the vibrations of sound to the bones of the head.

B. The more efficient and adjustable structures of the external and middle ear.

a. The concha ; little more than an ornament in Man, but in most animals a collecting trumpet directed by muscles towards the source of the sound upon which attention is concentrated.

Love.—"The Limits of Hearing," *Jour. of Anat. and Phys.*, vol. xxiii. p. 336, 1889.
Helmholtz.—"Mechanism of the Ossicles of the Membrana Tympani," translated by Hinton, London, 1874 (*New Syd. Soc.*).

b. External meatus; a tube which makes a gentle curve, with convexity upwards and backwards. The inner two-thirds of its wall are supported by bone, its outer third by fibro-cartilage. Its inner end is closed by—

c. The membrana tympani, obliquely placed, its outer surface looking forwards and slightly downwards.

The drum is slightly trumpet-shaped, being drawn into the umbo by the attachment of the handle of the malleus. The umbo is below the centre of the membrane. Just above the elbow of the malleus it—here called the membrana flaccida—contains no membrana propria. The fibres of the membrana propria (which is covered by skin on the outer, by mucous membrane on the inner surface) are arranged both circularly and in a radiate manner; they are inelastic.

d. The movements of the tympanic membrane are transmitted to the perilymph by means of a chain of bones (malleus, incus, os orbiculare, and stapes) which form a bent and jointed lever. The tip of the short process of the incus, which is attached to the wall of the tympanum by the ligament of the incus, may be considered as the fulcrum of the bent lever; from this point to the umbo is half as far again as to the fenestra ovalis, and therefore the movements of the foot of the stapes have two-thirds the amplitude of the movements of the membrana tympani.

The movements of the bones are further guided by the following ligaments, (*a*) ligamentum mallei anticum, which attaches the processus Folianus of the malleus to the anterior wall of the tympanum close to the Glaserian fissure. The axis of rotation of the lever passes through this ligament and the ligament of the incus. (*b*) The external ligament of the malleus, which lies in the axis of rotation of that bone, and (*c*) the superior ligament which suspends the malleus, and serves to check the excursions outward of its handle.

The rounded head of the malleus is received into a concavity in the body of the incus. At the lower edge of the cavity is a cog which fits into a notch above another cog on the neck of the malleus; by this arrangement the incus is compelled to transmit intact the inward movements of the membrana tympani, but when the membrane moves outwards, the head of the malleus rotates in the concavity of the incus and the joint gapes; this is of importance, because, while the membrana tympani has a comparatively wide range of movement, the foot of the stapes is firmly attached in the bony ring of the fenestra ovalis by a ring of connective tissue (containing elastic fibres) not more than 0·1 mm. wide, and has therefore a very limited range of movement.

Tensor tympani muscle; the membrana tympani is not always tense; when at rest it is comparatively lax. As soon as a sound attracts attention, the membrane is rendered tense by contraction of the tensor tympani. If the sound is painfully loud, the vibrations of the membrane are probably damped by the further contraction of the muscle. The muscle, which passes up the Eustachian tube in the plane of the membranes, bends round the processus cochleariformis to be inserted into the base of the handle of the malleus, at right angles to the membrana tympani.

Stapedius muscle passes from behind forwards into the neck of the stapes. The exact use of this muscle is uncertain, but by pulling the front of the foot-plate of the stapes outwards it diminishes the pressure on the perilymph.

The Eustachian tube keeps the air-pressure inside the tympanum at the same level as that of the external air.

Conduction of waves of sound.—The tympanic membrane collects the waves of sound, and answers their vibrations. The movements of the membrane are transmitted to the perilymph by the chain of bones, not in the form of molecular vibrations, but by molar movement.

Pro. Light levers attached to the membrana tympani and the stapes

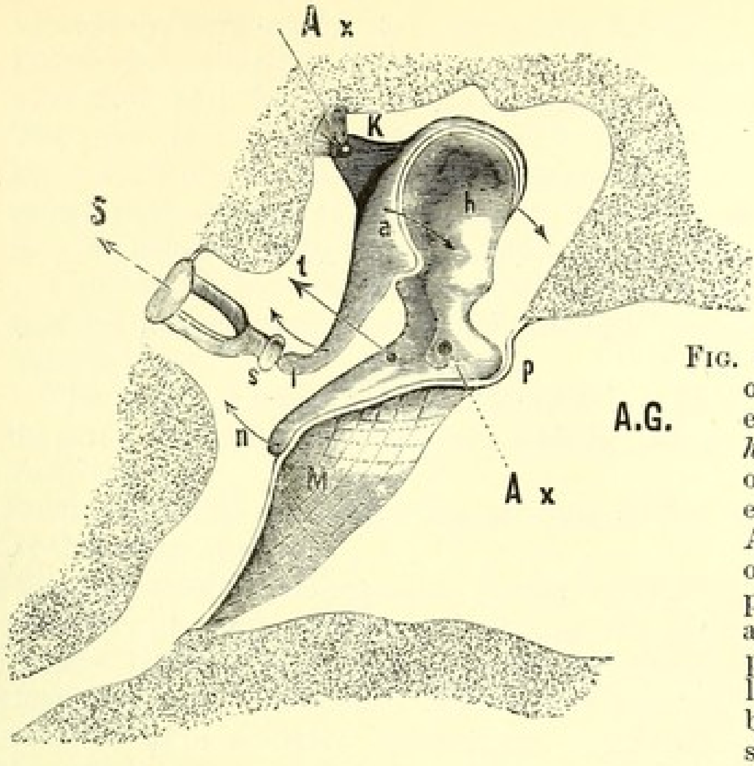

FIG. 59.—Drawing of the bones of the left ear intended to exhibit their mechanism. *h*, Malleus; *a*, incus; *s*, os orbiculare and stapes; AG, external auditory meatus; Ax, Ax, the axis of rotation of the jointed lever which passes from behind forwards almost vertically to the plane of the diagram, parallel to the plane of the membrana tympani, M; K, the short process of the incus to which the ligament of the incus is attached; this is the fulcrum about which the jointed lever swings; *t*, the line of traction of the tensor tympani. The small arrows indicate the direction of movement of the different portions of the several ossicles.

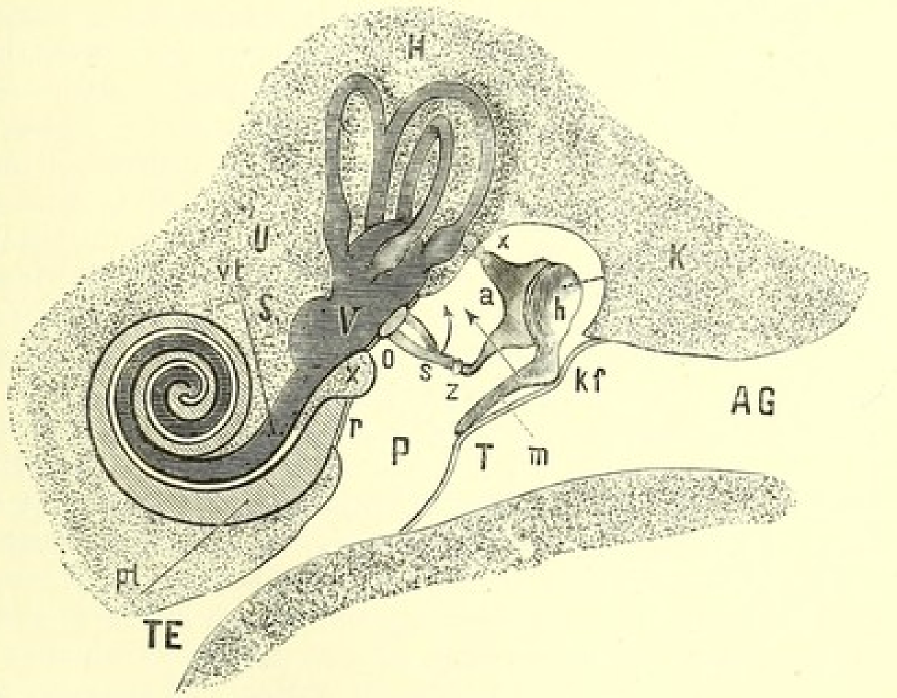

FIG. 60.—Diagram to illustrate the mode of propagation of sound-waves to the internal ear. AG, External auditory meatus; *m*, membrana tympani (30 times as large as the fenestra ovalis), which is set in vibration by the pulsations of sound; T, the tip of the long process of the malleus; *kf*, membrana flaccida; *h*, head of malleus; *a*, incus; *x*, its short process and ligament; *z*, os orbiculare; *s*, stapes; *o*, fenestra ovalis. The jointed lever formed by the four bones swings about its fulcrum, *x*, and transfers the vibrations of the membrana tympani (diminished $\frac{1}{3}$ in amplitude) to the foot of the stapes; V, the vestibule containing perilymph by which the vibrations are discharged over the membranous utricle and saccule which lie within it, over the membranous semi-circular canals, and along the scala vestibuli to the helicotrema and down *pt*, the scala tympani, to *r*, the fenestra rotunda. The canalis cochleæ (unshaded in the diagram) is separated by the membrane of Reissner from the scala vestibuli and by the basilar membrane from the scala tympani; TE, the Eustachian tube.

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vibrate synchronously, and, except for the diminution in amplitude already mentioned, similarly. The jointing of the lever prevents molecular vibration, and damps the fundamental note of the membrana tympani. The pitch of its fundamental tone is uncertain. Possibly certain parts of the membrane accentuate particular notes. Its peculiar trumpet-like form causes it to act as if it were a mosaic of many small membranes, so that it may be considered to have no specific tone of its own (*M'Kendrick*).

The tympanic membrane, with the chain of ossicles and the muscles acting upon them, constitute a protective and accommodating mechanism.

The tensor tympani muscle is supplied by N.V through the otic ganglion; its action is reflex, the afferent stimuli being started by vibration of the membrane.

The Eustachian tube maintains the pressure in the middle ear at the same level as that of the outer air.

It is closed usually, but opened during swallowing. Swallowing with the mouth closed and nostrils compressed, causing the pressure in the middle ear to be reduced below that of the atmosphere, the membrana tympani is sucked inwards and partial deafness produced. This shows how effective the tensor tympani muscle must be as a damping mechanism. A loud note, too sudden to allow of contraction of the tensor tympani, causes pain.

Conduction within the inner ear. The perilymph moves as a whole, each inward-push of the base of the stapes causing the membrane which closes the fenestra rotunda to bulge outwards, towards the tympanic cavity. The waves in the perilymph must therefore travel up the scala vestibuli, through the helicotrema and down the scala tympani. Vibrations are also discharged over the semicircular canals. Nowhere do the waves or vibrations disturb the terminal sense-organ directly. The nerve-terminals lie within the closed membranous labyrinth which lies within the perilymph.

Are the hair cells of the organ of Corti agitated by flexor waves as they pass up the scala vestibuli, or as they return up the scala tympani?

Probably the latter, through the membrana basilaris. The membrana tectoria possibly protects the hair-cells from the waves conducted through the membrane of Reissner to the endolymph within the canalis cochlearis.

Con. Foster thinks that very few vibrations reach the helicotrema; the majority pour across the canalis cochlearis, from the canalis vestibuli to the canalis tympani.

What is the primitive auditory apparatus?

All simple organs of hearing, as can be seen in the transparent pteropods, and even so low down the animal scale as the medusæ (Phialidium), consist of vesicles, lined by hair-cells to which the nerves are connected. In some cases the vibration of the hairs in response to sounds can be observed. The vesicle usually contains irregular masses of calcareous matter, the otoliths.

Is there any distinction of function between the several parts of the highly developed ear?

Apparently (1) the maculæ acusticæ of the utricle and saccule (which contain otoliths) receive information as to the amplitude of the sound waves, *i.e.*, the amount of sound or noise. (2) The organ of Corti would seem to be the analytical sense-organ. (3) The semicircular canals, with their ampullæ, appear to have the distinct function of judging of the orientation of the body.

The cochlea is supplied by the radix cochlearis of the auditory nerve, the rest of the labyrinth by the radix vestibularis. These two nerves acquire their myelin-sheaths at different periods; they have different connections within the central nervous system.

It is tempting to suppose that the whole vestibular nerve is concerned, not with hearing, but with orientation, the cochlea alone being the organ of hearing.

Pro. 1. The continuity of the utricle and (in birds, &c., but not in Man) saccule, with the semicircular canals, is so obvious as to make it difficult to believe that they have distinct functions. The canalis reuniens is narrow so as to separate these structures from the cochlea, rather than connect them with it.

2. The otoliths (in Man otoconia) in the utricle and saccule, which rest upon the hairs of the maculæ acusticæ, look as if fitted to originate impulses when the head is moved in any direction in a straight line. If this is their true function, the utricle and saccule appreciate linear movement—the semicircular canals rotary movements.

Con. 1. The maculæ and cristæ acusticæ resemble primitive organs of hearing.

2. The cochlea is only found in its full development in mammals. Fishes cannot be said to have a cochlea at all, and yet they undoubtedly hear.

What qualities do we distinguish in sound?

Sound reaches the ear in the form of backward and forward vibrations. The loudness of the sound depends upon the amplitude of vibration; its tone or note upon the rapidity with which the vibrations follow one another; its quality upon the prominence of the over-tones which accompany the prime tone.

The ear needs to recognise aperiodic vibrations, or noise, and periodic vibrations, or musical notes.

It needs to discriminate simple tones of from 30 or 40 to 30,000 or 40,000 vibrations per second. In music, notes range from 40 to 4000 vibrations per second.

It needs to analyse compound tones.

When vibrations are superposed, the wave produced has a special "form," which depends not only upon (*a*) the numerical relation between the two sets of vibrations, but also upon (*b*) the phase of the longer wave upon which the shorter wave is superposed.

The ear can resolve compound waves into simple pendular vibrations.

(It will be remembered that the eye has no power of resolving superposed undulations of light.)

When the numerical relations between the tones is a simple fraction, the resulting wave has a regular periodicity, and we recognise the compound sound as a harmony. For example, the octave $= \frac{2}{1}$, the fifth $= \frac{3}{2}$, the third $= \frac{5}{4}$.

When the relation between the tones is complex, the maximum reinforcements or summits of the compound waves occur at considerable intervals, and we hear beats. The piano-tuner recognises that a note is out of tune when, on striking it at the same time with another note with which it should give a harmony, he detects beats. We dislike compound notes in which the least common multiple of the constituent notes is so large that the compound wave is very long, and its periodic interruption produces a sensation of roughness.

It is curious to notice, however, that intricate minor cords predominate in primitive music, *e.g.*, Hungarian, Scotch, and Welsh music (*Cobb*).

Can the ear also take cognisance of the form of the wave?

Von Helmholtz, by means of his "vowel-tone apparatus," liberates vibrations at different intervals, so that while the constituent vibrations are the same, the form of the wave can be varied at pleasure. He believes that the sensations produced are indistinguishable.

Lord Kelvin [1] is of a contrary opinion.

[1] "Beats of Imperfect Harmonies," by Sir William Thomson, *Proc. Roy. Soc., Edin.*, 1877–8.

The Cochlea, as the organ for analysing waves of sound. If the basilar membrane be detached from the lamina spiralis and the outer wall of the cochlea (ligamentum spirale), it is found to have somewhat the form of the sounding-board of a grand piano—length 33·5 mm., width from the entrance of the nerve-fibres to the spiral ligament, at the base of the cochlea, 21 mm., at the apex 36 mm.

The membrane contains a large number (about 24,000) elastic fibres, transversely disposed.

It carries the organ of Corti, which is composed of two rows of rods of Corti. The rods of Corti arch over a tunnel, their heads being articulated together. The outer rods are rather more numerous than the inner ones. By their phalangar processes the rods give attachment to the reticular membrane, a regular network, supported also by the cells of Deiters, and allowing the hairs of the cells of Corti to project into the endolymph through its meshes.

The organ of Corti is covered by a spongy membrane containing elastic fibres (the membrana tectoria, or membrane of Corti), which is attached on the inner side to the vestibular lip of the lamina spiralis, while its outer edge is free.

On the inner side of the rods of Corti the inner hair-cells are arranged in a single row. They are formed of very soft granular protoplasm, flask-shaped, with a large nucleus in the body of the flask, while the mouth of the flask presents a hyaline border, from which project about a dozen short rods arranged in a curved row.

The outer hair-cells are arranged four abreast. Each is really a pair of twin-cells—the cup-shaped hair-bearing cell of Corti, and the cylindrical cell of Deiters which unites the reticular membrane to the basilar membrane.

The cells of Corti are formed of very watery protoplasm. A nucleus lies near the bottom of the cup. The circular mouth of the cup is covered by a hyaline plate, which bears eight or ten short rods arranged in a semicircle, with its concavity directed towards the rods of Corti. A small round body (Hensen's body) lies near the mouth of the cup. The cells of Deiters consist of a cylindrical lower portion and a tapering process. The tapering process consists of a cuticular band attached to the reticular membrane, and passing down the inner side of the body of the cell to rest upon the basilar membrane. The rest of the cell is very soft; it contains a round nucleus. On both sides of the organ of Corti the hair-cells pass by gradations into the ordinary cubical epithelium which lines the canalis cochlearis.

Nerves of the Cochlea.—The cochlea is supplied by the ramus cochlearis of the auditory nerve. Within the spiral lamina its fibres pass through bipolar cells (ganglion spirale) without subdivision or demedullation.

The fibres pierce the lip of the lamina spiralis by a series of foramina nervina, at the same time losing their medullary sheaths. The naked fibres then radiate outwards, ending in a little nest of fibrils for each of the inner hair-cells and cells of Corti. No other structures are connected with the nerves. They form, by anastomosis or by changing their direction, spiral strands, the first of which lies beneath the inner hair-cells, the second just inside the tunnel of Corti, the third, fourth, fifth, and sixth beneath the several rows of the cells of Corti.

How does the organ of Corti analyse musical sounds?

A. Does it consist of a series of vibrating and sensory combinations?

In structure it appears to comprise from 3000 to 5000 pieces of apparatus, each made up of two rods of Corti, one inner hair cell and four (in some parts three or five) outer hair-cells. The fibres of the basilar membrane, the rods of Corti, the cuticular filaments of the cells of Deiters, and the reticular membrane, taken together, seem to determine the note to which each separate piece of apparatus is tuned; the hair-cells to convert the vibration of sound into a nervous impulse.

If it consist of a large number of responsive instruments, can we understand how each takes up its proper note?

a. Von Helmholtz thought at one time that each pair of rods was tuned for a particular note.

Pro. This would give about as many pieces of apparatus as a musician can recognise pure sounds—say, 400 to each of seven octaves, or 33 to a semitone.

Con. 1. The rods are inelastic.

2. They are unequal in number—about 5600 inner rods to 3850 outer rods.

3. They are absent from the cochleæ of birds.

b. Hensen suggested the elastic fibres of the basilar membrane.

Con. Although sufficiently numerous, and although varying in length, the variation in length between the longest and shortest is insufficient to account for the range of sounds which we can appreciate unless it is accompanied by a considerable difference in tension.

B. Are we making a mistake in looking for a separate nerve-ending for the reception of each unit of sensation?

Pro. 1. In ordinary life, many of the endings would be stimulated so seldom that they would lose their functional activity.

2. Towards the upper part of the range of hearing, although, by hypothesis, there can be only one nerve-ending for a group of tones,[1] we do not perceive a certain tone (of, *say*, 27,000 vibrations) any more distinctly than another (of, *say*, 27,010 vibrations), as would be inevitable in such an analytic apparatus as we conceive the cochlea to be; but all are equally loud and clear, whether they coincide with a terminal apparatus or fall midway between two.

3. For each individual the number of anatomical elements is fixed, but his power of discriminating musical tones can be vastly increased by practice.

4. The retina resolves undulations of coloured light into groups corresponding to "primary sensations;" the cochlea may act in the same way.

SMELL.

The sense by which we appreciate the chemical nature of substances suspended in a gaseous medium. The most developed, important, and thought-provoking of the senses in carnivora; weak or absent in aquatic mammals; weak in Man, but showing evidence of its former importance in its close connection with memory. Scents recall scenes more vividly, it is said, than sounds.

Mechanism. The olfactory mucous membrane lines the two upper meatus of the nose. It is supplied by the olfactory nerve, and presents a columnar epithelium, the cells of which are of three kinds.

1. Cylindrical cells, which do not bear cilia except where they border the respiratory epithelium and are transitional. The outer half of the cell is wide and granular, the inner side or stalk narrow, irregular, footed; the nuclei oval, darkly staining.

[1] Using the word *tone* in the sense of a pure musical sound, irrespective of its position in the gamut.

2. Fusiform cells, with narrow outer limb, ending in a kind of style or bunch of cilia which projects beyond the surface. Their nuclei are round, clear, nucleolated; their inner processes thread-like, and perhaps continuous with nerve-fibres, of which there is an abundant plexus in the dermis.

These cells are believed to be the olfactive cells.

3. Basal cells, round or pyramidal, massed amongst the stalks of the other cells, and forming in some animals a single regular sheet.

Odorous particles are brought into contact with the olfactory membrane by sniffing.

The loss of the apparatus in aquatic mammals may be due to the necessity for closing the respiratory apparatus under water, or may be due to the fact that the mammalian olfactory membrane can only discriminate particles suspended in air. Fishes have well-developed olfactory organs; but since they use them in water, it may be a mistake to describe the sense which they serve as a sense of "smell," since it is more nearly allied to our sense of taste.

Stimuli; particles of extreme minuteness suspended in air. It is impossible to filter the particles of musk from air, even by a cotton-wool filter, which keeps out all germs; the loss in weight of musk which has scented a room for years is almost inappreciable. No gas of less atomic weight than 15 (ethane) stimulates the olfactory apparatus. It appears, therefore, that the vibrations of the lightest molecules are too rapid to affect the sense. Odorous particles are in general easily oxidised (*Graham*); they have considerable power of absorbing heat (*Tyndall*).

TASTE.

The sense by which we distinguish between bodies in solution.

Mechanism; taste-bulbs are found in numbers on the side of the papillæ circumvallatæ and its adjoining vallum, and scattered elsewhere about the tongue, soft palate, and even the under surface of the epiglottis. They are nests of cells in the stratified epithelium of the tongue. The cells are set vertically, and extend from the dermis to the surface. The marginal cells are half-moon shaped; their outer borders cuticularised; they constitute the wall of the bulb. The central cells are fusiform, and carry a style which projects out of the pore left between the outer or supporting cells. The bulbs are supplied by abundant fibres from the glossopharyngeal nerve.

Are they organs of taste?

Pro. 1. The cells resemble those of other sensory epithelia.

2. The sense of taste is chiefly located where they are most abundant.

3. They degenerate when the glossopharyngeal nerve is cut.

Con. There is no reason to think that all regions in which they occur (*e.g.*, the back of the epiglottis) are sensitive to taste.

Are there other organs of taste?

Klein.—"Contributions to the Minute Anatomy of the Nasal Mucous Membrane," *Quart. Jour. Micr. Sci.*, vol. xxi. p. 98, 1881.

Bowman.—"The Sense of Taste." Collected Works of Sir W. Bowman, London, 1892.

Tuckerman.—"The Development of the Taste Organs of Man," *Jour. of Anat. and Phys.*, vol. xxiii. p. 559; xxiv. p. 130; xxv. p. 505.

Pro. 1. The glossopharyngeal nerve, if this be the nerve of taste, is distributed in the form of a plexus to other parts of the mucous membrane as well as to the taste-bulbs.

2. Disease of the chorda tympani and of the fifth nerve within the brain leads to loss of taste, but this result has not been observed after disease of the glossopharyngeal nerve only.

Are there specific nerves of taste?

Pro. 1. Different parts of the tongue are especially sensitive to certain tastes; the back to bitter, the tip to sweets and salts, the sides to acids; but the middle of the dorsum of the tongue is almost insensitive. The palate is sensitive.

2. Weak electric currents applied to the tongue develop sensations of taste which differ in different parts of the tongue. They cannot be altogether attributed to electrolysis.

3. Cocain in graduated doses paralyses the tongue, first for painful sensations (so that a strong electric current produces sensations of taste only), then for bitter, then for sweet, salt, and acid tastes in order.

4. The leaves of Gymnema sylvestre paralyses for bitter and sweet tastes only.

5. A certain bromine derivative of saccharin (para-brom-benzoic sulphinide) tastes sweet on the front of the tongue, bitter on the back.[1]

Conditions of sensation.

Substances are only sapid when in solution.

They are most active at about the body temperature, and paralyse the taste-organs when very hot or very cold (*e.g.*, quinine is not tasted just after hot or ice-cold water has been drunk). They provoke sensations in about 0·2 sec., and the sensation endures for a long time preventing subsequent stimulation. (Castor oil is not tasted—it is partly however a question of feeling—after the mouth has been rinsed with brandy, or with a strong solution of oil of lavender or of chloroform.)

THE SKIN AS A SENSE ORGAN.

Mechanism. 1. Sensory nerves end (or rather commence) in the subepithelial plexus of the dermis. From this plexus filaments pass into the Malpighian layer of the epidermis to form an intraepithelial plexus. Filaments from this plexus appear to end free between the epithelial cells; perhaps they are connected with cells in a manner not yet recognised.

The gold-chloride method, which is almost the only one available for this investigation, gives uncertain results.

a. Groups of epithelial cells appear in certain cases to be depressed beneath the epidermis. Such are:—

2. Grandry's corpuscles in the bill of the bird (fig. 61).

Two hemispherical epithelial cells, with a nerve-plate between them.

b. Touch-corpuscles; oval bodies, 60 to 100 μ in length, found in the papillæ of the dermis (fig. 63).

Their structure is extremely obscure, but they appear to consist of a large number of epithelial cells separated by nerve knots or discs; the definiteness of all their constituents, except the nuclei, being lost.

3. Nerve-endings, in which the most conspicuous feature is the overgrowth of the connective tissue-investments of the nerve.

a. End-bulbs found in tendons, in the papillæ of the dermis of the conjunctiva, lips, genital organs, and some mucous membranes (fig. 62).

[1] Howard and Kaske.—*Studies of the Johns Hopkins Biological Laboratory*, June 1887, p. 13.

They consist of a core, almost homogeneous, but containing granules or in some cases nuclei, and invested by a complicated capsule formed from the neurilemma and Henle's sheath.

b. Pacinian corpuscles or corpuscles of Vater. Visible with the naked eye on the course of the nerves of the fingers and toes, about joints, and along the nerves of the periosteum, and on the nerves of the mesentery. They are usually obtained from the mesentery of the cat.

The axis-cylinder passes up the centre of a homogeneous core, which is invested by a great number of connective tissue-laminæ, enclosing lymph-spaces (fig. 64).

Are all these several kinds of end-organ subservient to cutaneous sensation?

It is impossible to correlate their presence with the presence of any particular form of sensitiveness, and we must therefore suppose that they are only accessory in some way to common sensation.

Pro. 1. Common sensation in all its aspects is present in regions of the skin in which only the plexiform ending can be found.

2. Touch-corpuscles, although very numerous in the skin on the palmar surface of the end of the fingers (50 to each □ mm.), are also present in the bed of the nail, front of the forearm, nipple, conjunctiva, and tip of tongue, but are absent from other parts of the body.

The parts named are very sensitive, but their sensitiveness does not differ in kind from that of other parts of the body.

3. End-bulbs occur in the conjunctiva and skin of lips and genital organs, and also in mucous membrane, that of the rectum for example.

4. The remarkable, and at present unaccountable, distribution of Pacinian corpuscles has been referred to already.

Does the skin contain more than one kind of "specific" nerve-ending or organ, stimulation of which, whether by its accustomed stimulus or by some other stimulus, gives rise to a characteristic sensation?

Pro. 1. The sensations which originate in the skin may be classed in three divisions—(*a*) common sensibility or pain, (*b*) sensations of touch, (*c*) sensations of temperature.

2. One or other class is often abolished by disease, *e.g.*, in many cases of tabes pricking is felt as if the needle-point were only in contact with the skin, not piercing it. In other cases the power of distinguishing temperatures is lost, while the skin remains sensitive to touch, and *vice versa.*

3. The distribution of the three kinds of sensory apparatus is not co-terminous.

a. **Common sensibility**, or sensibility to pain, appears to reside in all organs.

Pro. 1. Slight inflammation makes every organ acutely sensitive.

2. However scars and wounds are stimulated, the sensation produced is of pain, not of touch or temperature.

Con. Liver, muscles, retina, &c., may be cut or cauterised without its being felt; in the last case the irritation causes sensations not of pain, but of light.

This can only be explained on the supposition that the sensibility which is highly developed in the skin needs in other organs to be brought out by unusual conditions. Under normal circumstances it is not wanted, and therefore not present. Its appearance is pathological, but whether due to a change in the organ or a change in the sensorium cannot be determined.

b. **Tactile Sensations** are distinguishable into :—

a. Power of discriminating points in contact. Two points are recognised as separate by the tip of the tongue when 1·1 mm. apart; by the terminal phalanx of the finger when 2·2 mm. apart; by the skin between the shoulders only when 66 mm. apart.

β. Sensitiveness to pressure is distributed in spots surrounded by insensitive areas.

c. **Sensitiveness to differences of temperature** is distributed in a different manner to tactile sensitiveness, *e.g.*, the forehead is much more sensitive than the hand.

Further, the areas which are most alive to the presence of bodies hotter than the skin, do not everywhere coincide with those which are most sensitive to cold. Two cold bodies can be discriminated at a less distance apart than two hot bodies. The temperature-spots are arranged for the most part in lines, which have a tendency to radiate from the roots of hairs. Their distribution is suggestive of an intimate dependence upon underlying nerve-filaments.

Confusion of sensation; alteration in the temperature of bodies often affects our estimate of their weight, or enables us to recognise differences of weight previously inappreciable. It is generally held that excessive stimulation by heat, cold, or violent pressure gives rise only to painful sensations; although some observers state that this is not the case if the heat-stimulation is restricted to a "heat-spot."

∴ the cutaneous sense-organs are not perfectly distinct from one another.

MUSCULAR SENSE.

By this term is meant the sense by which we recognise the force and range of muscular movements.

It is even doubted whether such a sense exist, owing to the difficulty there is in making sure that no other sense supplies the information; for instance, when a movement is made we see its effect; if the eyes are shut we feel the stretching or slackening of the skin, the changes of pressure on the skin, the altered position of the body.

Is there a sense of muscular action independent of the effect of this action upon the skin, &c.?

Pro. 1. We seem to ourselves to be able to estimate the amount of work being done by our muscles.

2. In various forms of commencing locomotor ataxy, the power of using the muscles with the proper degree of force is lost before any change in the sensitiveness of the skin can be detected.

If this sense exist, is it an attribute of nerve-centres? Do we feel the force with which the brain discharges impulses?

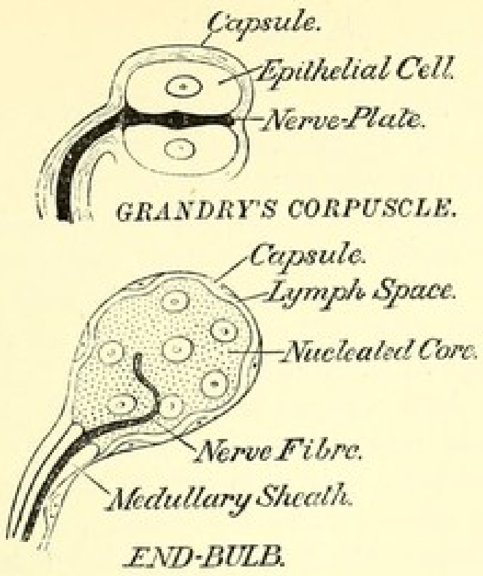
Con. It seems to make no difference in our sensations whether the movement is made voluntarily, or as the result of electrical stimulation of the muscle or its nerve.

If there be a muscular sense of peripheral origin, where are the sense-organs?

Muscles are supplied with nerves which end in a plexus, as well as with fibres ending in motorial end-plates.

Pacinian corpuscles are found near the attachment of tendons. Tendons are also supplied with nerves which end in a plexiform manner (Golgi's organs).

Pollitzer.—"The Temperature Sense," *Jour. of Phys.*, vol. v. p. 143.
Bastian.—"The Muscular Sense: its Nature and Cortical Localisation," *Brain*, vol. x. p. 1, 1888.
Waller.—"The Sense of Effort: an Objective Study," *Brain*, 1891.



FIGS. 61 and 62.—A corpuscle of Grandry and an end-bulb.

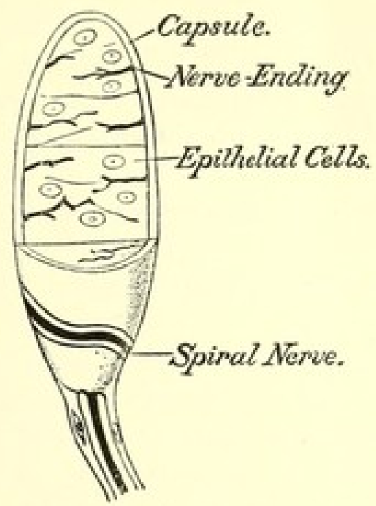


FIG. 63.—A touch-corpuscle.

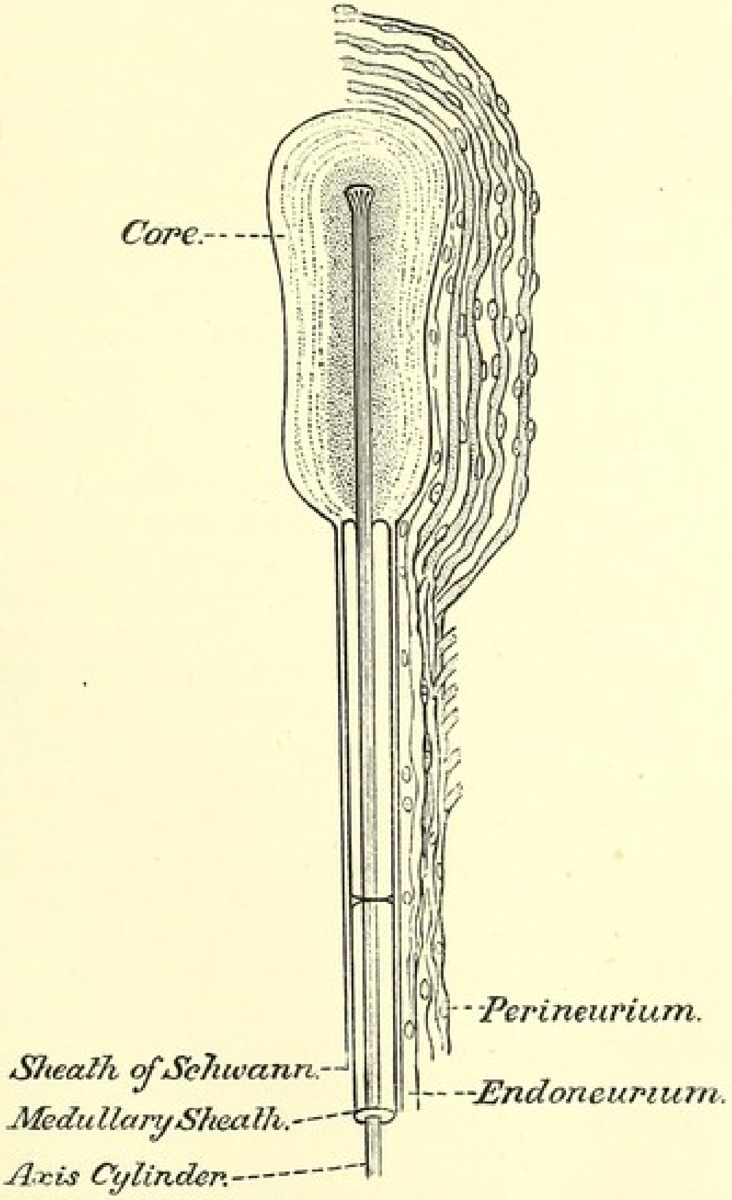


FIG. 64.—A Pacinian corpuscle. The axis-cylinder loses its medullary sheath when it enters the core of the corpuscle. The perineurium is developed into a series of concentric laminæ which enclose lymph-spaces. The homology of the core is doubtful, it is granular near the axis-cylinder, faintly striated in its peripheral portion.

To face p. 138.]

SENSE OF ORIENTATION.

It is generally believed that an animal is able to determine the position of its body in space, without the aid of the senses already considered. This belief is based, however, rather upon the results of certain experiments upon the semicircular canals of the ear, which point them out as the organ of the sense of orientation, than upon subjective observations.

1828, *Flourens* observed that when one of the membranous semicircular canals of a bird is cut, it rotates its body (or moves its head) in the direction of the cut canal. It loses its power of co-ordinating complicated movements; can no longer fly, although, if an aquatic bird, it can still swim.

Rabbits so mutilated move the eyes rather than the head.

In fishes the operation produces no obvious change.

1870, *Goltz* attributed these results to the loss of certain sensations, normally developed by the pressure of the endolymph in the ampullæ of the canals. He concluded that animals possess a sense of position, provoked by the action of gravity upon the fluid within the semicircular canals.

This (statical) theory is not generally admitted, although it is exceedingly difficult to put it to a subjective test. The sensorium is at every instant in receipt of myriads of impulses, which result from the pressure of the body upon the ground, chair, or couch, and these must be eliminated before we try to judge whether there is a sense devoted solely to the estimation of position. The writer has very frequently made the experiment of diving into deep water with his eyes shut; allowing the body to assume any chance position, and then trying to form a judgment as to its orientation. He convinced himself that in all cases in which movements of the water and so forth did not supply the information, his judgment was quite at fault.

Can we estimate the extent to which the body is displaced? (Dynamical theory.)

1. When a man is placed upon a rotating table and protected from movement of the surrounding air, he can, it is said, approximately estimate the angle through which the table is rotated.
2. When a constant current is passed through the head from mastoid process to mastoid process (Purkinje's experiment), the subject leans his head against the anode, because surrounding objects appear to be moving in the direction of the current.
3. In Menière's disease, which commences in the ear, the patient suffers from the feeling that the ground is falling away; to escape from falling over with it he throws himself down in the opposite direction.
4. When the body is rapidly rotated with the eyes shut, the things in the room appear, when the rotation ceases and the eyes are opened, to be rotating in the opposite direction. Bend the head forward during the rotation and raise it on stopping, and the floor seems to be rising on one side and falling on the other.
5. The bird with its semicircular canal divided behaves in a way which shows clearly that it is suffering not from the absence of sensations upon which it relies, but, like the man in 2, 3, and 4, from disordered sensations of movement.

The semicircular canals are the organs of the sense of movement. Sensations are originated by rotation of the column of fluid in one of the canals.

Sewall.—"Experiments upon the Ears of Fishes with Reference to the Function of Equilibration," *Jour. of Phys.* vol. iv. p. 339.

Pro. 1. The position of the canals in space, (1) vertical and antero-posterior, (2) vertical and transverse, (3) horizontal (in each case with regard to the axis of the petrous portion of the temporal bone), is favourable to such an interpretation of its function.

2. It is possible to open the horizontal canal, and then to make the endolymph circulate along it by blowing through a fine tube. The animal moves its head from side to side. Mere increase or decrease of the pressure in the canals does not cause movement.

SENSATION IN GENERAL.

It would conduce to a proper understanding of the physiology of sensation if, instead of each sense being described as presenting certain characters which may or may not be peculiar to itself, each set of conditions of sensation could be summarised for all the senses. It is, however, in the nature of the case, impossible to make such a tabulation complete. The eye localises stimuli with extreme accuracy, the ear gives scarcely any information as to the position of objects in space; stimuli affecting the sense of pressure and muscular sense can be measured with accuracy, but how can we determine the amount of a stimulus applied to the tongue or the nose? Again, differences in amount of light can be measured, but how shall we estimate the mathematical relation between two stimuli of heat, or, if we could do this, how reduce our results to a zero condition of the organ when the power of the skin to appreciate differences of warmth or cold depends so much upon its own temperature and blood-supply? In the following tables the more important and easily comprehended results alone are made use of.

Another difficulty faces the student who is not acquainted with psychology, in the use of terms in a technical sense which does not always coincide with their common acceptation. To the psychologist "a simple sensation is a necessary fiction." Psychology deals only with "presentations of sense," into which simple sensations —fixed in their relation to time and space—are built up before being presented to the mind. The physiologist, on the other hand, has to deal with stimuli and their effect upon the sensorium, and therefore he uses the term "sensation" when he means that constituent of a presentation of sense which is, or would be if it could be isolated, the direct result of the stimulus which he is considering, before it had awakened other sensations which were lying dormant.

Again, the mind interprets presentations of sense in the light of experience. It is impossible for the mind to divest itself of its experience and take cognisance of the presentations of sense as isolated phenomena, for if there were no experience there would be no mind. Sensations therefore appear in consciousness as perceptions or sensory judgments. In the following tables these obvious distinctions can be only partially observed. By a "sensation" is to be understood the effect upon consciousness of stimulating a sense-organ when experience plays an insignificant part; by "perception" or "judgment" the effect of a stimulus when our feeling is the result in the highest degree of experience.

The sense-organs are the windows through which the mind looks out upon the world (*Lubbock*). The mind therefore perceives all sensations (except those of

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The line of argument followed in the above abstract is not altogether endorsed by Cyon. See *Recherches expérimentales sur les Fonctions des Canaux semi-circulaires et sur leur Rôle dans la Formation de la Notion de l'Espace.*

Crum-Brown.—"Cyon's Researches on the Ear," *Nature*, 1878. *M'Kendrick's Physiology*, p. 694.

Ladd's *Elements of Physiological Psychology*, 1892, not only presents the subject in its philosophical aspects, but also supplies abundant physiological data.

Lubbock's "Senses of Animals," *Intern. Sci. Series.*

muscular sense and the sense of orientation) as outside the body. It projects them on to the surface of the body if their cause lie in the skin; at a distance in space if they are the result of stimulation of the retina. Touch and sight are therefore distinguished as the "geometrical senses." Some of the most complex sensations of which we are capable are "sensations of double contact." When a man is holding a chisel or a paint-brush he feels not only the pressure with which it is grasped by the fingers, but also the contact of the instrument with the material upon which it works. This is one of the best illustrations of the way in which the mind refers to the outer world, the effects upon consciousness of certain molecular changes which are taking place in the brain.

Comparison of the several senses.

Points of similarity in the structure of their organs.

Organs of sensation are divisible into three classes:—(1) Those connected with muscles, tendons, glands, and other deep-seated (mesoblastic and hypoblastic) structures. Very little is yet known as to the manner in which these structures are connected with afferent nerves. (2) Nerve-connections with cells of skin, including all such modified epidermal cells as are found in touch-corpuscles, &c. (3) The organs of special sense.

The organs of special sense consist of modified epithelial cells; the cells in each organ assume two forms, of which one or both carry vibratile hairs or equivalent processes.

	Larger cells.	Smaller cells.
Olfactory membrane	Columnar.	*Fusiform.*
Retina	Cones.	Rods.
Maculæ and cristæ acusticæ . .	Rod-cells.	*Cylinder-cells.*
Cochlea	Deiter's cells.	*Corti's cells.*
Taste-bulbs	Cortical.	*Central.*

It is impossible at present to homologise the cells of the two classes with any degree of certainty, but those underlined have probably a supporting function; those in italics bear vibratile hairs, and are therefore presumably the end-organs of the nerves.[1]

Nature of the stimulus.

It must be interrupted or vibratile.

Sight: undulations of æther, which act upon the epithelial cells only indirectly, through the pigment cells. The rods and cones receive chemical stimuli from the pigment, and do not respond to the waves of light (p. 126).

Hearing: to and fro vibrations, or condensations and rarefactions of matter.

Smell: the rapid vibration of bodies of low molecular weight.

Taste: the slower vibration of bodies of large molecule.

The sense of touch may be added to the list, since natural stimulation is best simulated by an interrupted current.

It must have a certain duration and intensity. There is for each organ a range of most acute response, and an upper limit beyond which the stimulus gives rise to pain, instead of provoking its special sensation.

The minimal duration for sight is less than the duration of the electric spark ($\frac{1}{1,000,000}$th of a second) for green light, but greater for red, since the spark appears to be green, not white.

The minimal duration necessary for sound to stimulate the sense of

[1] With regard to the cells of the maculæ and cristæ acusticæ, there is abundant room for doubt; many histologists reverse their positions as given above, both as to hair-bearing and function.

hearing cannot be estimated owing to the elasticity of the air, which continues to pulsate long after the cause of the sound has ceased to act.

The minimal intensity has been estimated for all the senses.

The following are some of the results :—

Sense.	Least appreciable stimulus.
Smell . .	$\frac{1}{2,000,000}$ milligramme of an alcoholic solution of musk.
Sight . .	$\frac{1}{300}$ of the amount of light emitted by the full moon, reflected from white paper.
Taste . .	1 part of sulphate of quinine in 1,000,000 of water.
Touch . .	A pressure of ·002 grm.

Smallest appreciable increment of sensation.

The difference in intensity between two succeeding stimuli must have a certain minimal value if the mind is to recognise the one as stronger than the other.

Weber's law may be expressed in several ways, as for instance, "The smallest difference in intensity between two sensations which the mind can discriminate is a constant factor of the sum of the two sensations."

Or, "When the strength of the stimulus ascends in geometrical progression, the strength of the sensation increases in arithmetical progression."

Or, "The sensation varies as the logarithm of the stimulus."

The "shadow test" is the simplest proof of *Weber's* law. Throw two shadows of a given object upon a white surface by two candles placed side by side. Move one candle backwards: the shadow which it throws grows fainter, until at last it cannot be seen. Use two bright lamps, instead of candles, placing them in the first instance in the same two positions as the candles. Move one of the lamps backwards, and note that the shadow which it casts ceases to be visible when it reaches the same spot at which the candle-shadow faded out of view.

However weak or strong the lights used (within certain upper and lower limits), the second shadow always disappears when it only diminishes the illumination of the spot which it covers by $\frac{1}{100}$ of the amount of surrounding illumination.

The smallest fraction of the sum of two stimuli which is recognised as an increment :—

Sense.	Constant.
Sight . .	$\frac{1}{100}$ of the total amount of light.
Hearing . .	Extremely difficult to measure.
Touch . .	$\frac{1}{30}$ of the total amount of pressure.
Temperature .	Varies with the temperature and blood-supply of the skin.
Muscular sense .	$\frac{1}{80}$ of the sum of the two weights.

Characteristics of sensations.

They last for a certain time after the stimulus has ceased to act.

Sensation.	Duration of Positive After-Image.
Smell, Taste, ...	long.
Sight, ...	$\frac{1}{10}$ second.
Sound—	
Musical, ...	$\frac{1}{16}$ second.
Aperiodic, ...	$\frac{1}{500}$ second.
Touch, ...	$\frac{1}{1000}$ second.

This may be expressed in other words as follows: If two consecutive stimuli fall upon a sense-organ without leaving a certain interval of time between them, the two give rise to a single continuous sensation. It will be understood that the length of the interval which must elapse between two stimuli, if they are to give rise to distin-

PLATE XXV.

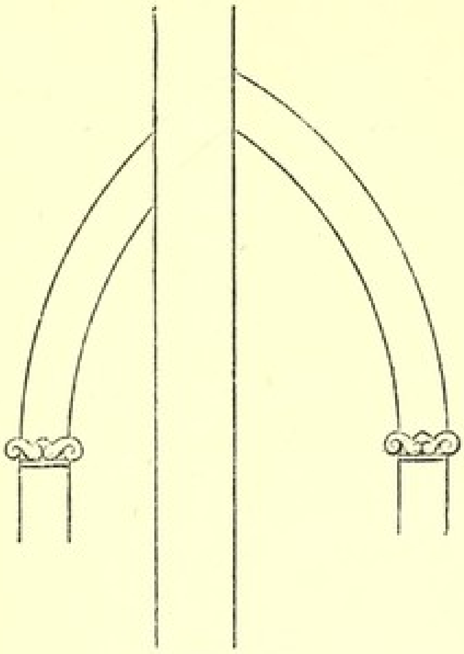

Fig. 65.

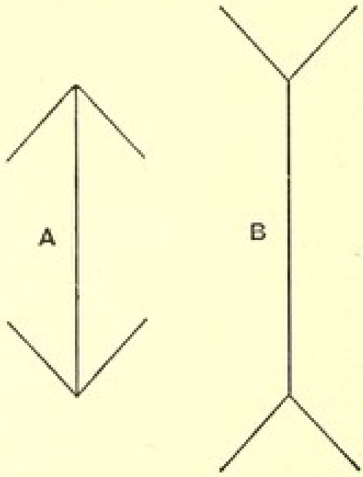

Fig. 66.

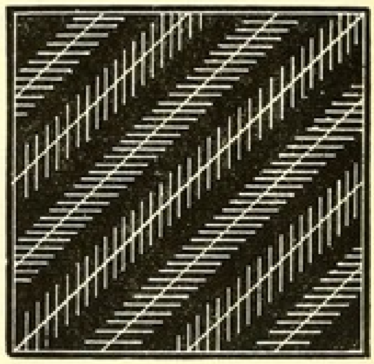

Fig. 67.

FIGS. 65, 66, and 67.—Three diagrams illustrating the way in which our judgment of form may be at fault.

Fig. 65.—A perfect Gothic arch with a vertical line drawn through its apex, and therefore bisecting the arch, and another line parallel to this. The left side of the arch appears to curve-in more quickly than the right.

Fig. 66.—The lines returning from the two ends of the straight line A induce us to believe it to be shorter than it really is; the lines diverging from the ends of B induce us to exaggerate its length. A and B are equal.

Fig. 67.—Parallel lines crossed by oblique lines appear to diverge.

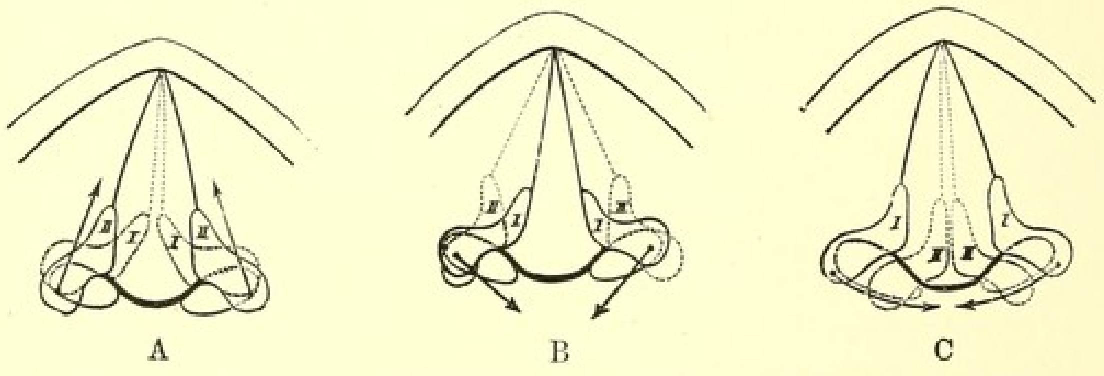

FIG. 68.—Diagram showing the action of the three principal intrinsic muscles of the larynx. A, The arrows are in the lines of action of the M. crico-arytenoidei laterales. They rotate the arytenoid cartilages inwards and diminish the size of the rima glottidis. B, The M. crico-arytenoidei postici rotate the arytenoid cartilages outwards, increasing the rima glottidis. C, The M. arytenoidei proprii consist of transverse fibres, attached to the two arytenoid cartilages. By their contraction they draw the cartilages together, closing the respiratory area of the rima and limiting the space through which the blast of air passes to the slit between the vocal cords. Their action is needed therefore to prepare the larynx for the production of voice.

[*To face p.* 143.

guishable sensations, depends upon (*a*) the force of the stimuli, and (*b*) whether or not they appeal in exactly the same way to exactly the same part of the sense-organ.

The slowest vibration which gives rise to the sensation of a musical note is variously estimated at from 4 to 30, whereas the noise made by electric sparks which follow one another with a rapidity of 500 to the second, is recognised as a rough (or interrupted) sound.

Stimulation fatigues a sense-organ. The consequence is that if a neutral field is then presented to the organ, the part of the field which appeals to apparatus in the sense-organ which is already tired appears to have qualities the reverse of those to which the organ has already responded.

Negative image or successive contrast. After gazing for some time at a black patch upon a white field, look at a plain surface and note that a white patch appears upon it. After looking steadily at a red object, raise the eyes to the ceiling and note that an image of the object appears in green.

Negative images are also obtained when the eyes are shut. Focus carefully for some time a particular spot on a window-frame and then shut the eyes; the frame appears in white upon a black ground. This negative image may be converted into a positive image in many ways, by gently pressing upon the eyeballs for instance. The positive or negative image persists for a long time, or the one succeeds the other several times, so that simple fatigue of the sense-organ does not offer a sufficient explanation of the phenomenon.

Pure water tastes sweet after sulphate of magnesia, but the long duration of the positive after-image (due probably to the sapid substance remaining in contact with the tongue) makes it difficult to obtain negative images of taste.

Perceptions are relative, not absolute.

Irradiation. A white square on a black ground appears larger than a black square of exactly equal size on a white ground.

Contrast. White near black looks whiter, red near green looks redder, blue near yellow looks bluer, than they do at a distance from the contrasting colour.

A shrill note appears shriller after a low note; a sweet taste sweeter after a sour taste.

Contrast is most noticeable, however, in perceptions of pressure and temperature. Cool water appears warm to a cold hand, cold to a warm hand. When the finger is dipped in a vessel of mercury, the pressure of the mercury is felt only at its surface, as if the finger were encircled by a ring.

Sensory judgments.

The information which the several senses collect is so widely different in kind that comparisons can hardly be made. It may be pointed out, however, that whereas smells and tastes have no localisation, although the odours which we smell appear to be in the surrounding air and not in the nose, tactile sensations are referred to the surface of the body; vision gives information with regard to the localisation of objects in the outer world and their power of absorbing light (brightness, colour); while sensations of sound are referred to the outer world, but with very little idea of the situation in space of the body which is giving rise to them.

The world as we imagine it v. *the world as it actually is.* Between our concep-

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Wright.—"A Suggestion as to the Possible Cause of the Corona observed in certain After-Images," *Jour. of Anat. and Phys.*, vol. xxvi., part 2, p. 192, 1892.

tion of things and the things themselves several stages intervene, at each of which discrepancies arise: this may be expressed diagrammatically:—

Matter—*force*—sense-organs—*nerve-impulses*—mind.

It will be noted that the sense-organs, even taken collectively, respond to certain forces only, not to all, and the mind therefore receives a partial and not a complete picture of the universe.

Sensory judgments. Sensations convey no information with regard to surrounding objects, except by comparison with our memories of sensations previously received.

A. The mind overlooks imperfections in the sense-picture; *e.g.*, it fills up the gap in the field of vision caused by the blind spot.

The blind spot is filled-in in one of two ways.

(*a*) By "completion" of the field. This is what usually happens. We know what appearance is likely to be presented by the unseen spot, and therefore by a psychical process we replace it in the field.

(*b*) By "contraction" of the field. Draw four noughts and five crosses at regular intervals upon a sheet of white paper, and to the left side of the pattern make a small mark. Look at the mark with the right eye, holding the paper in such a position as will bring the central image on to the blind spot, and then allow the eye to go a little out of focus; the four noughts immediately draw in towards the centre of the pattern, because the mind has not sufficient data from which to complete the picture.

This experiment is of immense importance, as an illustration of the psychology of sensation. We must not imagine that a particular spot in the retina is in connection with a particular mechanism of the brain, the excitation of which in a certain manner produces a certain mental image of the outer world, since we find that while the image upon the retina remains stationary, its counterpart in the mental picture is displaced. The student will apply this illustration in various ways, and express the conclusions which may be drawn from it in various forms. Axiomatically, it may be said that "perceptions have no objectivity until judgment is passed upon them by the mind."

Sensibility is by no means uniformly distributed over the skin, but on the contrary it is localised in certain spots which may be discovered by investigating the surface with a needle, with warm objects, cold objects, &c. These spots do not coincide, but may be distinguished and mapped out as hot-spots, cold-spots, pressure-points, pain-points, and tickling-spots. When, however, the skin is in contact with a flat surface or with warm or cold water, the perception which results is perfectly uniform, because the mind fills in the insensitive areas.

B. Interpretation of perceptions by comparison with memories of perceptions obtained through the same sense.

The taste of sapid substances only obtains a psychical meaning when it is compared with other tastes of similar quality; it is then classed with those which it most nearly resembles as bitter, sweet, sour, or saline.

C. Interpretation by comparison with sensations obtained through different sense-organs. It is by such comparison that sensation gives the most information concerning the nature of surrounding objects, *e.g.*,

a. The image upon the retina lies in a single plane, and yet we see the objects as hollow or solid, because we associate the appearance they present with investigations made by the sense of touch.

In monocular vision we *judge of solidity* by the incidence of shadow.

In binocular vision we conclude that when the images upon the two retinæ do not exactly coincide, one eye is regarding the object from one side, the other from the other. If a photograph, taken with the camera in the position of the right eye, is mounted beside another photograph taken with the camera in the position of the left eye, and the two pictures are then brought on to corresponding points on the two retinæ, the effect upon our sensorium is the same as if we actually looked at a reproduction of the view in three dimensions instead of upon a flat surface. Some persons can effect the superposition of the two pictures without the aid of any apparatus, but for most people it is necessary that the visual axes should be allowed to converge. This is accomplished by the aid of the stereoscope, an apparatus containing two prisms, so placed that while the pictures are straight in front of the two eyes, the eyes converge in looking at them. The realism of the effect is enhanced by looking at the pictures through magnifying glasses.

The alterations in accommodation necessary to focus the different parts of a solid object aid our judgment of its form, but it appears to be solid even when illuminated by an electric spark. This shows that the mind can resolve into a single picture images which do not fall upon corresponding points of the two retinæ.

Judgments of distance and size. We judge of the distance of an object from the eye by (*a*) the angle at which the eyes converge, (*b*) the clearness of image, and (*c*), if we have reason to know its actual dimension, by the size of its image upon the retina.

Conversely, we judge of the size of an object by the size of its image upon the retina, combined with our knowledge of its distance.

Opera-glasses and telescopes, by increasing the size of the image, and in consequence our power of examining it in detail, appear to bring the object nearer to us.

The distance from the body of the source of a sound is estimated by the loudness of the sound, as compared with its known loudness when close at hand.

The power of localising a tactile sensation is the result of a long process of education, vision and muscular sense being used to discover the spot upon the skin which is being stimulated.

Our power of localising sounds is very limited. Sounds are located upon the one side or the other side of the head, according to the degree to which they affect the two ears respectively. If when the eyes are shut two coins are clicked together in the median plain of the head, the subject experimented upon is just as likely to refer the sound to the back of the head when it is produced beneath the chin, as to place it correctly.

Johannes Müller's law of the "specific energy of nerves":—

That nerves of special sensation are only capable of carrying their customary (specific) impulses?

Pro. It is asserted that direct stimulation of the optic or auditory nerve by electricity or the knife always gives rise to a sensation of sight or hearing, as the case may be, but never of pain. This is, however, denied.

Con. 1. Excessive stimulation of any sense-organ is distressing although it is very difficult to say whether the discomfort produced by brilliant light or violent sound can be properly described as pain.

2. Irritant gases in the nostril or cayenne pepper on the tongue produce an undeniably painful sensation; but possibly they stimulate other nerves in addition to the nerves of smell and taste.

Strictly speaking, the theory cannot be applied to nerves. The business of a nerve is to carry an impulse, whether motor or sensory, specific or general. It is the sensorium which interprets all impulses received through the nerves of special sense, as "specific sensations" or sensations having the character of those usually received from the same source.

The specialised end-organs can only react to their own specific stimuli—the retina to light, the cochlea to sound; and therefore the nerves of special sense have no chance, under normal conditions, of conveying to the sensorium sensations of pain.

In the case of the skin, evolution is still proceeding; nerve-endings are becoming more and more "specific," but they (or at any rate some of them) have not as yet lost all power of responding to other sensations. All stimuli applied with sufficient force to the skin produce pain; and it is possible, under suitable conditions, to deceive the skin into interpreting sensations of heat or cold as sensations of weight, and otherwise confusing its stimuli.

SECTION X.

VOICE AND SPEECH.

Voice, as defined by physiologists, is the sound produced by the vibration of the vocal cords.

The quality (timbre) of the voice depends upon the prominence given to particular overtones by the resonating chambers of the pharynx, nasal meatus and their sinuses, and the mouth.

The resonance of the ventricles of the larynx has a marked effect upon the quality of the voice in certain animals. The ventricles are very large in the howling monkeys (Mycetes).

Speech[1] is (1) the modification of the timbre of the voice by alterations in the shape of the resonating chambers, and (2) the modification of its form by (α) adding to it the sound produced by the passage of the blast through the throat and mouth variously constricted, (β) the blocking of the column of air by the larynx, fauces, tongue, teeth, and lips, and (γ) its aspiration by increasing the initial force of the expiratory effort. It is almost justifiable to term these several additions made to the voice "articulations," since it is owing to them that the segmentation of speech into syllables becomes possible.

Mechanism of the larynx. The vocal cords are two folds of mucous membrane which form the margins of the rima glottidis. Each "cord" is triangular in section; covered by stratified epithelium of moderate thickness; the subcutaneous tissue is free from glands and lymphoid tissue, and consists of a reticulum of areolar connective tissue, containing a very large number of extremely fine elastic fibres; some of the fibres are arranged radially, but the direction of the greater number coincides with the long axis of the cord; they are most numerous just beneath the mucous membrane.

As a vibrating body, therefore, the vocal cord may be compared to a fold of skin which is rendered tense by the distension with lymph of the spaces of the subcutaneous connective tissue, and elastic by the presence, in this pad, of numerous elastic fibres.

In the adult male the vocal cord averages 15 mm. in length, in the female 11 mm. The chief growth of the male larynx occurs at puberty, when the boy's voice "breaks," falling an octave in pitch, owing to the doubling in length of the vocal cord. In producing tones of medium pitch the pressure in the trachea is raised to 160 mm. Hg., for tones of high pitch to 920 mm.

The muscles of the larynx modify (a) the size of the rima glottidis, and (b) the tension of the vocal cords.

[1] When treating of the physiology of speech, or indeed of any other function or mechanism, it is desirable to use terms in a physiological sense, rigidly excluding any suggestion of purpose. Speech being the medium by which ideas are conveyed, it is difficult to exclude from an account of the mechanism of speech, terms which are only applicable to it in its philosophical aspect.

Lennox Browne.—*Voice, Song, and Speech*, London, 1887.
Von Meyer.—"The Organs of Speech," *Intern. Scien. Series*.

The cords are tightened by the contraction of the crico-thyroid muscles, drawing upwards the front of the cricoid cartilage, and so depressing its back, which bears the arytenoid cartilages to which the hinder ends of the vocal cords are attached.

The cords are slackened by the contraction of certain fibres of the thyro-arytenoid muscles, which lie parallel to the vocal cords, and have practically the same attachments (fig. 68).

The thyro-arytenoid muscle does not consist solely of the fibres just described, which run the whole length of the cord. It may be divided into a larger external portion, which arises from the concave surface of the thyroid cartilage and crico-thyroid membrane, and is inserted into the arytenoid cartilage, into the aryteno-epiglottic fold, into the epiglottis (thyro-epiglotticus), and into the wall of the ventricle of Morgagni. This portion has no direct effect upon the tension of the cord; neither do the most external fibres of the internal portion affect its tension, but pass obliquely round the ventricle to be inserted into the false vocal cords. The fibres of chief interest in connection with the production of voice are those which run from the anterior attachment of the vocal cord to the processus vocalis of the arytenoid cartilage; they are isolated or form small bundles, which, on the inner side, become mixed up with the elastic fibres of the cord. It is believed that some of them are attached to particular portions of the cord, and are able, therefore, to relax one part of the cord and tighten the rest, or limit the length of the cord upon which the blast of air acts (Ludwig's portio ary-vocalis).

Falsetto voice is produced with the vocal cords thus divided into internodes (*Oertel*).

Range in pitch of the notes produced by the human larynx; a little less than two octaves on the average for any individual; about three octaves for all classes of voice taken collectively (*i.e.*, for choral music).

Vowel sounds differ from one another, not in the pitch of the note produced by the larynx, but in the quality given to the sound by its overtones. By changing the shape of the oral cavity, the particular overtones which are characteristic of each of the vowels are reinforced.

The pitch of the vowels (*i.e.*, the pitch of their characteristic overtones) may easily be worked-out by singing each vowel in front of a piano, and determining the note on the piano to which it is most easily sung; or, in other words, the note to which the mouth, when shaped for the vowel, constitutes a resonating chamber.

SECTION XI.

CENTRAL NERVOUS SYSTEM.

The study of the physiology of the brain and spinal cord is conducted on lines which diverge widely from those along which an insight has been obtained into the manner of working of other parts of the body. Theories as to the action of the nervous organs are chiefly based upon a consideration of their structure, gross and minute, their development and comparative anatomy. Direct experiment has contributed information as to the fundamental relations of the several parts of the system, but the higher functions of the nervous system can be analysed by introspection only. The subject, therefore, naturally divides as follows:—

A. Structure and development as throwing light upon function.

B. Action.

a. As determined by experiment.

b. As investigated by subjective analysis.

Development.

The earliest changes in the fertilised ovum are connected with the formation of the nervous system.

By successive division of the single cell within the zona pellucida is formed a "mulberry mass." Owing to the accumulation of fluid within the ovum, a single layer of cells (primitive ectoderm) is spread out as a lining to the inner surface of the zona pellucida; the rest of the cells (primitive entoderm) adhere to the deep surface of this layer throughout a certain region, the "embryonic area." Over this area the ectodermal wall of the hollow sphere is thickened as the blastoderm, while the entoderm (termed as far as the limits of the embryonic area—hypoblast) extends further outwards, and forms eventually a more or less perfect second lining for the sphere (fig. 69).

Gastrulation of the embryo. In Invertebrata, and also in Amphioxus, and to a certain extent in some other members of the Vertebrata, the hypoblast is formed not as just described by delamination, but by invagination. A part of the hollow "morula" is tucked in, and in this way a two-layered "gastrula" is formed, the hypoblast forming the wall of the digestive cavity, the epiblast the outer superficial layer of the body. This is the condition in the hydra and in sea-anemones. It was taught by *Haeckel* that this is the primitive method for the formation of hypoblast, but that the early stages have been abbreviated in higher animals.

Primitive streak and groove. The ectoderm (epiblast) is especially thickened near the hinder end of the pyriform blastoderm, and the thickened ridge extends forwards towards its broader end. This is the primitive streak; a groove on its dorsal surface—the primitive groove. The groove is deepest in front, where it may pierce the blastoderm as the blastopore. The groove is therefore regarded as

Bastian.—"The Brain as an Organ of Mind," *Intern. Sci. Series.*
Bain.—"Mind and Body," *Intern. Sci. Series.*
Luys.—"The Brain and its Functions," *Intern. Sci. Series.*
Ferrier.—"*The Functions of the Brain*," 2nd edition, London.
Mercier.—*The Nervous System and the Mind*," London, 1888.
Victor Horsley.—*The Brain and Spinal Cord*, Griffin, 1892.

an extension of the primitive opening into the gastrula (mouth of the hydra). In front of the patent blastopore it presents a second opening. This anterior opening is known as the neurenteric canal, because it places the neural canal, and the cavity beneath the hypoblast, which afterwards becomes the alimentary canal, in communication. Although it has but a very transitory existence, various tumors and other abnormalities are best explained by supposing that they arise in connection with the neurenteric canal (fig. 70).[1]

Medullary groove and neural canal. The epiblast in front of the anterior end of the primitive streak is raised into two longitudinal folds, the medullary folds; these folds border a groove, the medullary groove. Just within the lips of the folds, the epiblast is thickened to form the series of rudiments of the root-ganglia.

The medullary folds meet one another in the mid-dorsal line, and form a tube which is first closed-in in the posterior cephalic region. From the epithelial wall of this tube the whole of the central nervous system, and also the motor roots of the spinal nerves, are formed. The rudiments for the sensory ganglia are left outside the tube, and the fibres of the posterior roots, as well as peripheral sensory nerves, grow out from the cells which these rudiments contain. In origin, therefore, the nervous system is entirely ectodermal. There are indications of a primitive connection of the neural canal with the hinder end of the permanent alimentary canal (figs. 72 and 73).

Histogeny of the central nervous system.[2]—The cells which form the wall of the neural canal are easily distinguished into two classes :—A. The more numerous cells which serve for the support of the nervous tissue—the spongioblasts—which develop into neurogleial cells; and (B) the mother-cells of nerve-cells or "germ-cells."

A. The spongioblasts form an internal limiting membrane, a radially-disposed supporting tissue for the grey matter, and on the surface of the grey matter a close-set reticulum (velum confine). Through the meshes of the velum confine the nerve-fibres are guided in their course upwards or downwards in the white matter, or outwards towards the periphery.

B. The germ-cells dividing freely give origin to neuroblasts, which take up their position in the grey matter as nerve-cells, a single process of each of which constitutes the axis-cylinder of a peripheral nerve-fibre.

The origin of the cells which form the coverings for the nerves—the myelin-sheath and sheath of Schwann—is, as yet, involved in obscurity.

Formation of the posterior roots.—The cells of the ganglionic rudiments already described give origin to two processes, which arise at first from opposite poles of the cells. After a time the two processes are bent together, so that the cell of the ganglion is connected with the sensory nerve by a short handle which joins it at right angles. By this arrangement the nerve-cell is able to preside over the nutrition of the fibre without its being necessary for impulses to pass through the cell. The posterior root grows into the embryonic cord, but it is uncertain how much tissue is introduced into the cord with the root. The fact that the same artery supplies spinal ganglion and substantia gelatinosa is suggestive of the immigration of the latter, at any rate, from the ganglionic rudiment.

Further development of the spinal cord.—The rapid enlargement of the grey matter and the addition to its surface of the white columns changes the shape of the cord from an oval tube to its characteristic bilateral form.

At the fourth month the hinder end of the cord ceases to develop, and from

[1] Bland Sutton.—"The Relation of the Central Nervous System to the Alimentary Canal," *Brain*, vol. x. p. 429, 1888.

[2] For a detailed account of recent researches, see Obersteiner and Hill, *Central Nervous Organs*, 1890, p. 28 *et seq.*

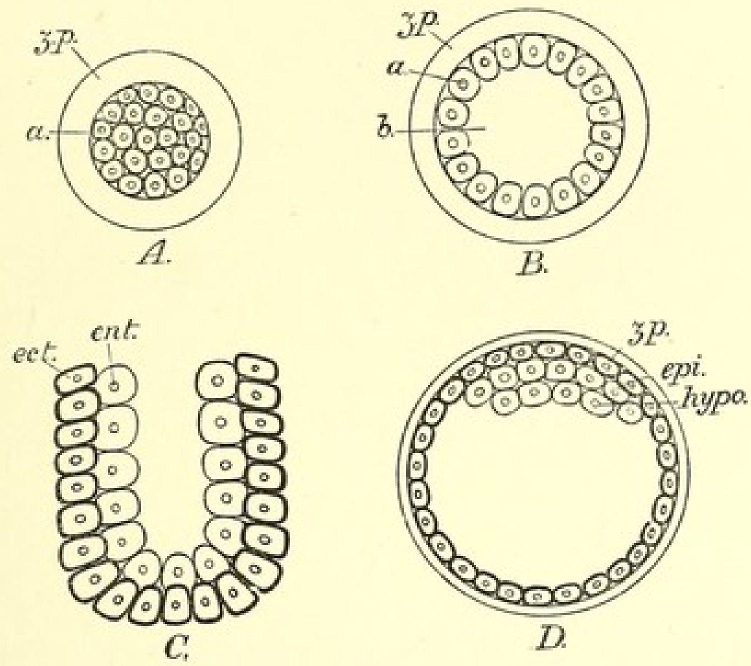

FIG. 69.—Diagrams illustrating the phylogenetic meaning of the earliest stages in the development of a holoblastic ovum. A, The morula formed by subdivision of the cell-contents of the ovum; *a*, a cell of the "mulberry mass;" *zp*, the zona pellucida. B, The disposition of the cells of the morula in a single layer beneath the zona pellucida owing to the accumulation of fluid in the centre of the morula. C, Gastrula produced by the pitting-in of the hollow morula; *ent*, entoderm; *ect*, ectoderm. D, The corresponding stage in the vertebrate embryo in which the hypoblast, formed by the growth of the cells about the blastopore, is disposed beneath the epiblast in the embryonic area. Hypoblast corresponds to entoderm, epiblast to ectoderm, but the pitting-in is only represented by the primitive groove.

To face p. 150.]

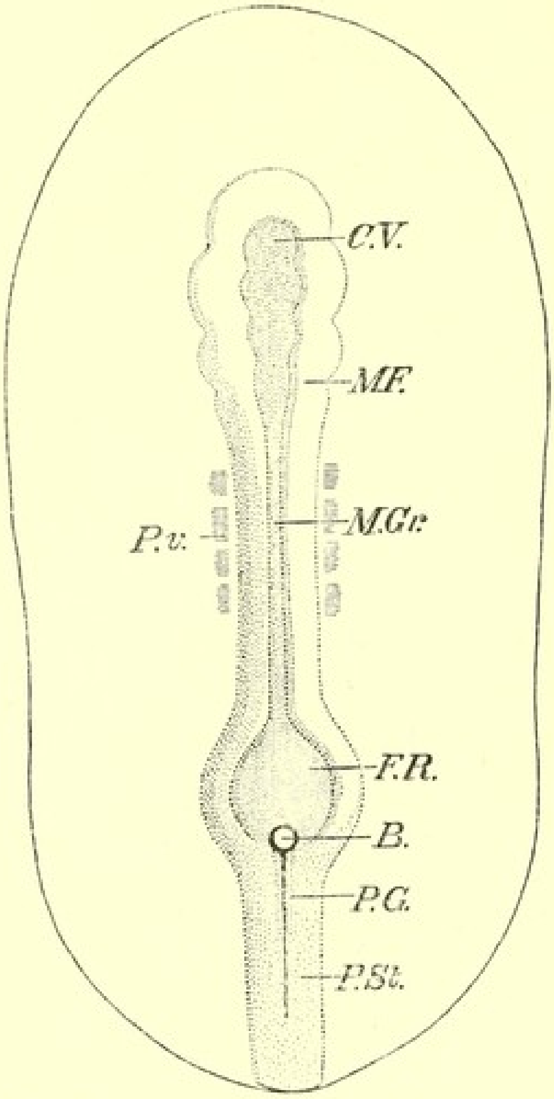

FIG. 70.—Diagram showing the earliest stages in the development of the embryo. P.St., The primitive streak ; in its centre, P.G., the primitive groove perforating the blastoderm at B, the patent blastopore. The whole of the primitive groove is the homologue of the mouth of the gastrula ; it extends along the whole length of the medullary plate and does not end at B as shown in the diagram. Throughout the greater part of its extents its lips are in apposition, but an aperture is left between them at B, and again in front of B they separate to form the neurenteric canal. Blastoderm and neurenteric canal are, in mammals, usually represented by columns of cells, not by holes. The mesoblast grows from the margin of the primitive groove ; F.R., fossa rhomboidalis ; M.Gr., medullary groove ; M.F., medullary folds ; C.V., cerebral vesicles ; P.v., protovertebræ.

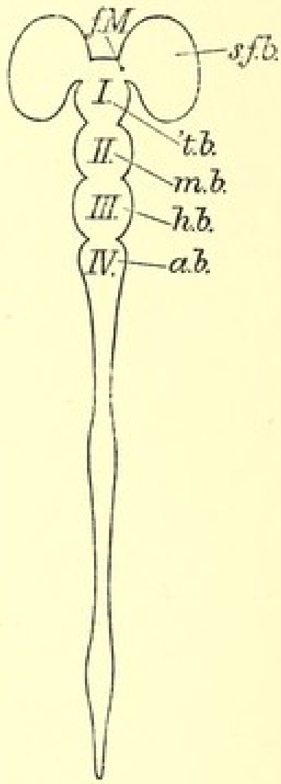

FIG. 71.—The primitive central nervous system. I, II, III, IV. The cerebral vesicles, *f.*M., foramen of Monro, by which the *s.f.b.*, the secondary fore-brain, communicates with *'t.b.*, the 'tween-brain ; *m.b.*, the mid-brain ; *h.b.*, the hind-brain ; *a.b.*, the after-brain.

this time forward the nervous structures in the cord become more and more concentrated towards its anterior end, until at birth the vertebral canal from the third lumbar vertebra downwards contains only the undeveloped portion of the cord (filum terminale) and the nerves (cauda equina) which issue from the lumbar and sacral intervertebral foramina (p. 160).

Further development of the brain.—At its anterior end the neural tube is dilated into four vesicles. Only in the case of the second cerebral vesicle is the roof developed into nerve-substance, forming the corpora quadrigemina. The roof of the first vesicle remains ependymatous as the velum interpositum; the roof of the third and four vesicles as the vela medullaria anterior et posterior. The cerebral hemispheres are not formed from any part of the primary neural tube, but from a vesicle, the secondary fore-brain, which grows out of the anterior cerebral vesicle. This quickly divides into two separate vesicles, which are continuous with the olfactory tracts (rhinencephala). The outer wall of the secondary fore-brain becomes the cortex cerebri, its floor the corpus striatum. The corpus callosum breaks across from one hemisphere to the other at a later date. The fornix is a thickening in the margin of the aperture (the foramen of Monro), by which the cavity of the secondary fore-brain (lateral ventricle) communicates with the cavity of the primary fore-brain (third ventricle) (figs. 71 and 78).

Histology.—According to the most recent view of the minute anatomy of the central nervous system, it consists of cells (originally neuroblasts), from each of which grow one process which becomes medullated at some little distance from the cell—the axis-cylinder process, and a number of dendritic "protoplasmic processes." The axis-cylinder process or nerve-fibre passes without segmentation from the cell in the central system to its distribution, whether in a muscle or within some other part of the cerebro-spinal axis. At its termination it separates into a brush of non-medullated processes which bear nuclei—the nerve-nuclei of an end-plate, and "granules" of the cortex cerebri and cortex cerebelli. Such a cell-system (excluding the nuclei of the brush) has been termed by *Waldeyer* a neuron.[1] The neurons belong to three categories:—A. Those of which the cells lie in the cortex and the fibril-brush in the grey matter of the cord. B. Those of which the cells lie in the grey matter of the cord and fibril-brush in a motorial end-plate. C. Those of which the cells lie in the central grey matter of the cerebro-spinal axis, and the fibril-brush in this grey matter at some other level, or else in the cortex.

The position in the system of the third class of neurons is the most doubtful, since (*a*) many sensory fibres which enter the cord ascend for a long distance in the postero-mesial column without branching; and (*b*) the mode of commencement within the grey matter of the intra-axial fibres, which carry impulses to other parts of the system, has not yet been determined. Studies in invertebrate histology seem to prove that they commence in a plexus, and do not start from cells.

Certain efferent fibres join distributive (sympathetic) ganglion-cells, in which one medullated fibre is suddenly converted into a number of non-medullated fibres.

Afferent (sensory) fibres are processes of the cells of the spinal ganglia. They either branch at once in the central grey matter, or run for a longer or shorter course within the white columns.

The position in the scheme of the cells of Clarke's column, which have few if any protoplasmic processes, is uncertain.

The grey matter as a labyrinth of conducting paths.—Until recently physiologists regarded the dendritic processes of the cells in the grey matter as

[1] See "Abstracts of Current Nerve Anatomy and Physiology," *Brain*, winter number, 1891, p. 567.

forming a network of alternative paths for the distribution of sensory impulses to appropriate motor mechanisms.

Difficulties. 1. An actual anastomosis between the processes cannot be demonstrated. The grey matter seems to be a felt-work rather than a network. 2. Sections prepared by *Golgi's* method (bichromate of potassium, followed by nitrate of silver or chloride of mercury) seem to show that the protoplasmic processes may join neurogleial cells, and otherwise behave as if they were not nervous but nutritive only—the roots by which the cells obtain supplies of food; and, on the other hand, *Golgi* believes that he has demonstrated the existence of fine fibrils ("collaterals") which leave both motor and sensory fibres at right angles, and enter into the formation of a plexus, which would answer to the physiological necessities of the case.

Per contra. Golgi's conclusions must not be hastily accepted, since his method of impregnation effects a precipitation of chromate of silver in the lymph-paths around the cells and their processes, and it has yet to be proved that this precipitation, which surrounds indifferently the nerve-cells and neurogleial cells, never occurs in channels or passages in which no process lies.

SPINAL CORD.

Structure.

The lining epithelium of the spinal canal consists of columnar cells, which send basal processes for some distance into the so-called substantia gelatinosa centralis. The cells are ciliated in lower animals, but it is doubtful whether they retain their cilia in Man. They are not supported by a basement membrane, and in many animals they shade off into the undoubtedly nervous tissue by insensible gradations.

Grey matter, divisible into:—

Substantia gelatinosa Rolandi, the constitution and significance of which is exceedingly ambiguous. It is a conspicuous mass of small cells in the embryo. In the adult it has been described as consisting of small cells of two kinds, (*a*) supporting, (*b*) nervous. It is traversed by fibres of the posterior root.

Substantia spongiosa; contains supporting cells, molecular substance, large and small nerve-cells.

A. Large motor cells, average diameter 100 μ, nucleus 18 μ. Most of these cells lie in the anterior horn, although some cells of large size are found in the processus reticulares. They are divisible into two great morphological groups, (*a*) those which supply the muscles formed from the somites (the skeletal muscles or myotomes), and (*b*) those which supply the muscles derived from the lateral plates (the splanchnic muscles). The cells of the latter group (*b*) constitute the true "lateral horn," which can only be distinguished with certainty in the cervical region, where it gives origin to XI (the spinal accessory nerve), and in the axis of the brain, where it gives origin to VII and the motor division of V.

The large motor cells are also arranged in a number of nuclei which belong to separate muscles or groups of muscles.

B. Cells of Clarke's column; lie with their long axes in the direction of the long axis of the cord. Average size 50 $\mu \times 100\ \mu$, or rather less. They give off few, if any, protoplasmic processes, and are for the most part bipolar. Their upper process passes into the direct cerebellar tract

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Hill.—*Plan of Central Nervous System*, Cambridge, 1885. Hunterian Lectures, 1883–4, reported in *Brit. Med. Journal.*

Mott.—"Microscopical Examination of Clarke's Column in Man, the Monkey, and the Dog," *Jour. of Anat. and Phys.*, vol. xxii. p. 479, 1888.

(*Lockhart Clarke* showed that the process takes this direction). Since these cells are only found in the vagus nucleus, thoracic, and upper lumbar region, and in the sacral nucleus of Stilling (S 2 to S 4), it has been inferred that they give origin to the medullated visceral fibres, which leave the cord in these situations (*Gaskell*). Their apparent connection with the cerebellum has not been explained.

C. Intermedio-lateral cell-column, lying near the outer border of the grey matter, in the bay between the anterior and posterior horns, and composed of small fusiform cells. This column is distinguishable in the dorsal region only, and may perhaps be connected with the vaso-constrictor and other katabolic visceral fibres which are connected with this part of the cord (*Gaskell*).

D. Fusiform cells, about 18 μ in long diameter, which lie in the posterior horn beneath the substantia Rolandi.

E. Cells, intermediate in size between D and A, are scattered throughout the grey matter.

Connection with the cord of the roots of spinal nerves.

A. The large fibres of the anterior roots are the axis-cylinder processes of large cells, which are grouped in the cord near the plane of exit of the fibres. Some fibres come from cells in the anterior horn of the opposite side, *via* the anterior commissure.

B. Small medullated fibres of the ramus visceralis accompany both anterior and posterior roots, but chiefly the latter.

C. The connection of the posterior roots with the cord is hardly understood.

They are nourished by the cells of the root-ganglia, and do not terminate in the segment of the cord which they join.

1. This is well seen in the case of the sensory division of V, which spreads for a long distance up and down the grey matter, instead of joining a localised nucleus. Motor nerves start from "nuclei"; sensory fibres spread both up and down on the inner and outer sides of the grey matter.

2. When a posterior root is cut, the portion of the nerve which is separated from the ganglion, whether on its proximal or its distal side, degenerates (*Waller*).

Max Joseph has shown that a few of the fibres which pass through the ganglion die when the nerve is cut on the distal side of the ganglion; these fibres therefore have their nutrient cells farther afield than the ganglion.

The degenerated fibres can be followed throughout the whole length of the column of Goll.

The lateral portion of the root, which consists of smaller fibres, spreads up and down the caput cornu posterioris in the boundary zone of Lissauer.

The coarser fibres of the mesial portion curve through the root-zone of Burdach's column, but do not at once enter the grey matter. They assume a longitudinal course in Burdach's column, and either return to the grey matter at an anterior level, or inclining inwards into Goll's column, place themselves on the outer and ventral side of those fibres which have already joined this column from the more posterior roots.

Connection with the grey matter of the fibres of the white columns.

1. Certain fibres of the posterior root do not join the grey matter of the cord, but ascend in Goll's column. It may be, however, that they are connected with

Reid.—"Relations between the Superficial Origins of the Spinal Nerves from the Spinal Cord and the Spinous Processes of the Vertebræ," *Jour. of Anat. and Phys.*, vol. xxiii. p. 341, 1889.

Tooth.—"On the Relation of the Posterior Root to the Posterior Horn in the Medulla and Cord," *Jour. of Phys.*, vol. xiii., Suppl. No., p. 773, 1892.

the grey matter by collaterals (*Golgi*). It is generally supposed that instead of ascending without interruption to the cortex, they enter the grey matter of the nuclei funiculi gracilis et cuneati.

2. The fibres of the direct cerebellar tract are regarded as continuations of axis-cylinder processes of the cells of Clarke's column.

3. Whether or not the remaining intra-axial ascending fibres commence in cells is unknown. The direction in which they degenerate indicates that their neuroblasts lie at their lower ends.

4. How the descending fibres are connected with the grey matter is unknown; but it is probable that they break up into a plexus in the grey matter, and also that they divide while in the white columns, their branches joining the grey matter at different levels.

The white matter of the cord consists of shorter and longer longitudinal fibres. The shorter the fibres the nearer they lie to the grey matter. With the apparent exception of the direct pyramidal tract, descending fibres lie nearer the grey matter than do ascending fibres.

> *Size.* The fibres of Goll's column are very fine; those of the direct cerebellar tract are coarse; in other regions fine and coarse fibres are mixed together.

The situation and extension of the several tracts which the cord contains have been traced by the following methods:—

A. Observation of the time at which the fibres acquire a medullary sheath (*Flechsig's* method). When they are first laid down the fibres are destitute of medullary sheath, and have therefore a pinkish-grey colour. They acquire a sheath in the order in which they come into function, *i.e.*, as impulses begin to pass along them. This gives to the tract a glistening white appearance, by which it can be traced. It is obvious that sensory or ascending tracts must convey afferent impulses to the grey matter before efferent impulses can be discharged into motor tracts.

> *Order of myelination.* Posterior and anterior root-fibres; ground-bundles; the mixed lateral zone and Gowers' column; Goll's column; lateral cerebellar tract; and lastly the pyramidal tracts, in Man, at the time of birth.
>
> This sequence indicates that root-fibres come into function first; then commissural fibres uniting neighbouring regions; lastly, long commissural fibres.

B. Observation of the course of degenerations, whether (*a*) produced by section (the Wallerian method), or (*b*) occurring as the result of disease.

C. Determination of the tract along which the negative variation produced by passing a current into the columns at some other level, or into the cortex, is chiefly conducted (the method of Horsley and Gotch).

Can any of these fibre-columns be regarded as pure columns in the sense of containing only fibres which, having once joined an ascending column, are continued to its upper limit; or in the case of the descending columns, can we say that all the fibres which they distribute to the grey matter have come from the brain?

> *Con.* 1. When the cord is divided, a very extensive degeneration is found in the segments near to the lesion, both above and below it. This

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Turner.—"On Hemisection of the Spinal Cord," *Brain*, vol. xiv. 4, p. 496.

Mott.—"Results of Hemisection of the Spinal Cord in Monkeys," *Roy. Soc. Phil. Trans.*, 1892, B., p. 69.

Tooth.—"Secondary Degeneration of the Spinal Cord" (*Gulstonian Lectures*), Churchill, 1889.

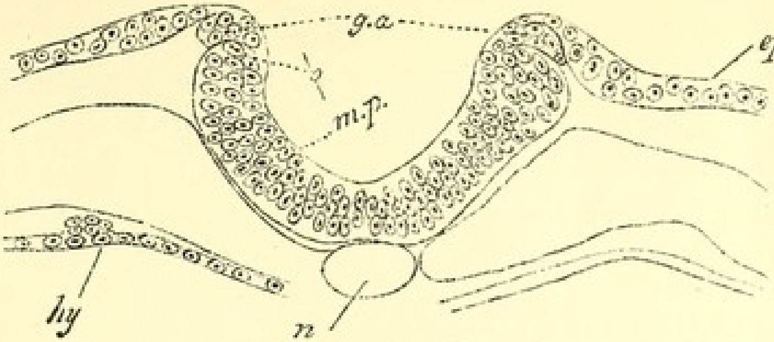

FIG. 72.—Transverse section through the blastoderm before the union of the medullary folds. *n*, The notochord; *hy*, hypoblast; *mp*, medullary plate; *ga*, the rudiments of the spinal ganglia; *ep*, epiblast.

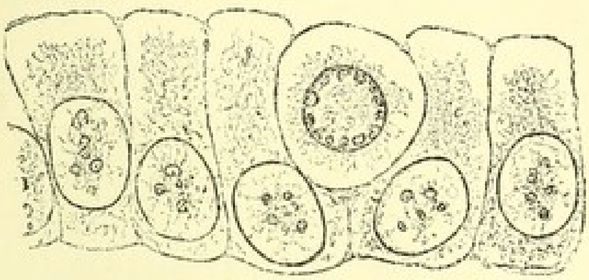

FIG. 74.—The earliest differentiation in the wall of the neuro-epithelial tube, at this time only one cell thick. A single germ-cell, which will afterwards become a neuroblast, lies in a group of spongioblasts.

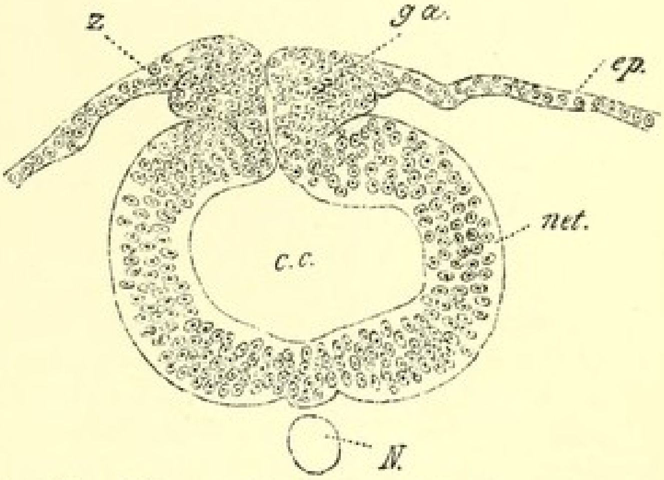

FIG. 73.—The neural tube formed by the meeting of the margins of the medullary plate. N, Notochord; *cc*, central canal; *net*, neuro-epithelial tube; *ga*, rudiment of spinal ganglion; *ep*, epiblast.

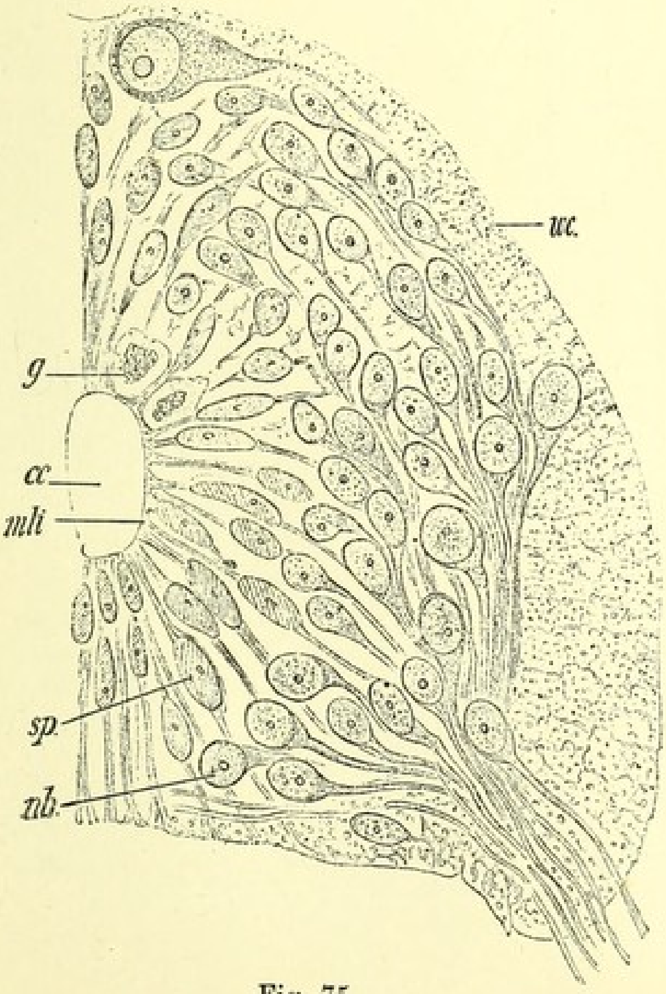

FIG. 75. — The histogenetic changes by which the neuro-epithelial tube is converted into the spinal cord. *cc*, Central canal; *mli*, membrana limitans interna; *g*, germ-cell; *sp*, spongioblast; *nb*, neuroblast; *wc*, white columns, the supporting tissue of which is a close net-work formed from the ramifications of the outer segments of the spongioblasts.

Fig. 75.

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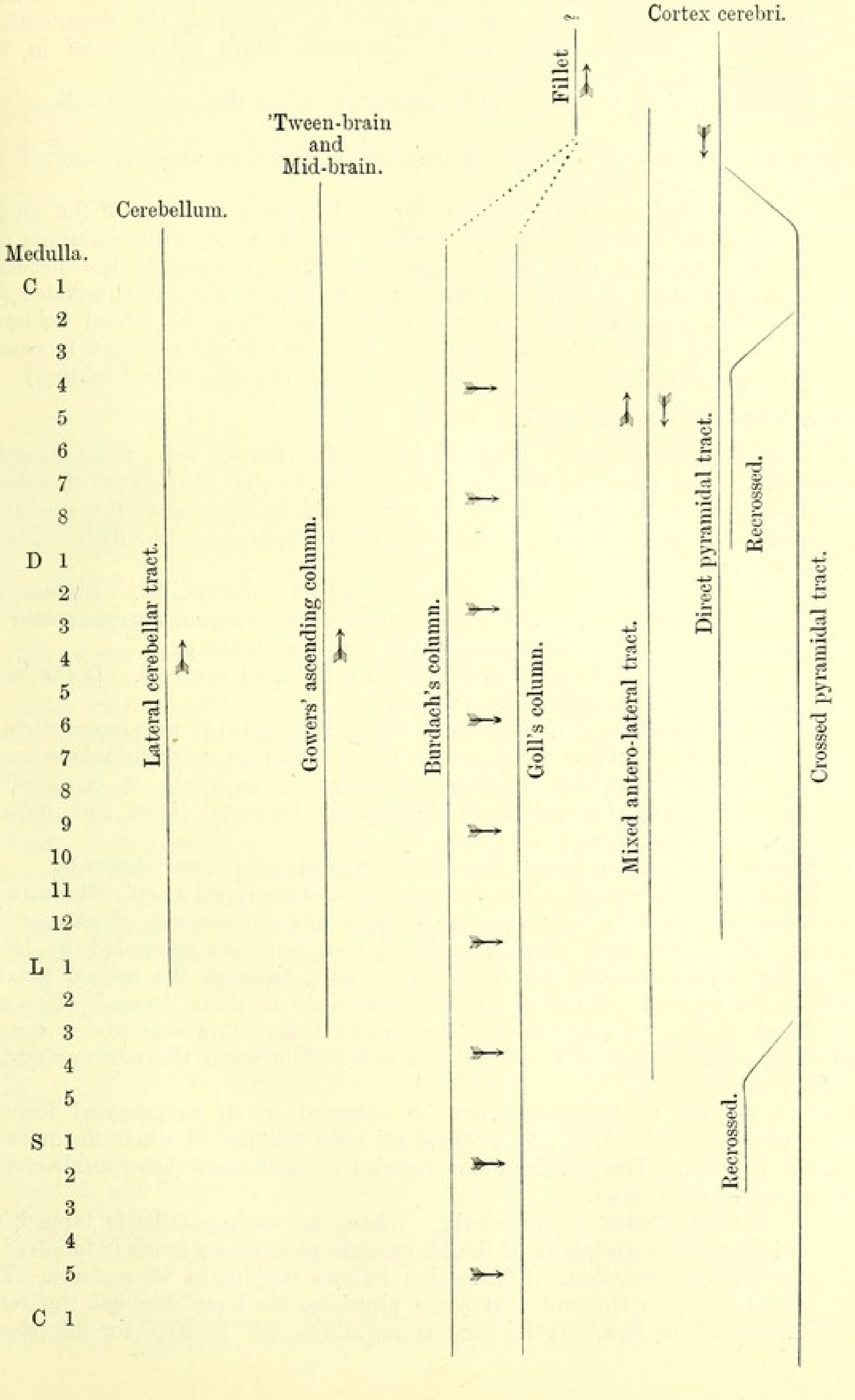
TABLE

Showing the Extension within the Central Nervous System of the Chief Tracts of Fibres.



gradually segregates into the long columns, but the degeneration dwindles as it is followed, even up Goll's column or up the direct cerebellar tract.

2. The degeneration produced by destruction of the "face-area" in the cortex does not stop short at the medulla; that resulting from destruction of the "arm-area" does not stop short at the cervical enlargement; and when only the "leg-area" is destroyed, the degeneration dwindles gradually, many more degenerated fibres being found in the cervical than in the lumbar region.

Do sensory impulses travel up their own side or up the opposite side of the cord?

Brown-Séquard taught that afferent impulses cross to the opposite side of the cord soon after entering it.

Con. Horsley and *Gotch* have shown that when a portion of the cord is isolated and a current is passed through its lower end, while its upper end is in connection with a galvanometer:—80 per cent. of the negative variation which results from stimulation travels up the side stimulated (60 per cent. ascending the posterior and 20 per cent. the lateral column), while only 20 per cent. crosses to the opposite side (15 per cent. to ascend the opposite posterior column, 5 per cent. the opposite lateral column).

Functions of the spinal cord.

A. *Control of metabolism.* The belief that the nervous system has a trophic action—that apart from its influence in leading to the production of specific metabolites (secretions, &c.) it maintains the proper balance between assimilation and dissimilation, and so maintains the vitality of the tissues—is chiefly based upon clinical evidence.

Pro. 1. Disease of the cord is followed by bed-sores, &c. Disease of a nerve frequently leads to the appearance of an eruption (herpes zoster) or other indication of disturbance in the nutrition of the skin.

2. If the dorsal cord is divided the animal recovers. If the lower segment is destroyed the animal dies.

Difficulties. 1. Lesions of the C.N.S. lead to vaso-motor disturbances. 2. They put a stop to those conscious or unconscious movements by which injurious pressure is avoided; it is therefore practically impossible to distinguish between direct and indirect trophic actions.

B. *Reflex action*, or the transit of afferent impulses into motor channels.

a. Reflexes of adjustment. These are the most stereotyped of all reflex actions. The position of the body is maintained by incessant contractions of antagonistic muscles. When the body appears to be at rest, impulses generated by forces acting upon it from without are ceaselessly passing through the central nervous system to the muscles, producing rippling variations in their "tone." The sensitive hand of the "thought-reader" recognises these vibrations under normal conditions, whereas they only make themselves visible when the nervous system is unduly excitable.

Certain reflexes of adjustment can be obtained in an exaggerated form in healthy people by a kind of ruse; others are only obtainable when the nervous system is diseased. The patellar reflex belongs to the former class; ankle-clonus, jaw-jerk, &c., to the latter.

Patellar reflex or knee-jerk. When the tendo patellæ is tapped, the slight sudden stretching of the M. quadriceps extensor cruris is followed by its reflex contraction. Contraction follows tapping in ·03 seconds. This is so short an interval that some physiologists have doubted the reflex nature of the jerk, but the time named allows ·01″ to ·015″ for the passage of the grey matter; a delay which is amply sufficient if we suppose that, for this fundamental and inevitable reflex, afferent and efferent tracts are always, to use an electrical expression, "switched-on."

Does the afferent impulse originate in the spot tapped?

Con. The knee-jerk occurs when the nerves to the tendon are cut, and therefore the afferent impulse probably originates in the muscle.

b. Protective reflexes. The afferent impulses for these reflexes originate in the organs of special sense or in the skin, whereas those of class *a* originate chiefly in tendons and muscles. Amongst protective reflexes must be classed:—(*α*) holding the breath and closing the glottis in the presence of noxious vapours, starting at a flash of light or at a loud sound, and a vast number of other cases in which warning of danger is given by the special senses; (*β*) movements in response to tickling.

It has been suggested (*Robinson*) that the movements in response to tickling are for the purpose of protecting vital parts, but it may be, on the other hand, that tickling merely stimulates a mechanism which exists for the purpose of relieving pressure and renewing the capillary circulation in parts exposed to prolonged pressure, as the soles of the feet, palms of the hands, folds of joints, ribs pressed against the arms when sleeping, &c.

c. Visceral reflexes. Afferent impulses from the viscera do not, as a rule, awaken consciousness. They flow over into efferent channels, and induce appropriate movements, either (1) altogether without our cognisance; or (2) we know what is happening only through the change in the pressure exerted by the viscus on surrounding sensitive structures; (3) the afferent impulses from the viscus may give rise to a "massive" sensation.

The sensory connections of the viscera.

Sherrington has shown that sensory nerves overlap one another in their cutaneous distribution. To such an extent is this the case, that the division of a single posterior root never destroys sensibility to touch or pain in any region of the skin. The supply of sensory nerves to the viscera does not keep step with the supply to the skin from corresponding segments of the spinal cord, inasmuch as the cutaneous areas with which the visceral nerves are related do not overlap.

Head[1] has investigated the connection of the afferent nerves of the viscera with the several segments of the spinal cord. He finds that (*a*) the pain which accompanies disease of the viscera is referred to definite regions on the surface of the body; (*b*) these regions are found to be abnormally sensitive, *e.g.*, the head of a pin is mistaken for its point, warm water appears to scald; (*c*) the reflexes obtainable from these sensitive areas are exaggerated. Using these three tests, he is able to associate the sensory sympathetic nerves with segments of the spinal cord as follows:—

[1] Head.—"On Disturbance of Sensation, with especial reference to the Pain of Visceral Disease." *Thesis for the degree of M.D. in the University of Cambridge. About to appear in Brain*, 1893.

Lombard.—"The Nature of the Knee-jerk," *Jour. of Phys.*, vol. x. p. 122.

Bowditch and Warren.—"The Knee-jerk and its Physiological Modifications," *Jour. of Phys.*, vol. xi. p. 25.

Waller.—"Tendon-reflex," *Jour. of Phys.*, vol. xi. p. 384.

Sherrington.—"Note toward the Localisation of the Knee-jerk," *Brit. Med. Jour.*, No. 1628, p. 545.

Edinger (translation), *Structure of the Central Nervous System*, Philadelphia, 1890.

Langley.—"On the Origin from the Spinal Cord of the Cervical and Upper Thoracic Sympathetic Fibres," *Phil. Trans. Roy. Soc.*, vol. 183, B., p. 85, 1892.

The heart,	with	D. 1, 2, 3.
The lungs,	,,	D. 1, 2, 3, 4, 5.
The stomach,	,,	D. 6, 7, 8, 9.
The intestines,	,,	D. 9, 10, 11, 12 (to upper part of rectum).
,,	,,	S. 2, 3, 4 (the rectum).
The liver and gall-bladder,	,,	D. 7, 8, 9, 10.
The kidney and ureter,	,,	D. 10, 11, 12.
The bladder,	,,	D. 11, 12, L. 1, S. 2, 3, 4.
The prostate,	,,	D. 10, 11, 12, L. 5, S. 1, 2, 3.
The epididymis,	,,	D. 11, 12, L. 1.
The testis,	,,	D. 10.
The ovary,	,,	D. 10.
The uterus,	,,	D. 10, 11, 12, L. 1, S. 2, 3, 4.

The absence of any afferent visceral nerves connected with the cervical and upper lumbar regions is to be particularly noted as related to the absence in these regions of rami communicantes, properly so called.

The sensory fibres of the viscera are probably the large medullated fibres (diam. 7 μ to 9 μ) found by *Gaskell* in the sympathetic system, but not connected with either lateral or collateral ganglia. Their distribution, as traced anatomically by *Edgeworth*, exactly coincides with *Head's* physiological results.

MEDULLA OBLONGATA (AFTER-BRAIN).

Structure.—As the spinal cord enters the skull, the several parts of which it is composed undergo certain changes in form and arrangement (fig. 77).

A. *The central canal* opens out into the fourth ventricle.

Object. Every nerve-cell in the spinal cord is surrounded by a bath of lymph. Where, however, very important masses of grey matter, all or any of which are liable to sudden variations in functional activity, are collected together, they are brought, as it were, to the margin of a lake of lymph, over which the pressure due to local turgescence is distributed. This applies to the grey matter of the cortex, as well as to that which bounds the 3rd and 4th ventricles.

B. *The grey matter* of the anterior horns is raised up to the mid-dorsal line (eminentia teres); Clarke's column lies next on the outer side (ala cinerea); the grey matter of the posterior horns, capped with substantia gelatinosa, is most external; the grey matter of the lateral horn, or some of it, is detached from the rest by the crossing fibres of the pyramids, and constitutes the antero-lateral nucleus.

The hypoglossal and sixth nerves take origin beneath the eminentia teres; the vagus, part of the glossopharyngeal, and the nervus intermedius Wrisbergi, from the ala cinerea; parts of the eighth, fifth, and ninth from the external grey matter; the antero-lateral nuclei give origin to the seventh, and to the motor root of the fifth.

In addition to those which form defined nuclei, a great number of large cells are scattered throughout the substantia reticularis of the medulla oblongata.

C. The arrangement and points of exit of *nerve-roots* are altered. Fibres which originate in the lateral horn part company with the anterior roots and come out independently, at first through the lateral column, and more anteriorly between the lateral column and restiform body; XI, VII, Vm. The visceral roots are independent of both anterior and posterior roots, but place themselves beside the latter as X and VII v. (nervus intermedius—chorda tympani).

D. *The posterior columns* are displaced from their dorsal situation to allow of the bringing up of the grey matter to the floor of the fourth ventricle. Their fibres sweep round and through the grey matter as arcuate fibres, and take up their position on the opposite side as the fillet, which lies between the grey matter, the olive, and the pyramid.

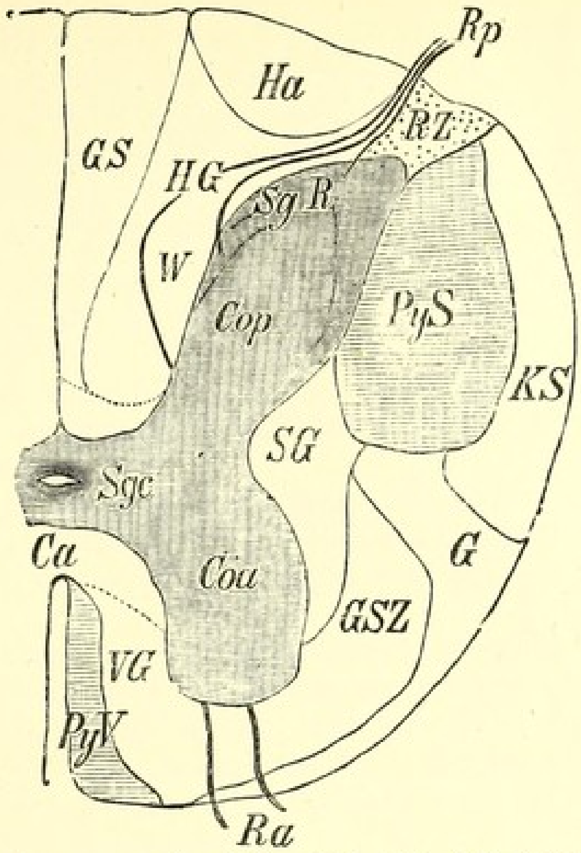


FIG. 76.—Diagrammatic transverse section of the spinal cord. *PyV*, Anterior pyramidal tract; *VG*, anterior ground-bundle; *Ca*, anterior commissure; *Ra*, anterior nerve-roots; *GSZ*, mixed lateral zone; *SG*, lateral ground-bundle; *G*, Gowers' bundle; *KS*, direct cerebellar tract; *RZ*, border zone; *Rp*, posterior nerve-roots; *HG*, ground-bundle of the posterior column, consisting of the root-zone, *W*, and the postero-external tract, *Ha*; *GS*, Goll's column; *Coa*, anterior horn; *Cop*, posterior horn; *Sg.R*, substantia gelatinosa Rolandi; *Sgc*, substantia gelatinosa centralis.

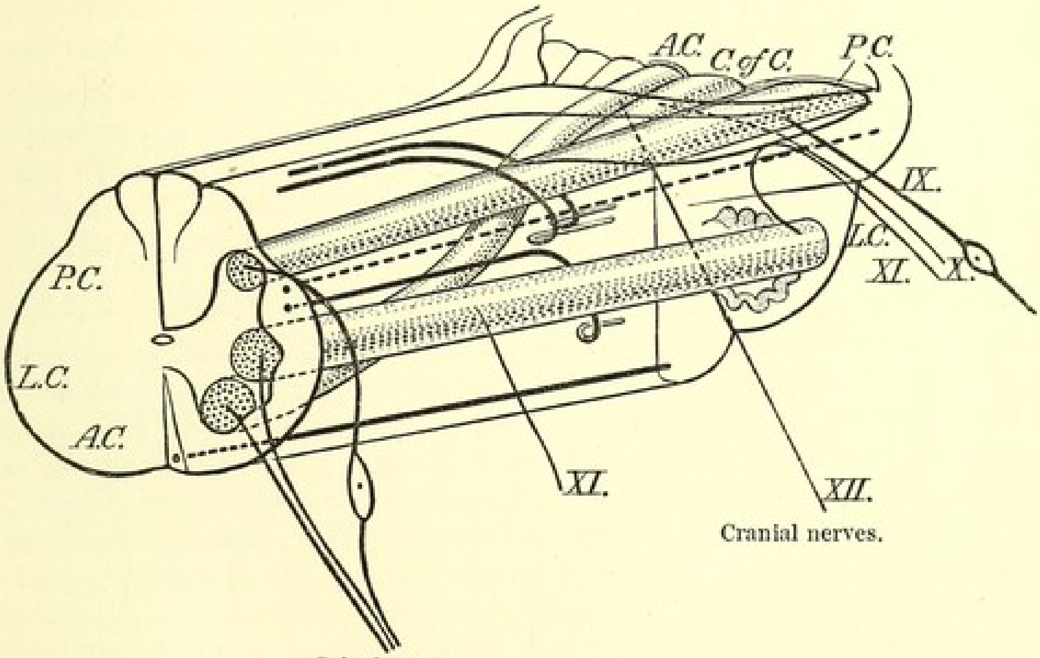


FIG. 77.—Diagram showing the chief transpositions which the several constituents of the spinal cord undergo on entering the medulla. A.C., The anterior cornu (cell-column) of the spinal cord occupies, in the medulla, a mid-dorsal position, and gives origin to the hypoglossal nerve, XII; C. of C., the column of Clarke is absent in the cervical cord (in the medulla, it lies beneath the ala cinerea, and gives origin to fibres of the vagus, X., &c.); L.C., the lateral cornu gives origin, throughout the greater part of the cord, to fibres which accompany the anterior roots (in the upper cervical region, to fibres which take an independent course, as the spinal accessory XI; in the medulla the cell column is detached from the rest of the grey matter, as the antero-lateral nucleus, and gives origin to XI, VII and V*m*). The diagram shows the way in which the fibres of the posterior column curve round, as the external and internal arcuate fibres, to take up their position in the opposite inter-olivary region, as the fillet; the direct (lateral) cerebellar tract (dotted) passes into the restiform body of the same side. The fibres of the crossed pyramidal tract sweep round between the anterior and lateral cornua to the anterior pyramid, where they are joined by the direct pyramidal tract which does not cross.

To face p. 158.]

It is generally thought that a large number of the fibres of the posterior columns end in the two masses of grey matter which stream into these columns from the mesial side of the posterior horn, the nuclei funiculi gracilis et cuneati. Many fine arcuate fibres leave the posterior columns behind these nuclei, others pass through them or take origin within them. From these nuclei numbers of fibres pass into both restiform bodies.

The crossed pyramidal tract unites with the direct pyramidal tract of the opposite side in forming the pyramid. Its fibres traverse the grey matter of the anterior (and lateral) horns.

E. The inferior peduncle of the cerebellum (corpus restiforme) collects from the cord, the direct cerebellar tract, fibres from the posterior columns of both sides, and fibres from the olive.

F. A plicated layer of small-celled grey matter, *the olive* (or inferior olivary nucleus) is intercalated between the anterior and the postero-lateral columns. The fibres which pass out at its hilus traverse the opposite olive, and reinforce the restiform body.

G. In the hind-brain (the medulla oblongata being the "after-brain") the cerebro-spinal axis is reinforced by an immense number of fibres which come from the middle peduncle of the cerebellum, and spread out to form the pons Varolii. Some of these fibres are commissural between the two hemispheres of the cerebellum; others join nerve-cells either on their own side or on the opposite side, and then run forward to the cerebrum.

Functions of the medulla oblongata.—It is the seat of a large number of important reflex actions, of which IX and X are the chief afferent nerves, viz., vaso-constriction, sweating, respiration, sneezing, coughing, sucking, and mastication, secretion of saliva, swallowing, vomiting, closure of the eyelids. Of these reflex actions the first three are carried out by a widely-distributed mechanism, the dominant portion of which alone lies in the medulla.

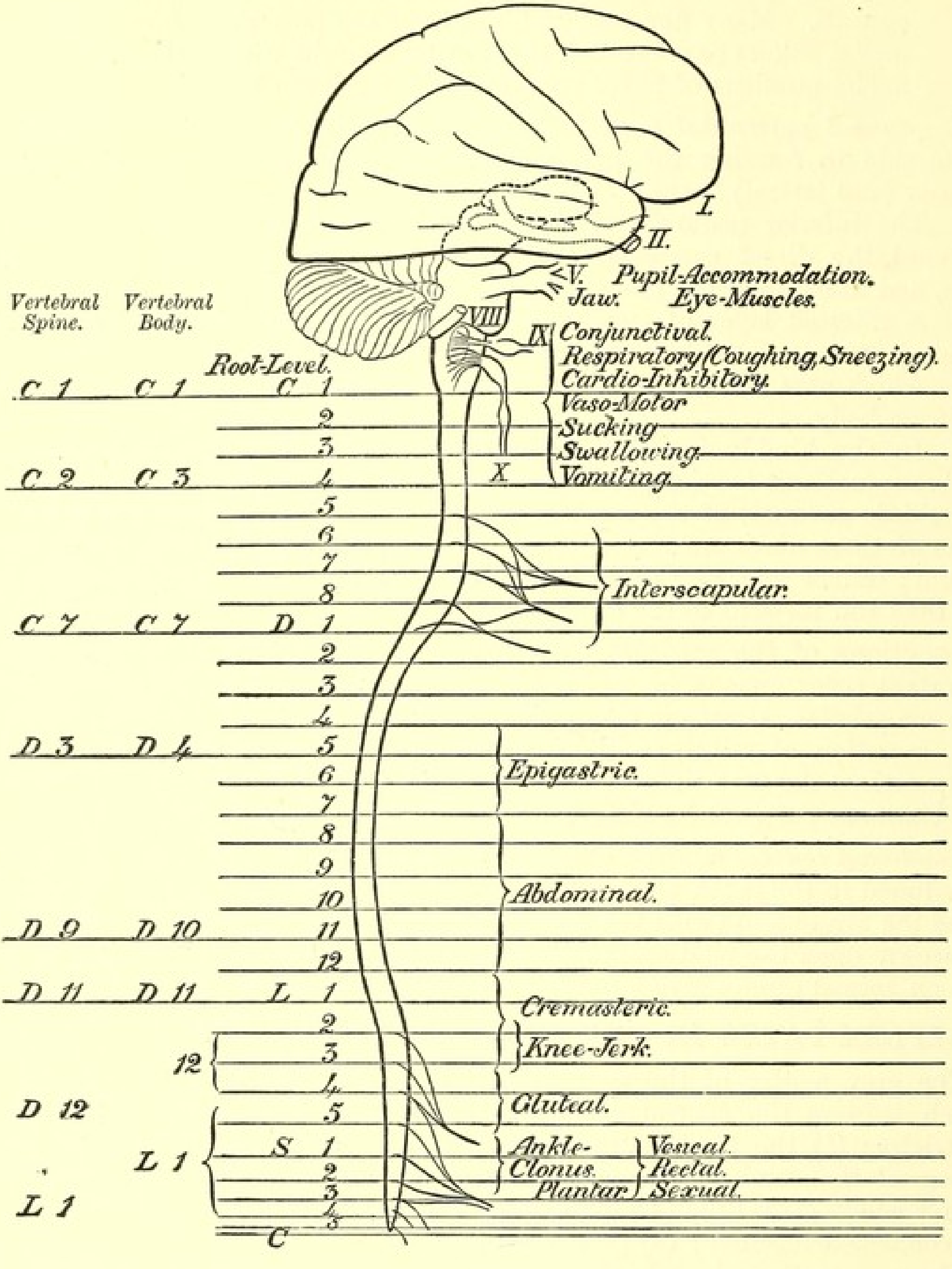
Emotional reflexes are first obtained when the centre for a nerve of special sense is included in the reflex arc. An animal is capable of starting at a loud sound provided the hind-brain (with the centre for the auditory nerve) is left intact. Light is thrown upon the relation between sounds heard and sounds uttered, by the fact that an animal cannot give a reflex cry unless its hind-brain is intact.

REFLEX PATHS IN THE CENTRAL GREY TUBE.

The grey matter of the nervous system is divisible into (*a*) the grey matter which borders the central canal, and its dilatations into the fourth and third ventricles; (*b*) the grey matter found on the surface of the cerebral vesicles—cortex of the cerebellum, corpora bigemina and cerebral hemispheres; (*c*) grey matter which gives origin to intra-axial fibres, by which different parts of *a* and *b* are connected together; (*d*) peripheral ganglia.

The grey matter which borders the central canal contains the nuclei of efferent nerves. These nuclei are connected with afferent nerves by innumerable paths, certain of which are recognisable physiologically as the tracts along which impulses travel when they take part in reflex actions. The condition of the grey matter in its several regions can be investigated by testing reflex conduction. In commencing disease (inflammatory, excitable conditions) it is usually more easy; after destructive changes it is abolished. The possible effect of the disease upon other parts of the system which control the reflex in question must always be borne in mind.

The following Table enumerates the reflex actions which may be tested, to determine the condition of the axial grey matter in the planes through which the reflected impulses pass. It also shows the plane in the cord through which the reflex occurs, and its level with regard to both the bodies and the spines of the vertebræ.



Certain of these reflex actions can only be obtained when the grey matter of the cerebro-spinal axis is abnormally excitable, *e.g.*, ankle-clonus (the repeated jerking forward of the foot after it has been bent-up forcibly towards the shin), gluteal, abdominal, epigastric, and interscapular reflexes (twitchings of the muscles which follow tickling in these regions), jaw-reflex (jerking of the lower jaw when a paper-knife pressed against the molar teeth, is tapped); others are always or almost always obtainable, *e.g.*, the contraction of the cremaster muscle when the skin just below Poupart's ligament, supplied by the genito-crural nerve, is tickled in a boy; the plantar reflex and the knee-jerk.

Inhibition is the restraining of the processes which occur in one part of the nervous system (or in muscular tissue) by the activity of some other part.

Typical. Reflex movements of the hind limbs of a frog take longer to obtain, and are less certain, when the optic lobes are uninjured, than when the axis is divided beneath the optic lobes. A crystal of salt placed upon the lobes increases their restraining power. Quinine administered to the animal acts in the same way, but its action is set aside by dividing the medulla. These experiments appear to indicate that the optic lobes have an active controlling power.

Very many so-called inhibitory actions, however, do not indicate an active restraint, and all other explanations must be excluded before this is allowed.

The central nervous system is functionally united into a whole, and the activity of each part affects the activity of every other part, *e.g.*, during the act of swallowing, the pulse beats more quickly because the cardio-inhibitory reflexes are diminished; sneezing, respiration, micturition, &c., are checked by strong sensory stimulation. If, while the cortex of the rolandic area of the brain is being stimulated by a current which would ordinarily produce a movement of certain muscles, a strong stimulus be applied to a sensory nerve, the cortical stimulation is rendered ineffective; actions which are ordinarily reflex become voluntary when attention is directed to them. Such instances of "inhibition" can be explained by supposing (A) that when impulses are passing through a reflex-path, neighbouring paths are blocked; (B) that if the route towards a higher centre is open, a part of the afferent impulse passes upwards to the higher centre (the amount of the impulse so diverted depending upon the state of attention of the higher centre); whereas, when this ascending route is closed, the whole impulse flows across a reflex-path.

Such conceptions are merely illustrations; the nervous system is not a congeries of reflex-arcs, but a co-ordinated machine. This is well seen in the case of the patellar reflex, which is either augmented or depressed by a great variety of actions and sensations, the effect of which depends in many cases upon the length of the interval which elapses between their occurrence and the tapping of the tendo patellæ.

HIND-BRAIN.

Structure.—The cerebro-spinal axis passes through the pons, which encircles it like a signet-ring. On leaving the pons it divides into the two crura cerebri, which contain many more longitudinal fibres than the medulla. It is clear, therefore, that fibres have been added to the axis while it was within the pons; they probably come from (*a*) the nuclei of the sensory nerves of this region (VIII and V), and from (*b*) the middle cerebellar peduncle of the opposite side. The fibres from the cerebellum having crossed the median line, and formed connections with the cells which are scattered throughout the reticular formation, turn forwards at right angles to their original course. These pontine tracts are added to the inner and outer sides of the crusta. The pyramidal tracts occupy the central portion of the crusta on its ventral side.

The fillet is, as already stated, the continuation upwards of the posterior columns of the cord in the after-brain and hind-brain. It is reinforced by numerous fibres. On reaching the pons it divides into (*a*) a small (peduncular) bundle which joins the crusta on its mesial side; (*b*) the lateral fillet which inclines outwards and upwards to the posterior tubercles of the corpora quadrigemina—to this the name *fillet* was originally applied on account of its appearance on the surface of the crus; and (*c*) the mesial fillet which inclines in a similar way towards the anterior tubercles, although it is not seen on the surface owing to the superposition of the brachia corporum quadrigeminorum and mesial geniculate body. The upper termination of

Waller.—"The Sense of Effort: an Objective Study," *Brain*, 1891.

the fillet is not understood. It seems improbable that it ends in the corpora quadrigemina. When the neural tube is re-formed in the mid-brain, its fibres return to the dorsal position which they occupied in the cord, but their further course to the optic thalamus and internal capsule has not been made out. Numbers of arcuate fibres sweep round from beneath the corpora quadrigemina in the mid-brain, before the aqueduct of Sylvius opens into the third ventricle, exactly as they do in the after-brain where the central canal of the spinal cord dilates into the fourth ventricle.

Posterior longitudinal bundle, a tract of white fibres which lies close to the grey matter on its ventral side in the after-brain, hind-brain, and mid-brain. It conveys impulses connected with the co-ordination of the movements of the eye, ear, and head, &c.

MID-BRAIN.

Structure.—The most primitive part of the brain.

The grey matter constitutes a tube which surrounds the central canal. It contains the nuclei of IV and III. V is also continued upwards into this region.

The root of V tapers as it ascends. Large cells lie beneath it in the grey matter.

IV; the only nerve connected with the dorsal side of the brain, and the most completely decussated of all the nerves, cranial or spinal, takes origin in a group of large cells which lies in the ventro-lateral part of the grey tube.

III arises by numerous roots, of which the anterior are connected with small cells which lie near the back of the third ventricle; these fibres supply the pupillary and ciliary muscles. The posterior roots, composed of fibres which are coarser than those of the anterior roots, join several distinct groups of large cells situate farther backwards. The nucleus for the rectus internus (giving origin to many fibres which cross the middle line) lies nearest to the nuclei for the internal muscles of the eye; the nucleus for the inferior oblique is farthest back.

The corpora quadrigemina contain lenticular nuclei of grey matter. Each *anterior tubercle* is connected with the optic tract. In sub-mammals it is very large (c. bigeminum), receiving the bulk of the tract. In mammals, the main part of the optic tract is connected with the optic thalamus and cortex of the brain.

Function. To distribute visual impulses to the appropriate mechanisms for movement of the eyeball, head, and body.

The white matter is divided by the substantia nigra into (*a*) a dorsal portion or tegmentum which contains the fillet, posterior longitudinal bundle, superior peduncle of the cerebellum, and a large number of longitudinal and arcuate fibres; and (*b*) the crusta which lies on the ventral side of the substantia nigra, and contains certain tracts by which the cerebrum is connected with the lower parts of the axis, viz., (1) in the centre of the crusta, on its ventral side, the pyramidal tract; (2) on the inner side, fibres which can be traced upward into the frontal lobes and downwards into the hind-brain; (3) on the outer side, fibres which reach the parietal, occipital and (?) temporal lobes of the brain; (4) intercalated between the cerebral tracts just named and the substantia nigra, fibres which are limited to the mid- and hind-brain.

CEREBELLUM.

Structure of the Cortex.—It is thin and thrown into folds (folia), which are deeper and more numerous than the convolutions of the cerebral cortex.

The elements of which it is composed are arranged in regular layers. A single sheet of large cells (cells of *Purkinje*) is placed between the outer (molecular) and inner (granular) layers. The peripheral processes of the cells of Purkinje branch like the boughs of a tree in the molecular layer. The "granules" are minute

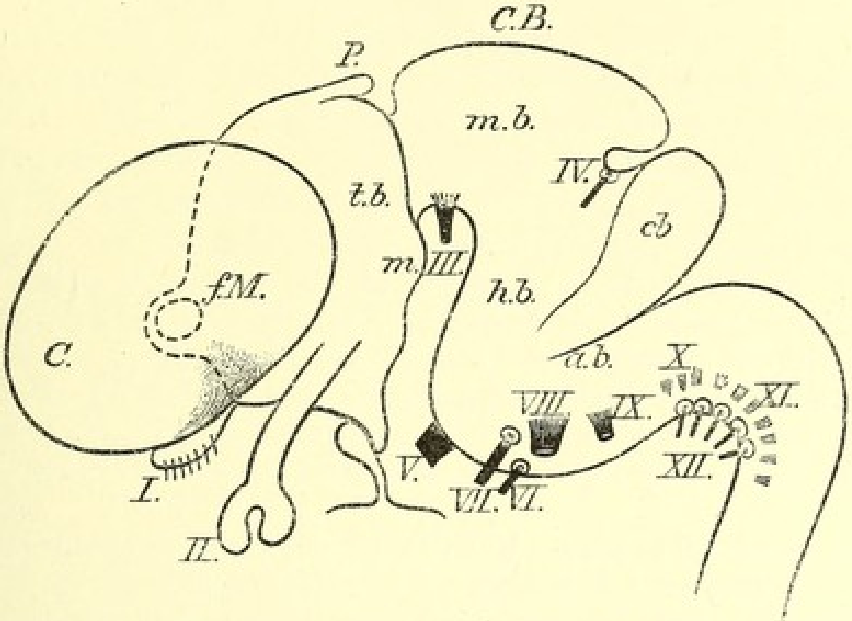


FIG. 78.—Diagram of the development of the brain and the cranial flexures. *t.b.*, the 'tween-brain (1st cerebral vesicle); by *f.*M., the foramen of Monro, its cavity (the 3rd ventricle) communicates with the lateral ventricle, enclosed within C., the cerebral hemisphere; P., the pineal body; the floor of the 3rd ventricle is seen to be depressed into the infundibulum, which forms, in connection with the buccal invagination, the pituitary body; *m.*, the corpus mammillare; *m.b.*, mid-brain (2nd cerebral vesicle); C.B., corpora bigemina; *h.b.*, hind-brain (3rd cerebral vesicle); *cb.*, cerebellum; *a.b.*, after-brain; I–XII, cranial nerves.

To face p. 162.]

bipolar cells, collected into groups between clumps of molecular substance embedding a plexus of nerve-fibrils. From the base of each cell of Purkinje, a single axis-cylinder-process passes into the medullary centre.

Plan of structure. A. (*Hill.*) Afferent fibres enter the granular layer, where they break up into fibrils. The fibrils are connected with minute bipolar cells (granules), the opposite processes of which pass between the cells of Purkinje into the molecular layer, where they join the branch-system of the cells of Purkinje. A single efferent fibre leaves the base of each cell of Purkinje.

B. A diametrically opposed explanation is given by *Golgi*, *Kölliker*, and others, who conclude from the study of silver and mercury impregnations, that the peripheral processes of the cells of Purkinje are nutrient; they consider that the association-field is formed by the anastomosis of branches given off from the axis-cylinder-processes of the cells of Purkinje, and fine fibres which enter the molecular layer and fall back towards the granular layer, forming a network around each cell of Purkinje.

The nucleus dentatus enclosed in the centre of each hemisphere resembles the olive in structure. The superior cerebellar peduncle enters its hilus.

The nuclei of the roof are composed of large multipolar cells. They appear to be connected with the vestibular branch of VIII and perhaps also with V.

Peduncles. A. *The restiform body* comprises (*a*) the direct (lateral) cerebellar tract, (*b*) fibres from the nuclei of the posterior columns of both sides, (*c*) fibres from the opposite olive; *a* is supposed to enter the cortex of the vermis, *c* to enter the "fleece" of the corpus dentatum; *a* and *b* are certainly ascending tracts.

B. *The superior peduncle*, taking exit from (or entering?) the hilus of the corpus dentatum, decussates with its fellow beneath the posterior tubercles of the corpora quadrigemina, swells out into the nucleus ruber tegmenti, and is lost beneath the optic thalamus.

C. *The middle peduncle* forms the pons Varolii; some of its fibres are commissural, others join cells in the opposite side of the pons, and pass forward to the cerebral cortex in the crus cerebri, on either side the pyramidal tract. They enter all parts of the cortex cerebelli.

It is to be noticed (1) that no descending fibres are known with certainty to connect the cerebellum with the nuclei of motor nerves in the spinal cord, or other parts of the cerebro-spinal axis; (2) that the cerebellum varies in size as the cerebral hemispheres; (3) it atrophies with the opposite cerebral hemisphere, with the cortex of which it is connected by the pontine fibres of the crus cerebri.

Evidence of function.

A. Removal of the whole or part of the cerebellum produces, for a time at any rate, a want of co-ordination of movements.

If the injury is one-sided, and especially if the middle peduncle is divided, the animal rotates towards the injured side ("forced movement").

B. Stimulating the cortex cerebelli causes the animal to move its eyes in various directions (*Ferrier*).

C. Disease of the cerebellum frequently shows itself in want of power, want of muscular tone, and uncertainty of gait.

Theories as to the mode of action of the cerebellum.

1809, *Rolando* regarded the cerebellum as the source of nerve-force.

Pro. 1. Its lamellæ seemed to him to resemble the elements of a voltaic pile.

2. Destruction of one side seemed to cause hemiplegia; of both sides, complete paralysis.

1822, *Flourens* (endorsed by *Majendie*) assigned to the cerebellum the duty of co-ordinating movements.

1862. *Lussana.* The seat of the muscle-sense.

1884–1893, *Luciani* teaches that the cerebellum exercises "a sthenic, a tonic, and a static influence" upon the neuro-muscular system.

Pro. 1. Disease or removal of the cerebellum results in want of force (asthenia), want of tone (atony), and irregular or ill-adjusted force and duration of actions (dysmetria or astasia).

2. *Luciani* succeeded in keeping dogs alive for long periods (a year and more) after removal of the cerebellum. They exhibited cerebellar ataxy, but neither want of ability to initiate voluntary movements, deficient sensation, nor disturbance of intellect; while hardly able to walk they could swim. The bitches whelped and tended their puppies in a normal manner.

Summary. The cerebellum receives fibres from all parts of the central grey tube; gives fibres to the cortex cerebri. Direct connections between the cerebellum and the nuclei of motor nerves are unknown. It appears, therefore, to be intercalated in the course of some of the fibres which connect afferent (sensory) nerves with the cerebrum.

It is concerned neither with sensation, volition, nor intellect; neither is there sufficient evidence to show that it is connected with organic life.

∴ Its functions are accessory to those of other parts of the central nervous system.

PRIMARY FORE-BRAIN.

The *grey matter*, which is chiefly composed of the optic thalami, is continuous with the grey matter of the aqueduct.

The optic thalamus consists of several parts which are not distinctly separated from one another, viz., (*a*) the anterior nucleus, (*b*) internal nucleus, (*c*) external nucleus prolonged into the pulvinar; (*d*) to the pulvinar is added the lateral geniculate body which receives the outer division of the optic tract, on the inner side of the inner nucleus is placed (*e*) the ganglion habenulæ. The thalami are connected in the middle line by the grey commissure.

Minute structure. The characteristic formation consists of large multipolar cells (the bodies of which are exceedingly soft, and apt to disappear whatever hardening method be adopted), embedded in granular substance containing a loose plexus of medullated and non-medullated fibres. It varies in structure in its several regions; neurogleia (connective tissue) is abundant in the ganglion habenulæ; the pulvinar is distinguished by dense embedding substance and sparse large cells.

The *floor* of the third ventricle is composed of thin grey matter drawn down into the infundibulum; its *roof* is ependymatous, the velum interpositum.

The white fibres sweeping beneath the thalamus, spread out like a fan and ascend to the cerebral hemisphere on its outer side in the internal capsule.

Vestigial structures.—This portion of the cerebro-spinal axis cannot be understood unless it be recognised that its form is greatly changed from that which it presented in the ancestors of the Vertebrata.

a. The infundibulum is regarded by *Owen*, *Dohrn*, *Gaskell*, and others as the original prevertebrate gullet.

Spencer.—"On the Presence and Structure of the Pineal Eye in Lacertilia," *Quart. Jour. Micr. Sci.*, vol. xxvii. p. 165, 1886.

Beard.—"Morphological Studies: I. The Parietal Eye of the Cyclostome Fishes," *Quart. Jour. Micr. Sci.*, vol. xxix. p. 55, 1888.

b. The pituitary body is formed by the coalescence of two rudiments derived from the fore-brain and the buccal cavity respectively.

c. The pineal body is the remains of a parietal cyclopian eye, which appears to have been functional in the amphibia of the pretertiary period.

d. The ganglia habenulæ were probably the optic ganglia of the pineal eye.

THE CEREBRAL HEMISPHERES.

Development: from the secondary fore-brain.

Phylogeny: they appear to be a late addition to the primitive nervous system, and to increase in relative importance as the animal scale is ascended.

Indubitable "cortex" makes its first appearance in reptiles. The corpora striata take the place of the cortex in birds. The cortex far exceeds the corpora striata in amount, in the higher mammals.

Structure.—Each hemisphere consists of grey and white matter.

- Grey matter =
  - A. Mantle.
    - *a.* Cortex of rhinencephalon.
    - *b.* General cortex.
  - B. Basal grey matter.
    - Nucleus amygdaleus.
    - ,, lenticularis.
    - ,, caudatus.
- White matter =
  - A. Fibræ propriæ.
  - B. Intra-hemispheral commissures (cingulum, part of fornix, &c.).
  - C. Inter-hemispheral commissures (corpus callosum, anterior commissure, lyra).
  - D. Peduncular fibres.
    - *a.* Cerebello-cerebral.
    - *b.* Sensory, or ascending to the cortex from optic thalamus, mid-brain, hind-brain, after-brain, and spinal cord.
    - *c.* Fibres to the nuclei of all motor nerves (including the pyramidal tracts for the spinal cord).

Connections.—A. All parts of the cortex cerebri are connected with the cerebellum. The cortex of the mid-brain is chiefly connected with the optic thalamus and the occipital cortex.

B. The motor (rolandic) area is connected with nuclei of all motor nerves. Fibres for the motor nuclei in the pons and medulla occupy the genu of the internal capsule, and in the crusta lie on the mesial side of the pyramidal tract. Fibres for the motor nuclei in the cord lie in the front of the posterior limb of the internal capsule and in the middle of the ventral portion of the crusta; in the pons they are separated into bundles; in the medulla they form the pyramid; in the cord, the anterior (direct) and lateral (crossed) pyramidal tracts.

C. All parts of the cortex are in connection with sensory nerves. It is impossible to say whether this connection between the cortex and afferent nerves is ever direct, or whether, as seems more likely, it is always broken in the central grey tube.

Sensory fibres of the posterior roots of spinal nerves run for a long distance in the posterior columns without joining the grey matter of the cord. On reaching the medulla, they sweep round (as arcuate fibres) to the ventral aspect of the grey matter on the opposite side, where they form the fillet. In front of the pons the fibres of the fillet recover their dorsal position. The course which they take when the grey matter again opens out into a ventricle (the third ventricle) is uncertain; whether through arcuate fibres, or by a more direct course, they pass under the back of the thalamus into the posterior limb of the internal capsule.

Minute anatomy of the cortex.

Meynert distinguished five layers: (1) molecular layer, (2) layer of small pyramids, (3) layer of large pyramids, (4) layer of granules and small irregular nerve-cells, (5) layer of fusiform cells.

The stratification is not rigid. The further from the surface, the larger the pyramids; but, although small pyramids are thickly massed beneath the molecular layer, a gradual transition is observed from small to large. The granules are not (as in the cerebellum) restricted to the layer beneath the large pyramids.

Palisade-like sub-pial ependyma-cells, send supporting processes deep into the cortex, which is also held together by numerous many-branched neurogleial (connective tissue) cells, "spider-cells," or cells of Deiters.

Interpretation. The cells of the cortex can be classified into, at the least, four types.

1. Pyramids, which give origin by their axis-cylinder-processes to efferent fibres. It seems probable that the size of the pyramid varies as the length of its efferent process.

Pro. The largest pyramids are found in the "leg area" and "trunk area," *i.e.*, top of the ascending parietal convolution and paracentral lobule, and also, scattered or in small groups, in the occipital cortex.

2. Granules, which are probably connected with the fibrils into which ascending (sensory) fibres divide on reaching the cortex.

Pro. 1. They resemble the granules of the cerebellum.

2. They are most numerous in the parts of the cortex in which we have reason to believe that the greatest number of sensory fibres end, *e.g.*, the occipital cortex.

3. It appears probable that the nerve-fibre process of a neuron terminates by dividing into fibrils which carry granules. This mode of termination is exhibited in a motorial end-plate.

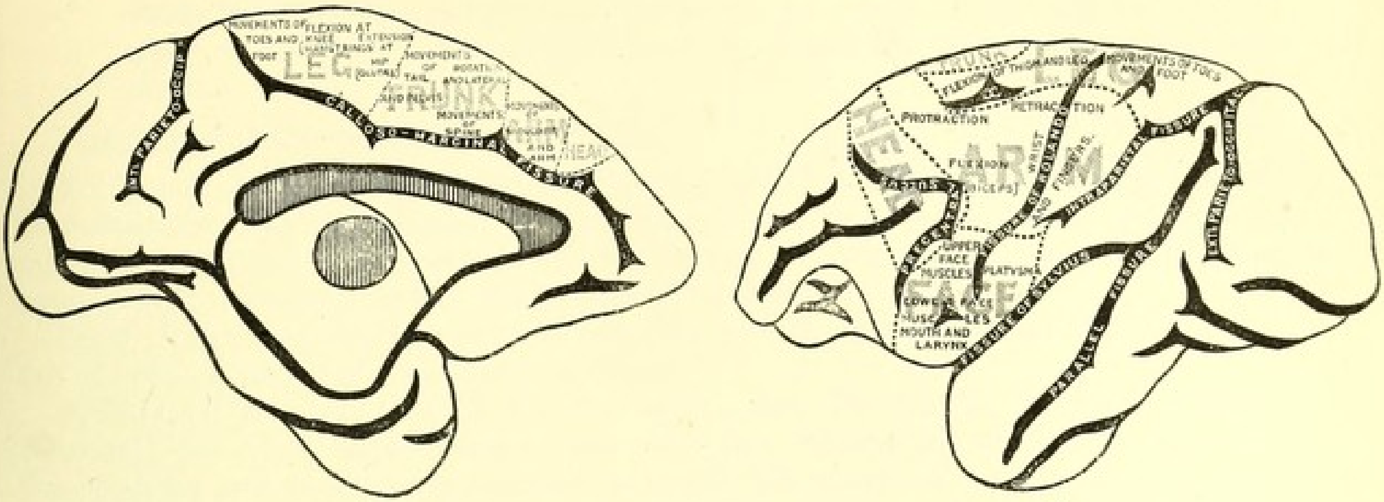
3. The fusiform cells were recognised by *Meynert* as connected with short commissural fibres (fibræ propriæ).

Pro. They are placed parallel with the surface, beneath the sulci; vertical to the surface at the ridges of the convolutions, *i.e.*, they lie in the direction of the fibræ propriæ.

4. Irregular nerve-cells of moderate size, such as are scattered everywhere throughout grey matter.

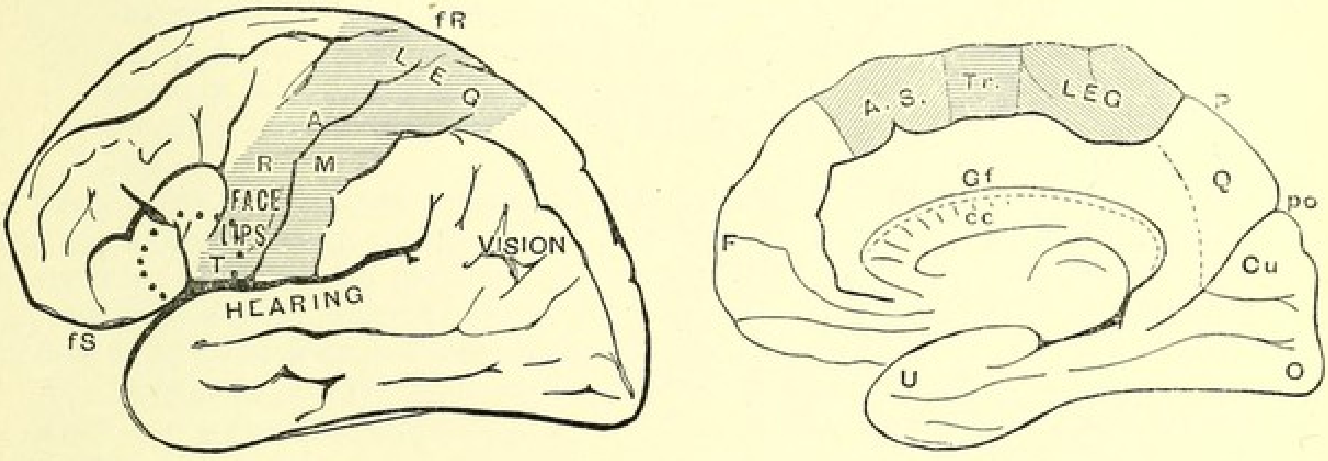
It appears probable, therefore, that an association-field is constituted with the processes of the granules on the ascending, and the processes of the pyramids on the descending limbs of the arcs. According to the established view as to the nature of grey matter, the network or feltwork is formed by the branching processes of pyramidal cells.

Con. Golgi, and others who rely upon the results obtained by his methods, take an entirely different view as to the constitution of grey matter. They do not recognise the nervous nature of "granules." They divide cells into two types: I. Motor cells, whose axis-cylinder-processes,



A B

Fig. 79.—The motor-areas in the cortex of the monkey's brain as determined by stimulation (*Horsley* and *Schäfer*, *Phil. Trans. Roy. Soc.* 1888). A, The mesial surface of the brain, showing the base of the rolandic lobe ; B, the external surface. The front of the brain is to the right in A, to the left in B.



A B

Fig. 80.—A, The external surface of the left hemisphere of the human brain ; B, the mesial surface of the right hemisphere, showing the allocation of function in the cortex, as inferred chiefly from clinical evidence ; A–fR, fissure of Rolando ; fS, fissure of Sylvius ; T, centre for tongue, &c., within the dotted circle which surrounds the cortical centre for speech ; B–F, frontal pole ; Gf, gyrus fornicatus ; *cc*, corpus callosum ; P, parietal lobe ; Q, quadrate lobule ; *po*, parieto-occipital fissure ; Cu, cuneus ; O, occipital pole ; U, uncus.

although they give off many lateral processes, pass without losing their independence into medullated fibres; and II. Sensory cells, the axis-cylinder-processes of which resolve themselves by frequent branching into a network of fibres. It is this comparatively open network which constitutes the association-field. The branched processes of the cell are looked upon as nutritive, not nervous; roots by which the cell sucks up nourishment.

Functions of the cerebral hemispheres.

From very ancient times it has been recognised that the cerebrum is the seat of consciousness, intelligence, and volition, but it was not thought that its cortex, which was regarded as incapable of stimulation, was directly concerned with the reception of sensations or the production of movement, until in—

1870, *Hughlings Jackson* pointed out that certain forms of epileptiform attacks are of cortical origin ("Jacksonian epilepsy").

1873-4, *Hitzig and Fritsch* (in Germany), and *Ferrier* (in England), simultaneously described experiments which show that stimulation of definite spots in the rolandic area produces movements of particular groups of muscles.

1873-83. It was denied by many physiologists that the stimulation affects the cortex, because:

1. A strong electric stimulus was used in these early experiments. With a more careful regulation of the narcosis, a weaker stimulus is found to answer, but it is still, for all animals, many times as strong as the minimal current for stimulating a nerve-muscle preparation; for Man it needs to be very strong indeed.

2. If the cortex be removed, the same movements follow stimulation of the underlying white matter.

Con. 1882. It was shown by *Bubnoff* and *Heidenhain* that the contractions which result from cortical stimulation differ in certain particulars from those produced by stimulating the white matter; have specific characters, that is to say, *e.g.*, (1) they are abolished by deep morphia-narcosis, while the white centre remains irritable; (2) they are inhibited by strongly stimulating a sensory nerve; (3) the contraction is more prolonged; (4) the latent period is $\frac{1}{3}$ longer; the minimal stimulus needed is less.

Since 1882, it has been recognised that the cortex itself is irritable, and that the movements which result from its stimulation have certain differential characters; the areas for particular movements have been accurately marked out, especially by *Ferrier*, *Horsley*, *Beevor*, and *Schäfer*. The localisation of functions is best understood from a chart (see figs. 79 and 80).

The movements always occur on the opposite side of the body.

They are sometimes (especially in the case of the eyes, mouth, and trunk) bilateral.

In the case of speech, not only does the cortical mechanism of one side govern the intricate movements of both sides of the mouth and throat, but the right centre loses its function, the posterior part of the inferior frontal convolution on the left side only being concerned with speech. The speech-centre on the right side re-acquires its function if the left side is diseased.

The controlling power of each cortical area is most pronounced in its centre, and dies away towards its margin.

Areas overlap.

Ross.—*On Aphasia*, London, 1887.
Bateman.—*Aphasia*, 2nd edit., London, 1890.

They control *movements* of the several joints, rather than individual muscles, or groups of muscles. The area for each joint can be subdivided into areas for its flexion, extension, abduction, adduction, &c.

The areas are associated together; strong stimuli spreading from area to area in a definite "march." The same progress from movement to movement is observed in a fit of Jacksonian epilepsy.

The differentiation of its functions varies as the predominant development of the cortex cerebri.

It cannot be recognised in the rabbit. In the dog the centres are ill-defined. They are more discrete and more minutely subdivided in the monkey. Localisation is carried still further in Man.

Ablation of motor areas produces paralysis, which is temporary in the dog.

Goltz, by using a jet of water, washed away the whole of the motor area and much of the surrounding cortex from both hemispheres of a dog's brain. The animal was reduced to a condition of idiocy, but showed no paralysis.

In the monkey it lasts longer, but recovery is possible.

In Man recovery may take place, although usually the voluntary control of the muscles is permanently lost.

The extent to which the animal relies upon particular spots in the cortex for the volitional origination of particular movements, increases with the increase of intelligence. Anatomically, the limitation to the rolandic area of the cerebral connections of the cord keeps step with this specialisation. Hence the descending degeneration (of the pyramidal tract) which follows removal of the rolandic area is much more extensive and complete in the monkey than it is in the dog.

Interpretation of the results of stimulation and ablation.

A. It was hastily supposed that the areas in question simply contain a motor mechanism upon which the Will plays.

Con. 1. If an animal is slightly under the influence of morphia, a subminimal stimulus becomes effective when the skin over the muscles governed by the cortical area, which is being stimulated, is simultaneously stroked. This proves the existence in the area of sensori-motor apparatus.

2. Philosophically, it is impossible to imagine the "Will" as acting directly upon a motor mechanism; volition is preceded by consciousness, and we can only conceive of the Will as acting on the afferent side of the sensori-motor couples. In other words, sensations of movement must be stored in the cortex before it can become the seat of volitional action.

Beevor and Horsley.—"Minute Analysis of the Various Movements produced by stimulating the Cortical Centre for the Upper Limb," *Phil. Trans. Royal Society*, 1887, p. 153.

Horsley and Schäfer.—"A Record of Experiments upon the Functions of the Cerebral Cortex," *Phil. Trans.*, 1888, B., p. 1.

Horsley and Schäfer.—"Excitation of Various Parts of the Motor Tract," *Jour. of Phys.*, vol. vii. p. 96.

Beevor and Horsley.—"A further Minute Analysis by Electric Stimulation of the so-called Motor Region of the Cortex Cerebri in the Monkey," *Phil. Trans.*, 1888, B., p. 205.

Sanger Brown and Schäfer.—"An Investigation into the Functions of the Occipital and Temporal Lobes of the Monkey's Brain," *Phil. Trans.*, 1888, B., p. 303.

Beevor and Horsley.—"Results obtained by Electrical Stimulation of the so-called Motor Cortex and Internal Capsule in an Orang-outang," *Phil. Trans.*, 1890, B., p. 129.

Semon and Horsley.—"An Experimental Investigation of the Central Motor Innervation of the Larynx," *Phil. Trans.*, 1890, B., p. 187.

Gotch and Horsley.—"The Mammalian Nervous System, its Functions and their Localisation determined by an Electrical Method," *Phil. Trans.*, 1891, B., p. 267.

Sherrington.—"Nerve-tracts Degenerating Secondarily to Lesions of the Cortex Cerebri," *Jour. of Phys.*, vol. x. p. 429, xi. 399.

B. Not motor areas, but sensori-motor areas. The seat of sensations connected with movement.

What is the nature of the sensations received by the rolandic cortex?

a. Are they common (skin) sensations?

Pro. 1. In Man a cortical lesion which produces anæsthesia invariably produces paralysis also; the converse cannot be asserted with equal assurance, but it is usually true.

2. *Mott* finds that in monkeys the paralysis produced by passing a knife under the cortex is accompanied by marked loss of common sensation.

Con. *Horsley* and *Schäfer* have shown that in the monkey, removal of the cortex of the gyrus fornicatus produces anæsthesia and analgesia of the opposite side of the body without paralysis; whereas removal of the rolandic area produces paralysis without anæsthesia. They conclude, therefore, that this gyrus, and not the rolandic area, is the cortical seat of common sensation. The portion of the gyrus fornicatus thus allocated to common sensation appears to be the base of the rolandic lobe, and it seems as if the tactile sensations connected with movement had been withdrawn from the rest of the motor area into its base.

b. Are they "muscular sensations"?

Maintained especially by *Charlton Bastian.*

This is very difficult to test clinically, and impossible to check by experiments on animals.

c. Are they sensations of innervation or effort?

If there be a sense of the amount of nervous energy expended in executing voluntary movements, this sense must clearly be localised in the rolandic area.

It is generally allowed that, in Man, paralysis is always accompanied by loss of power of localising sensations; also, that when a cortical area has been removed for the purpose of putting a stop to Jacksonian fits, the "aura," or sensation which precedes a fit, is no longer felt, even though the fits return.

It is therefore pretty clear that the rolandic area is a seat of sensation, but the question is—of what kind?

Is it necessary that the paralysis produced by removing the cortex depend upon the abrogation of *current sensations*, or sensations which accompany movement?

Con. *Munk* maintains that if the cortex be the tissue in which *memories of sensations* are stored, its removal would cause paralysis, since a purposeful movement could not be discharged in the absence of recollections of previous movements of a like kind. The Will would have no guide as to the force, character, or quality of the impulse required.

The possibility of re-training the animal, whose motor areas have been removed, to perform actions for which for a time it was paralysed, is in favour of this view, that the rolandic cortex is the storehouse of movement-memories.

It also explains the fact that the actions which can be executed through the cortex only have the character of skilled movements.

On the other hand, there is a philosophical difficulty in conceiving the movements first made by a child as anticipated by a representation of the movement in consciousness. It appears necessary that

Waller.—"The Sense of Effort: an Objective Study," *Brain*, pts. liv. and lv. p. 179, 1891.

movement should always precede sensation of movement, and not *vice versa*.

The functions of the remainder of the cortex.

The several regions of the cortex are not distinguished by any such difference in minute structure as would justify us in supposing that the work which they respectively do, differs in kind.

Up to the present no light has been thrown upon the physiology of the cortex which lies in front of the rolandic area.

All or almost all the rest of the cortex appears to be allocated to the several senses, thus :—

I. **Smell.**—The anatomical disposition of the cerebral mechanism of this sense is peculiar. The olfactory bulb which lies within the skull corresponds in general features to the retina. The crus of the olfactory bulb (olfactory tract) expands in macrosmatic animals into a lobe of the brain (rhinencephalon, pyriform lobe, &c.), which differs in appearance from the rest of the hemisphere. In microsmatic Man this lobe is reduced to the uncinate convolution. The fascia dentata is a part of the olfactory mechanism, since it is completely absent in the anosmatic cetacea.[1]

The relative development amongst animals of the part of the brain which would appear to correspond to the extremity and mesial aspect of the temporo-sphenoidal lobe in Man, points out this region as the cortical mechanism of smell; but neither experimental nor clinical evidence is at present conclusive. Stimulation of the gyrus hippocampi of the monkey induces movements of the lip and nostril on the same side (*Ferrier*). Olfactory sensations do not, in Man or monkeys, constitute the substratum of intellectual operations to anything like the same extent as do visual and auditory sensations. Hence the difficulty in determining their cortical location. In the dog, sensations of smell constitute, as it were, the yarn out of which thought-patterns are woven; but, as already stated, a dog minus its cortex is a much more efficient animal than a monkey in the same case.

II. **Sight.**—The most highly specialised of the cortical sensory mechanisms is that of sight.

In animals with independent visual fields the optic nerves decussate. The primitive crossed connection of the sense-organ and brain gives place in animals with stereoscopic vision to a plan whereby corresponding points of the two retinæ are, so to speak, focussed upon the same spots in one hemisphere only; the fibres of the optic nerves are gathered up in the optic tracts in such a way that the right halves of both retinæ are connected with the right hemisphere, the left halves with the left hemisphere.

The optic tract is connected with A, the back of the optic thalamus (through its pulvinar and external geniculate body), and with B, the anterior corpus quadrigeminum.

A is the connection with the seat of consciousness: fibres from the thalamus (the optic radiations of Gratiolet) ascend to the occipital cortex. It is uncertain whether fibres pass directly from the optic tract to the cortex without interruption in the thalamus.

B is the connection with the centres for movements of the eyeballs.

The delimitation of the visual area is uncertain.

Stimulation of the occipital cortex (*Schäfer*), or of this region, and also of the angular gyrus (*Ferrier*), produces movements of the eyeballs.

[1] Hill.—"The Hippocampus," *Phil. Trans. Roy. Soc.*, 1892.

Ferrier.—*Cerebral Localisation*, London, 1890.
Windle.—"Brain in a Case of Motor Aphasia with Deafness," *Jour. of Anat. and Phys.*, vol. xxi. p. 79, 1886.
Mills.—"On the Localisation of the Auditory Centre," *Brain*, pt. lvi. p. 465, 1891.

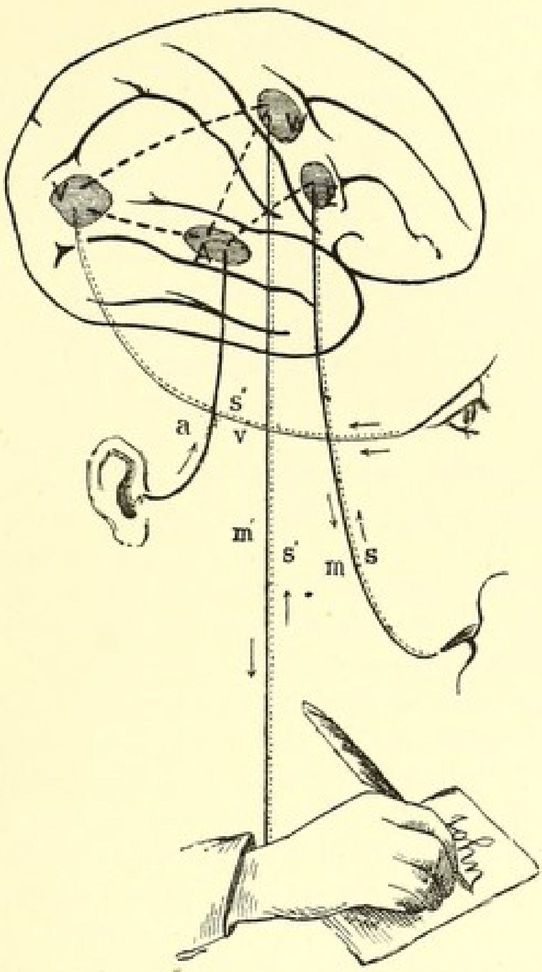


FIG. 81.—The co-ordinated cortical mechanism by which the word heard or seen is transformed into the word spoken or written (*Ross*). The shaded areas on the surface of the brain are the centres for hearing and sight, for movements of the mouth and hand, respectively.

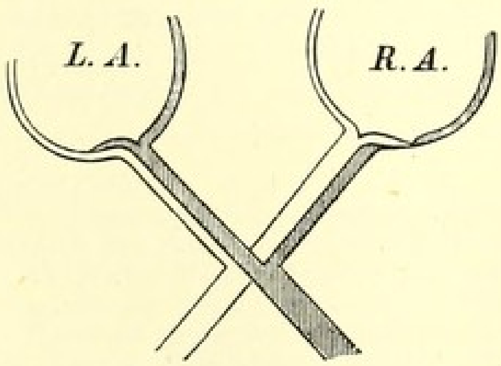


FIG. 82.—The relation of the retina to the optic tracts in Man. The right tract collects the fibres from the right halves of both retinæ ; the left tract, from the left halves.

To face p. 170.]

Horsley and *Schäfer* only succeeded in producing permanent hemiopia when they destroyed the angular gyrus as well as the occipital lobe. *Munk* believes that the visual area is limited to the occipital lobe.

Hearing.—The auditory nerve finds its primary connections in the medulla.

Its cortical centre is assigned to the posterior portion of the upper (or upper and middle) temporal convolutions.

Pro. 1. Stimulating this region induces movements of the ears.

2. Removing the region results in deafness.

This has been denied, and is very difficult to prove. All the sensory nerves have primary centres in the central grey matter, which centres provide for reflex protective movements. It is therefore exceedingly difficult to distinguish between such responsive movements as might be performed in the absence of the cerebrum—starting in answer to a loud sound, for example (*Vulpian*)—and movements which indicate that afferent impulses have overflowed into motor channels in the cortex cerebri.

It appears that *the higher the position of the animal in the intellectual scale the more dependent it is upon its cerebral cortex as an association-field.*

3. The superior temporal convolution is usually atrophied in deaf-mutes, especially on the left side of the brain.

A suggestion (*v. Monakow*) that the medial geniculate and posterior quadrigeminal tubercles stand in the same relation to hearing, as do the lateral geniculate and anterior quadrigeminal tubercles to vision, needs proof.

Generalisations with regard to the functions of the cortex. The cortex is a secondary formation which is added to the primary grey centres late in phylogeny. It only attains considerable dimensions in reptiles and mammals.

It is a second association-field, being connected by afferent and efferent fibres with the central grey matter.

It consists, therefore, of a series of sensori-motor arcs or combinations; it being understood that *sensory* and *motor* are terms which are properly applicable only to the primary connections of peripheral nerves; they do not define the character of the impulses received and discharged by the cerebral cortex.

The cortical grey matter is not uniformly connected with all parts of the central grey matter, but is primitively divided into areas connected with the several segments of the lower grey matter.

The dependence of the animal upon its cortical, as distinguished from its central, grey matter varies as its height in the scale of existence. The cortical grey matter exhibits a progressive specialisation of function, its several territories being more and more minutely subdivided into areas. In the case of bilateral movements, each cortical area governs both sides of the body. The whole mechanism of speech is worked from the left side only, the right speech-area lying dormant.

Wundt.—*Essays*, Leipzig, 1885.

Clevenger.—*Comparative Physiology and Psychology*, Chicago, 1885.

Maudsley.—*Natural Causes and Supernatural Seemings*, London, 1886.

M'Cosh.—*Psychology: the Motive Powers, Emotions, Conscience, Will*, London, 1887.

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Sully.—*The Teacher's Handbook of Psychology*, 2nd ed., London, 1887.

Kirchner.—*A Students' Manual of Psychology*, London, 1888.

Murray.—*A Handbook of Psychology*, 2nd ed., Paisley, 1888.

Bastian.—"On the Neural Processes underlying Attention and Volition," *Brain*, pt. lvii. p. 1, 1892.

Bristowe.—"On the Nature and Relations of Mind and Brain," *Brain*, part xiv., 1, p. 18.

Ireland.—"On the Discordant Action of the Double Brain," *Brit. Med. Jour.*, 1891, No. 1587, p. 1167.

There is reason to think that in monkeys the areas for tactile sensibility are restricted to the gyrus fornicatus or base of the rolandic lobe, the areas in the outer portion of which are highly specialised for movement.

The sensori-motor association-field of the cortex is the seat of consciousness, intelligence, and volition.

The nuclei amygdaleus, lenticularis and caudatus, are distinguished from the optic thalamus by the smaller size and greater firmness of their multipolar cells, and the greater density of the ground-substance. They are parts of the cerebral hemisphere, and intimately related to the cortex. Their functions are unknown.

The cerebral commissures.

The corpus callosum and anterior commissure unite the two hemispheres together. The anterior commissure is the great link between the hemispheres in the lower, the corpus callosum in the higher mammals. The corpus callosum is absent in monotremes and marsupials. It does not merely unite corresponding points, but its fibres radiate from any given spot in the one hemisphere to various points in the opposite hemisphere (*Sherrington*).

Roy and Sherrington.—"The Regulation of the Blood-Supply of the Brain," *Jour. of Phys.*, vol. xi. p. 85.

Cappie.—*The Intracranial Circulation, and its Relation to the Physiology of the Brain*, Edin., 1890, T. Thin.

Spencer and Horsley.—"Changes Produced in the Circulation and Respiration by Increase of the Intracranial Pressure or Tension," *Phil. Trans.*, 1891, B., p. 201.

Halliburton.—"Cerebro-Spinal Fluid," *Jour. of Phys.*, vol. x. p. 232.

Hill.—"The Brain of Ornithorhynchus Paradoxus," *Trans. Royal Society*, 1892.

Symington.—"The Cerebral Commissures in the Marsupialia and Monotremata," *Jour. of Anat. and Phys.*, vol. xxvii. p. 69, Oct. 1892.

SECTION XII.

REPRODUCTION.

The ovary lies on the back of the broad ligament. It consists of a mass of stroma abundantly supplied with blood- and lymph-vessels, is covered by peritoneal epithelium and contains ova in various stages of growth, as well as the vestiges of ruptured Graafian follicles. The germinal epithelium which covers it is composed of cubical cells. Before birth a large number of these epithelial cells sink into the stroma of the ovary. One cell in each nest (about 70,000 in all) is the ovum (occasionally there are two); the other cells, termed cells of the tunica granulosa, minister to the nutrition of the ovum (fig. 83).

The stroma consists of spindle-shaped cells intermediate in character between connective tissue and plain muscular fibres; they effect a displacement of the Graafian follicle inwards into the substance of the ovary during the maturation of the ovum and outwards towards the surface when it is ready to escape.

The ovum is distinguished from the other epithelial cells of the follicle in that it increases in size but does not divide. It attains eventually a diameter of 0·2 mm. When ripe its cell-wall is a clear homogeneous membrane (·01 mm. thick)—the zona pellucida, or zona radiata as it is sometimes called, because it is marked by radiating lines.

> The zona radiata is by some histologists regarded as a secretion of the cells of the tunica granulosa, and not the cell-wall of the ovum. The radiating lines are looked upon as pores, which are even said to contain protoplasmic processes of the cells of the tunica granulosa.

The cell-protoplasm of the ovum (vitellus) is loaded with granules of nutritious substance (fig. 84).

Its nucleus (germinal vesicle of Purkinje, 1825) is ·04 mm. in diameter, and contains one or more conspicuous nucleoli (germinal spots of Wagner, 1836).

Although the ovum does not undergo cell-division until after impregnation, its nucleus divides while it is still within the ovary. 1875, *Bütschli*, and 1876, *van Beneden* described the formation and extrusion of portions of the nucleus as "polar bodies." Two polar bodies are usually extruded, and this process has been regarded (by *Balfour* and others) as the sacrifice by the hermaphrodite ovum of the female portion of its chromatin-skein, in order that it may be prepared to receive the male portion of the chromatin-skein of the spermatozoon, and so originate a new hermaphrodite cell. This view is not, however, generally accepted by morphologists.[1] The appearances presented by the ovary show that ova are

[1] For a full description of the phenomena of nuclear division and discussion of the theories of heredity, see *M'Kendrick's Physiology*, vol. i. pp. 201–244.

Cunningham.—"E. van Beneden's Researches on the Maturation and Fecundation of the Ovum," *Quart. Jour. Micr. Sci.*, vol. xxv. p. 107, 1885.

discharged even before puberty, but their discharge is not regular or accompanied by other physiological changes until puberty (12th to 15th year). The ovary continues to discharge ova at regular intervals of 28 days until the climacteric (*i.e.*, about the 45th year).

The cells of the tunica granulosa becoming very numerous, form a layer two or three deep, which lines the wall of the follicle, and a mass heaped up around the ovum, the cumulus or discus proligerus.

The follicle is lined by a structureless membrana propria, and growing faster than the cells it encloses, comes to contain liquor folliculi (lymph).

After a Graafian follicle has ruptured, the cells of the tunica granulosa benefit by the liberal arrangements which have been made for the nutrition of the ovum, and increase not only in number but also in size, forming a lobulated mass of large epithelial cells remarkably resembling in appearance the cells of the suprarenal and pituitary bodies. The wall of the follicle projects into this mass at many points, conveying to it additional blood-vessels. The hæmatoidin derived from blood which escapes into the follicle at the time of its rupture, and the "lutein" which is formed at a later period by the atrophy of its cells, give to the mass a yellow colour; hence it is termed the corpus luteum. The ripening of another follicle is the signal for the atrophy of the corpus luteum. This occurs at the next menstrual period if the ovum last discharged is not fertilised, but not until after the birth of the embryo if one grow in the uterus. The "false" and "true" corpora lutea are formed, therefore, for the purpose of keeping the ovary in a state of quiescence by diverting its vital activities.

As the corpus luteum atrophies, its cells are seen to be undergoing fatty degeneration, leucocytes enter the follicle and carry away the remnants of the cells, and eventually the position of the follicle is only marked by its folded and swollen lining membrane (theca folliculi) which has undergone a peculiar waxy degeneration. A little loose connective tissue, in which a few pigment-granules and leucocytes are seen, fills the crumpled theca.

Menstruation, or the monthly discharge of the catamenia, is marked by an increase in the blood-supply of the ovaries, uterus, and other organs of generation.

The catamenia consist of blood (from 120 to 200 grammes), accompanied by copious secretion from the uterine and vaginal glands, carrying with it portions of the mucous membrane of the uterus which appear to have undergone some amount of fatty degeneration. The mucous membrane may come away in small pieces, or may (in cases which must be regarded as inflammatory, although habitual to the individual) be detached in a complete cast.

Ovulation. It is usually supposed that an ovum (alternately from each ovary), or more than one ovum, is discharged at each menstrual period into the mouths of the Fallopian tubes. The vascular turgescence of the ostium abdominale of the tube causes a kind of erection which makes the tube clasp the ovary. The erection is probably aided by plain muscle-fibres.

Object of menstruation. The greatest uncertainty enshrouds this subject. It is

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Schwann.—"Microscopical Researches into the Accordance in the Structure and Growth of Animals and Plants." Trans. by Henry Smith. London, 1847. (*New Syd. Soc.*)

Turner.—"The Cell Theory, Past and Present," *Jour. of Anat. and Phys.*, vol. xxiv. p. 253, 1890.

Cunningham.—"Review of Recent Researches on Karyokinesis and Cell-Division," *Quart. Jour. Micr. Sci.*, vol. xxii. p. 35, 1882.

Waldeyer.—"Karyokinesis, and its Relation to the Process of Fertilisation," part 2, *Quart. Jour. Micr. Sci.*, vol. xxx. pp. 159 and 215, 1889.

Oliver.—"Menstruation—its Nerve-Origin—not a Shedding of Mucous Membrane," *Jour. of Anat. and Phys.*, vol. xxi. p. 378, 1887.

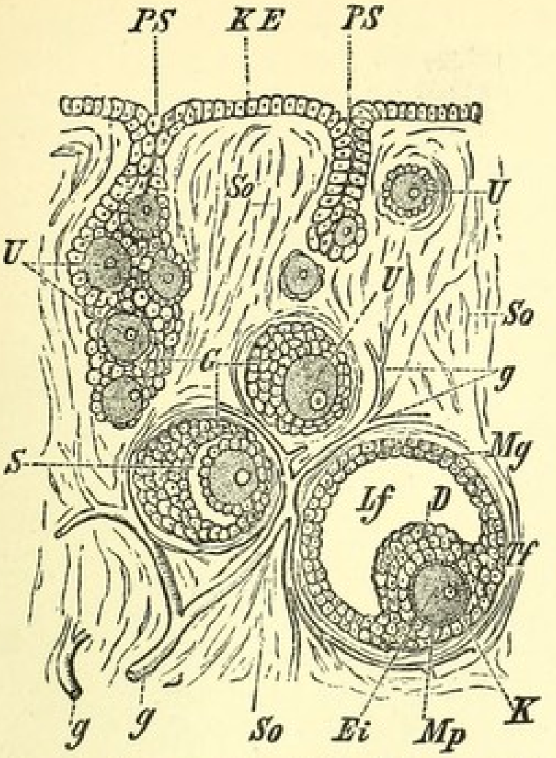

FIG. 83.—Diagrammatic section of a superficial portion of the ovary. *KE*, Germinal epithelium; *PS*, an ovarian tube (these tubes are only seen in the fœtus); *U*, primitive ova surrounded by a group of smaller epithelial cells; *So*, stroma, G, Graafian follicles; *S*, space in follicle; *Mg*, membrana granulosa; *Lf*, liquor folliculi; *D*, discus proligerus; *Tf*, theca folliculi; *Ei*, ovum; *K*, its nucleus; *Mp*, zona pellucida; *g*, blood-vessels.

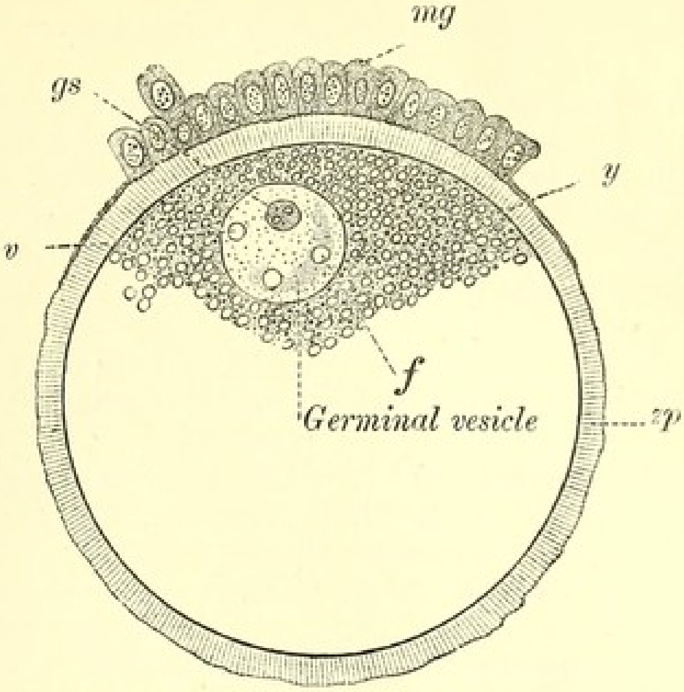

FIG. 84.—An ovum, bearing on a portion of its surface cells of the membrana granulosa, *mg*. *gs*, The germinal spot; *v*, *f*, vacuoles; *y*, food-yolk; *zp*, zona pellucida.

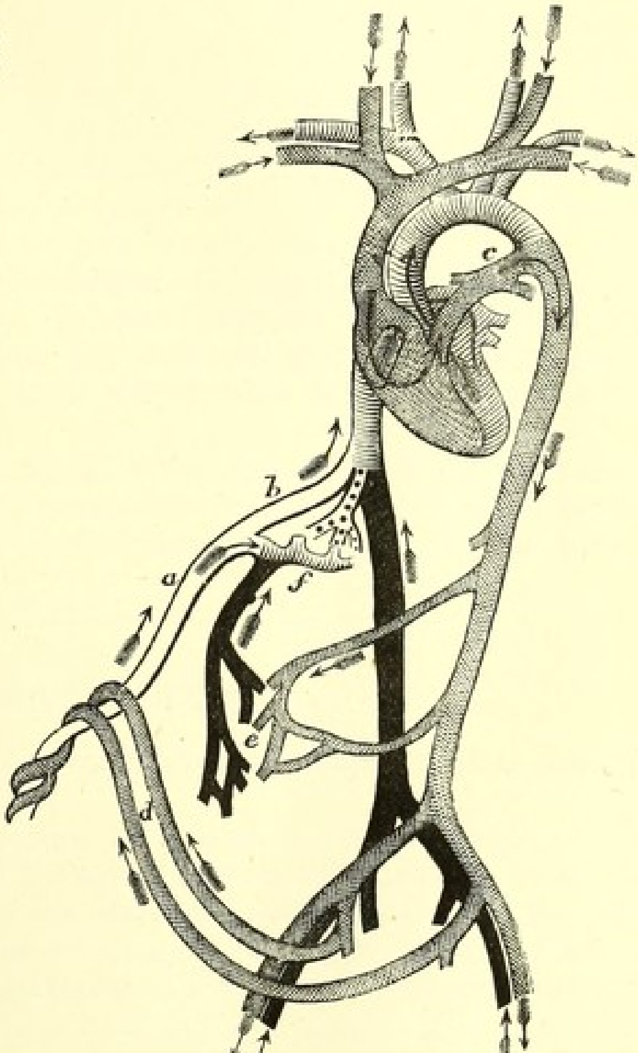

FIG. 85. Diagram of the fœtal circulation (*Cleland*). *a*, The single umbilical vein; *b*, ductus venosus (beneath the liver); *c*, ductus arteriosus; *d*, the two umbilical arteries; *e*, the vessels of the yolk-sac and intestines; *f*, the venæ advehentes of the liver. The extent of the venosity of the blood is indicated by the depth of shading.

Fig. 85

undoubtedly connected with the attachment of the ovum (which has been fertilised, as is usually supposed, either in the ovary or in the Fallopian tube), to the wall of the uterus; but two opposite views are held with regard to the relation between the two processes.

A. *Reichert*, *Williams*, and others believe that the mucous membrane becomes soft and vascular, in order that it may constitute a suitable bed for the ovum. If the ovum attaches itself, the membrane is not shed. In other words, the uterus attempts each month to form a membrana decidua, which is only cast off if it is not wanted.

B. *Pflüger* thinks that the old mucous membrane is shed in order that a fresh soft membrane, or, in the human species, a raw surface, may be prepared upon which the ovum can graft itself.

Observation of animals favours the latter theory (B).

Pro. They allow coition as the œstrum (or period of "heat" or "rut") is subsiding.

Although differing in degree, the process must be fundamentally the same in women, and we are probably justified in concluding that the intra-uterine life of the embryo commences soon after the last menstrual period, and not just before the time at which the next period would have occurred but for impregnation.

Con. Fœtation may commence without the appearance or reappearance (during lactation) of menstruation, *i.e.*, the ovum may attach itself to the uterine wall which has not been "refreshed" (in a surgical sense).

Difficulties. Impregnation, although more likely to occur soon after menstruation, may occur at any time during the intra-menstrual period. How is this to be explained if ova are only shed at the period? (*a*) Does the ovum remain in the Fallopian tube and retain its vitality for nearly a month? *Pro.* The embryo may be found in the Fallopian tube or (in animals) in the horn of the uterus opposite to the ovary in which it has left a corpus luteum, showing a considerable power of migration. (*b*) Can the spermatozoa lie in wait for an ovum for an equally long time? Or (*c*) are ova shed at any time as the result of coition, or (*d*) are they discharged at frequent intervals in the absence of any special stimulus. Surgeons (*Lawson Tait* and others) who are constantly operating upon the abdomen report that they have found ripe Graafian follicles at a considerable interval from a menstrual period.

Impregnation depends upon the union, while the ovum is either in the ovary or in the Fallopian tube, of the male pronucleus (head of the spermatozoon) with the female pronucleus (germinal vesicle from which polar bodies have been cast off).

SPERMATOGENESIS.

The testes are formed in the same situation as the ovaries. They descend into the scrotum during the seventh month.

Each testis contains about 800 seminal tubules of an average length of two feet.

The tubuli seminiferi are lined by several layers of epithelial cells, the progenitors of which were derived from the same germinal epithelium as the primitive ova. As in the case of the epithelial cells engulphed in the stroma of the ovary, so also in the testes, the cells are distinguished into those which give rise to sexual

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Griffiths.—"Observations on the Function of the Prostate Gland in Man and the Lower Animals," *Jour. of Anat. and Phys.*, vol. xxiv. p. 27, 1889.

elements, and others which serve for their support; but in the testes the former are the more numerous.

The germinal cells or spermogonia divide, by caryokinesis, giving rise to spermatocytes. The spermatocytes (by caryostenosis) split into spermatids or mother-cells of spermatozoa. Each spermatid contains a nucleus (in which the nuclein or chromatin is no longer disposed as a skein, but in a lump), certain granules (cytomicrosomes) which subsequently condense into the "accessory nucleus," and a small quantity of body-protoplasm.

The spermatid is converted into a spermatozoon by the elongation of its nucleus into the head, and the outgrowth of the protoplasm which constitutes the body of the spermatozoon into a vibratile tail. The accessory nucleus remains in the middle segment or body.

The accessory nucleus appears to be that portion of the nucleus which, cell division being at an end, is no longer required by the spermatozoon. It has been supposed to be the analogue of the polar globules of the ovum, but this is doubted by most histologists. It falls away from the spermatozoon before fecundation; for this process the head (nucleus) alone is required.

The spermatozoa are formed near the lumen of the tubule. Their tails project centripetally and vibrating as soon as formed, drive the heads of the spermatozoa toward the membrana propria into the soft protoplasm of the supporting cells. Here they are fixed until mature, when the supporting cells gradually lift them into the lumen of the tubule.

Growth of the embryo.

Cell-division, by which the blastoderm is formed, commences immediately after impregnation. The whole contents of the holoblastic human ovum divides, but the zona pellucida is not affected. Division is accompanied by growth which can only occur at the expense of water and nutritious substances absorbed from the contents of the Fallopian tubes. The zona pellucida becomes villous for the attachment of the ovum and the better absorption of its food. In this condition it reaches the uterus.

Formation of the placenta. In all mammals above monotremes and marsupials, each of the two trunks into which the aorta divides posteriorly, gives off a branch which is carried to the surface of the ovum along a diverticulum of the hind-gut called the allantois. (The commencement of the allantois is subsequently dilated into the bladder, which is, eventually, quite cut off from the hind-gut.) The

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Blomfield.—"The Development of the Spermatozoa," *Quart. Jour. Micr. Sci.*, vol. xxi. p. 415, 1881.

Blomfield.—"Review of Recent Researches on Spermatogenesis," *Quart. Jour. Micr. Sci.*, vol. xxiii. p. 320, 1883.

Brown.—"On Spermatogenesis in the Rat," *Quart. Jour. Micr. Sci.*, vol. xxv. p. 343, 1885.

Lockwood.—"The Development and Transition of the Testes, Normal and Abnormal," *Jour. of Anat. and Phys.*, vol. xxi. p. 635; vol. xxii. pp. 38, 461, and 505, 1887.

Hubrecht.—"Studies in Mammalian Embryology: The Placentation of Erinaceus Europæus, with Remarks on the Phylogeny of the Placenta," *Quart. Jour. Micr. Sci.*, vol. xxx. p. 283, 1889.

Heape.—"The Development of the Mole (Talpa Europea)," *Quart. Jour. Micr. Sci.*, vol. xxiv., 1883, and vol. xxvii. p. 123, 1886.

Sidebotham.—"Note on the Fate of the Blastopore in Rana Temporaria," *Quart. Jour. Micr. Sci.*, vol. xxix. p. 49, 1888.

Robinson and Assheton.—"The Formation and Fate of the Primitive Streak, with Observations on the Archenteron and Germinal Layers of Rana Temporaria," *Quart. Jour. Micr. Sci.*, vol. xxxii. p. 451, 1891.

Robinson.—"Observations upon the Development of the Segmentation Cavity, the Archenteron, the Germinal Layers, and the Amnion in Mammals," *Quart. Jour. Micr. Sci.*, vol. xxxiii., part 3, p. 369, 1892.

allantois pushes its way between the two layers of the amnion, and its vessels, with some connective tissue, ramify upon the deep surface of the false amnion, which in turn lines the zona pellucida. Vascular loops are thrown out into the villi of the zona pellucida, and the ovum is thus surrounded by vascular tufts (the chorion) by which it absorbs food from the mucous membrane of the uterus with which it is invested (decidua reflexa).

The part of the chorion between the ovum and the uterus (chorion frondosum) develops into a great vascular pad, the placenta; the rest of the chorion (chorion laeve) atrophies.

The vessels of the chorion frondosum are received into pits in the mucous membrane of the uterus. The membranes which invest the fœtal vessels (viz., (1) the zona pellucida and (2) the outer layer of the amnion) are thinned almost to vanishing, and in the latter part of fœtal life the epithelial lining of the uterus is also reduced to a membrane, so that the vessels of the fœtus are brought as near as possible to the maternal vessels, from the blood in which all the oxygen for respiration and all the food of the fœtus are obtained by osmosis; into which all the carbonic acid and other waste matters are discharged, with the exception of such as accumulate in the meconium, and the small quantity of urea, &c., found in the amniotic fluid. The maternal vessels (sinuses) are immensely dilated "capillary" vessels, filled with blood by small arteries with narrow openings.

Fœtal and maternal vessels are so intricately woven together, that the placenta cannot be detached without tearing off the greatly hypertrophied maternal mucous membrane (decidua serotina).

Nutrition of the embryo. The embryo obtains its food from, and excretes waste materials into the maternal blood. In addition to this, the fœtal vessels serve the same purpose as gills, the maternal blood being the reservoir of oxygen and receptacle for carbonic acid.

> The blood-pressure in the umbilical arteries is from, 40 to 80 mm. Hg., and that in the vein much higher than ordinary venous pressure, viz., 15 to 30 mm. Hg.
>
> The aërated blood in the fœtus contains 7 to 20 vols per cent. of O_2; the blood in the umbilical arteries 2 to 6 vols per cent. of O_2. The fœtal blood is always far from being saturated with oxygen.

Diffusion between fœtal blood and maternal blood occurs rapidly. Strychnin, atropin, &c., given to the mother poisons the fœtus. Strychnin or curare injected into the fœtus poisons the mother. Sugar injected into the maternal vessels appears in the fœtal tissues; and if it is injected into the mother in such quantity as to cause concentration of her blood, the fœtal blood supplies the maternal blood with water, and in turn becomes concentrated.

The considerable quantity of glycogen, which is found in the placenta and also in fœtal tissues indicates that carbohydrates are transferred from mother to fœtus, as such. Proteids can only diffuse after being changed into peptones, but nothing is known regarding the form in which they are transferred to the fœtus. The passage of fat is also difficult to explain.

Functions of the fœtus. Its muscles, as soon as developed, begin to contract, producing local and general movement. Movements begin to be noticeable at about the commencement of the fifth month ("quickening of the child"). Since such movements are in the main reflex, the lower parts of the cerebro-spinal system are functional. Excretory functions of the liver are early in action; bile-pigment and bile-salts appearing in the liver about the third month.

Helm.—"Muscular Fibre and Connective Tissue of the Uterus during Pregnancy," *Trans. Roy. Soc. Edin.*, vol. xxxv., 1890.

Parturition. The commencement of contractions (labour pains) at a fixed date (280 days) after the last menstruation, has been explained in various ways: blocking of the uterine vessels with epithelial cells, fatty degeneration of the decidua, gradual increase of carbonic acid and deficiency of oxygen, have been alleged as immediate causes, but on insufficient grounds. It is due to the culmination of a number of conditions.

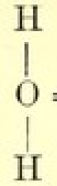
Lactation. During pregnancy the mammary gland prepares for work. Even during the first three months of the first pregnancy the areola round the nipple becomes larger and more pigmented, showing that changes are occurring. Towards the end of pregnancy the gland-tissue opens out and new acini are formed along the course of the ducts; all the acini enlarge; their single-layered epithelium becomes more columnar, its cells larger, clearer, and with large fat-globules amongst their contents; a clear secretion containing large fat-globules accumulates within the acini.

For the first three days the milk (colostrum) secreted is concentrated, yellow, and filled with the fat-containing cells of the gland thrown off *in toto* or in fragments. Colostrum has an important laxative action, helping the baby to evacuate the meconium, which is accumulated in its intestines.

Full secretion is set up in three or four days and lasts for about ten months. 1 to 1·3 litres is secreted per diem.

The percentage of casein and fat increases to the end of the second month, but sugar diminishes. The amount of fat begins to diminish at the fifth month. The casein also falls off towards the end of lactation (p. 90).

The simplest compound of the diatomic element oxygen with hydrogen is



= water.

If a carbon-hydrogen compound is to be combined with an oxygen-hydrogen compound, each must part with an atom of hydrogen in order that an atomicity on each side may be left free to effect the union,—an arm disengaged to hold on with, as we represent it in our graphic formulæ.

The OH of the water is termed hydroxyl, and bodies in which one or more compound atoms of hydroxyl are combined with a hydrocarbon, are termed *alcohols*.

$C_2H_5(OH)$, **ethylic alcohol**, is found in urine, in muscle, and perhaps elsewhere, in very minute quantity. It is formed by fermentation of sugar in the intestine.

$C_{26}H_{43}(OH)$, **cholesterin**, occurs in blood-corpuscles, nervous tissues, and bile. Its formula illustrates the most characteristic of all the properties of carbon, namely, its power of condensation or combining with itself. If this body belonged to the paraffin series its formula would be $C_{26}H_{53}(OH)$, but certain of the atomicities of the carbon are combined with one another. It is owing to this capacity for self-saturation on the part of carbon that its compounds exist in such enormous variety.

> Gall-stones are mainly composed of cholesterin, which may be extracted by boiling alcohol. It is soluble in ether, and is best crystallised (in rhombic plates) from a mixture of alcohol and ether.
>
> *Test.* Allow some crystals to form on a slide and then warm them with a mixture of sulphuric acid and water (5 : 1). The edges of the crystals turn red.

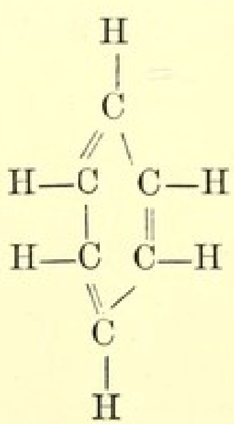
$C_3H_5(OH)_3$, **glycerin**, is combined with fatty acids to form fats.

> *Test.* When heated (whether it be free or combined with a fatty acid) it gives off water, forming acrolein, a body with a characteristic pungent smell. It is to this body that the disagreeable odour of burnt milk is due.

Glycerin. *Acrolein.*

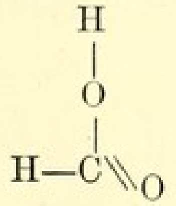
$$C_3H_5(OH)_3 - 2H_2O = C_3H_4O.$$

C_6H_5OH, **phenol** or (popularly) **carbolic acid**, is a monatomic alcohol of the condensed hydrocarbon, C_6H_6, benzene. The formula of benzene is represented by Kekule, thus:—



By substitution of other atoms and groups of atoms for its H's, it gives rise to the aromatic groups of bodies. Phenol is found in combination as an ethereal sulphate in the urine, as are also $C_6H_4(OH)_2$, **pyro-catechin** (which also occurs in cerebro-spinal fluid), and C_7H_7OH, **cresol.**

Acids. Another way in which O, H, and C are united together is by their union into a group, thus—



and then the introduction of this group (as carboxyl) into some other organic molecule. Substances formed in this way are termed acids, because of the extreme readiness with which they part with the hydrogen of the hydroxyl combination taking any other element, as for instance Zn or Na, in exchange. Alcohols set comparatively little store upon this hydrogen, and will exchange it for a metal, but the organic acids behave in this respect like inorganic acids, such as H_2SO_4 or HCl.

Monatomic acids formed from the paraffins are termed *fatty acids,* because certain members of the series unite with glycerin.

H,CO,OH, **formic acid,** occurs in various situations.

CH_3,CO,OH, **acetic acid,** is found in the stomach and intestines, and in minute quantities in bile and sweat.

C_2H_5,CO,OH, **propionic acid,** occasionally in sweat.

C_3H_7,CO,OH, **butyric acid,** in sweat, fæces, urine.

C_5H_{11},CO,OH, **caproic acid,** occurs as a glyceride in butter, as may also—

C_7H_{15},CO,OH, **caprylic acid,** and—

C_9H_{19},CO,OH, **capric acid.**

$C_{15}H_{31}$,CO,OH, **palmitic,** and—

$C_{17}H_{35}$,CO,OH, **stearic,** combined with glycerin, constitute, with the glyceride of oleic acid, the **fat** of the body.

In the fats all three hydroxyls of glycerin are replaced by an acid, *e.g.*,

$$C_3H_5 \left\{ \begin{array}{l} C_{15}H_{31}COO \\ C_{15}H_{31}COO \\ C_{15}H_{31}COO \end{array} \right. = \text{palmitin,}$$

or in other words, the hydrogen of these separate fatty acids is replaced by one molecule of allyl (C_3H_5).

> Notice that in working out chemical formulæ, each of the molecules which is to be brought into combination must give up something (usually a hydrogen) in order that an atomicity (or arm) may be left free for the purpose of attaching the group to the rest of the compound. *E.g.*, glycerin gives up OH, and the fatty acid gives up H; two unsatisfied atomicities are thus provided, and union made possible.

Fats are saponified by replacing allyl with a metal, thus:—

$$\begin{array}{llll} & C_{15}H_{31}COO & KHO & \\ C_3H_5 & C_{15}H_{31}COO + & KHO = C_3H_5(OH)_3 + & \textit{Potassic palmitate} \\ & C_{15}H_{31}COO & KHO & 3C_{15}H_{31}COOK. \end{array}$$

Soaps are also formed (in the intestine) by the union of an alkali with a fatty acid, thus:—

$$2C_{15}H_{31}COOH + Na_2CO_3 = 2C_{15}H_{31}COONa + CO_2 + H_2O.$$

The fat of nervous tissues is more complicated, for instead of all three hydroxyls of glycerin being replaced by a fatty acid, only two are so replaced, and the third is replaced by phosphoric acid.

Glycerin-Phosphoric Acid.

$$C_3H_5\begin{cases} OH \\ OH \\ PO_4H_2 \;\; (i.e.,\; H_3PO_4 - H) \end{cases}$$

is first formed, and then the two remaining hydroxyls are replaced by stearic acid, thus:—

$$C_3H_5\begin{cases} C_{17}H_{35}COO \\ C_{17}H_{35}COO \\ PO_4H_2. \end{cases}$$

And further, one of the hydrogens of the phosphoric acid is replaced by cholin, $C_2H_4,N(CH_3)_3(OH)_2$.

Free **fatty acids** occur in old pus.

Calcic salts (soaps) of palmitic and stearic acid constitute the chief bulk of adipocere, the waxy substance into which flesh is converted some time after burial in damp soil. This formation of fats from proteids is especially interesting as throwing light upon the origin of fat in the body.

Oleic acid, $C_{17}H_{33}COOH$, and its glyceride (**Olein**) are liquid.

Acids of other series.

Carbonic acid series; general formula, $C_nH_{2n}OH,COOH$. These acids contain two disposable H's, one of which (the carboxyl H) is sacrificed more readily than the other (the hydroxyl H); they therefore form two classes of salts—

$OH,COOH$, **Carbonic acid**,

$C_2H_4OH,COOH$, **Lactic acid**, exists in three modifications: (1) sarcolactic or para-lactic acid, which is the very important product of muscular action. It is distinguished from the other lactic acids by its dextro-rotary action on polarised light. This substance has probably an important physiological rôle, for it appears to cause dilation of blood-vessels, and thus by its direct action effects organic adaptations which would otherwise seem to require nerve-influence.

2. Ordinary (ethidene) lactic acid formed from milk-sugar by fermentation,

$$C_6H_{12}O_6 = 2C_3H_6O_3.$$

3. Ethene lactic acid also forms during muscle-contraction or in rigor mortis in very small quantity.

> *Test.* Mix 10 cc. of a 4 per cent. solution of carbolic acid with 20 cc. of water, and one drop of liquor ferri perchloridi of the B.P. A mere trace of either kind of lactic acid (1 in 10,000) turns this violet liquor yellow.

Oxalic acid series: general formula, $C_nH_{2n}(COOH)_2$.

$(COOH)_2$, **Oxalic acid.**

Oxalate of lime is sometimes deposited from urine in dumb-bell shaped crystals.

$C_2H_4(COOH)_2$, **Succinic acid**, occurs in the spleen, thymus, thyroid, hydrocele fluid and urine.

$C_{24}H_{40}O_5$, **Cholalic acid**, is combined with glycin or tannin to form the glyco-cholic or taurocholic acid of bile. Its rational formula is unknown.

> *Test.* Add to liquor suspected to contain bile-salts a crystal of cane

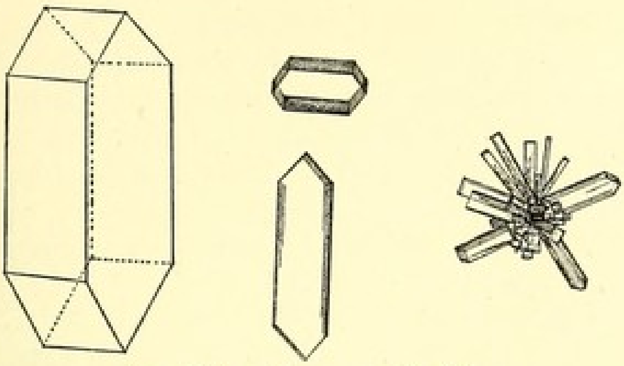


FIG. 86.—Zinc sarco-lactate.

Type-crystal : Four-sided prism with truncated ends.

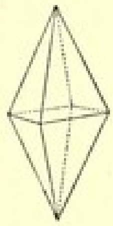


FIG. 87.—Calcic oxalate.

Type-crystal : Rhombic octahedron.

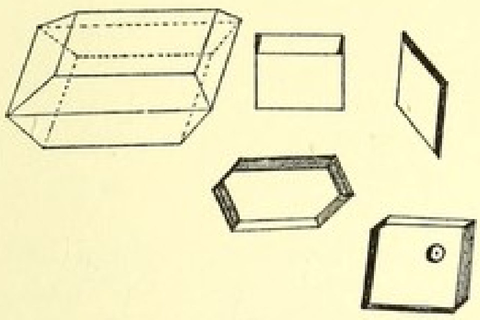


FIG. 88.—Cane-sugar.

Type-crystal : Square tablet with bevelled edges.

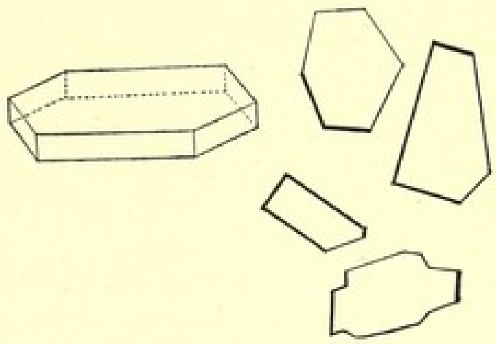


FIG. 89.—Grape-sugar (dextrose).

Type-crystal : Hexagonal plate.

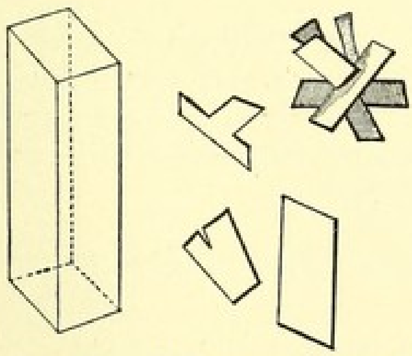


FIG. 90.—Milk-sugar (lactose).

Type-crystal : Rhombic prism.

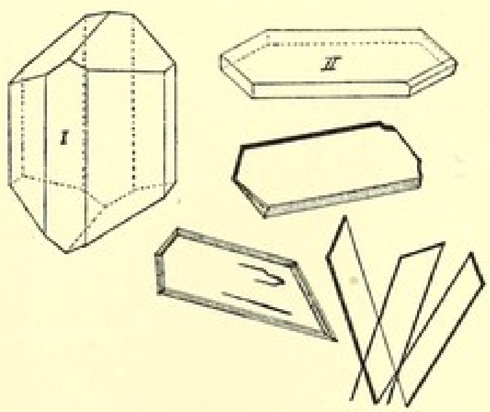


FIG. 91.—Inosite.

Type-crystals : I, Asymmetric prism (rare) ; II, asymmetric table.

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sugar and a small quantity of sulphuric acid ; warm, but do not allow the temperature to rise above 70° C. A full purple colour results. (Furfur-aldehyde or Pettenkofer's reaction.)

Carbohydrates are the great reserves of non-nitrogenous substance both in plants and animals. Consequently they constitute a large bulk of the food of animals.

We should know little as to their constitution were it not for the existence of **mannite**, which occurs in the juice of the ash (*Fraxinus excelsior*) when grown in warm countries. It is imported from Sicily as a mild aperient for infants. Mannite is a normal hexatomic alcohol, $C_6H_8(OH)_6$, formed from the paraffin, C_6H_{14}. Dextrose may be made from mannite by reducing it with sodium amalgam, thus :—

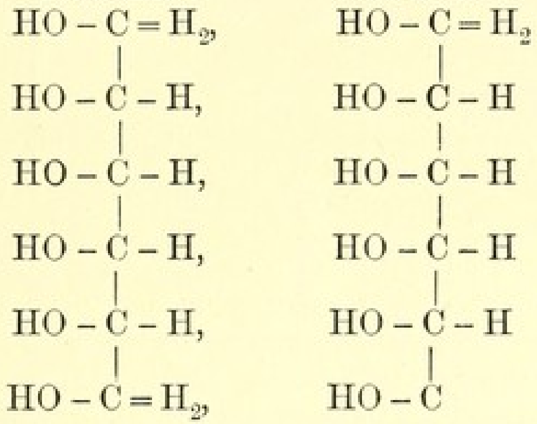
Mannite. *Dextrose.*

$$C_6H_{14}O_6 - H_2 = C_6H_{12}O_6.$$

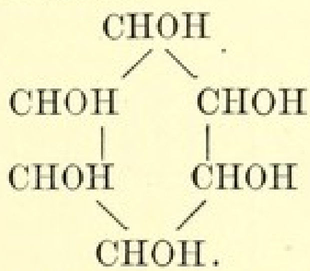
Carbohydrates are all, with the exception of inosite, derivatives of the hexatomic alcohol mannite ; they are divisible into three classes :—

1. *Glucoses*, which are aldehydes of mannite, thus :—

Mannite. *Glucose.*



Inosite, a sugar which is found in muscle, kidney, liver, nervous, and other tissues, and in urine (perhaps normally), does not however appear to be an aldehyde. It is distinguished from all other sugars in that it does not rotate polarised light, for which reason (law of *le Bel* and *van t' Hoff*) it is supposed to have the following symmetrical formula :—



Test. Evaporate it with a little nitric acid on a platinum dish : treat the residue with ammonia and calcic chloride, and evaporate to dryness at a gentle heat ; a bright red or violet residue is left.

2. *Sucroses* are condensed glucoses :—

$$2C_6H_{12}O_6 - H_2O = C_{12}H_{22}O_{11}.$$

3. *Amyloses* are still further condensed, and may be regarded as anhydrides of the glucoses :—

$$nC_6H_{12}O_6 — nH_2O = nC_6H_{10}O_5.$$

For the sake of accuracy, *n* should be prefixed to the formula, since the atomic weight of the amyloses is unknown.

The carbohydrates may be classified as follows :—

Formula.	Solubility.		Colour with Iodine.	Alcoholic Fermentation.	Precipitates Cu_2O from $CuSO_4+KHO$.	Rotation of Polarised Light.	Crystalline Form.
$C_6H_{10}O_5$.	Starch.	Insol.	Blue.				
Amyloses.	Glycogen.	Sol (opalescent).	Blood-red.				
	Dextrin.	Sol.	Brown-red.				
$C_{12}H_{22}O_{11}$.	Lactose.	In six times its weight of water.	Nil.	Not at all.	Nil.	R.	Hard rhombs.
Sucroses.	Maltose.	Sol.	...	With difficulty.	$\frac{2}{3}$	R.	Acicular crystals.
	Cane-sugar.	$\frac{1}{3}$ its weight.	...	,,	$\frac{2}{3}$	R.	Prisms.
$C_6H_{12}O_6$.	Inosite.	Sol.	...	Not at all.	Nil.	Nil.	Monoclinic prisms.
Glucoses.	Dextrose.	Equal weight.	...	Easy.	1	R.	Cauliflowers.
	Galactose.	Sol.	...	Moderate.	Yes.	R.	
	Lævulose.	Syrup.	...	Moderate.	1	L.	Uncrystallisable.

Relation of carbohydrates in the body.

Glycogen is the comparatively indiffusible form in which carbohydrate is stored in the liver, muscle, and probably other tissues; it is converted into dextrose for transport in the blood. Carbohydrates enter the stomach chiefly in the forms of starch, cane-sugar, dextrose, and lactose. Dextrose and lactose are not altered by the gastric juice; cane-sugar is converted into maltose and lævulose. By the saliva and pancreatic juice, starch is changed into maltose. Within the intestines, under the influence of inverting ferments, cane sugar, lactose, and maltose are changed into dextrose and lævulose, dextrose and galactose, and dextrose, respectively.

Glucosides.—In plants a great variety of organic radicles are combined with glucose in the form of glucosides, *e.g.*, gallic acid and glucose = tannin; saligenin and glucose = salicin.

Glucosides are also found in the body, *e.g.*, **mucin, cerebrin, chitin.**

Nitrogenous compounds.

Nitrogen can be introduced into an organic molecule in several ways. The constitution of the most numerous of the nitrogenous compounds found in the body can be understood from the following typical combination:—

$$\begin{array}{ccccc} \begin{array}{c} H \\ | \\ H-C-H \\ | \\ H \end{array} & + & \begin{array}{c} H \\ | \\ H-N \\ | \\ H \end{array} & = & \begin{array}{c} \textit{Methylamine.} \\ CH_3NH_2. \end{array} \end{array}$$

The formula for bodies of this kind can be written either with the group about the tetratomic carbon, or with the group about the triatomic nitrogen, as the starting-point. The physiologist will find it convenient to use the former method whenever possible; upon this basis NH_2 (amidogen) is the radicle which is substituted for one atomicity in the main group, and the substances as a class are termed *amides.*

Amines, on the other hand, are best regarded as derivatives of ammonia, *e.g.*,

$N(CH_3)_3$, **trimethylamine**, is a product of decomposing proteids. It gives the characteristic smell to fish, and is normally present in urine. When isolated it is a strongly alkaline oily fluid, boiling at 9° C.

Amides of the fatty acids.

$CH_2,NH_2,COOH$, **glycin** (glycocoll), is amido-acetic acid. It is found in combination with cholalic acid as the glycocholic acid of bile, and with benzoic acid as hippuric acid. It unites with urea to form uric acid. $C_6H_4,(CH,NH_2CO)COOH$, **hippuric or glycin-benzoic acid,** is present in large amount (as hippurates) in the urine of herbivora, chiefly owing to the presence of benzoic and other aromatic bodies in their fodder; they secrete a certain quantity, however, even when starving. The urine of sucking herbivora is almost free from hippuric acid. It appears in human urine if benzoic acid is ingested.

Benzoic acid + glycin = hippuric acid.

$$C_6H_5COOH + CH_2NH_2COOH = C_6H_4(CH,NH_2CO)COOH.$$

It crystallises in four-sided prisms; is readily soluble in hot alcohol and ether, but only slightly soluble in water. With sulphuric or nitric acid it splits into benzoic acid and glycin. It reduces Fehling's solution.

$CH_2,(NH,CH_3)COOH$, **sarcosin,** methyl-glycin or methyl-amido-acetic acid, is formed from creatin by the action of baryta-water.

$C_5H_{10},NH_2,COOH$, **leucin,** is one of the chief products of the decomposition of proteids, whether by strong acids or alkalies or during putrefaction, or within the alimentary canal by the action of pancreatic juice. It crystallises in yellowish-brown warty spheres.

Diamide of carbonic acid.

$CO(NH_2)_2$, **urea** or **carbamide**, may be made from ammonia and carbonic anhydride by passing them into alcohol.

Ammonic carbamate.

$$2NH_3 + CO_2 = NH_2COONH_4$$

heat

Urea.

$$NH_2COONH_4 - H_2O = NH_2CONH_2.$$

It is the ultimate product of the decomposition of proteids within the body, and may be regarded either as carbonic anhydride, in which one atom of oxygen is replaced by two of amidogen, or as ammonia in which two molecules united together have given up two atoms of hydrogen in exchange for one of carboxyl, thus—

$$CO\begin{cases} NH_2 \\ NH_2 \end{cases} \quad \text{or} \quad \begin{matrix} N\begin{cases} H \\ H \end{cases} \\ CO \\ N\begin{cases} H \\ H \end{cases} \end{matrix}$$

It was first prepared synthetically in 1828 by *Wöhler*, by heating ammonic cyanate to 100° C. This reaction has a double interest. *Firstly*, it is the reaction which disproved the belief of the time, that the chemist could never make in his laboratory the substances which nature makes in the body. *Secondly*, according to a view advanced by *Pflüger* in 1875, it illustrates in a typical way the contrast between nitrogenous substances within the body, in which the nitrogen is directly united with carbon in a cyanogen (CN) compound, and dead nitrogenous substances in which nitrogen and hydrogen (amidogen) are especially united together. Bodies of the former class are less stable than those of the latter, and are susceptible to the action of neutral oxygen (respiration).

Urea crystallises in silky four-sided prisms with oblique ends, or, when rapidly crystallised, in delicate white needles. It is converted by hydration into ammonic carbonate under the influence of the ferment Torula ureæ, which grows readily in stale urine,

$$CO(NH_2)_2 + 2H_2O = (NH_4)_2CO_3.$$

It behaves like ammonia in (A) forming salts with acids.

Nitrate of urea		*Oxalate of urea*
$CO(NH_2)_2HNO_3$	and	$CO(NH_2)_2H_2C_2O_4$

are readily obtained by adding acid to concentrated urine. The characteristic form of the crystals in each case renders these reactions useful as tests.

B. Not only does urea combine with acids, but also, like other amides, it unites with metallic oxides. It is in the form of a compound with HgO that urea is precipitated for purposes of quantitative estimation.

Liebig's volumetric method. Prepare a solution of nitrate of mercury by dissolving mercury in nitric acid. Triturate this solution by experiment with a standard solution of pure urea until it is of such a strength that 1 cc. combines with 10 milligrammes of urea.

Estimate the chlorides in the urine in order that the amount of the mercury-solution which they would precipitate may be deducted, or, in ordinary cases, simply make an average allowance for chlorides.

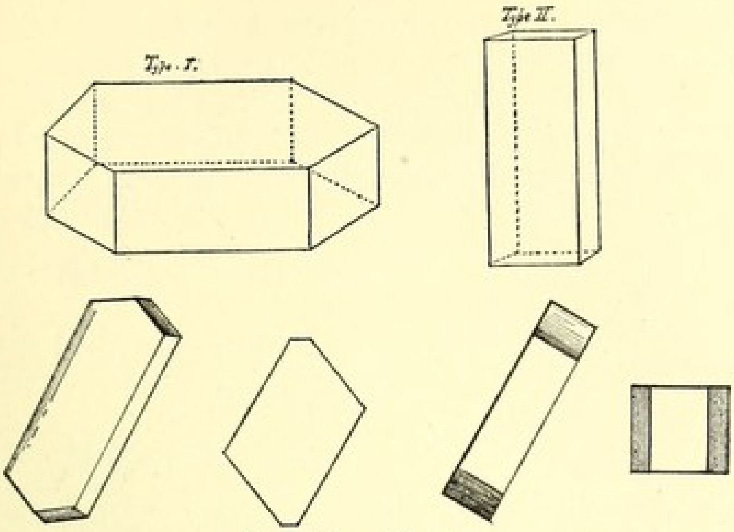


FIG. 92.—Glycin.

Type-crystals: I, Flat six-sided prism; II, square prism.

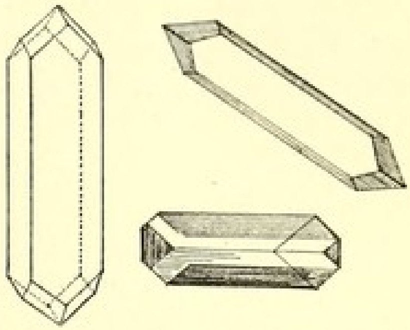


FIG. 93.—Hippuric acid.

Type-crystal: Four-sided prism with pyramidal ends.

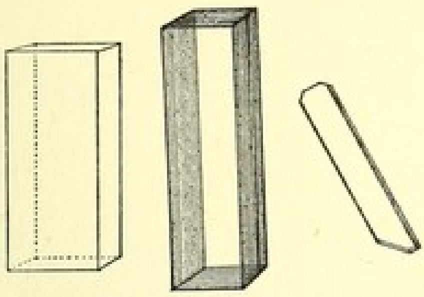


FIG. 94.—Urea.

Type-crystal: Square prism.

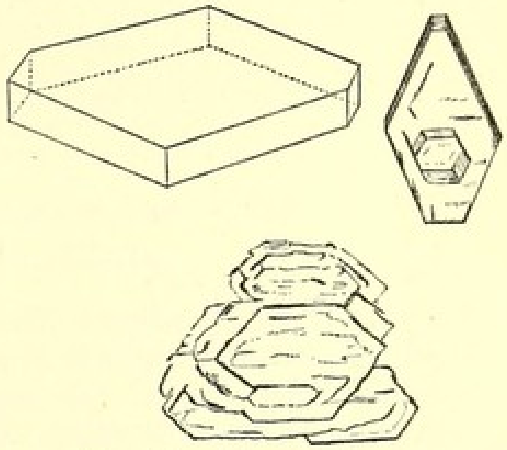


FIG. 95.—Nitrate of urea.

Type-crystal: Flat six-sided prism (tablet).

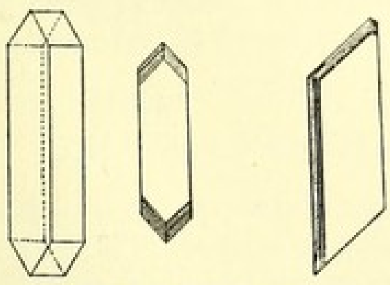


FIG. 96.—Oxalate of urea.

Type-crystal: Prism with truncated ends, varying to a rhombic plate.

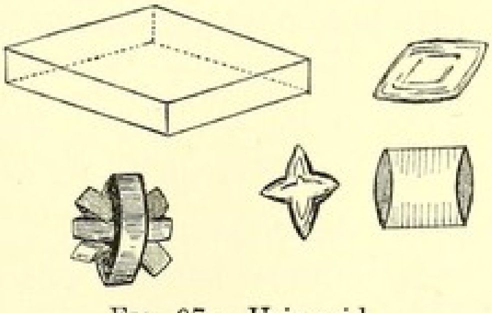


FIG. 97.—Uric acid.

Type-crystal: Rhombic plate (but rounded and tending to form aggregations of two or more individual crystals).

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Precipitate sulphates and phosphates by baryta mixture; filter; add the mercury-solution until no more precipitate is formed, or test the mixture frequently for excess of mercuric nitrate, by adding a drop of it to a drop of a solution of sodic carbonate on a piece of glass blackened on the under surface. As soon as it contains free mercuric nitrate it gives a yellow colour with the sodic carbonate.

C. Just as ammonia takes organic radicles into its molecule, forming amines (or amides), so urea gives up hydrogen in exchange for groups of elements, forming compound ureas, *e.g.*,

Alloxan.

$$CO\left\{\begin{array}{l}NH_2\\ N=C_3O_3\\ \quad\text{(mesoxalyl)}\end{array}\right.$$ is a monureide of mesoxalic acid; urea + mesoxalic acid − H_2O.

Acetyl-urea.

$$CO\left\{\begin{array}{l}NH_2\\ NH,CH_3CO\\ \quad\text{(acetyl)}\end{array}\right.$$ is a monureide of acetic acid; urea + acetic acid − H_2O.

Many other bodies of the same kind are known, some containing one, and others two molecules of urea, the union being effected with elimination of either one or two molecules of water.

When heated to 150° C., urea melts and gives off ammonia—

$$2CO(NH_2)_2 - NH_3 = \underset{\textit{Biuret.}}{C_2O_2N_3H_5}.$$

Biuret still further heated gives off ammonia—

$$3C_2O_2N_3H_5 - 3NH_3 = \underset{\textit{Cyanuric acid.}}{2C_3H_3N_3O_3}.$$

C_2H_3, NH_2, C_6H_4OH, COOH, **tyrosin** (amido-oxyphenyl-propionic-acid), is a product of the decomposition of proteids both in the intestines and in the laboratory; usually accompanies leucin, and is especially interesting as showing the existence in the proteid-molecule of an aromatic group of elements.

$H,C_2H_4NH_2$, SO_3, **taurin** (amido-ethyl-sulphonic acid), is found in bile united with cholalic acid, as taurocholic acid. It contains the greater part of the sulphur taken in animal food, and is therefore more abundant in the bile of carnivora than in the bile of herbivora.

The uric acid group.

$C_5H_4N_4O_3$, **uric acid.** The composition of this body is most uncertain, but since it has been prepared synthetically by Horbaczewski, by heating a mixture of glycin and urea for 24 hours in a closed tube to 200° C.,

$$\underset{\textit{Glycin.}}{C_2H_5NO_2} + \underset{\textit{Urea.}}{3CO(NH_2)_2} = \underset{\textit{Uric acid.}}{C_5H_4N_4O_3} + 3NH_3 + 2H_2O$$

and since it is in some respects a more stable body[1] than urea, it may be regarded as fairly certain that it contains cyanogen (CN) rather than amidogen (NH_2) radicles.

It crystallises in rhombic rectangular plates or in rectangular prisms, which are very apt to retain urinary colouring-matter. The crystals are often aggregated in

[1] The urine of mammals is the source of much of the nitrates of South America; while the urine of birds contains unchanged uric acid after lying for thousands of years in guano-deposits.

irregular angular masses, which are peculiarly irritating to the mucous membrane in cases of gravel.

Uric acid is extremely insoluble, 1 part requiring 15,000 parts of cold and 2000 parts of hot water for its solution. The acid-lithium-urate is the most soluble of the salts which the body can secrete. Hence the use of lithia-water in gout.

Test. Evaporate to dryness with nitric acid. The residue is reddish-yellow, but turns purple on the addition of ammonia, or bluish-violet with soda or potash (murexide test).

When decomposed, uric acid is apt to yield urea and compound ureas, *e.g.*,

When treated with cold nitric acid, it combines with water and oxygen to form alloxan and urea,

$$2C_5H_4N_4O_3 + 2H_2O + O_2 =$$

Alloxan.

$$2CO{}^{NH_2}_{N(C_3O_3)} + 2CO{}^{NH_2}_{NH_2}.$$

When boiled with a strong alkali,

Alloxan. *Mesoxalic acid.*

$$2C_4H_2N_2O_4 + 2H_2O = 2C_3H_2O_5 + 2CO(NH_2)_2$$

and mesoxalic acid when oxidised gives oxalic and carbonic acids, which with urea may therefore be regarded as the oxidation-products of uric acid.

Percentage of nitrogen in each of the chief substances in which this element is excreted—

$$\text{Urea} \quad = CON_2H_4 \frac{28 \times 100}{60} = 46$$

$$\text{Uric acid} \quad = C_5H_4N_4O_3 \frac{56 \times 100}{168} = 33$$

$$\text{Hippuric acid} = C_9H_9NO_3 \frac{14 \times 100}{179} = 8.$$

Why do some animals secrete urea, others hippuric acid, and others again uric acid?

A. Of the three, urea is the lowest term; in fishes, amphibia, and mammals, therefore, the decomposition of proteid is pushed to its utmost limits, resulting in the formation of a diamide—a compound of carbonic acid and ammonia.

B. The benzoic acid in the fodder of herbivora meets with glycin, with which it conjugates. Glycin is secreted by the liver in glycocholic acid. This, when reabsorbed, is oxidised into urea. Since hippuric acid is not excreted after extirpation of the kidney, and since benzoic acid and glycin (or benzoic acid alone), when added to blood in the renal artery, cause hippuric acid to appear in the urine, it may be inferred that benzoic acid normally conjugates with glycin in the kidney.

C. The facts just adduced indicate that glycin is a most important antecedent of urea. It is possible that much glycin is formed in the body beside that which conjugates with cholalic acid in the liver, and it has been suggested by *Latham*[1] that in reptiles, birds, and human beings suffering from the gouty diathesis, some of the glycin, instead of being further oxidised into urea, unites with urea already formed, as in Horbaczewski's experiment.

[1] *Croonian Lectures*, 1886.

Con. 1. The synthesis of uric acid from glycin and urea is not a simple conjugation, but is accompanied by the elimination of ammonia and water. *Latham's* view requires, therefore, the formation of certain intermediate products which have yet to be isolated.

2. When the liver of a goose is extirpated, the animal excretes during the six to twenty hours for which it survives scarcely any uric acid. Ammonia and lactic acid appear in the urine instead, in proportions which make it possible that uric acid is normally formed in the liver by their union.

To what is the formation of uric acid due?

To deficient oxidation?

Pro. 1. Uric acid oxidises into urea and compound ureas.

2. It is secreted by slow-breathing reptiles, by people who take much proteid food and very little exercise, and (in the form of urates) in febrile conditions, when the demand on the part of the tissues for oxygen may be supposed to exceed the supply.

Con. 1. It is the nitrogenous excrement of birds, which use more oxygen in proportion to their body-weight than other animals.

2. Uric acid is not an antecedent of urea. The formation of uric acid instead of urea, must be looked upon as a diversion of the lines of metabolism at some point not as yet ascertained.

Causes of the formation of stone in the bladder, gravel, gouty deposits about the joints, &c.

1. Production of uric acid in abnormal quantity—due to an hereditary tendency to this form of metabolism; to the absorption of proteids imperfectly digested owing to dyspeptic conditions, &c.

2. Unsuitability of the urine, owing to its high acidity, poverty in mineral salts, and low pigmentation, to serve as a vehicle for uric acid.

Uric acid is dibasic. It forms neutral urates ($M_2\bar{u}$), acid urates or biurates ($MH\bar{u}$), and hyperacid quadrurates ($MH\bar{u}$, $H_2\bar{u}$).

Neutral urates are never formed in the body, but uric acid is always secreted in the form of quadrurates, which are soluble in urine of normal constitution; but in pure water, or in urine which does not contain acid salts and pigment in the normal proportions, they break down into uric acid and insoluble biurates.[1]

$C_5H_4N_4O_2$, **xanthin**, and $C_5H_4N_4O$, **hypoxanthin**, may be obtained from uric acid by deoxidation with sodium-amalgam. These two substances are of frequent occurrence as products of proteid metabolism.

$C_5H_5N_5O$, **guanin**, is found in guano.

$C_4H_6N_4O_3$, **allantoin**, occurs in the urine of fœtal and newborn animals.

$C_4H_9N_3O_2$, **creatin**, methyl-guanidin-acetic acid, is found in muscle, blood, and elsewhere. When boiled with baryta water,

$$C_4H_9N_3O_2 + H_2O = \underset{\textit{Sarcosin.}}{CH,CH_3NH_2,COOH} + \underset{\textit{Urea.}}{CO(NH_2)_2}.$$

Sarcosin is methyl amido-acetic acid, and differs from glycin in possessing an additional CH_3; and although sarcosin and urea will not unite, if cyanimide (CN,NH_2) instead of urea is heated with sarcosin, creatin is formed.

This is another proof of the truth of *Pflüger's* theory, that the descent from living to dead substance is due to the substitution of NH_2 in place of CN radicles.

[1] Sir William Roberts.—*Proc. Med. Chir. Soc.*, 1890, p. 85.

$C_4H_7N_3O$, **creatinin**, is creatin − H_2O. It is a constant constituent of urine to the amount of about 0·6 gramme per litre, but varies with the proteid in the diet.

Other nitrogenous compounds.

$C_{10}H_{14}N_4O_{11}$, **inosinic acid**, an uncrystallisable substance found in muscle-plasma.

C_9H_9N, **skatol**, or methyl-indol, and—

C_8H_7N, **indol**, appear in the intestine, and both are excreted in urine as double salts with potassium-sulphate, thus :—C_8H_6N,K,SO_4. Phenol, cresol, and pyro-catechin are secreted in the same form. Indoxyl-sulphate of potassium was termed by mistake indican, because like vegetable indican (which is a glucoside) it is converted into indigo by mineral acids.

> *Test* for "indican" in urine. Add a little fuming nitric acid, and then pour hydrochloric acid gently down the tube. The hydrochloric acid sinks to the bottom of the tube, and at its plane of junction with the urine, indigo is deposited.

KCNS, **potassic sulphocyanate**, occurs in saliva. It has probably a disinfecting action in the mouth.

> *Test.* Add to saliva a little ferric chloride, sulphocyanide of iron is indicated by a blood-red colour.

Ptomaines [1] (πτῶμα, a corpse), and **leucomaines** [2] (λεύκωμα, white of egg). Substances which resemble vegetable alkaloids in their composition and poisonous effects.

(1) Some of these bodies are produced in putrefying animal matter, in bad cheese (tyrotoxicon), in shell-fish under certain conditions (mytilotoxine), &c. (2) Others are produced by bacteria in certain diseases: such are typho-toxine (of typhoid fever), tetanine (of tetanus), &c. These are the most poisonous of the ptomaines, and are distinguished by *Brieger* as "toxines." (3) The leucomaines are bodies produced by animal metabolism without the interference of bacteria; some are poisonous (as neurin and cholin), others are not. Indeed, it is impossible to fix a limit to the application of the terms ptomaines and leucomaines, since they are all compound ammonias, and most of the products of proteid decomposition or metabolism come within this category.

Many actions formerly attributed to the control of nerves are probably brought about by direct chemical stimulation, and it is possible that ptomaines and leucomaines are the agents by which the central nervous system is influenced in such a manner as to affect the temperament in dyspeptic conditions, constipation, jaundice, &c.

On the other hand, actions which were hastily attributed to the ptomaines produced by bacteria, when they were first discovered, are now known to be due to poisonous proteids.

Proteids (πρωτεῖον, pre-eminence), *Mulder's* name for the complex nitrogenous bodies which are essential to all living organisms.

It is probably in the very nature of living protoplasm that it should be in a constant condition of molecular flux; its molecules ceaselessly forming new combinations, as nutrient substances are assimilated on the one side, and oxidised metabolites excreted on the other. If this be true, and it is difficult otherwise to account for vital activity, the actual formula for protoplasm can never be expressed, although the plan of arrangement of its molecules may be discovered; nor, apart from its exhibition of vital properties, can a chemical test be devised which will distinguish living protoplasm from dead proteid. The power of reducing weak solutions of silver-nitrate is said to be distinctive of living protoplasm.

Although a numerous class of bodies, differing widely in physical properties,

[1] Term introduced by Selmi. [2] Term introduced by Gautier.

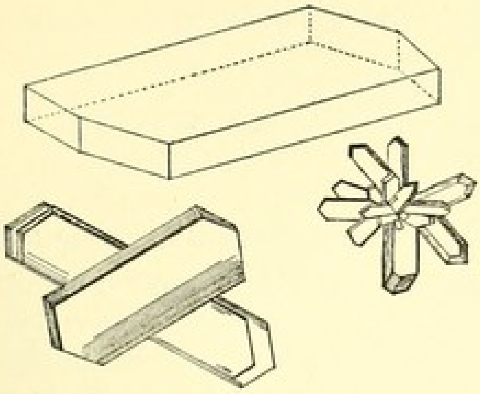

FIG. 98.—Creatin.

Type-crystal : Six-sided plate.

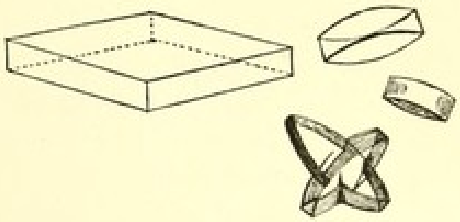

FIG. 99.—Creatinin.

Type-crystal : Four-sided plate (but with rounded edges owing to imperfect development).

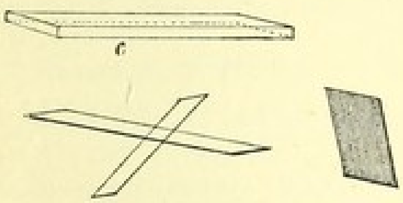

FIG. 100.—Oxyhæmoglobin from human blood.

Type-crystal : Oblique four-sided plate.

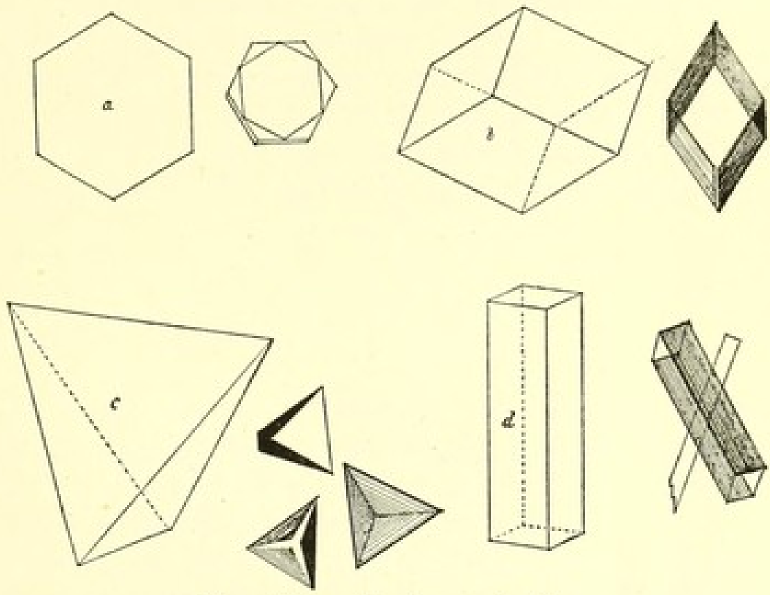

FIG. 101.—Oxyhæmoglobin.

a, From squirrel. *Type-crystal :* Equilateral hexagonal plate.
b, From hamster. *Type-crystal :* Rhombohedron.
c, From guinea-pig. *Type-crystal :* Tetrahedron.
d, From cat or dog. *Type-crystal :* Square prism.

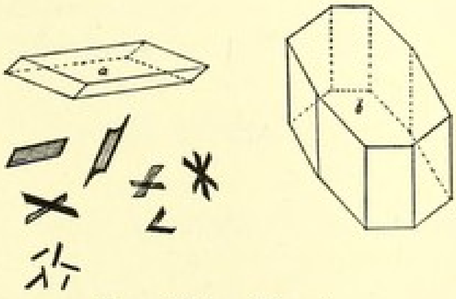

FIG. 102.—Hæmin.

Type-crystal : a, Asymmetric rhomboid plate ; *b*, asymmetric (? triclinic) prism.

To face p. 190.]

proteids all have nearly the same percentage composition, and give certain common reactions.

Percentage composition (Hoppe-Seyler).

C	H	N	O	S
51·5	6·9	15·2	20·9	0·3
to 54·5	7·3	17	23·5	2·0

Products of the decomposition of proteids.

In the body; urea, carbonic acid, water; all the various nitrogenous "extractives" being intermediate. Glycogen and fat appear to be derived from proteid by the metabolic activity of the organism.

Heated in sealed tubes with baryta-water to a high temperature; ammonia and carbonic acid in the same proportions in which they result if urea is treated in the same way, together with various other bodies. On this account, *Schützenberger* looks upon proteid as a ureide or compound of urea, and considers that the carbon and hydrogen are united in imidogen (NH).

For reasons already detailed, *Pflüger* considers that in living proteid the carbon and nitrogen are immediately united together as cyanogen (CN).

Destruction by heat, putrefaction, strong mineral acids or oxidising agents causes proteids to split up chiefly along two lines; the bodies on the one side belonging to the aromatic series (derivatives of C_6H_6 and its homologues), and on the other side to the fatty acid series (derivatives of CH_4 and its homologues); various acids on both sides being amidated.

Common reactions.

All proteids are insoluble in alcohol and ether.

All are lævorotary.

Xantho-proteic reaction; add nitric acid and boil, a yellow liquid results. A precipitate may or may not be formed when the nitric acid is added, and this, if formed, may or may not be completely dissolved on boiling. Allow the liquid to cool and then add ammonia, it becomes orange-coloured.

Millon's reaction. Dissolve one part by weight of mercury in two of strong nitric acid. Dilute the product with twice its bulk of water and allow the precipitate thus formed to settle. The supernatant liquid is known as Millon's reagent. With proteids in solution it gives a white precipitate, which turns brick-red on boiling.

Piotrowski's reaction. Add a few drops of a dilute solution of sulphate of copper; a green precipitate forms (unless the proteid is either deutero-albumose or peptone); add excess of caustic soda and the precipitate dissolves, giving a violet solution. If the proteid is peptone or albumose, provided very little sulphate of copper is used, the solution is rose-red.

The most remarkable differences between the proteids seem to depend upon the amount of water contained in their molecule; thus

		Acid Albumin.				
Least H_2O.		↑				*Most H_2O.*
Coagulated albumin.	←	Albumin.	→	Albumose.	→	Peptone.
		↓				
		Alkali-Albumin.				

Classification of the Chief Proteids according to Solubility.

Coag. by heat.	Sol. in water.		**Serum-albumin** (not prp. by ether). **Egg-albumin** (prp. by ether). **Muscle-albumin.**		Violet solution with $CuSO_4$ and excess of KHO.
	Sol. in 1 % NaCl.	Prp. with NaCl when saturated.	**Paraglobulin** (prp. CO_2. Coag. at 68°). **Globin.** **Fibrinogen** (coag. at 52°. Easily prp. by saturation with NaCl). **Myosinogen.**		
			Vitellin (not prp. by NaCl).		
	Sol. in 10 % NaCl. Insol. in 1 % HCl.		**Fibrin.**		
	Sol. in HCl.		**Syntonin** (coag. by heat when suspended but undissolved. Prp. by alkalies).		
Not coag. by heat.	Sol. in KHO.		**Alkali-albumin** (prp. by HCl, but not perfectly if phosphates are present). **Casein** (coag. by rennet, 1 in 800,000 parts).		
	Sol. in water (except heteroalbumose).		*Proteoses* (intermediate products of digestion. Made also by heating with water, dilute mineral acids or superheated steam).		Biuret reaction (rose-red with $CuSO_4$ and KHO).
		Prp. by sat. with $(NH_4)_2SO_4$. Prp. by $CuSO_4$. Sol. in Pure Water.	**Protoalbumose.**	Prp. by $MgSO_4$.	
		Insol. in Pure Water.	**Heteroalbumose.**		
			Deuteroalbumose.	Not prp. by $MgSO_4$.	
		Not prp. by sat. with $(NH_4)_2SO_4$.	*Peptones*— **Hemipeptone** (split by pancreatic juice). **Antipeptone** (not split by pancreatic juice).		

Albuminoids.—Substances closely allied to proteids, from which they are doubtless derived. They do not give the copper-sulphate test, although they may answer to other tests, especially Millon's reaction.

Soluble in cold dilute alkalies, such as lime-water or baryta-water.	Prp. by acetic acid.	**Mucin.** A widely distributed substance occurring in several modifications in mucus, cement substance of epithelium, ground-substance of connective tissues, synovia, saliva, electric organs, and very largely in the bodies of invertebrates. Mucin is a glucoside; yielding, when treated with dilute sulphuric acid, a reducing but nonfermentable sugar ($C_6H_{12}O_6$). The carbohydrate is combined with a proteid in the form of "animal gum" ($C_6H_{10}O_5$) in which form it may be separated by dissolving mucin in dilute HCl and precipitating the acid-albumin with soda. **Nuclein**, a substance like mucin, but containing abundance of phosphorus. It constitutes the chromatin of nuclein, and occurs also in milk and yolk of egg. **Nucleo-albumins**, or compounds of globulins and nuclein, are abundant in cell-protoplasm. The mucin-like substance in bile is a nucleo-albumin, **Plastin.**
	Swells with acetic acid.	**Colloid.** The mucin-like substance found in the thyroid body.
Sol. in hot water, but sets in a jelly on cooling.	Acetic acid gives a prp., sol. in excess.	**Chondrin** (chondrigen); also a glucoside.
	Acetic acid gives no prp.	**Gelatin**; does not yield sugar; it closely resembles proteid, and is converted by digestion, or by heating to 140° C. in water, into a peptone-like body (not gelatinisable). In its decompositions it gives no aromatic substances. It constitutes the chief bulk of the animal matter of bone, tendon, and other connective tissues, in which it is present in the form of its anhydride, collagen.
Insoluble in water.		**Elastin**, the excessively insoluble substance found in yellow elastic tissue, sarcolemma, &c. Like gelatin, it contains no sulphur. It digests very slowly, yielding elastoses. **Eleidin**; a stage in the formation of keratin. **Keratin**; the basis of horny epidermal tissues. **Spongin, chitin, silk**, and other sulphur-free bodies which take the place of keratin amongst invertebrates.

Poisonous and protective proteids.

As already pointed out, many actions formerly supposed to be distinctively vital, are now attributed to the production within the economy of ptomaines and leucomaines; bodies resembling vegetable alkaloids.

It is now known that some of the most virulent poisons are proteid in nature (certain forms of globulin, albumin, syntonin, or albumose), as for example (1) snake-poison (*Sir Joseph Fayrer* and others), spider-poisons, &c. The most deadly of these is the venom of the cobra, of which about ·006 gramme is a fatal dose.

2. The *toxalbumins*, or rather albumoses, which are produced by the activity of bacteria.

3. *Albumoses* and *peptones* produced during natural digestion, if injected into the blood.

On the other hand, certain proteids contained in the animal juices are fatal to bacteria. Hence they are termed *protective proteids.*

Aitken.—*On the Animal Alkaloids*, London, 1887.

Brown.—*A Treatise on the Animal Alkaloids, Cadaveric and Vital; or the Ptomaines and Leucomaines. With Introduction by Armand Gautier*, London, 1887.

Hankin.—"A Bacteria-killing Globulin," *Proc. Roy. Soc.*, vol. xlviii. p. 93, 1890.

Pigments.

1. The oxygen-carriers, viz., **hæmoglobin**, **hæmocyanin** (a blue pigment containing copper), **chlorocruorin** (a green pigment containing iron), the two latter found in invertebrates; *histohæmatins*, of which **myohæmatin** is the best known.

2. *Derivatives of hæmoglobin*, viz., **hæmatoidin** (of old blood-clots); **bilirubin** (of bile); **urobilin**, &c. (of urine); **stercobilin**, &c. (of fæces).

3. *Lipochromes*, or fatty pigments, *e.g.*, **lutein** and **visual purple.** Like fats, these pigments are soluble in ether, benzene, turpentine, &c.

4. *Melanins*, *e.g.*, the black pigment of the retina, and the pigment of skin and hair.

MacMunn.—"On the Chromatology of the Blood of some Invertebrates," *Quart. Jour. Micr. Sci.*, vol. xxv. p. 469, and vol. xxx. p. 51.

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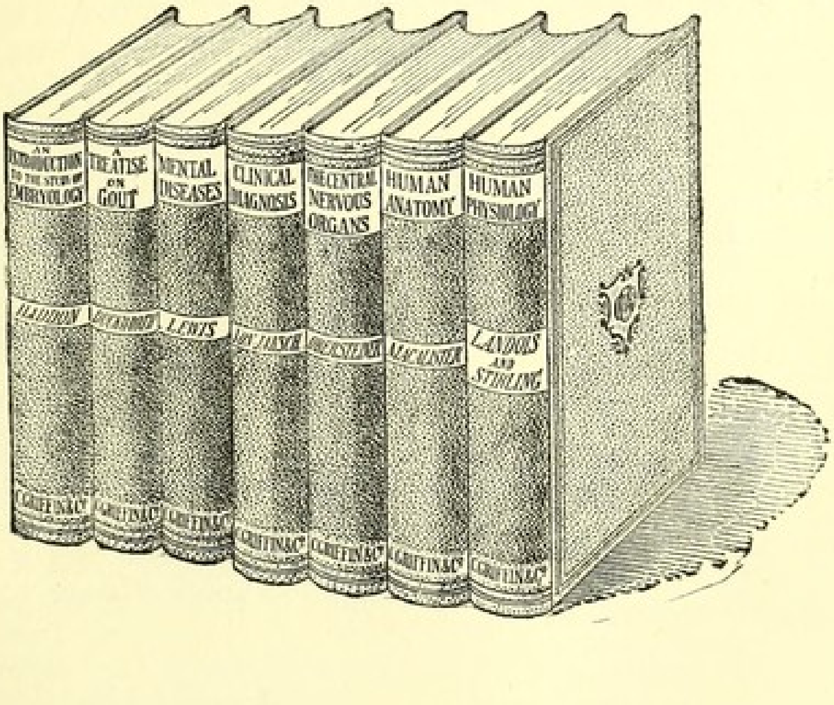

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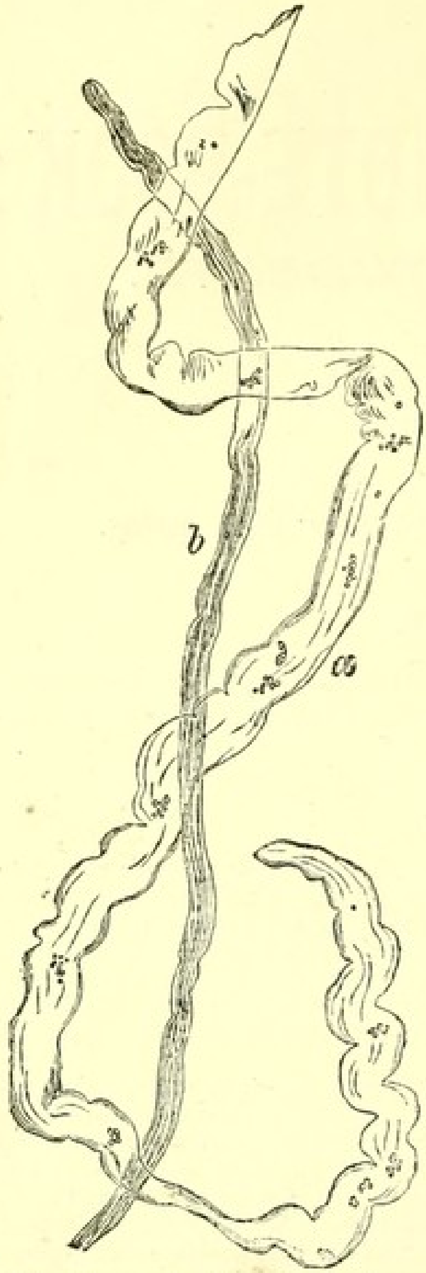

Fig. 86.—*a*, *b*. Cylindroids from the urine in congested kidney.

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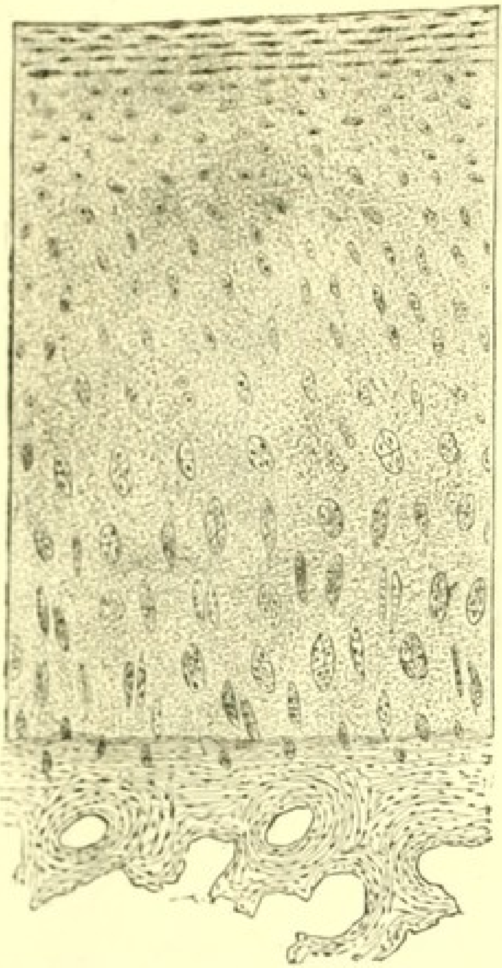

Fig. 1.—Human Articular Cartilage, from head of a metatarsal bone (Normal).

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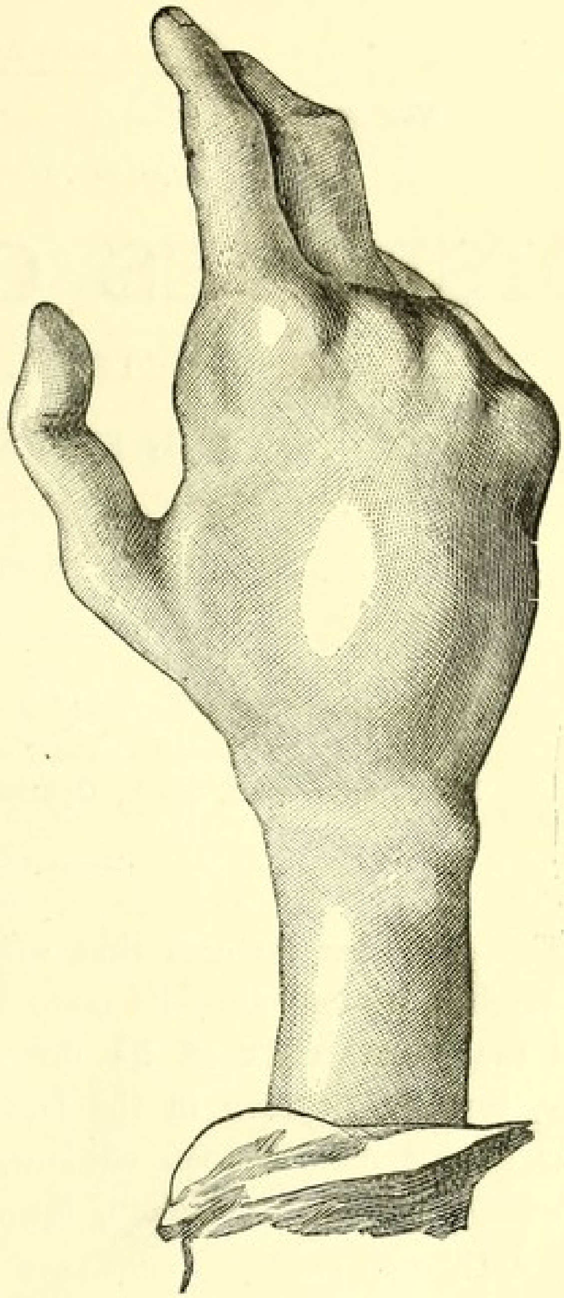

Fig. 1.—Gangliform Swelling on the Dorsum on the Hand of a Child aged Eight.

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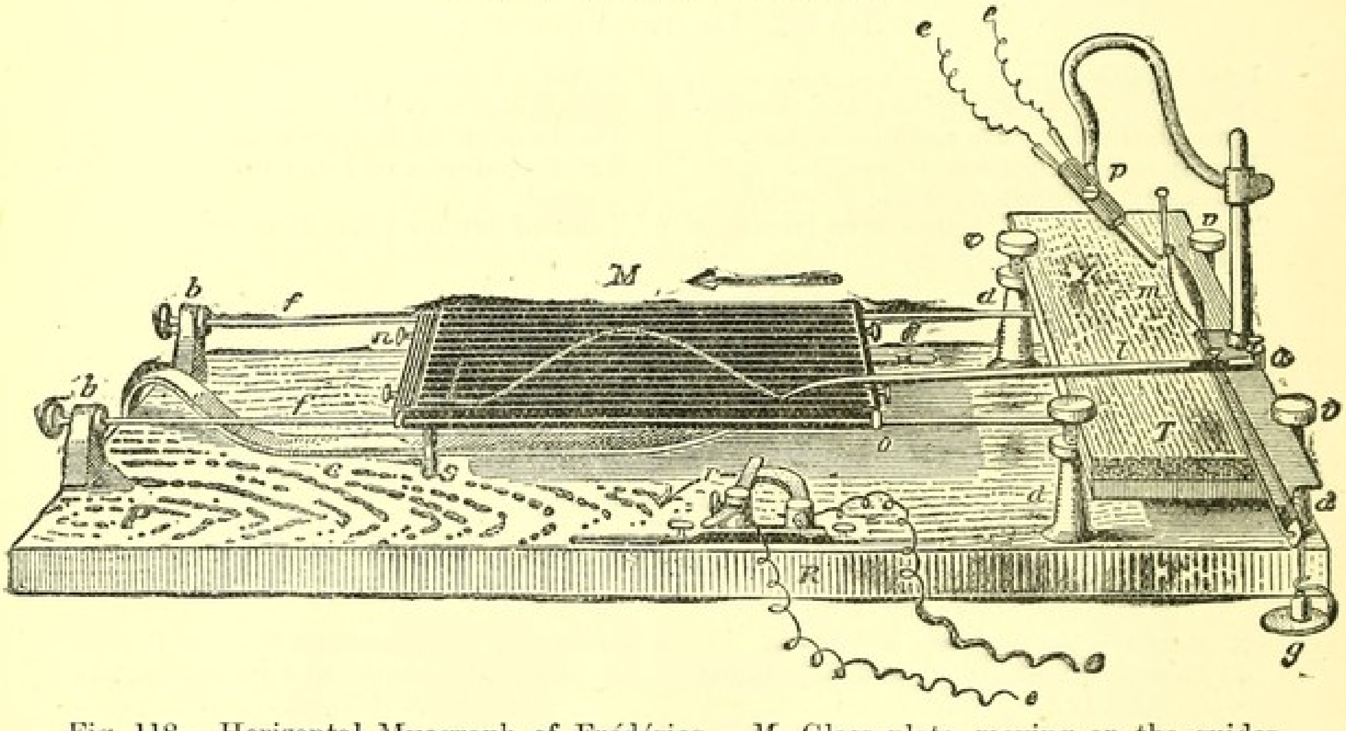

Fig. 118.—Horizontal Myograph of Frédéricq. *M*, Glass plate, moving on the guides *f*, *f*; *l*, Lever; *m*, Muscle; *p*, *e*, *e*, Electrodes; *T*, Cork plate; *a*, Counterpoise to lever; *R*, Key in primary circuit.

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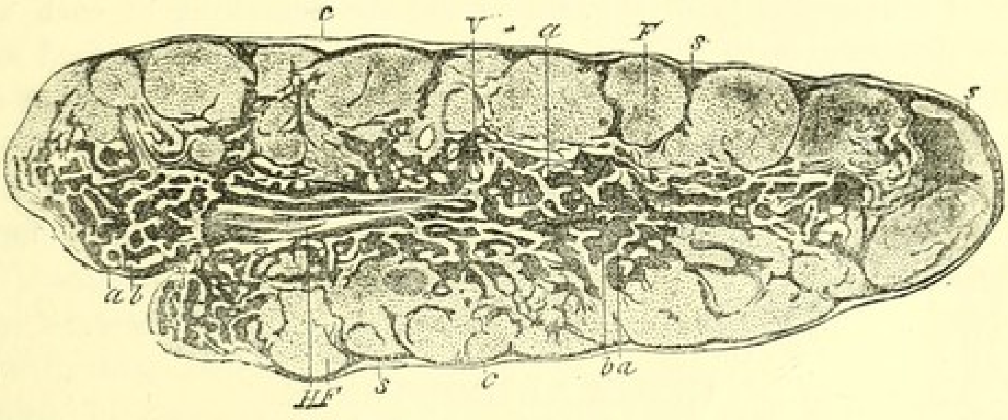

Fig. 200.—L.S., Cervical Ganglion of Dog. *c*, Capsule; *s*, Lymph sinus; *F*, Follicle; *a*, Medullary cord; *b*, Lymph paths of the medulla; *V*, Section of a blood-vessel; *HF*, Fibrous part of the hilum, × 10.

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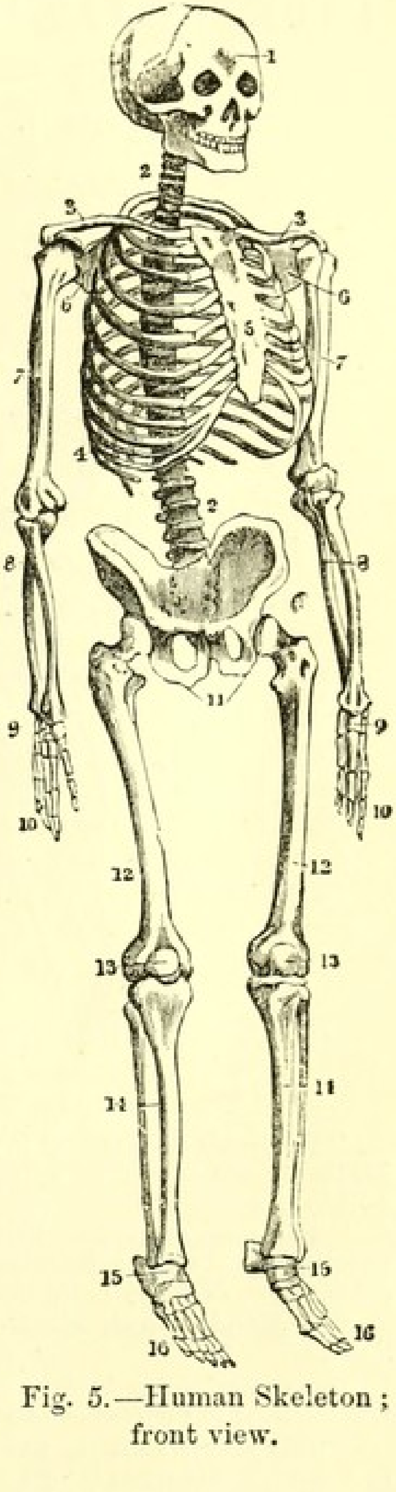

Fig. 5.—Human Skeleton; front view.

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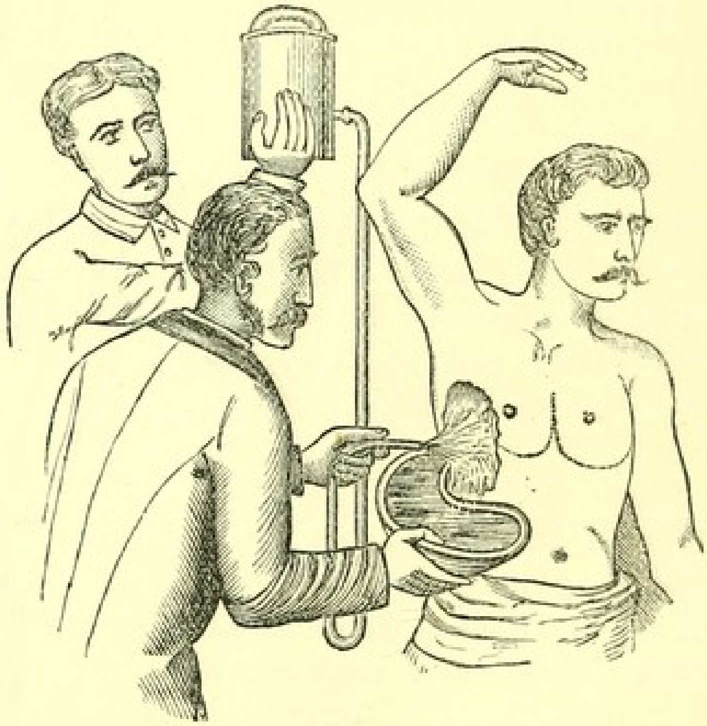

Fig. 72.

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