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PHYSIOLOGY

GUENTHER

The Medical Epitome Series.

PHYSIOLOGY.

A MANUAL FOR STUDENTS AND PRACTITIONERS.

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AUTHORS' PREFACE.

It has been the aim of the authors in the preparation of the present volume to gather together those facts of Physiology with which medical students and practitioners should be familiar. It is not the intention to produce a work which shall take the place of more elaborate text-books, but to supplement them by covering the essential features of the subject.

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NEW YORK, 1903.

EDITOR'S PREFACE.

In arranging for the editorship of *The Medical Epitome Series* the publishers established a few simple conditions, namely, that the Series as a whole should embrace the entire realm of medicine; that the individual volumes should authoritatively cover their respective subjects in all essentials; and that the maximum amount of information, in letter-press and engravings, should be given for a minimum price. It was the belief of publishers and editor alike that brief works of high character would render valuable service not only to students, but also to practitioners who might wish to refresh or supplement their knowledge to date.

To the authors the editor extends his heartiest thanks for their excellent work. They have fully justified his choice in inviting them to undertake a kind of literary task which is always difficult—namely, the combination of brevity, clearness, and comprehensiveness. They have equalled the conscientious efforts with which the editor has performed his duties from first to last. Co-operation of this kind ought to result in useful books, in brief manuals as contradistinguished from mere compends.

In order to render the volumes suitable for quizzing, and yet preserve the continuity of the text unbroken, the questions have been gathered at the end of each chapter. This new arrangement, it is hoped, will be convenient alike to students and practitioners.

VICTOR C. PEDERSEN.

NEW YORK, 1903.

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PHYSIOLOGY.

CHAPTER I.

GENERAL INTRODUCTION.

Physiology is the science that treats of the phenomena of normal living matter. As living matter may be either of animals or of plants, so there is a separation of physiology into corresponding divisions—animal and vegetable.

Human physiology consists of those facts of *animal* physiology which have been derived from experiments upon human beings, together with much that has been ascertained for closely allied animals and can be inferred to hold true for man. The chemistry of living things is now a distinct science,—*physiological chemistry*,—although it was not so formerly. The term *physiology*, derived from the Greek words φύσις and λόγος, is synonymous etymologically in its broadest application and acceptation with *natural philosophy*, and the earliest physiological conceptions were formed in prehistoric times, inseparable as such from the general mass of knowledge which during the course of later centuries grew into theological, scientific, philosophical, and other aggregations of ideas.

The science of physiology as it exists to-day has been gradually evolved out of the joint labors of thousands and thousands of workers. Of these, there are some that stand preëminent and mark in a way the principal epochs in the history of the subject. In the earliest times among the philosophers who dealt with problems that are now physiological may be mentioned *Empedocles*, *Hippocrates*, *Heracleitus*, and particularly *Aristotle* (384–322 B. C.). *Galen* (131 to about 200 A. D.) distinctly recognized the nature and importance of physiology. His system of medicine, from which the physiology of the time is inseparable, held an almost indisputable sway for nearly thirteen centuries. *Harvey* (1578–1657 A. D.), whose name stands foremost among those of his time, discovered the circulation of the blood. His greatest accomplishment was the establishment of the experimental method in physiology upon a firm basis. With him originated the conception "*omne vivum ex ovo.*" *Haller* (1708–1777 A. D.) was the first to recognize the necessity of bringing together the mass of physiological facts and theories that had arisen during the sixteenth and seventeenth centuries into an independent science. This he did in his *Elementa Physiologiæ Corporis Humani*. *Johannes Müller* (1801–1858 A. D.) was perhaps the greatest physiologist of all times. He impressed upon his science the general form or aspect that it wears to-day.

The aim of physiology is the investigation of life. The term life is, however, not readily definable. In general, any given piece of matter is said to be alive when it manifests the *fundamental properties* of living things. These properties may be defined as follows:

1. **Irritability** is that property of protoplasm which enables it to undergo characteristic physical and chemical changes when acted upon by certain influences called *stimuli*. Usually there is a liberation of energy in the response out of all proportion to the energy applied in the stimulus.

2. **Conductivity** is that property of protoplasm by virtue of which a condition of activity aroused in one portion of the substance may be transmitted to any other portion.

3. **Contractility** is that property of protoplasm which enables it to change its form when irritated by stimuli.

4. **Nutrition** is that property of protoplasm which enables it to convert dead food material into its own living substance.

5. **Reproduction** is that property of protoplasm which enables it to separate into a number of parts, each of which may develop into the parent form. None of the fundamental properties serve absolutely to distinguish living from dead matter, since all are simulated more or less completely by phenomena in the non-living world.

Life is always associated with a peculiar form of matter called protoplasm, and is never found elsewhere.

Protoplasm has therefore been called the "*physical basis of life.*" It may be defined as the active substance of which living things are composed. It is usually colorless, semifluid or gelatinous in consistency, of greater refractive power than water, and granular in appearance. Consisting largely of water, it nevertheless does not mix with water as long as it is living. Its specific gravity is greater than 1 (paramœcium, 1.25), but varies in many organisms by the formation and disappearance of vacuoles.

The *fluid nature* of protoplasm is shown—

1. By the streaming phenomena in plant-cells and in the pseudopodia of rhizopods.

2. By its formation into spherical masses whenever it is freed from its cell-walls.

3. By the assumption of a spherical form by fluids when imbedded in a mass of protoplasm. Granules and all foreign substances lie in a *ground substance*, which at times is perfectly homogeneous, but usually has a structure resembling a network.

Of the many attempts to explain the *finer structure* of protoplasm, that of Bütschli is the most successful. According to this investigator, protoplasm is an emulsion, the vacuoles or globules of which, through mutual pressure, according to well-known mathematical principles, give rise to the appearance of a network. The granules, etc., never lie within the vacuoles, but always between them. Bütschli has imitated in every detail the appearance of protoplasm by artificial emulsions. These were prepared by mixing intimately cane-sugar or potassium carbonate with old olive oil. A minute quantity of the mixture, placed in a drop of water under the microscope, showed not only all the peculiarities of the protoplasmic structure, but also spontaneously took on amœboid movements.

Protoplasm is not a *chemical* but a *morphological* term—*i. e.*, it does not consist of a definite chemical compound, but of the greatest variety of substances, some of which are the most complicated with which chemists have to deal. It contains *carbohydrates*, *fats*, *water*, *salts*, and always *proteids*. The elements which are present, —C, N, H, O, S, P, Cl, K, Na, Mg, Ca, and Fe—are all of low atomic weight. Protoplasm with very few exceptions is divided into microscopical masses, each of which possesses one or more differentiated portions called a *nucleus*.

Such a mass with its nucleus is a cell. A cell may be defined as the elementary unit of all organisms, no matter how simple or how complicated they may be. Every organism begins its individual history as a cell separated from a preëxisting organism. From time to time this cell (*ovum*, *spore*, etc.) divides itself into two or more parts, each of which in due time divides again, the resulting divisions in every case forming complete cells. In the protozoa the daughter-cells separate, and each leads an independent existence, but in many-celled animals they remain connected and become dependent upon one another.

A **histological differentiation** takes place as the animal develops, so that they form *groups of cells* which are totally different in appearance, and results in tissue- and organ-formation. They take on different functions, *pari passu*, and one group of cells will perform a certain work for the good of the entire economy. They thus lose their individuality and become dependent upon one another. This is known as the *physiological division of labor.*

The exact molecular structure of living matter is unknown, but there is no doubt that it is of very great complexity. It differs from dead protoplasm in its unstable, labile nature, reacting to an enormous number of substances which are indifferent to dead protoplasm. It manifests a continual tendency to undergo changes, while dead protoplasm, if protected from external agencies, can be kept indefinitely. The nitrogen-containing oxidation products derived from the two are radically different. Those from living matter—uric acid, creatin, adenin, xanthin, guanin, etc.—are all characterized by the possession of the *cyanogen group*, CN. This group is one of great internal energy, so that compounds containing it have a marked tendency to undergo dissociation. This is especially the case in the presence of oxygen. It is a well-known fact that cyanogen compounds also have the *property of polymerization*—that is, of combining with compounds having a structure like their own, so as to form more complex combinations. By this process they become less and less stable, until the instability reaches its acme by the introduction of oxygen, when the compound undergoes a breaking-down process resulting in the formation of simpler, more stable, bodies. The act of dissociation liberates energy, which appears in the manifestations of life. Pflüger has suggested that in the change from living to dead protoplasm the cyanogen grouping is converted to the inert ammonia grouping by the absorption of water. It is convenient to designate the expression, mass of living matter, by the shorter terms *biogen* or *bioplasm*. *By biogen is understood the smallest quantity of living matter that can manifest the property of nutrition.*

That part of nutrition designated as *metabolism* is the most characteristic of all the properties of living matter. By it is meant the total series of changes by which substances are built up into living matter (*anabolism*) and again broken down (*katabolism*). Anabolism and katabolism have opposite effects on living matter, but they, nevertheless, go on simultaneously in the same cell, and under normal conditions are always active. When they equal one another the cell is at rest—a condition that has been called *autonomous equilibrium*. If anabolism is in excess of katabolism, the cell increases in bulk or grows, while an excess of katabolism over anabolism will result in atrophy. The relations of anabolism to katabolism may be expressed by the symbol $\frac{A}{D}$. There is no reason to suppose that biogens are all of the same structure; on the contrary, they are probably as numerous as the cells have different functions. Therefore the relation $\frac{A}{D}$ is more correctly expressed as $\frac{a_1 + a_2 + a_3 + a_4 \ldots}{d_1 + d_2 + d_3 + d_4 \ldots}$, where each of the factors a_1, a_2, $a_3 \ldots$ and d_1, d_2, d_3, ... may vary independently of the others and within very wide limits as the case may be.

In any given cell where processes of one kind are in excess over the other, a reaction arises which renders the biogen more resistant to further change of the same character, and favors a tendency in the other direction. If, for instance, anabolic changes have been called out in a cell by a stimulus, they generate in time an acceleration of katabolic processes until the two are in equilibrium. The general condition of the cell, however, is *above par*, and is called *allonomous equilibrium*. When the stimulus is removed, anabolic processes are lessened, and therefore increased katabolism now decreases also; but katabolism, although decreasing, is in excess, and its reaction tends to increase anabolic processes until both are in equilibrium. There is thus an *internal self-adjustment of metabolism* in living matter. It must be borne in mind that metabolism is probably not limited to the building-up and breaking-down of the biogen, but may be brought about in other substances under the influence of living matter. Such changes are designated *contact changes.*

In order that metabolism may continue living matter must have a sufficient supply of such material as it can build into its structure. These materials are called *foods*, and may be defined as substances which, taken into the cell, aid in the repair or in the formation of new biogens, adding to the sum-total of energy which the cell may liberate, and are finally cast off by the cell in *altered chemical condition.* The taking-in of food by an organism is termed *ingestion.* In very few cases is the ingestion of solid foods possible, so that in order that they may be made use of they are *digested*—*i. e.*, they are acted upon by complex nitrogenous bodies known as *ferments* or *enzymes*, which convert them into soluble forms. Enzymes are the products of animals and plants possessing the power of producing chemical changes in other bodies without apparently undergoing any change themselves. As the conversion takes place within or without the protoplasm it is designated as *intra-* or *extra-cellular digestion.*

The steps through which dead matter passes in its synthesis to living matter are very incompletely known. In *green* plants which thrive on the *inorganic compounds*, carbon dioxide, water, and simple nitrogenous salts, the first step is observable in the cells of the leaf, where, under the influence of chlorophyll and the energy of the sun's rays (yellow chiefly), the carbon dioxide of the air is split into its elements and the carbon is united with hydrogen and oxygen in the proportions of water to form starch $(C_6H_{10}O_5)_n$. The latter is visible, microscopically, as minute granules, and its formation has been proved to go hand-in-hand with the disappearance of carbon dioxide. This forms the starting-point for the formation of all other bodies in the plant. Reconverted to sugars probably, it disappears from the cells, is united with nitrogen, which has been taken into the plant in the form of nitrites and nitrates, and is finally built into the structure of living matter. *The successive steps are not known.* Animals cannot live on *inorganic* salts, but require their nitrogen in the form of proteids, and in this sense are dependent upon plants for continued existence.

The Nucleus.—In all cells the presence of a nucleus or nuclear matter is indispensable to metabolism. Nucleus and protoplasm separated from each other very quickly degenerate.

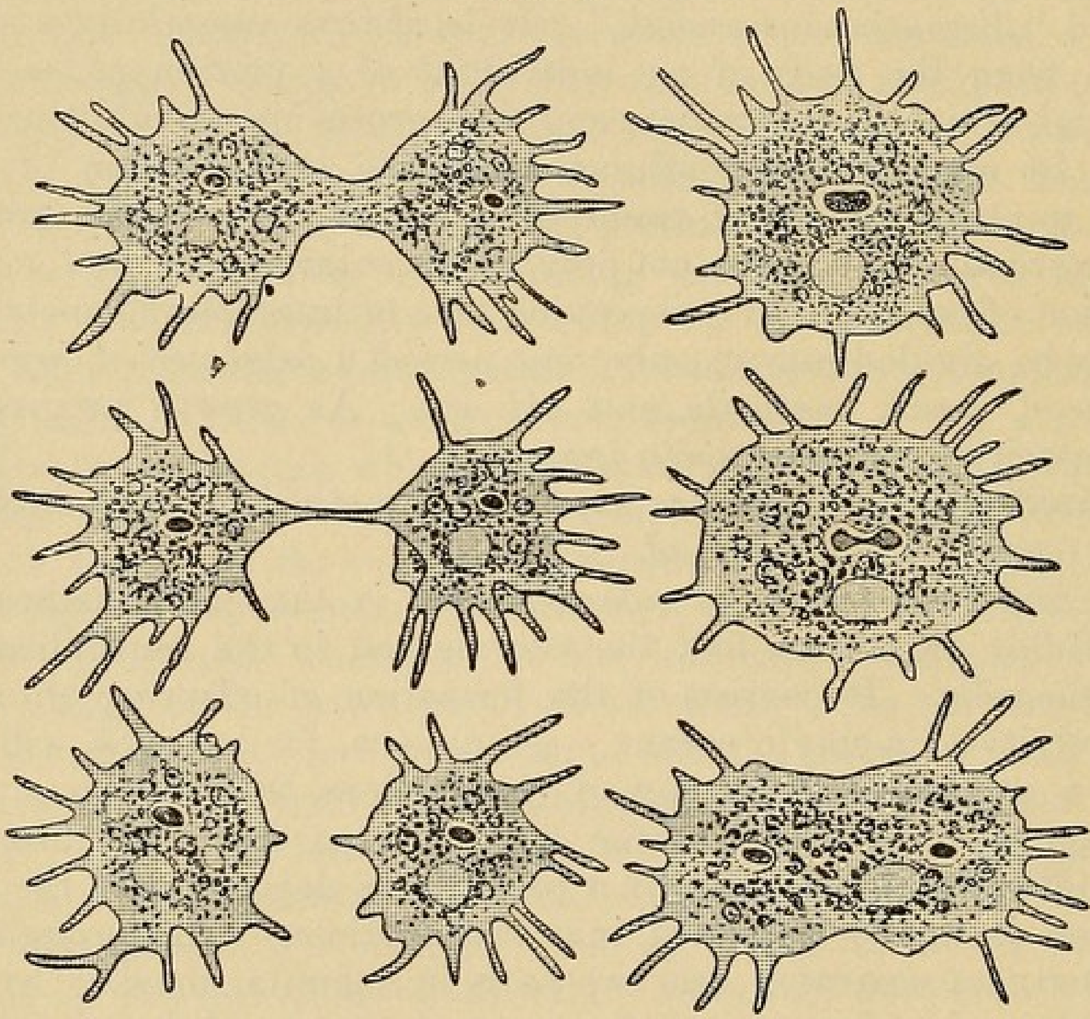
Cell-growth.—The *formation of new biogens* or *growth* takes place only when nuclear matter is normally present, and continues until the cell has reached its maximum size. At this stage the extent of surface of the cell determining the quantity of nutriment that can be absorbed is insufficient to supply the mass of living matter. Such a point is always reached, sooner or later, because, as the cell grows, the surface increases only as the *square* while the volume increases as the *cube* of their like dimensions. Reproduction now takes place, which has appropriately been termed "*discontinuous growth.*" It is always essentially a separation from the body of an individual of a portion of its own material, which under proper conditions grows into an adult organism. In man *growth* continues from the segmentation of the ovum to about the age of twenty-five, and is increased by systematic exercise. It consists not only of an enlargement and multiplication of cells, but of a deposition also of intercellular material. It may be divided into an *embryonic period*, a *fœtal period*, *infancy*, *childhood*, *youth*, *maturity*, and *old age*. As growth progresses, the capacity for more growth lessens.

Reproduction.—There are two distinct methods of reproduction, —the *asexual* and the *sexual*.

Asexual procreation, or *agamogenesis*, is the chief method in unicellular organisms, and the sole method in the multiplication of tissue-cells. It consists of the formation of offspring through the activity of a single parent. An amœba, for instance, will exhibit a gradual lengthening of the nucleus, followed by a constriction at the equator of the long axis, so that it assumes the shape of a dumb-bell, and by a progressive deepening of the constriction is finally separated into two portions. The protoplasm now becomes separated into two parts in a similar manner by the formation of a furrow running around the amœba, and falling into the same plane as the constriction of the nucleus. There arise, in this manner, two nucleated masses of protoplasm which lead an independent existence and in turn divide again. This is known as *simple*, *direct*, or *amitotic* division.

When cells divide, there are, however, generally present complicated changes of the nucleus, giving rise to *indirect*, *mitotic*, or *karyokinetic* division. The ordinary resting nucleus undergoes changes, so that the chromatic substance is transformed into threads of equal length loosely coiled together. Simultaneously there occur a disappearance of the nucleoli and of the nuclear membrane, while radiations in the cytoplasm of the cell at opposite sides of the nucleus mark the positions of the centrosomes. This stage is known as the *mother-skein*. Each of the chromatic threads now divides lengthwise, so as to appear double. They grow shorter, become V-shaped, and arrange themselves about the equator of a spindle which has been formed between the centro-

FIG. 1.

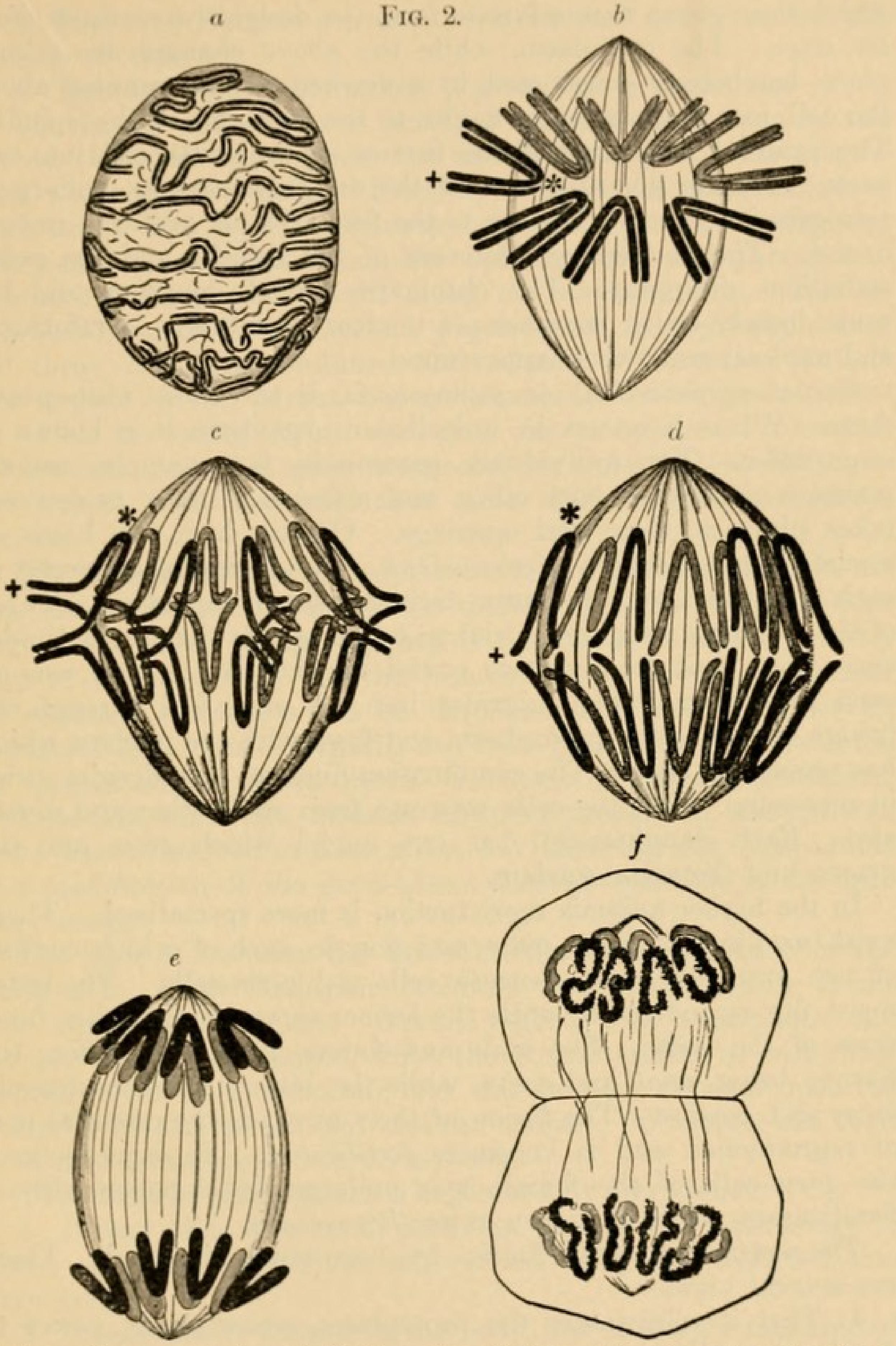


Amœba polypodia in six successive stages of division (after F. E. Schultze, from Verworn).

somes, extending from one to the other. The free ends of the chromatic filaments point outward, so that they have the appearance of a wreath or star which gives to this the name of the *mother-wreath* or *aster stage*.

The third stage consists in the migration of the segments, during which the apices of the divided chromatic filaments separate from one another and move toward their respective centrosomes, around

FIG. 2.



Schematic representation of mitotic nuclear division (after Flemming, from Verworn): *a*, Mother-skein stage; *b*, aster stage; *c* and *d*, migration of chromosomes; *e*, diaster stage; *f*, daughter-cells.

which they group themselves to form the *daughter-wreaths* or *diaster stage.* The cytoplasm, while the above changes are taking place, has become constricted by a marked furrow running about the cell in a plane at right angles to the long axis of the spindle. The gradual deepening of the furrow separates the cell into two parts. During this time each of the daughter-wreaths undergoes retrogressive changes leading to the formation of ordinary resting nuclei. The connecting filaments of the spindle and the polar radiations disappear. The chromatic threads lengthen and become loosely coiled together ; a nuclear membrane is reformed, and nucleoli make their appearance.

Sexual reproduction, or *gamogenesis,* is the most wide-spread form. When it occurs in unicellular organisms, it is known as *conjugation.* Two individuals, paramœcia for example, assume positions parallel to each other, and a fusion of their protoplasm takes place at their oral openings. Ciliates have two kinds of nuclei—a *macro-* and a *micro-nucleus.* The former degenerates in each individual, but the latter divides twice in succession. Three of the resulting daughter-nuclei go to pieces, but the fourth divides once more, thus forming two nuclei for each cell. Now, one of each pair of the nuclei migrates into the other cell through the bridge of connecting protoplasm, and fuses with the nucleus which has remained there. The combination-nucleus now divides twice in succession, while the cells separate from each other and divide also. Each daughter-cell has two nuclei which grow into the macro- and the micro-nucleus.

In the higher animals reproduction is more specialized. There exist two kinds of *sexes,* male and female, each of which consists of two groups of cells—*somatic* cells and *germ* cells. The latter serve for reproduction, while the former serve all the other functions of the body. The male and female germ-cells differ, the former being *small* and *active,* while the latter are comparatively *large* and *passive.* The fusion of their nuclei is the essential part of reproduction and is known as *fertilization.* In some metazoa the germ-cells of the female may undergo development without fertilization, which is known as *parthenogenesis.*

The significance of fertilization has been much discussed. There are several views :

1. That it rejuvenates the protoplasm, renewing its power to divide asexually.

2. That reproduction prevents variation and preserves the uniformity of the race.

3. That by fresh combinations it gives rise to variations.

The living matter of the fertilized ovum is acted upon by two forces—*heredity*, which preserves its characteristics, and *adaptation*, which changes them. Heredity includes the transmission of both *actual* and *potential* characteristics from parents to offspring. The resemblance is most complete between child and parent, and diminishes directly backward along the ancestral line. The resemblances may be *anatomical*, *physiological*, or *psychological*, or all three variously combined and related. Characters that do not appear in the parent, but are transmitted from grandparent to child, are called latent and give rise to *atavism* or *reversion*. *This occurs most often when two strains are crossed; thus half-castes are usually more degraded than either their civilized or savage parent.*

The inheritance of *acquired characters* is a problem that has not yet been solved. It cannot be denied to exist in unicellular organisms, where the protoplasm of the parent becomes directly that of the offspring. In the human being, cases of transmissal of acquired characters can be explained otherwise. However, germinal infections of syphilis can take place through the ovum or spermatozoon. Intra-uterine infections of typhoid, scarlatina, endocarditis, small-pox, measles, croupous pneumonia, and anthrax have been observed to take place, but these are not comparable to a modification of the germ-plasm through heredity in the ordinary sense.

The basis of heredity lies undoubtedly in the substance of the germ-cells. Some biologists maintain that the *chromatic* is the sole germinal substance. Others regard *both protoplasm* and *nuclear* matter as essential, since the characteristics of every cell depend upon its metabolism, and this in turn depends upon the integrity of protoplasm and nuclear matter. Whatever the basis is, it may be designated as *germ-plasm*.

The **origin of germ-plasm** is explained by two views:

1. It may arise from small particles, *gemmules* (*"little germs"*), given off from the various cells of the body and collected into germ-cells.

2. It may not be formed in the body, but be simply transmitted from generation to generation, and be directly continuous from one

individual to another. In this case parts of the body are derivatives from the germ-plasm and cannot return to their primitive condition.

There are also two views as to the **structure of germ-plasm**:

1. That it possesses a complicated structure and contains the rudiments of the cells, tissues, and organs of which the body is composed. This may be called the **theory of preformation.**

2. That germ-plasm is *isotropous,—i. e.*, one part is essentially like every other part,—and that histological differentiation is the result largely of external influences. This is called the **theory of epigenesis.** The transmission of hereditary characters is not so complete that the offspring are absolutely like their parents. Every individual varies a little from every other. These variations are either acquired subsequently to fertilization or are inherent in the germ-plasm. Those of the germ-plasm are due to nutrition and to sexual reproduction. Having granted variations of germ-plasm which produce divergencies in the adult organism, Darwin has shown that in the *struggle for existence* all those individuals most closely adapted to their environment survive in the long run and produce most offspring which in turn inherit the same favorable characters. Those not so well adapted to their environment gradually become extinct. There arises thus a selection of those most fitted to live, which is termed *natural selection.*

The fertilized germ-cell undergoes a series of changes by which it becomes more complicated, and which constitutes its *life-history*, or *ontogeny*. Through heredity those of one organism are closely similar to those of another of the same species. But by adaptation through variations and through natural selection groups of organisms begin to differ in their ontogeny, and consequently in their adult state, so that they in time form distinct species. This has taken place with all life on the earth, and these changes *in toto* constitute phylogeny. *Phylogeny* is the result of the same factors as ontogeny. In fact, ontogeny is an abbreviated history of phylogeny, modified to some extent by secondary adaptations.

Cell Stimulation.—Living matter is responsive to various changes in its environment which are called *stimuli*. These may be grouped into *mechanical, thermal, photic, electrical,* and *chemical* stimuli. Each may produce either of two results. If the normal phenomena are intensified or increased quantitatively, the result is called an *excitation*. If they are decreased, it is called an *inhibition*. It is possible that the nature of the phenomena may change in character, giving rise to *necrobiotic phenomena*, such as are seen in *fatty* or *amyloid degeneration*. Examples of excitation by various stimuli are very familiar.

The most obvious result of the *action of chemicals* is seen in the production of movements. If, for instance, there are added to a medium containing amœbæ a few drops of a weak solution of an acid, alkali, or salt, the activity of the animals is at first increased, but soon their pseudopods are retracted and they take on a more or less spherical shape. The same effects are produced in other organisms possessing pseudopodia, while the cilia of infusoria have their movements enormously increased. Various forms of muscle-fibres (myoides, smooth and striated muscles) contract and tend to take on a spherical form. Crystals of sodium chloride applied to the motor nerve of a muscle will produce an irregular series of twitches. In this connection may be mentioned a curious phenomenon observed by Biedermann. If the sartorius muscle of a frog is immersed in a solution of 5 grammes of sodium chloride, 2 grammes of sodium phosphate, and ½ gramme of sodium carbonate in a litre of water at a temperature of from 3° to 10° C., the muscle will fall into *rhythmic contractions*, which are never to be observed in the muscle under normal conditions.

Chemical stimulation may cause active relaxation as well as contraction. Amœbæ and myxomycetes, when deprived of oxygen, gradually cease all movement, but when oxygen is again provided, marked activity is manifested in that the protoplasm moves toward the source of oxygen by the extension of its pseudopodia. Living matter may be stimulated by chemicals in other ways. Many marine organisms like the flagellate noctiluca are capable of producing light. If to a quantity of sea-water containing such animals a drop of distilled water, concentrated solutions of salts, acids, alkalis, etc., are gently added, they will occasion the production of a slowly increasing circle of light as the diffusing substance gradually spreads out.

It has been shown by Voit that an adult hard-working man requires about 118 grammes of proteid in order that he may not lose weight. This amount is daily broken down to furnish energy expended in his work. If the amount of proteid is now increased, the excess is not necessarily, as might be expected, built up into the structure of his body, but is metabolized and excreted as urea, etc. It is assumed, in this case, that the excess of proteid has stimulated both anabolism and katabolism. A superabundance of carbon dioxide supplied to a chlorophyll-containing plant stimulates metabolism and leads to an increased production of starch. In many cases chemical substances stimulate anabolism more than katabolism. This is particularly true during the growing years of a child. Pathology offers many examples of what are, very probably, instances of chemical stimulation where a rapid multiplication of cells—of the epidermis, for example—leads to the formation of tumors.

Mechanical stimulation includes all alterations of pressure, no matter how produced, to which living matter is subjected. The slightest touch applied to the pseudopodia of a rhizopod will cause their retraction. An amœba under stronger stimulation becomes spherical. In many cases, as in actinospherium, a rapid secretion of a sticky material takes place, which serves normally to hold small infusoria that constitute food for this organism. Stentor and vorticella, when touched, withdraw from the source of irritation with lightning-like rapidity. Smooth and striated muscle-fibres contract when struck by a sharp blow. Phosphorescent organisms of the ocean reveal their presence whenever the water is disturbed. The rhythmic movements of the cilia of ciliates are accelerated and increased in amplitude by mechanical stimulation.

Any sudden marked change, whether of an increase or decrease, in the *temperature* of the medium surrounding an organism will act as a stimulus. Slow changes act differently. There is an average temperature to which any given organism is subjected. It may be stated as *a general rule* that every increase above the average up to a certain maximum temperature will cause increased activity, while a decrease in temperature causes an opposite result. A good example is to be found in the formation of alcohol and carbon dioxide from grape-sugar through the action of yeast-cells. Cold-blooded animals, frogs and salamanders, become lively during warm and very inactive during cold weather, which is correlated with corresponding metabolic changes. Warm-blooded animals, however, by means of the mechanisms which regulate and maintain a high internal temperature, show an increased metabolism in cold weather, thus proving an exception to the foregoing rule.

Growth of various organisms is greatly influenced by temperature. Seeds begin to germinate only when the warmth has reached a certain point: this for Indian corn is 9° C.; for the date, 15° C. Bacterial cultures thrive, likewise, only at definite temperatures. The tubercle bacillus begins to grow and propagate at 28° C. The effect of temperature on ciliary movements can readily be investigated by viewing a portion of the mucous membrane from the œsophagus of the frog under the microscope, and subjecting to warm and cold saline solutions. A glass rod, heated to redness and brought against the motor nerve of a frog's muscle, will produce a quick contraction.

There are in existence certain vertebrates (proteus) in which the entire skin is *sensitive to light.* This is true to a still greater extent of the ordinary earth-worm. But among the higher animals the end-organs in the retina are alone clearly responsive to *photic stimulation.* It has been found that when the skin is constantly exposed to the intense light of the electric arc lamp that the epithelial cells of the skin undergo a genuine necrosis, which is not brought about by the heat-rays, but by the short waves of the violet end of the spectrum. The stimulating power of light on the chlorophyll-containing bodies of green plants is easily shown for the absorption of carbon dioxide and the formation of starch take place only in the presence of light. The rhizopod pelomyxa responds to sudden illumination in the same manner as it does to any other stimulus—namely, by quickly taking on a spherical form. Certain flagellate and ciliate organisms are also so sensitive to light that they respond by quick movements.

The excitation effects of the *electrical currents* have been investigated most throughly in nerve and muscle. A sudden change in the intensity of a current arouses a nerve impulse in the nerve, and calls forth a contraction of the muscle. An electrical current, however, stimulates also while it is flowing uninterruptedly through any living structure. This is shown in nerve by the heightened irritability at the kathode or region where the current leaves the nerve; in actinospherium, by a disintegration of the organism at the region of the anode, where the current enters the structure and which ceases as soon as the current is interrupted. Amœbæ and leucocytes withdraw their pseudopods and become spherical when subjected to an electrical shock; smooth, striated, and cardiac muscle gives vigorous responsive contractions and relaxations; the protoplasm of plant-cells is formed into spherical masses, and phosphorescent animals emit light.

The **inhibition of living matter** is much more difficult to recognize. A *chemical inhibition* is shown by the action of anæsthetics. *Mechanical inhibition* has been demonstrated by several investigators by showing that the growth of bacteria is stopped by regular vibrations. Heat and cold will both produce *thermal inhibition* as they respectively approach the coagulation-point of protoplasm and the zero-point. There is no indisputable evidence of inhibitory power of light (*photic inhibition*). The changes at the positive electrode when a current is passed through a nerve may be regarded as an example of *inhibition by electricity*.

Cell Tropism.—Organisms that are capable of independent locomotion when acted upon by an influence coming from a definite direction move either toward or away from the source of the stimulus. If the latter is a chemical irritant, the phenomenon is known as *chemotropism* or *chemotaxis*, and is *positive* or *negative* according as the animal moves toward or away from the source of the stimulus. In like manner, pressure, temperature, light, and electricity produce respectively *baro-*, *thermo-*, *helio-*, and *galvanotropism*.

The Origin of Life.—It may be said that as long as the earth was a molten mass of excessively high temperature life could not have existed as we know it to-day. During the evolution of the earth living matter must have arisen as the result of physical and chemical factors, as all chemical compounds whatsoever have arisen. The formation of living matter was as necessarily the product of evolution as was the formation of water. At first it was probably capable of manifesting vital phenomena indefinitely, which, as a matter of fact, is true of germ-cells at the present time. Under proper circumstances by means of germ-plasm life is passed from individual to individual, and in this sense cannot be said to suffer death.

Cell Death.—According to Weismann, *death* has been evolved for the good of the species, since in time, through wear and tear, the vitality of aged individuals is lessened and it is to the advantage of the species that such individuals should no longer propagate nor even exist. The term death has, however, many shades of meaning. In one sense since living matter is continually undergoing katabolic changes. It is continually dying. The term may be applied to the whole organism or to individual tissues.

Somatic Death.—The first occurs when one or more functions of the body are so disturbed that harmonious action of all the functions becomes impossible. The most convenient sign of somatic death is the cessation of the heart-beat, which, however, is not always the cause of death. The *death of the tissues* does not necessarily take place with somatic death. The nervous system dies very soon ; the heart lasts longer, the last portion to beat being the right auricle. The smooth muscle of the intestines remains irritable for three-quarters of an hour, and striated muscle at times for hours.

Some of the most important problems of general physiology are as yet highly speculative in character, but most physiologists believe that as knowledge increases they will all, like the phenomena of lifeless bodies, be explained as the result of the properties of matter and energy working under definite laws.

QUESTIONS ON CHAPTER I.

Define the term physiology.
What are the principal divisions of physiology?
What is meant by human physiology?
Give the derivation of the term physiology.
When were the earliest physiological ideas formed?
Name some of the earliest physiologists.
What services did Galen, Harvey, Haller, and Müller render?
What is the aim or object of physiology?
How is it possible to tell whether a given piece of matter is alive or not?
What are the fundamental properties of living things?
Define each.
Are they absolutely characteristic of living matter?
What is the "physical basis of life"?
Describe protoplasm.
What is the evidence that protoplasm is a fluid?
What is the finer structure of protoplasm?
Why is protoplasm not a chemical term?
What substance is always present in protoplasm?
What characterizes the elements of living matter?
What is a cell?
What are "histological differentiation" and "physiological division of labor"?
What evidence is there that dead protoplasm differs from living?
Describe the properties of the cyanogen group.
What is a biogen?
What are metabolism, anabolism, and katabolism?

What are the relations of anabolism to katabolism during rest, growth, and atrophy?
Are all biogens alike?
Describe the internal self-adjustment of metabolism.
What is meant by "contact changes" of biogens?
What is food?
What is ingestion?
What are enzymes?
How is starch formed in the plant-cell?
What is the source of the nitrogen of plants?
What is the function of the nucleus in cells?
Explain why reproduction has been called "discontinuous growth."
What is growth due to? Effect of exercise?
Give the various stages of growth.
Describe both methods of cell-division.
What two methods of reproduction, and how do they differ?
Describe conjugation.
How do male and female germ-cells differ?
What is fertilization?
What is parthenogenesis?
What is the object of fertilization?
What forces are active during the development of the ovum?
What is atavism or reversion?
Discuss the inheritance of acquired characters.
What is the source of germ-plasm?
What is meant by preformation and epigenesis?
What are variations of germ-plasm due to?
What is natural selection?
Define phylogeny and ontogeny.
What opposite results may stimuli produce in living matter?
How may stimuli produce necrobiotic changes?
Give examples of excitation and inhibition of active protoplasm.
Define positive and negative chemotropism.
What can be said of the origin of life?
Give various meanings of the term death.
What is the cause of somatic death?

CHAPTER II.

SECRETION.

THE term *secretion* may be used to designate either the *liquid* or *semiliquid products* of glandular organs which are discharged upon free or closed surfaces; or to designate the *process* itself by which these products are formed. According as the surface is free (skin, mucous membrane) or closed (blood and lymph cavities) the secretion is termed an *external* or an *internal* secretion. Such substances serving a useful purpose are *typical secretions;* when of no further use, are *excretions.* There is no longer any doubt that *gland-cells are active in the formation of their secretions.* The proofs are:

1. The gland-cells undergo a microscopical change.
2. Specific substances in the secretion which are not found in the blood or lymph.
3. The liberation of energy in the form of heat, pressure, and electricity.
4. The results of the stimulation of the nerve-supply.
5. The action of certain drugs.

The processes of *filtration, diffusion,* and *osmosis* cannot, however, be entirely excluded for acting in conjunction with the physical and chemical properties of the living structure of gland-cells. By *filtration* is meant the passage of fluids through a membrane as the result of differences of hydrostatic pressure. *Diffusion* is the interpenetration of the molecules of two fluids when brought into contact. *Osmosis* or *dialysis* is the diffusion that takes place through membranes separating two fluids.

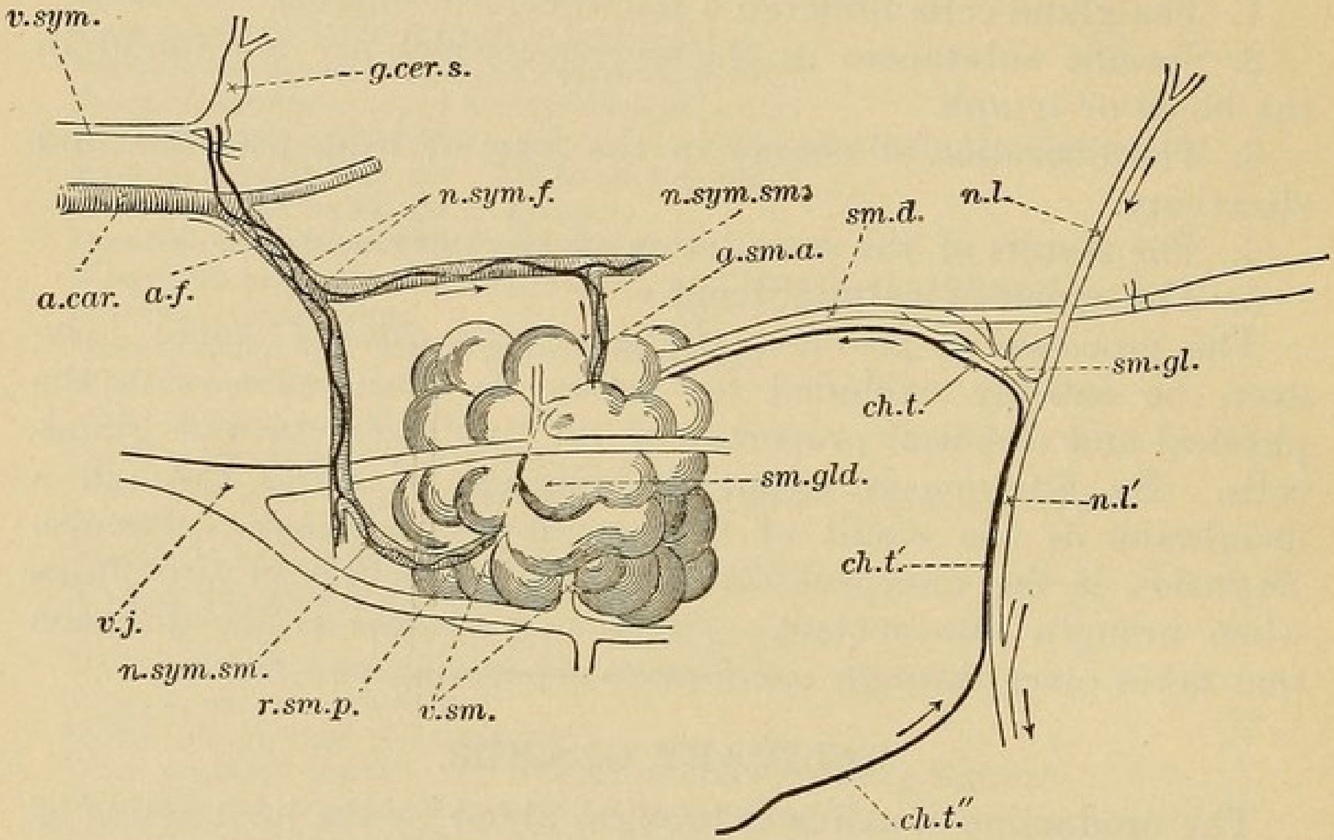
SALIVARY GLANDS.

The production of saliva is brought about by the joint action of three larger pairs of glands, the *parotids, submaxillaries,* and *sublinguals,* and by *innumerable smaller ones* lying in the mucous membrane of the mouth and tongue. In close proximity to the parotid lies a glandular mass called by Klein the *inferior admaxillary* (*socia parotidis of man*), and in the connection with the sublingual is a separable portion, the *superior admaxillary.* These, as well as many unicellular glands, pour their secretions into the buccal cavity.

The distinction between *albuminous* and *mucous glands* becomes definite only when applied to individual cells. A series of glands might be gathered, showing every gradation from those entirely mucous to those entirely albuminous. The demilunes of Heidenhain in mucous glands are albuminous cells. The two types of cells differ not only histologically, but also in the character of their products. The *secretion from albuminous cells* contains, besides enzymes, water, salts, and albumin, while *that from mucous cells* contains mucin, which makes it stringy and viscid.

The *activity of secretory cells* is well shown by the salivary glands. During secretion the granules which are present gradually disappear from the outer side of the cells, and a clear non-

Fig. 3.



Diagrammatic representation of the submaxillary gland of the dog, with its nerves and blood-vessels. The dissection has been on an animal lying on its back, but since all the parts shown in the figure cannot be seen from any one point of view, the figure does not give the exact anatomical relations of the several structures (Foster).

sm. gld. The submaxillary gland, into the duct (*sm. d.*) of which a canula has been tied. The sublingual gland and duct are not shown. *n.l.*, *n.l'*. The lingual branch of the fifth nerve; the part *n.l.* is going to the tongue. *ch.t.*, *ch.t'.*, *ch t''*. The chorda tympani. The part *ch.t''.* is proceeding from the facial nerve; at *ch.t'.* it becomes conjoined with the lingual *n.l'.*, and afterward diverging, passes as *ch.t.* to the gland along the duct; the continuation of the nerve in company with the lingual *n.l.* is not shown. *sm. gl.* The submaxillary ganglion with its several roots. *a. car.* The carotid artery, two small branches of which, *a. sm. a.* and *r. sm. p.*, pass to the anterior and posterior parts of the gland. *v. sm.* The anterior and posterior veins from the gland, falling into *v. j.*, the jugular vein. *v. sym.* The conjoined vagus and sympathetic trunks. *g. cer. s.* The upper cervical ganglion, two branches of which, forming a plexus (*a. f.*) over the facial artery, are distributed (*n. sym. sm.*) along the two glandular arteries to the anterior and posterior portions of the gland.

The arrows indicate the direction taken by the nervous impulses during reflex stimulation of the gland. They ascend to the brain by the lingual and descend by the chorda tympani.

stainable material is substituted. The nuclei become more spherical and lie nearer the centre of the cell-body, which shrinks in size. The granular material is apparently used up in the formation of the secretion, and since the enzymes formed are specific substances, the former are taken to be their source and designated as *zymogen granules*. The forerunner of *ptyalin* is called *ptyalinogen*; of *pepsin*, *pepsinogen*, etc.

The *pressure* in the duct of the submaxillary has been observed at 190 mm. Hg, while the blood pressure in the carotid at the time was but 112 mm. Hg. The question of the *amount of heat* given off during the activity of the gland is still unsettled. Ludwig and Spiess originally determined the saliva to be 1° warmer than the blood in the carotid. Heidenhain, by the thermo-electric method, found the difference to become greater on stimulation of the sympathetic. The *electrical* changes in glands are analogous to the action currents in muscles. The current may be ingoing, outgoing, or diphasic in character.

Nervous Factors.—The salivary glands have a *cranial* and a *sympathetic* nerve-supply, whose influence may be illustrated by the results obtained from the submaxillary of the dog. When the *chorda tympani*, whose fibres are cranial in orgin, is stimulated with weak induction shocks, the saliva obtained is relatively abundant, thin, and watery, containing not more than 1 to 2 per cent. of solids. The gland becomes redder in color, the veins are distended, and the blood shows a distinct pulse, indicating a dilatation of the small arteries and that the chorda tympani carries dilator fibres. Stimulation of the *sympathetic* fibres produces a scanty secretion, which is thick and turbid and may contain 6 per cent. of solids. The gland becomes paler, the blood flow is lessened, showing that a vasoconstriction has occurred.

Circulatory Factors.—That the character of the secretion is not entirely due to the changes in the *amount of blood* flowing to the glands is shown by the following facts:

1. The blood-flow may be cut off entirely when stimulation of the chorda tympani still gives a secretion.

2. Injection of atropine produces an increased flow of blood, but no secretion upon stimulation of the chorda.

3. Injection of hydrochlorate of quinine gives a vascular dilatation, but no secretion until the nerve is stimulated.

When the chorda is irritated with shocks of increasing intensity, it is found that the amount of water and salts secreted increases proportionately to a maximum limit, which for salts is about 0.77 per cent., no matter what the condition of the gland may be. The production of organic constituents soon reaches a maximum and then declines, and is closely dependent upon the previous condition of the gland. In order to explain these facts Heidenhain decided that there were *two sets of nerve-fibres*, one of which regulated the formation of organic substances (*trophic fibres*), and the other of which regulated the production of water and salts (*secretory fibres*). Moreover, their arrangement was such that the chorda carried a greater number of secretory, while the sympathetic carried more trophic fibres. Langley has recently offered a simpler explanation of the facts, attributing the differences of the chorda and the sympathetic saliva to the variations in the quantity of blood supplied, so that the assumption of only one kind of nerve-fibre is necessary.

Section of the chorda tympani produces after a few days a slow, continuous secretion for five or more weeks, when it ceases. This is called *paralytic secretion*. *Antilytic secretion* is the production of a flow by the corresponding gland on the opposite side, the nerves of which are still intact. *Section of the cervical sympathetic* causes a temporary dilatation of the blood-vessels, but has no other effect. *Atropine* prevents the secretion of saliva by destroying the endings of the cerebral fibres in the gland, leaving, when proper doses are used, the sympathetic fibres still capable of functioning. *Pilocarpine* has an antagonistic action to atropine, causing a continual secretion by stimulating the cerebral fibres in the gland. *Nicotine* causes a slight flow of saliva, followed by a paralysis. The drug acts upon the end-brushes of both the cranial and sympathetic fibres in the superior cervical and submaxillary ganglia.

Mechanism of Saliva Secretion.—The flow of saliva is normally a *reflex*, the *afferent impulses* passing along the glossopharyngeal and lingual nerves to the centre in the medulla, which lies near the nuclei of origin of the seventh and ninth nerves. The *efferent path* is for the *submaxillary gland* along the facial, chorda tympani, and lingual nerves. The secretion may be called out by the stimulation of many sensory nerves, sciatic, splanchnic, and vagus, as well as by psychical states as the thought of food or in nausea. Fear and embarrassment may inhibit the flow.

STOMACH.

Gastric Glands.—Two kinds of cells are present in the gastric glands, known as *chief cells* and *border cells*. The former are alone present in the *pyloric end* of the stomach, and it has been stated by Heidenhain that this portion of the stomach produces no acid. *The pyloric end, carefully resected and converted into a blind pouch, is alkaline in reaction.* This, by exclusion, leaves the border-cells as the *source* of the *hydrochloric acid* of the gastric juice. During the activity of the gastric glands histological changes take place especially in the chief cells, similar to those already described in the salivary glands. They also have a double supply of *cranial* and *sympathetic* nerves. Stimulation of the vagi after a latent period of from four and one-half to ten minutes gives a distinct flow. The delay is due to the simultaneous irritation of inhibitory fibres. Stimulation of the sympathetic gives no result. The effect of psychical states is shown in the "fictitious meal" experiment, in which the œsophagus of a dog is divided and the two ends are brought to the skin and sutured so as to open externally. Food taken by the dog does not reach the stomach, but nevertheless causes a flow of gastric juice, which has been shown to depend upon the integrity of the vagi. The sight of food is alone sufficient to cause a secretion. In order to determine the mechanism of the normal secretion of the gastric juice investigators have converted a part of the fundus of the stomach into a blind pouch with an external opening, while the continuity of the stomach was established by uniting the cut ends. The nerve-supply was not destroyed. The introduction of food into the stomach brought out a secretion in the resected portion in from fifteen to thirty minutes. This was interpreted to be due to the *absorption* of *digested substances* from the stomach. The quantity of the gastric juice secreted varies with the amount of food to be digested, while the quality depends upon the character of the food. There is no evidence that the cells of the gastric glands can be stimulated directly. The flow upon mechanical stimulation is effected through the fibres of the vagus and possibly of the sympathetic.

PANCREAS.

The cells of the pancreas are mainly of the *albuminous type*, in addition to which *irregular masses of cells* (*bodies of Langerhans*) are to be found. The latter are clear and small, with readily stainable nuclei. The others show a clear, well-defined, non-stainable zone toward the lumen. During activity the cell-boundaries become more distinct and the granular zone becomes narrower. Stimulation of the medulla increases the flow of the pancreatic juice and changes its organic constituents. There are present secretory nerves comparable to those of the salivary glands. Owing to the *sensitiveness* of the gland to variations in the blood-supply *stimulation of the sympathetic* will result in a flow of secretion only if the vasoconstrictor fibres are allowed to degenerate by previous section. *Stimulation of the vagus* also causes a marked secretion, both cases requiring a *long latent period*, due probably to simultaneous stimulation of inhibitory fibres. The normal secretion of the pancreatic juice begins very soon after the ingestion of food into the stomach, and is due to a reflex stimulus from the mucous membrane of the stomach and duodenum resulting from the acidity of the gastric juice. A relation has been shown to exist between the quantity and quality of the pancreatic secretion and the nature of the food.

LIVER.

The amount of bile secreted varies, but for man may be stated to be about 800 c.c. a day. The liver-cells which are in relation to the mixed blood of the portal vein and the arterial blood of the hepatic artery are probably *continuously active.* The bile, stored in the gall-bladder, is ejected intermittently. It has been shown that the quantity of bile formed varies with the quantity and quality of the blood supplied to the liver. Bile-salts stimulate liver-cells, and all such substances are designated as *cholagogues.*

Stimulation of the spinal cord diminishes the secretion, owing to constriction of the blood-vessels of the abdominal organs. *Section of the cord* resulting in loss of vascular tone and general fall of blood pressure, and velocity decreases the secretion. *Stimulation of the splanchnics* which have been cut diminishes secretion, owing to vascular constriction of the abdominal organs, while *sectioning* alone increases the secretion, since the resulting loss of vascular tone is limited to the abdomen, resulting in a greater flow of blood to that region. The determination of distinct secretory fibres for the formation of bile has so far been impossible. In jaundice due to the occlusion of the bile-ducts the bile is not reabsorbed by the blood directly, but by the lymphatics of the liver, and gets into the blood through the thoracic duct.

INTESTINAL GLANDS.

Evidence as a whole points to the fact that many cells of the intestinal glands undergo histological changes during activity, in that their granules disappear. *Section of intestinal nerves* so that the higher centres are separated from the mucous membrane leads to an accumulation of fluid ; but if the *inferior ganglion of the solar plexus is left intact*, the accumulation does not take place.

SEROUS SECRETIONS.

These are produced by the pleura, peritoneum, tunica vaginalis, and by the synovial membranes of joints, tendon-sheaths, etc. The *synovial* secretion is more glairy and viscid than is truly *serous secretion*, which is very much like lymph. The function of serous secretion is to prevent friction between surfaces that are in contact. It is of a pale yellow color, alkaline in reaction, viscid, and coagulable by heat.

LACHRYMAL GLANDS.

The conclusion reached for the salivary glands may be applied with little alteration to the glands of the nasal mucous membrane and to the lachrymal glands. The latter resemble an albuminous salivary gland, receiving *cranial* secretory fibres by way of the fifth nerve, and *sympathetic* fibres by way of the cervical sympathetic. Stimulation of most sensory nerves produces a secretion reflexly. The ducts of the gland lead to the conjunctiva of the upper eyelid, and usually the secretion is just sufficient to keep the eye moist, and is drained into the nasal cavity by way of the lachrymal duct. When the secretion is formed in superabundance, it appears as *tears*. These are alkaline in reaction and contain 1 per cent. of solids, chiefly chloride of sodium.

KIDNEY.

Although the kidney is richly supplied with nerves, there is no indisputable evidence of secretory fibres, but changes in the secretion of urine can be explained by variations in the blood-flow. It has been estimated that the supply of blood to the kidney may be from four to nineteen times as large as that of other organs of the body, and equals per minute 5.6 per cent. of the total quantity sent out by the left heart. The secretion of urine can be measured directly, but variations in blood-supply are determined by an instrument called an *oncometer*. A rich supply of vasoconstrictor fibres for the kidney emerge from the cord in the lower thoracic spinal nerves (dog), pass through the sympathetic system, and reach the kidney as non-medullated nerves. Stimulation of these nerves causes a shrinkage of the organ and a diminution of the secretion. When the fibres are cut, the arteries dilate, the organ enlarges, more blood passes through the kidney, and the secretion is augmented. The vasodilator fibres to the kidney emerge from the cord through the anterior roots of the eleventh, twelfth, and thirteenth spinal nerves. Normally these fibres—*i. e.*, *constrictors* and *dilators*—are brought into activity reflexly and regulate the formation of the secretion. Any factor that increases the difference in pressure in the renal artery and the renal vein will cause increased secretion of urine. Vascular dilatation of the vessels of the kidney, unless counterbalanced by a general fall of blood-pressure, will give an increased secretion. The following table is useful for reference:

Table of the Relation of the Secretion of Urine to Arterial Pressure (Kirke).

A. Secretion of urine may be increased—

(*a*) *By increasing the general blood-pressure by*—

1. Increase of the force or frequency of the heart-beats.
2. Constriction of the small arteries of areas other than that of the kidney.

(*b*) *By increasing the local blood-pressure by relaxation of the renal artery, without compensating relaxation elsewhere by*—

1. Division of the renal nerves (causing polyuria).
2. Division of the renal nerves and stimulation of the cord below the medulla (causing greater polyuria).
3. Division of the splanchnic nerves; but the polyuria is less than in 1 or 2, as these nerves are distributed to a wider area, and the dilatation of the renal artery is accompanied by dilatation of other vessels, and therefore by a somewhat general increase of blood-supply.
4. Puncture of the floor of the fourth ventricle or mechanical irritation of the superior cervical ganglion of the sympathetic, possibly from the production of dilatation of the renal arteries.

B. Secretion of the urine may be diminished—

(*a*) *By diminishing the general blood-pressure by—*

1. Diminution of the force or frequency of the heart-beats.
2. Dilatation of capillary areas other than that of the kidney.
3. Division of the spinal cord below the medulla, which causes a dilatation of the general abdominal area, and urine generally ceases being secreted.

(*b*) *By increasing the blood-pressure* by stimulation of the spinal cord below the medulla, the constriction of the renal artery which follows not being compensated for by the increase of general blood-pressure.

(*c*) *By constriction of the renal artery* by stimulating the renal or splanchnic nerves or the spinal cord.

Ludwig regarded the secretion of urine as due to simple filtration and osmosis taking place in the glomeruli, and to a concentration in the convoluted tubules of the fluid thus formed. Recent work has shown that the cells of the convoluted tubes have a distinct secretory function in the elimination of urea and related bodies. The evidence is:

1. In birds, where uric acid takes the place of the urea of mammals, the small solubility of the urates enables experimenters, by ligation of the ureters, to cause a deposit which is always found in the cells of the convoluted tubes.

2. Indigo-carmine injected into the circulation of a living animal may be precipitated by the injection of alcohol, when the pigment is always found in the convoluted tubes.

3. The inactive cells of the convoluted tubes are small, granular, and toward the lumen show a striated border. During activity they lose their striated border, project into the lumen of the tubule, making it smaller, and a clear vesicular area is formed near the nucleus. The vesicle ruptures and empties its contents into the lumen.

The excretion of water and salts takes place mainly through the glomerular epithelium. There are no secretory nerves. Section of the cord in the cervical region, which results in a general fall of blood-pressure, diminishes the secretion. In general it has been found that the secretion of urine varies both with the pressure of the blood in the glomeruli and the quantity of blood flowing through the kidney, and Heidenhain has insisted upon the latter factor as the essential one, giving as evidence the fact that compression of the renal vein stops the flow of the urine. This raises the pressure in the glomerulus, but stops the flow of blood. Ligation of the vein for one-half minute will stop the secretion for three-quarters of an hour, so that it probably depends upon the living structure of the epithelial cells. The action of substances, like potassium nitrate, which increase the flow of urine and are known as *diuretics*, is explainable in two ways:

1. They may cause hydræmic plethora by drawing water from the tissues, thus increasing the blood-pressure and favoring filtration.

2. The substances may act directly upon the cells of the glomeruli.

Abnormal constituents of the urine in disease, as albumin in nephritis or sugar in diabetes, escape from the blood through the glomerular epithelium. Urea in the blood acts as a stimulus to the cells of the convoluted tubules, causing its selection from the blood where its percentage is less and its excretion into the tubules where its percentage is greater.

URINE.

The urine is a clear, yellowish liquid, of a slightly acid reaction, a characteristic odor, salty-bitter taste, and an average specific gravity of 1017 to 1020. The daily amount formed may be placed at from 1200 to 1700 c.c. The **color** is due to a pigment, *urobilin*, derived from the bilirubin of the bile, and its various tints are due to various stages of oxidation. The **acidity**, which is due to *acid sodium* and *acid calcium phosphate*, is less during active digestion, particularly of vegetable foods. Herbivora have alkaline urine except during starvation. That there is no free acid present is shown by the fact that no precipitate is formed upon the addition of sodium hyposulphite. Upon standing fermentation usually results, due to the presence of bacteria, which causes first a precipitate of uric acid and urates and later of triple phosphates. The urine is very complex, because the kidneys eliminate not only the normal end-products of metabolism, with the exception of carbon dioxide, but also products of decomposition from the alimentary canal and substances, like drugs, that are not ordinarily regarded as foods. *A useful rule for approximately estimating the total solids in any given specimen of healthy urine is to multiply the last two figures representing the specific gravity by*

2.33. Thus, in urine of a specific gravity of 1025, 25 times 2.33 equals 58.25 grams of solids in 1000 c.c. of urine. In using this method it must be remembered that the limits of error are much wider in diseased than in healthy urine.

The most important constituents of the urine are *urea, uric acid, xanthin, hypoxanthin, guanin, adenin, creatinin, hippuric acid, conjugated sulphates, water,* and *salts.*

Urea, an amide of carbonic acid, is found in relatively large quantities (2 per cent. or more). Twenty-four hours' urine contains from 30 to 34 grammes. It is the end-product of the physiological oxidation of proteids and albuminoids. One gramme of proteids yields $\frac{1}{3}$ of a gramme of urea, as determined from the contained nitrogen. But as some nitrogen is eliminated in uric acid, creatinin, etc., the amount of urea cannot be taken as an indication of the total proteid broken down. Urea is also found in other secretions, as the milk and the perspiration.

The kidney does not manufacture urea, as is shown by these facts:

1. Urea does not form in the blood when irrigated through an isolated kidney.

2. The urea in the blood (0.03 to 0.15 per cent.) accumulates steadily as long as the animal lives if the kidneys are extirpated.

The evidence that urea is formed in the liver is as follows:

1. The blood of a well-fed dog, when irrigated through an isolated liver, increases in the amount of urea contained, which is not true of the blood of a fasting animal, from which may be concluded that the first contains substances which the liver can convert into urea.

2. This power is possessed only by the liver.

3. Ammonium carbonate added to the blood and irrigated through the liver is converted, at least partially, into urea.

4. Removal of the liver decreases the percentage of urea in the blood.

Urea arises from proteids by hydrolysis and oxidation with the formation of ammonia compounds, which are changed to urea in the liver. Ammonium carbamate may be one of the precursors of urea, having been found in the blood of dogs, and is easily converted into urea by the loss of water. However, other and more complex ammonia compounds, like leucin and glycocoll, can be converted into urea by the liver. The blood of the portal vein is normally three or four times as rich in ammonia compounds as is arterial blood. Since urea does not entirely disappear upon extirpation of the liver, it must have some other source, and a decomposition-product of proteid by trypsin—*lysatinin*—has been suggested as a possible source.

Uric Acid.—Its total quantity in the urine in twenty-four hours varies from 0.2 to 1 gramme. In birds and reptiles it takes the place of urea as the main end-product of the disintegration of proteids, and its place of origin has been proved to be the liver. In mammals this has not been substantiated. According to one investigator, uric acid is derived from nucleins being their specific end-products: for, among other things, it is found that feeding with substances rich in nucleins, like the thymus gland, leads to an increased elimination of uric acid. Upon feeding an animal with uric acid it is found that some of it is excreted as urea.

Xanthin, hypoxanthin, guanin, adenin, etc., which are closely related to uric acid, are probably derived from the same source. They are found in the greatest quantity in muscle.

Creatinin is derived partly from proteids eaten and partly from the metabolism of proteids in the body. Muscle contains creatin as a constant constituent, which, when taken into the stomach, is eliminated as creatinin, the latter differing from creatin in containing one molecule less of water. The quantity of creatinin in the urine of man a day is about 1.12 grammes.

Hippuric acid is excreted in the urine of man to the extent of about 0.7 gramme in twenty-four hours. Foods like vegetables, which contain substances that yield benzoic acid, increase the output, since a union of benzoic acid and glycocoll taking place in the kidney forms hippuric acid. Some, however, is the result of proteid putrefaction in the intestines.

Conjugated sulphates are ethereal salts of organic compounds of the aromatic and indigo series. Among the most important organic radicals are *phenol*, *cresol*, *indol*, and *skatol*. These are formed by putrefactive processes in the intestines from proteids, and are partly excreted in the fæces and partly passed into the blood. Since they are injurious they are combined with sulphuric acid to form the conjugate sulphates, which are harmless. *Sulphur* is also excreted as simple sulphates and as unoxidized sulphur compounds.

Water.—The quantities lost through the kidneys and skin stand in inverse proportion to one another. Since water lost through the skin affects the normal constitution of the urine through the medium of the blood, it is to be expected that other substances in the circulation might have similar influence. This, as a matter of fact, is true. A temporary alteration of the blood by the absorption of large quantities of water and the presence of diuretics increases the flow of water from the kidneys. If *saline diuretics* (potassium nitrate, sodium chloride, urea, dextrose, etc.) are injected into the blood, an abundant secretion soon takes place, which is accompanied by an enlargement of the kidney and a slight rise of blood-pressure. It has been shown that the power of these diuretics is proportional to their molecular weights, and it is therefore highly probable that through their osmotic power they withdraw water from the tissues to the blood. The diuresis which they bring about lasts only as long as the blood-pressure remains above normal.

Other diuretics are *caffein* and *digitalis*. If ½ grain of caffein is injected into the circulation, the kidney at first contracts in volume and the secretion of water is stopped. Soon, however, an expansion takes place and a copious urinary flow results. The general blood-pressure is also lessened and then heightened. Caffein seems to act on the renal vessels, diminishing and then augmenting the flow of blood through the glomeruli. Digitalis is rather uncertain in its action as a diuretic. It slows and strengthens the beat of the heart in certain subjects ; increasing the arterial pressure and lowering the venous pressure, which favors the flow of blood through the kidney, and produces an increase in the amount of water in the urine.

Inorganic Salts.—Those of the urine are chiefly the *chlorides*, *phosphates* and *sulphates* of the *alkalies* and *alkaline earths*. They are taken into the body partly as such and partly in the structure of proteids. Chloride of sodium occurs to the greatest extent, amounting to about 15 grammes in a day's urine.

SECRETIONS OF THE SKIN.

The **perspiration** is a colorless liquid with a peculiar odor, a salty taste, an acid reaction, and a specific gravity of 1004. The amount formed varies enormously with the temperature, with exercise, with psychical and pathological conditions, but may be put at an average of from 700 to 900 grammes a day, a little more than half the total of urine excreted. Its *constituents* are *water, inorganic salts, traces of fat, fatty acids, cholesterin,* and *urea.* Sodium chloride forms from 2 to 3.5 parts in a thousand, The urea of perspiration in determinations of destroyed proteid is usually neglected. During extraordinary muscular work the nitrogen eliminated by the skin amounts to 0.7 or 0.8 gramme. Sweat-glands are found over the entire surface of the skin, with the exception of the external ear. Their total number is about 2,000,000.

Insensible perspiration increases in quantity with increase of temperature until a certain critical point is reached, when it is markedly increased and appears as *visible sweat.* The percentage of carbon dioxide is increased at the same time. Normally the glands are stimulated by exercise and high temperature. In the latter case it is produced through the central nervous system. Instead of acting on the glands directly, the heat affects cutaneous sensory nerves and reflexly excites the glands. Sweating can be brought about by stimulation of the afferent nerves and by dyspnœa; by the latter, even if the cervical cord is sectioned. Sweat-centres are, therefore, surmised in the cord as well as in the medulla, but they have not been definitely demonstrated.

Sebaceous Secretion.—This is an oily, semi-liquid material, which sets on exposure to air and consists of *water, salts, albumin, cholesterin, fats,* and *fatty acids.* Its function is to keep the hair oiled, and perhaps to prevent too great a loss of water through the skin, and also too great an absorption. The sebaceous glands are usually found in connection with hairs all over the body, but on the prepuce, glans penis, and lips they occur separately. The secretion of the prepuce is known as *smegma præputii;* that of the external auditory canal, as *cerumen;* that of the skin of the newly born as *vernix caseosa.* In the formation of the secretion the gland-cells break down bodily and are replaced by new cells from the layer nearest the basement membrane.

MAMMARY GLANDS.

The secretion of the mammary glands is an alkaline, bluish-white fluid, having a specific gravity of 1030. It is a typical emulsion, consisting of a fluid plasma holding suspended fat-globules. When the secretion takes place from a newly active gland there are, besides the fat-globules, certain albuminous bodies known as *colostrum corpuscles*, which may be cells of the gland or may, perhaps, have their origin in wandering connective-tissue corpuscles. The plasma of the milk consists of water holding in solution casein, lacto-albumin, lacto-globulin, lactose, salts, traces of urea, creatin, and creatinin. The fat-globules consist chiefly of stearin, palmitin, and olein, which upon standing rise to the surface as *cream*. Their number in 1 c.c. of milk has been estimated to be from 1 to 5,700,000. They are not, as was formerly believed, surrounded by an albuminous envelope. Through their high refractive power they are chiefly responsible for the color of milk. The casein which is held in solution by calcium phosphate is, however, partly the cause of the color of milk.

The *reaction of milk* is often amphoteric, and may, especially in carnivora, be acid. Fresh milk is not coagulated by heat, but upon standing it slowly becomes acid through the formation of lactic acid by fermentation, and will then curdle if heated. The *scum* forming on cooked milk is a combination of casein and calcium. As it is often necessary in infant feeding to replace the mother's by cow's milk, it is important to consider some of the differences between various milks. The following table is modified from König:

Milk.	Specific gravity.	Water.	Casein.	Albumin and globulin.	Fat.	Lactose.	Ash.
Woman	1.027	87.41	1.03	1.26	3.78	6.21	0.31
Cow	1.031	87.17	3.02	0.53	3.69	4.88	0.71
Colostrum of cow.	. .	74.67	4.04	13.60	3.59	2.67	1.56
Goat	. . .	85.71	3.20	1.09	4.78	4.46	0.76
Sheep	1.034	80.82	4.79	1.55	6.86	4.91	0.89
Mare	1.034	90.78	1.24	0.75	1.21	5.67	0.35
Ass	. . .	89.64	0.67	1.55	1.64	5.99	0.51
Hog	. . .	84.04	. .	. . .	4.55	3.13	1.05

The *composition of human milk* varies with the constitution, with the state of nutrition, with age, with the complexion, at different stages of lactation, from the two breasts, etc. It is distinguished from *cow's milk* mainly by the low percentage of proteid and the high percentage of sugar. The difference in the proteid causes human milk to form a more flocculent and more easily digested precipitate when coagulated. Practically all the phosphorus is in organic combination as nucleon and caseinogen, and is not, as in cow's milk, found as pseudo-nuclein. The casein in woman's milk is more difficult to precipitate by acids, salts, and rennet and is also more easily redissolved by an excess of acid.

Human milk contains the fatty acids—oleic, stearic, palmitic, butyric, caproic, capric, and myristic, combined with glycerine. Cow's milk contains in addition caprylic and arachic acids. Human milk is poor in volatile acids. The chief base is potassium, while that of other animals is calcium.

The cells of the mammary glands, which during pregnancy become active for the first time, undergo histological changes of such a nature that each cell increases in size, undergoes a fatty metamorphosis, the nuclei divide, and then a portion, at least, of the cell, if not the whole of it, disintegrates. The fragments form the constituents of the milk. There are known instances where the secretion of milk has been suppressed by strong emotions, epileptic attacks, etc., indicating a control of the central nervous system. The connection between the gland and the uterus, which stand in close relation, is mainly through the blood.

That the secretion of milk may be continuous is not known with certainty, but it is probable that as it accumulates in the sacculated ducts of the gland the tension finally inhibits further secretion. The emptying of the ducts is the normal stimulus, either directly or reflexly, for a renewed activity of the gland. Otherwise the cells undergo retrogressive changes, but they never become as they were before the first pregnancy.

THYROID.

The secretion of the thyroid is a homogeneous, glairy liquid, known as *colloid substance*, and is contained within the closed vesicles and surrounding lymph-spaces of the gland. Its composition is not well known. Of the bodies related to the thyroids, *para-* and *accessory thyroids*, the latter probably have the same function. Complete removal of the organs, or *thyroidectomy*, as it is called, is followed by a train of symptoms that ends in death and is more fatal in the young than in the old. In dogs muscular tremors and spasms are accompanied by emaciation and apathy. Section of the motor nerves prevents the spasms, indicating that they are of central origin. In monkeys thyroidectomy resembles *myxœdema* in man. The symptoms are anæmia, failure of muscular and mental power, dryness of the skin, loss of hairs, and swelling of the subcutaneous tissue. They may be prevented by grafting a piece of the thyroid under the skin or anywhere in the abdominal cavity. In human beings favorable results have been obtained by the ingestion of thyroid extracts and by feeding with the fresh gland.

It appears that the thyroids and accessory thyroids, on the one hand, differ from the parathyroids, on the other, in that removal of the first causes slow trophic disturbances, while removal of the last results in acute disturbances and quick death. These glands may be regarded as functioning in two ways. They may either antagonize toxic substances that are found in the blood, or may produce a secretion which is necessary to the metabolism of the body in general, and particularly of the central nervous system. There has been isolated from the thyroid a substance which is peculiar in containing a large percentage of iodine, and which is for the most part, while in the gland, combined with proteids. It has been named *iodothyrin*. The parathyroids contain relatively larger amounts of this substance. It is quite stable, and possesses the same beneficial action as the thyroid extract.

PANCREAS.

Extirpation of the pancreas is followed by the appearance of sugar in the urine, polyuria, emaciation, muscular weakness, and ultimate death. The result depends upon the completeness of the removal ; one-fourth to one-fifth of the gland remaining prevents the symptoms. As in the case of the thyroid, they may be prevented by grafting a portion of the gland anywhere under the skin or in the abdominal cavity. The sugar of the blood is increased from 0.15 to 0.50 per cent., and the glycogen of the liver disappears. Carbohydrate foods are not used up, but are apparently eliminated in the urine. It is believed that the pancreas gives off a substance that is necessary either to the consumption of sugar in the body or else hinders the liberation of sugar from sugar-producing organs. It may be of the nature of an enzyme.

LIVER.

The liver in its production of urea and glycogen resembles those organs producing internal secretions. The blood of the portal vein brings sugars and proteids to the liver, which are converted into animal starch or glycogen $(C_6H_{10}O_5)_n$. The latter can be seen in the liver-cells microscopically. As the demand arises, it is by a process of hydration changed to dextrose, and secreted back into the blood, to be made use of by other tissues. Urea is made by the liver-cells from ammonia compounds, and secreted into the blood, to be excreted by the kidney. In both cases the liver functions for the good of the entire body. It is possible that it may also be essential to the conservation of iron of broken-down hæmoglobin and in the formation of conjugate sulphates.

SUPRARENAL CAPSULES (ADRENAL BODIES).

The removal of these bodies is more quickly fatal than the removal of the thyroids, death occurring in a few hours or a few days. The symptoms are muscular weakness, loss of vascular tone, and great prostration, resembling those of *Addison's* disease, which involves lesions of the adrenals. The glands may normally be supposed to remove toxic substances from the body, which are formed chiefly in the muscles. Aqueous extracts of the medulla of the gland injected into the vessels of an animal will cause a marked slowing of the heart-beat and a simultaneous rise of blood-pressure if the vagi are intact. When the latter are cut, the heart-beat is increased in its rate and the blood-pressure rises enormously. The effect is due to a direct action upon the muscles of the blood-vessels. It requires very little of the substance to produce maximum effects, but they are of a transitory nature. It has been found to be present in the adrenal vein, and is increased by stimulation of the splanchnic giving evidence of distinct secretory fibres to the gland-cells. An unstable, basic body, called *epinephrin*, has been isolated, which gives the same physiological effects when injected into the circulation as does the extract.

PITUITARY BODY.

Extracts of the infundibular portion of the pituitary body cause a rise of blood-pressure and a slowing of the heart-beat when injected intravenously. Removal of the pituitary body is followed by muscular tremors, spasms, dyspnœa, and death. Pathologically, lesions of the pituitary are connected with a disease of the bones causing hypertrophy, known as *acromegaly*.

TESTIS AND OVARY.

Brown-Séquard first investigated the internal secretion of the testis. He showed that an extract of the gland or of the spermatic fluid when injected under the skin will produce mental and physical vigor in cases of prostration, neurasthenia, and old age. The active substance has been isolated and called *spermin* ($C_5H_{14}N_2$). It is not essential to life, since the testes may be removed without fatal results. It is a well-known fact that ovariotomy and premature menopause may be followed by abnormal mental symptoms and often by a gain in weight. In *osteomalacia*, a disease giving rise to a softening of the bones, removal of the ovaries has been found to exert a favorable influence. In dogs complete ovariotomy is followed by a lessening of the consumption of oxygen, which is increased again by feeding with ovarian extracts. These facts show the influence of the ovaries upon the general nutrition.

KIDNEY.

Some investigators have described the effects of extracts of the kidney which cause a rise of blood-pressure. The active substance has been named *rennin*.

THYMUS GLAND AND SPLEEN.

Extracts of the thymus and spleen seem to have no specific effect.

The function of the latter organ is very little understood. It may be removed from the organism without serious injury, giving rise, it is asserted, to an enlargement of lymph-glands and to an increase in the amount of bone-marrow. It has also been found that the number of red blood-corpuscles is diminished. The following suggestions of the function of the spleen have been offered :

1. That the spleen manufactures blood-corpuscles. This is

without doubt true in man during fœtal life and at birth, but it is not known that it continues throughout life.

2. That the spleen destroys the red blood-corpuscles. The evidence for this theory is that spleen tissue is rich in iron-holding compounds, and that certain amœboid cells of the spleen have been seen apparently ingesting and destroying red blood-cells.

3. That the spleen produces uric acid. Uric acid is found in the spleen, but also in all lymphoid tissue.

4. That the spleen produces an enzyme which is carried to the pancreas in the blood, converting trypsinogen into trypsin. A striking feature of the spleen is its *rhythmic movements.* It undergoes a slow expansion and relaxation, with definite periods of digestion. These are due to vasomotor changes, the maximum vasodilatation occurring about the fifth hour after a meal. In cats and dogs there are, in addition, rhythmical changes taking place from minute to minute which serve to maintain a constant circulation through the organ. The spleen is well supplied with nerves, stimulation of which produce a contraction.

The *chemical substances* found in the spleen are interesting, since they indicate a marked metabolism. There is a large percentage of iron in an unknown organic combination. In addition, there are fatty acids, fats, cholesterin, xanthin, hypoxanthin, adenin, guanin, and uric acid.

QUESTIONS ON CHAPTER II.

What is meant by the term secretion?

Distinguish between external and internal secretions and excretions.

Give proofs that gland-cells are active during secretion.

Define filtration, diffusion, and osmosis.

What is the source of saliva?

Discuss albuminous and mucous glands and their products.

Describe the histological changes in salivary glands during activity.

What are zymogen granules?

Describe the nerve-supply of the salivary glands.

Give results of the stimulation of chorda tympani and sympathetic nerves.

What are the proofs that secretion is not simply due to increased blood-supply?

What is the relation of the composition of saliva to the strength of stimulation?

Give Heidenhain's and Langley's views on secretion.

What is paralytic secretion? Antilytic secretion?

Explain changes in secretion produced by drugs.

Give mechanism of normal secretion of saliva.

Discuss the cells of the gastric glands.

Give the results of stimulation of their nerve-supply.

In what ways may the gastric juice be caused to flow?

Describe changes in cells during activity.

Describe the cells of the pancreas and the changes they undergo when active.

What is the effect of stimulation of the medulla on pancreatic secretion?

Discuss results of stimulation of nerve-supply to pancreas.

What causes the pancreatic juice to flow normally?

How much bile is secreted in a day?

What is the relation of bile-secretion to the blood-supply?

Describe the effect on bile-secretion produced by stimulation of the cord and splanchnic nerves.

What can be said of the influence of the nerve-supply on the cells of the intestinal mucous membrane?

Discuss serous secretions.

What is the nerve-supply of the lachrymal glands?

What are tears?

Are there secretory fibres to the kidney?

Give the relation of the blood-supply to the secretion of urine.

What is an oncometer?

Describe the nerve-supply to the kidney.

In what way is the secretion of urine influenced by nerves?

Give evidence that cells are active in the formation of urine.

Where in the kidney does the excretion of water and salts take place?

Give reasons for thinking that the cells of the glomerular epithelium are active in secretion.

How is the action of diuretics explained?

Describe the urine and state the amount formed.

What is the color of the urine due to?

Why is the urine of complex composition?

What are the most important constituents of urine?

Discuss the urea of the urine.

What are the proofs that the kidney does not manufacture the urea?

What evidence is there that urea is formed in the liver?

What is the precursor of the urea in the blood?

Discuss the uric acid of the urine.

What is the source of the xanthin bases?

What is the source of creatinin?

Discuss hippuric acid of the urine.

What are conjugate sulphates?

In what other forms is sulphur excreted from the body?

What is the relation of the water lost through the kidney and the skin?

Discuss the action of caffein and digitalis on the secretion of water by the kidney.

What are the inorganic salts of the urine?

Discuss the secretions of the skin.

How are the sweat-glands stimulated to activity?

What is the method of action of temperature in producing secretion of sweat?

Describe the properties and method of formation of the sebaceous secretion.

Describe the secretion of the mammary glands.

What are colostrum corpuscles? Compare human milk with that of the cow.

Describe the histological changes that take place in the formation of milk?

What facts indicate a control of the central nervous system over the activity of the mammary glands?

Describe the normal secretion of milk.
What is colloid substance?
Give the symptoms of thyroidectomy in man and in the lower animals.
How can the spasms following thyroidectomy be shown to be of central origin?
How may the symptoms of thyroidectomy be prevented?
In what way do the parathyroids differ from the thyroids?
What is the function of the thyroid gland?
What is iodothyrin?
Describe the symptoms of extirpation of the pancreas.
How may the symptoms be prevented?
What is the function of the internal secretion of the pancreas?
Describe the glycogenic function of the liver.
What are some of the functions of the liver?
What are the symptoms of removal of the suprarenal capsules?
The symptoms of what disease in man do they resemble?
What is the function of the suprarenal capsules?
Describe the effects of injections of extracts of the medulla of the gland.
Explain the cause of the results obtained.
What evidence of secretory fibres to the suprarenal capsules?
Describe the physiological effects of epinephrin.
Give the effects of injections of the pituitary body.
What disease is connected with lesions of the pituitary?
Give the source and physiological action of spermin.
What evidence that the ovaries may have an effect on the general nutrition?
Give the source and physiological action of rennin.

CHAPTER III.

DIGESTION.

SUBSTANCES that constitute food may occur in a gaseous, fluid, or solid state. When in the last condition it is merely in a limited number of cases that it may be ingested. For most organisms the solid must be converted into the liquid form. This transformation is termed digestion and is effected by ferments. What we call food appears to consist of the most varied substances, but upon analysis is found to be composed of a small number of *food-stuffs.* There are seven classes.

1. **Proteids** are absolutely essential to animal organisms, since they are the sole available source of nitrogen. They serve for the repair of old tissue, for the formation of new tissue, and as a source of energy. They contain the elements C, H, N, O, S, and sometimes P and Fe. Hundreds of atoms are contained in a molecule; the formula for *egg-albumen,* for instance, has been

given as $C_{204}H_{322}N_{52}O_{66}S_2$. Owing to the uncertainty of their structure, classifications of proteids vary in minor ways. It will be sufficient to bear in mind that there are *simple* and *combined proteids.* As concrete examples of the first may be given egg-albumen and fibrin; of the second, hæmoglobin, mucin, and casein. Simple proteids may be divided into *albumins, globulins, albumoses, peptones, albuminates,* and *coagulated proteids.* Saturation of the solution with magnesium sulphate throws down the globulin, but not albumin. Saturation with ammonium sulphate throws down albumin, globulin, and albumose, but not peptone. The presence of proteid in solution may be detected by the following tests:

(*a*) *Biuret Test.*—To the solution to be tested add an equal volume of strong sodium hydrate. Heat to boiling-point, and add one or two drops of dilute copper sulphate solution. Reaction: a *pink* color, which is due to the diamide group in the proteid molecule.

(*b*) *Millon's Test.*—To the solution to be tested add two or three drops of Millon's reagent. This reagent is made by dissolving in the cold one part of mercury in an equal part by weight of concentrated nitric acid. To effect an entire solution a gentle heat must be finally applied, and then two volumes of water are added. If proteid is present in the solution, a white precipitate forms which, on boiling for several minutes, turns *red.* This reaction is due to an aromatic nucleus, since it is given by phenol and tyrosin.

(*c*) *Heller's Test.*—To the solution to be tested add an equal volume of concentrated nitric acid carefully, so as not to mix. The proteid is precipitated.

(*d*) To about 5 c.c. of the solution to be tested add two drops of strong acetic acid and then one or two drops of *potassium ferrocyanide.* Proteid precipitates. This is a very delicate test.

2. **Albuminoids** resemble and are derived from true proteid, but cannot take the place of the latter as a source of nitrogen to animals. They are of complex structure, and have the same nutritive value as carbohydrates. Gelatin is a well-known example.

3. **Carbohydrates** include starches, sugars, gums, etc. They are divisible into three main groups—*monosaccharides, disaccharides,* and *polysaccharides.* Those of the first group may possess either the structure of an aldehyde alcohol, when they are known as *aldoses,* or of a ketone alcohol, when they are known as

ketoses. Dextrose is an example of an aldose, while levulose is an example of a ketose. The most familiar example of a monosaccharide is *dextrose* ($C_6H_{12}O_6$). It may be detected by boiling with Fehling's solution. Disaccharides are represented by *cane-sugar* ($C_{12}H_{22}O_{11}$). Not reducing Fehling's solution, it may be detected by the *fermentation test.* This test may be made as follows: The solution to be tested is rubbed up with a little yeast and placed in a U-shaped tube, one arm of which is closed. The closed arm must be filled completely and free from air. After twenty-four hours' exposure to a warm temperature an accumulation of gas in the closed end, due to fermentation, denotes the presence of sugar. Polysaccharides are represented by starch $(C_6H_{10}O_5)_n$. The value of the $(_n)$ has been placed at from 6 to 200. This substance is insoluble in water, except at a high temperature, which produces soluble starch and perhaps many minor hydrolytic products. It may be detected by the addition of iodine solution, a *blue color* resulting.

4. **Fats,** like carbohydrates, consisting of carbon, hydrogen, and oxygen, are more valuable sources of energy, but not so cheap or so easily digested. Chemically, fats are *esters* resulting from the union of *glycerine* with a *monobasic fatty acid.* Ordinary fats are mixtures of the three chemical fats—*stearin, palmitin,* and *olein.* They are readily split by hydration into their components, glycerine and fatty acid. The latter uniting with a base gives rise to *saponification*—*e. g.:*

Stearin. + Potassium hydrate = Potassium stearate + Glycerine.

$$\left.\begin{matrix}(C_{18}H_{35}O)_3\\ C_3H_5\end{matrix}\right\}O_3 + 3\left.\begin{matrix}H\\ K\end{matrix}\right\}O = 3\left(\left.\begin{matrix}C_{18}H_{35}O\\ K\end{matrix}\right\}O\right) + \left.\begin{matrix}C_3H_5\\ H_3\end{matrix}\right\}O_3.$$

5, 6. **Water** and **salts** are absolutely essential to life, since the tissues must maintain a certain composition in water and salts which are continually being lost, so that they must be replaced in the food.

7. **Oxygen** being absolutely essential to the continued existence of life, may in this sense be considered a food. *Condiments* and *flavors* have a beneficial effect in promoting the flow of digestive juices and in increasing the palatableness of the food. Mustard and pepper increase absorption from the stomach.

These classes of food-stuffs enter in varying proportions into all substances that constitute the food of animals, and during digestion are changed chemically by being brought into contact with the digestive juices. The active substances in the latter are complex organic bodies termed *enzymes.* They are non-living substances containing nitrogen, and are soluble in water and glycerine; destroyed by temperatures from 60° to 80° C., and inhibited by cold and by the products of their own activity. The *coagulating ferments* are an exception to the statement that ferments are inhibited by the products of their activity. The most peculiar property of all ferments is that in their action they are not used up, so that a small amount of ferment will change an almost indefinite amount of the substance acted upon. They have been said to act by *catalysis,* which means by their mere presence. It is conceivable that a ferment may act through its physical properties or through certain chemical changes that it undergoes, but which leave it ultimately as it was at the beginning. Both possibilities may be illustrated by phenomena from inorganic nature. For instance, a trace of iodine added to amorphous phosphorus will convert the entire mass into red phosphorus. The iodine undergoes no chemical change, but acts through its physical properties, possibly by inducing a more active molecular vibration in the phosphorus, so that it assumes a more staple structure.

Chittenden has given an example illustrating the other possible method of action of enzymes. Carbon monoxide and oxygen, when perfectly dry, cannot be made to unite by means of an electric spark, but if a small quantity of water vapor is present, they combine readily. The following equations explain the reactions. In them it is seen that water takes part in the reaction, but remains finally as it was at the beginning:

$$2H_2O + CO + O_2 = CO(OH)_2 + H_2O_2.$$
$$H_2O_2 + CO = CO(OH)_2.$$
$$2CO(OH)_2 = 2CO_2 + 2H_2O.$$

There is much more certainty in regard to the changes produced in the bodies upon which the enzymes have acted. These are in all cases, probably, *hydration changes*—*i. e.*, the substances acted upon take up water and then break down into simpler combinations. The reasons for this belief are as follows:

1. Enzymes act only in the presence of water.

2. In many cases an examination of the substances before and after fermentation show directly a taking-up of water.

3. The action of ferments may be imitated by dilute acids or alkalies, which are the most powerful hydrolytic agents known.

Enzymes are classified according to the results that they bring about. They may be *proteolytic*, *amylolytic*, *fat-* and *sugar-splitting*, and *coagulating* ferments.

SALIVARY SECRETION.

The saliva is a transparent, viscid fluid of a specific gravity of 1002 to 1008. It is normally alkaline in reaction. The amount formed in twenty-four hours is about 1500 c.c. When taken from the mouth, it is known as *mixed saliva*, and is turbid, owing to suspended particles of matter. It contains characteristic *salivary corpuscles*, which are probably altered leucocytes. Chemically it consists of 99.5 per cent. water, holding in solution salts, proteids, and the ferment *ptyalin*. The viscidity is due to a glycoproteid, *mucin*. Saliva keeps the mouth moist in chewing and in speaking, dissolves certain substances, and so brings them in contact with the organs of taste, makes swallowing possible by wetting the food, and acts by means of its ferment on starches. *Ptyalin, by a process of hydration, converts starch to maltose through numerous intermediate steps.* The first change is probably the formation of soluble starch or *amylodextrine*, which, by further action of the enzyme, gives off a molecule of maltose, leaving a body known as *erythrodextrin*. The latter may be detected by the *red color* it gives upon the addition of iodine. Erythrodextrin, by a further splitting-off of a maltose molecule, is converted into a series of *achroödextrins*, which give *no color* reaction with iodine. These are, by the continued splitting-off of maltose molecules, finally all converted into maltose. Ptyalin acts in a neutral or slightly alkaline medium. Free hydrochloric acid to the extent of 0.003 per cent. stops its action, which, taken in connection with the fact that the food remains in the mouth but a very short time, indicates that the ptyalin digestion is not very important and is limited to the initial stages, that is, within the mouth only, as the acid of the stomach stops it. Cooked starch is more readily acted upon than raw, owing to the fact that the cooking destroys the cellulose envelope that surrounds the starch-grains.

GASTRIC JUICE.

The gastric juice, which is the next digestive juice to act upon foods, is a thin, nearly colorless liquid, of strong acid reaction and peculiar odor. Its specific gravity varies from 1001 to 1010. Its constituents are water-holding peptone, mucin, inorganic salts, hydrochloric acid, and the enzymes *pepsin* and *rennin*. The acid of the gastric juice is proved to be free hydrochloric acid in the following ways:

(*a*) When all the chlorides are precipitated by silver nitrate and the total chlorine is determined, more is found than can be held by the bases present.

(*b*) The secretion gives the color-tests for free mineral acids—methyl-violet solutions are turned blue, etc. The amount of free acid varies, but may be put at 0.2 to 0.3 per cent. It has been attempted to determine the source of the hydrochloric acid by injecting into the circulation of an animal substances like ferric lactate, followed by potassium ferrocyanide, which react only in the presence of a free mineral acid with the production of Prussian-blue. But this only in a general way proved its formation in the gastric mucous membrane, leaving the method of its formation unrevealed. During the active secretion of the gastric juice the alkalinity of the blood is increased and the acidity of the urine is decreased, corroborating the view that neutral chlorides are decomposed; the chlorine going to form the hydrochloric acid, while the bases pass back into the blood.

Pepsin is a proteolytic enzyme that acts only in acid media. A piece of fibrin, for example, when subjected to an artificial gastric juice, swells up and finally passes into solution. It is changed into a more diffusible form of proteid called peptone, but this conversion takes place through a number of intermediate steps. There is, first, the formation of an acid-albumin, which has been named *syntonin*. Upon neutralization of the medium, syntonin is precipitated, and upon further addition of the alkali is converted into *alkali-albumin*, which again passes into solution. Syntonin is, by hydrolysis, changed to a series of bodies known as *primary proteoses*. These in turn undergo cleavage with the formation of *secondary proteoses* or *deuteroproteoses*. The latter finally become, by the further action of the ferment, *peptones*.

Rennin.—Besides pepsin, the gastric juice contains an enzyme named rennin, that coagulates milk. The latter, if left undisturbed at the proper temperature, sets into a solid clot which shrinks and presses out a clear yellowish liquid called *whey*. The curd of human milk is not a solid, but is deposited in loose flocculi. Rennin acts upon the *caseinogen*, causing hydrolytic changes, with the formation of *paracasein* and *whey proteid*. The first unites with calcium salts and is precipitated as the curd. The conversion of starch by ptyalin may continue within the stomach for some time in the interior of the food boli which were formed in the mouth. It has been shown that cane-sugar may be converted to dextrose and levulose in the stomach, but otherwise carbohydrates are not acted upon. Fats are liquefied by the heat of the stomach, and *mechanically mixed* with other food-substances. Albuminoids undergo changes analogous to those of proteids. The mixture of food-substances passing from the stomach to the small intestine is known as *chyme*.

PANCREATIC JUICE.

In the intestine the food undergoes the greatest digestive changes. The pancreatic juice which enters the upper portion of the intestine is a clear, colorless, alkaline liquid, of a specific gravity of about 1015. Its composition varies, consisting of water, salts, and organic bodies. It contains the three important enzymes—*trypsin*, *amylopsin*, and *steapsin*. *Trypsin* acts on proteids in alkaline media, but may also act in neutral and weak acid media. The changes effected are similar to those which result from the action of pepsin, but the action is more rapid, the primary proteoses being omitted. The proteid, instead of swelling as in peptic digestion, undergoes erosion and disappears. It has been found that tryptic digestion will go further than peptic digestion, inasmuch, that of the peptone formed, a portion undergoes further changes into amido-acids and nitrogenous bases, and is designated as *hemipeptone*. The portion that resists further change is called *antipeptone*. Together they are known as *amphopeptones*. The most important of the simpler organic bodies formed are *leucin* and *tyrosin*. They are of smaller molecular weight and of simpler structure than peptones, and since they have little available energy and are useless in the repair of proteid tissue, their significance is problematical.

Amylopsin is the ferment of the pancreatic juice that acts on starches, and is *identical with ptyalin.* It forms an end product —maltose—and intermediate dextrins.

The fat-splitting enzyme of the pancreatic juice is known as *steapsin* or *lipase.* It acts by causing neutral fats to undergo hydrolysis, which results in their cleavage into glycerine and a free fatty acid. It was formerly thought that only a portion of the fat was thus changed, and that the fatty acid was united to some of the bases present in the pancreatic juice, forming a soap and emulsifying the remainder of the fat, which was then absorbed as fine globules. Recently another view has become prominent, which supposes all the fat to be converted into soluble glycerine and fatty acids, which are absorbed as such and later recombined as neutral fats in a fine state of emulsion called *molecular fat.*

BILE.

The constituents of bile are partly excretions and partly secretions. The quantity formed a day in man is from 500 to 800 c.c. It consists of water, salts, bile-pigments, bile-acids, cholesterin, lecithin, neutral fats, soaps, traces of urea, and a mucilaginous nucleo-albumin wrongly called mucin. The color of bile in carnivora is a bright golden red, due to the pigment bilirubin, while in herbivora it is green as the result of the pigment biliverdin. The color of the human bile varies from a yellow to a dark olive. It is feebly alkaline, and has a specific gravity of 1010 to 1050. *Biliverdin* ($C_{16}H_{18}N_2O_4$) is an oxidation product of *bilirubin* ($C_{16}H_{18}N_2O_3$). They are detected by *Gmelin's reaction*, which consists in bringing the solution to be tested in contact with *fuming nitric acid*, when a series of color changes result. The bile-pigments originate in the liver from hæmoglobin. They are mixed with the food in its passage along the intestine, and are partly reabsorbed and carried back to the liver in the portal blood. The bile-acids are found as the sodium salts of *glycocholic* and *taurocholic acid.* Both are present in human bile, and may be detected by *Pettenkofer's reaction*, which consists in adding to the liquid to be tested a few drops of a 10 per cent. solution of cane-sugar, and then, carefully, strong sulphuric acid. The temperature must be kept below 70° F. If bile-salts are present, a violet ring is formed at the junction of the liquids, which is due to the formation of a substance known as *furfurol.* The latter reacting with the bile-salts gives the color. The bile-salts are reabsorbed, partially at least, and again given off by the liver. The value of this process is not known unless it is to economize material, since the bile-salts serve to hold the excretion cholesterin in solution, which is constantly present in the bile, and serve also to assist in the absorption of fats from the intestine. *Cholesterin* ($C_{27}H_{46}O$) is eliminated by the liver-cells and remains unchanged in the fæces. It is a crystallizable, insoluble substance, found particularly in the medullary substance of nerve-fibres. The nucleo-albumin of the bile is formed by the cells of the ducts and gall-bladder, and gives to bile its mucilaginous character. Bile has feeble antiseptic powers, and to some extent retards putrefactive changes in the intestine, and it also neutralizes the acid chyme from the stomach.

INTESTINAL SECRETION.

The intestinal secretion, or *succus entericus,* may be obtained by the *Thiry-Vella* fistula, which is made by cutting out a portion of the intestine and bringing the cut ends to the abdominal wall, so as to form two openings. It is a yellowish liquid of alkaline reaction, having no influence on proteids and fats, but may convert starches to maltose and dextrin, invert cane-sugar to dextrose and levulose, and change maltose to dextrose. This shows the presence of amylolytic and inverting enzymes. The latter is called *invertase.*

SECRETION OF LARGE INTESTINE.

This secretion is composed mainly of mucus, is scanty, alkaline in reaction, and has no enzymes of its own. Digestive changes occur, however, for some time, and are due to enzymes brought down from above. Extensive bacterial decomposition takes place.

Bacteria may be found in any portion of the intestinal tract. It has been ascertained that the ileum, at its junction with the colon, is acid after a mixed diet. This is due to acetic acid (0.1 per cent.), which is formed through the action of bacteria. In the large intestine bacterial decomposition results in the formation of many substances. Some, like skatol, carbon dioxide, hydrogen sulphide, etc., promote movements of the intestine; some, like phenol and indol, are reabsorbed, to be eliminated in the urine.

Fæces.—The fæces vary in composition and amount with the nature and the quantity of the food. On a mixed diet the amount in twenty-four hours varies from 100 to 500 grammes in weight. Its constituents are indigestible materials, undigested food-stuffs, intestinal secretions, products of bacterial action, cholesterin, excretin, mucus, pigment, salts, gases, and micro-organisms. Among the products of bacterial action are *indol* (C_8H_7N) and *skatol* (C_9H_9N), which are crystallizable bodies giving odor to the fæces. The color is due to *hydrobilirubin*.

SUMMARY OF DIGESTION.

Proteid food is but slightly altered in the mouth, and only in a mechanical way. The muscle-fibres of meat, for instance, are crushed, and their connective-tissue sheaths broken by the action of the teeth, thus becoming somewhat white in appearance. Mixed with saliva, which has no digestive action on these food-stuffs, they are passed into the stomach and brought under the influence of the gastric juice. By the combined action of the hydrochloric acid and the ferment pepsin proteids pass through a series of steps which consist essentially of a taking-up of water and a breaking into simpler bodies. *Syntonin*, the first product formed, becomes converted into *proto-* and *heteroproteose*. These in turn are further changed to *deuteroproteoses* and to *peptones*. But the food does not remain in the stomach long enough for all the proteids to be changed to peptones. Some pass through entirely unchanged, while others have reached various stages of digestion.

In the intestine the energetic action of the trypsin changes those proteids that reach it more quickly to peptones than the gastric juice, the intermediate stage of the primary proteoses being omitted. Furthermore, of the peptones (*amphopeptones*), the hemi- group is still further changed to comparatively simple *amido-bodies* and *nitrogenous bases*. The most important of these are leucin and tyrosin. Finally, in the large intestine proteids that still remain are attacked and decomposed by bacteria, but some escape and are ejected in the fæces.

Albuminoids.—These bodies undergo changes analogous to those of proteids; the conversion in the stomach reaches chiefly only the gelatose stage, but the pancreatic juice produces gelatine peptones.

Carbohydrates.—The time that starches remain in the mouth is too short for the ptyalin of the saliva to produce any very great changes, and though the digestion may continue for some time within food-boli in the stomach, it probably does not pass the initial stages. The acidity of the gastric juice soon stops all carbohydrate digestion, and it is not until the food reaches the intestine that the amylopsin of the pancreatic juice actively begins the conversion of starches. The action of ptyalin and amylopsin is identical. Starch is modified into *soluble starch*, and then begin a series of hydration changes during which the starch molecule is split into *maltose* and *erythrodextrin*. The latter again into *maltose* and *achroödextrin*; achroödextrin again into *maltose* and a still *simpler dextrin*, and so on until only *maltose* results. In the intestinal secretion there is an enzyme which aids amylopsin in the conversion of starch to maltose. The sugars thus formed and others, eaten as such, are by means of inverting enzymes (*invertase* and *maltase*) of the intestine changed to monosaccharides. This is illustrated by the following equations:

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

$$\underset{\text{Cane-sugar.}}{C_{12}H_{22}O_{11}} + H_2O = \underset{\text{Dextrose.}}{C_6H_{12}O_6} + \underset{\text{Levulose.}}{C_6H_{12}O_6}$$

It has been found that cane-sugar may also be converted to dextrose and levulose in the stomach. Carbohydrates that escape digestion and absorption and reach the large intestine are largely destroyed by bacteria.

Fats.—These are not changed until they reach the fat-splitting ferment, steapsin, of the pancreatic juice, except that they are separated from the connective tissue by the action of the teeth and proteolytic enzymes, and are partially melted by the heat of the body in the stomach. In the intestine fats are changed to *glycerine* and a corresponding *fatty acid*. The latter may unite with bases present to form soaps, which emulsify the remaining unaltered fat. According to one view, fat is mainly absorbed in the form of an emulsion. According to another and later view, the greater part is converted to fatty acid and glycerine, absorbed as such, and then recombined to form neutral fat. While considering the action of digestive juices, it is interesting and important to remember that the ferment rennin of the gastric juice *coagulates milk*. The casein of the milk under the influence of the enzyme undergoes a hydrolytic cleavage, with the formation of paracasein and whey-proteid. Paracasein unites with calcium to form the insoluble curd. The action of rennin is confined to milk, and the value of the curdling action lies probably in an easier conversion of the milk proteids in the coagulated form. The digestion of milk after coagulation is carried on by the enzymes of the gastric and pancreatic juices.

SELF-DIGESTION OF THE STOMACH.

Why the stomach or any other portion of the intestinal tract brought into contact with digestive juices is not destroyed has given rise to much discussion. Normally, self-digestion does not occur, but if an animal is killed while in full digestion and the body is kept warm, the stomach will be destroyed. This has been found to take place in human bodies. If a portion of the stomach is deprived of its blood-supply, that portion will be attacked and a perforation of the stomach may result. The immunity of the stomach to the gastric juice has been explained in a number of ways, but not satisfactorily. It has been said that the epithelial lining of the stomach prevents the absorption of the gastric juice, but this explanation raises the question why the living epithelial cells are immune.

The secretion of mucus forming a protective coating for the stomach is an inadequate explanation, owing to the difficulty of conceiving such a means of protection to be as perfect as it is. Another theory which holds the alkaline blood to neutralize the acid of the stomach as it is formed cannot be applied in the case of the intestine, where the digestive juice is alkaline. An explanation is at present impossible. All that can be said is that the immunity of the intestinal tract is due to the fact that it is alive. Bernard introduced the hind-leg of a living frog into a dog's stomach through a fistula. It was digested. But in this case the cells of the frog's limb were first destroyed by the acid. It has been shown by Neumeister that a living frog's leg is not digested by a strong pancreatic digestive mixture of weak alkaline reaction, because in this case the cells are not killed.

NITROGENOUS ORGANIC BODIES, OR PROXIMATE PRINCIPLES.

Proteids	1. Native albumins found in nature,	Egg-albumin, Serum-albumin,	Soluble in water and coagulable by heat.
	2. Globulins found in nature,	Globulin, Paraglobulin, Fibrinogen, Myosin, Vitellin, Globin,	Soluble in 1 per cent. NaCl sol.; coagulable by heat; nearly all precipitated by alcohol.
	3. Derived albumins, derived from Class 1 by action of acids, alkalies, or ferments.	Acid albumin, Alkali-albumin, Casein,	Soluble in weak (1 per cent.) HCl sol.; not coagulable by heat; precipitated by neutralizing solution.
	4. Fibrin, from Class 1 by action of "fibrin-ferment,"	Fibrin,	Insoluble in cold 1 per cent. HCl sol., but soluble at 60° C.
	5. Coagulated albumin, by heat, etc., from Class 1,	Coagulated albumins,	Soluble in gastric juice, becoming peptones; and also in strong acids, becoming acid albumin.
	6. Peptones, by action of digestive ferments on Class 1.	Peptones,	Very soluble in water; not precipitated by heat, acids, alkalies, or alcohol. Peculiar in dialyzing freely.
Gelatins	Gelatin, soluble in hot water.		
	Mucin, soluble in weak alkaline solutions.		
	Elastin, insoluble.		
	Chondrin, soluble in hot water.		
	Keratin, insoluble; probably a complex compound.		
Products of the decomposition of nitrogenous matter.	Crystallizable acids—*e. g.*, glycin, leucin, taurin, etc.		
	Urea and its allies—*e. g.*, kreatin, uric acid, xanthin, etc.		
	Pigments—*e. g.*, bile-pigments, melanin, hæmatin, etc.		
Nitrogenous, but of uncertain composition.	Ferments—*e. g.*, amylolytic, proteolytic, milk-curdling, etc.		

NON-NITROGENOUS ORGANIC BODIES OR PROXIMATE PRINCIPLES.

Fats	Olein, liquid at ordinary temperatures.		Insoluble in water. Soluble in ether. " " chloroform. " " hot water. Saponify.
	Palmitin, solid " " (melts at 113° F.	United in fatty tissues.	
	Stearin, " " " (" 140° F.)		
	Cholesterin, chemically an alcohol, but closely allied to the fats.		
Carbohydrates	Starch, soluble in hot water, not in cold.	Not found in unchanged state in body, except as food.	Iodine-test (blue color).
	Glycogen, soluble in cold water.	In liver, by dehydration, glucose.	Iodine-test (red color).
	Dextrin, " " " "	Not found in body, except as food	All respond more or less readily to fermentation and copper-tests.
	Glucose, " " " "	Derived from saccharose and starch by ferment action.	
	Lactose, " " " "	Found in milk.	
	Maltose, " " " "	From starch by ferments, ptyalin.	
	Inosite, " " " "	Found in muscles and in heart.	Non-fermentable with yeast.
Fatty acids	Formic acid	Found only in perspiration.	
	Acetic "	Found only in perspiration.	
	Lactic "	" " " muscle-plasma.	

QUESTIONS ON CHAPTER III.

What is digestion?
What are food-stuffs? Give classes.
Into what subdivisions do simple proteids fall?
How are globulins separated from albumins?
How are peptones isolated from other proteids?
What purposes do peptones serve?
What can be said of the molecular structure of proteids?
Give tests for the identification of proteid.
How do albuminoids resemble proteids?
In what way are they like carbohydrates?
What are the main groups of carbohydrates? Examples.
How may dextrose be detected?
What is the test for cane-sugar?
What chemical is used for the detection of starch?
How do fats compare with carbohydrates as a source of energy?
What is saponification?
Of what value are water and salts to the body?
In what sense may oxygen be called a food?
What are the characteristics of enzymes?
In what ways are enzymes supposed to act?
How are enzymes classified?
Describe the saliva. What is its composition?
What is the function of saliva?
Give detailed steps of the action of ptyalin on starch.
What is the action of acid on the activity of ptyalin?
Why is starch more easily digested when cooked than when raw?
Describe the gastric juice.
What are the proofs that the acid of the gastric juice is free hydrochloric acid?
How is the reaction of the blood and the urine affected during active secretion of gastric juice?
What is pepsin?
Give detailed steps of the action of hydrochloric acid and pepsin on proteids.
Explain the action of the ferment rennin in detail.
Describe the curd of human milk.
In what ways are fats and albuminoids changed in the stomach?
Where does the food undergo its greatest digestive changes?
Describe the pancreatic juice. Its composition.
How does the action of trypsin differ from that of pepsin?
What are amphopeptones?
What is the source of leucin and tyrosin?
Compare the action of amylopsin and ptyalin.
What is lipase?
What is the action of steapsin on fat?
Describe the bile.
What causes the difference of the color in the bile of herbivora and carnivora?
How are the bile-pigments detected?
What is the source of the bile-pigments?
What is their fate?
What are bile-acids? How detected?
Give fate of bile acids. What is their function?

Describe cholesterin.
What makes the bile viscid?
How is the intestinal secretion obtained?
Describe the succus entericus.
Describe the secretion of the large intestine.
What is the reaction of the large intestine?
What is the reaction due to?
What changes do bacteria produce in the intestine?
Describe the fæces.
What substances give odor and color to the fæces?

CHAPTER IV.

MUSCULAR MECHANISMS.

MASTICATION.

In order that the food may readily be swallowed and acted upon by the digestive juices it is finely divided by the action of the jaws, which, by means of the incisors and canines, cut the food, and by means of the bicuspids and molars, crush it. The lower jaw is raised by the masseter, temporal, and internal pterygoid muscles; depression is largely passive, but is aided by the digastrics and slightly by the mylohyoid and geniohyoid muscles. When the infrahyoid group fix the hyoid bone, all the muscles passing between it and the mandible act to depress the latter; it is moved laterally by the external pterygoids acting separately, and forward by their joint action, and is retracted by the horizontal fibres of the temporals. The action is voluntary, the impulses coming through the trigeminal and hypoglossal nerves. The tongue and cheeks serve to bring and keep the food between the teeth.

DEGLUTITION.

This process is usually divided into *three stages:*

1. The food is properly placed on the tongue, which is elevated against the palate from tip to base, forcing the food toward the fauces.

2. The food is rapidly transferred through the pharynx by the contraction of the tongue and pharyngeal muscles, while simultaneously all passages with the exception of that to the œsophagus are closed. The mouth cavity is shut off by the tongue and

anterior pillars of the fauces; the nasal cavity by the soft palate, posterior pillars of the fauces, and uvula; the larynx by the depression of the epiglottis, adduction of the cords, and elevation of the larynx under the base of the tongue.

3. Having reached the œsophagus, the food is seized by the circular muscles, which contract from above downward in the form of a peristaltic wave. The most active contraction is just above the bolus of food. The total time involved by the food in reaching the stomach is about six seconds. *Liquids* when in the second stage are brought under pressure by the contraction of the mylohyoid and hyoglossi muscles, and quickly shot deep down into the œsophagus. Deglutition is a *reflex act*, with the exception of the *first* stage. Section of the œsophagus does not prevent the passage of the peristaltic wave. The *afferent fibres* are in branches of the fifth, ninth, and tenth nerves (especially in the superior laryngeal branch of the tenth). The *centre* in the medulla is not definitely localized. The *efferent fibres* are in the fifth, seventh (ninth), tenth, and twelfth nerves.

MOVEMENTS OF THE STOMACH.

When food is passed into the stomach it is moved about and thoroughly mixed with the gastric juice for several hours, while at regular intervals peristaltic waves sweeping over the organ force some of the digested mass through the relaxed pyloric sphincter into the intestine. The peristaltic waves begin feebly in the fundic end of the stomach, and increase in intensity until they reach a maximum at the *transverse band*, which contracts so markedly as to divide the stomach into two portions. Then follows a contraction of the antrum upon the food that has been moved into it, forcing the digested portions into the duodenum. Portions not digested set up an antiperistaltic wave and are thrown back into the fundus. Throughout the digestion of the food the fundus is in a *tonic* state and gradually contracts to smaller dimensions as the food disappears. The peristalsis of the stomach is independent of the nervous system. There is, however, a rich supply of nerve-fibres from two sources: from the *vagi* and from the *solar plexus*. Stimulation of the first causes a contraction, and stimulation of the second an inhibition, of the stomach. Their function is probably a regulatory one.

VOMITING.

Vomiting is a complete *reflex* action. It is preceded by a feeling of nausea, a flow of saliva, and retching movements which are brought about by spasmodic contractions of the diaphragm with a closed glottis. This causes the negative pressure in the thorax to increase and open the œsophagus, while simultaneously *pressure* is brought to bear upon the *stomach.* The abdominal muscles vigorously contracting force the contents out of the cardiac end of the stomach and up through the mouth. The glottis is closed, and the nasal passages also. *The stomach during vomiting may not be inactive, but the main factor in the ejection of its contents is the contraction of the abdominal muscles.* This was shown by Magendie, who substituted a bladder of water for the stomach and produced vomiting by injection of an emetic. It has been shown, moreover, that an emetic is without effect in a curarized animal. Vomiting is brought about by local irritation of the mucous membrane of the stomach, by tickling the pharynx, by psychical states, lesions of the brain, by toxic substances in the blood, etc. The *afferent path* when the reflex is from the stomach is through the vagus. A *centre* has been described near the calamus scriptorius, but its existence is not certain. The *efferent impulses* pass over fibres of the vagus, phrenics, and spinal nerves that supply the abdominal muscles.

MOVEMENTS OF THE INTESTINES.

These are of the same nature, but simpler than those of the stomach. There are two kinds—the *peristaltic* and the *rhythmic. Peristalsis* is effected mainly through a contraction of the circular muscle-fibres of the intestine, which involves successive portions and is followed by a gradual relaxation in the same order. This gives rise to a series of waves that normally pass from the stomach to the rectum. Waves in the reverse direction are known as *anti-peristaltic.* That peristalsis is due to some mechanism in the walls of the intestine has been shown by cutting out a portion and replacing it in a reversed position. Such animals show nutritive disturbances and examination reveals an accumulation of food at the upper end of the reversed part. The peristaltic waves pass over the intestine normally quite slowly, but abnormal waves may sweep over its entire length in a minute.

FIG. 4.

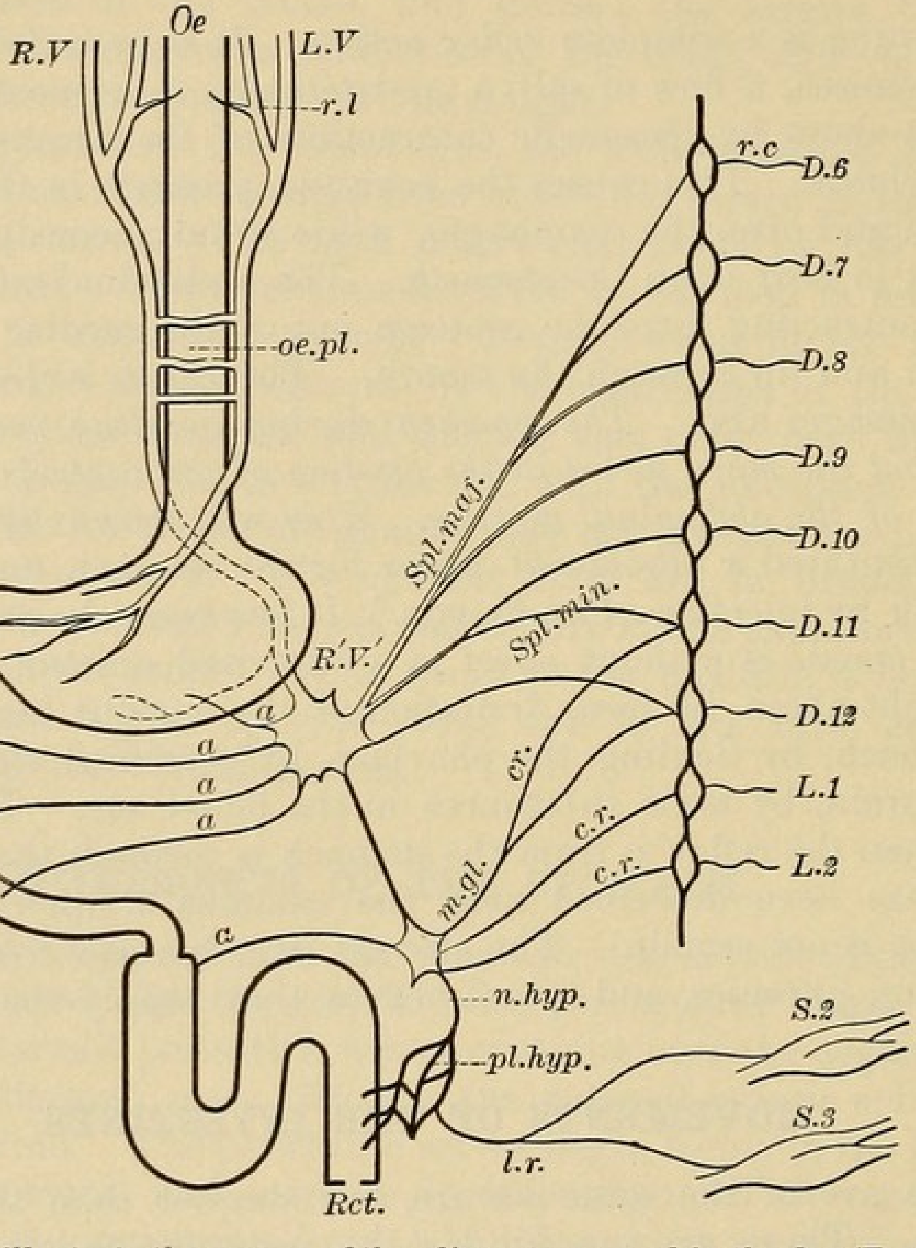


Diagram to illustrate the nerves of the alimentary canal in the dog (Foster). The figure is, for the sake of simplicity, made as diagrammatic as possible, *and does not represent the anatomical relations*. *Oe.* to *Rct.* The alimentary canal, œsophagus, stomach, small intestine, large intestine, rectum. *L. V.* Left vagus nerve, ending on front of stomach. *r.l.* Recurrent laryngeal nerve supplying upper part of œsophagus. *R. V.* Right vagus, joining left vagus in œsophageal plexus, *oe. pl.*, supplying posterior part of stomach and continued as *R'. V'.* to join the solar plexus, *here represented by a single ganglion* and connected with the inferior mesenteric ganglion (or plexus) *m.gl.* *a.* Branches from the solar plexus to stomach and small intestine and from the mesenteric ganglion to the large intestine. *Spl. maj.* Large splanchnic nerve arising from the thoracic ganglia and rami communicantes, *r.c.*, belonging to dorsal nerves from the sixth to the ninth (or tenth). *Spl. min.* Small splanchnic nerve similarly arising from tenth and eleventh dorsal nerves. These both join the solar plexus and thence make their way to the alimentary canal. *c.r.* Nerves from the ganglia, etc., belonging to eleventh and twelfth dorsal and first and second lumbar nerves, proceeding to the inferior mesenteric ganglia (or plexus), *m. gl.*, and thence by the hypogastric nerve, *n. hyp.*, and the hypogastric plexus, *pl. hyp.*, to the circular muscles of the rectum. *l.r.* Nerves from the second and third sacral nerves, *S.*2, *S.*3 (nervi erigentes), proceeding by the hypogastric plexus to the longitudinal muscles of the rectum.

The *rhythmic movements* are caused by the contractions of the circular muscles over extensive portions of the intestine at the same time. By pressing upon the veins of the submucous plexus they force the blood into the superior mesenteric vein, and so aid in maintaining a circulation through the intestines. These movements differ from peristalsis in not being prevented by nicotin, indicating a purely muscular nature.

The intestines have a *double nerve-supply.* The fibres of the vagi carry chiefly *motor* impulses, while those of the sympathetic, chiefly *inhibitory* impulses. The intestinal movements are not altered by complete severance of all extrinsic fibres, so that the latter probably have only a regulatory influence. It is known that the movements may be influenced by psychical states, so that there are evidently connections with higher centres.

DEFECATION.

When the undigested food has reached the lower part of the large intestine and the rectum, sensory impulses pass to the brain from the latter, giving rise to a desire to defecate. The normal peristaltic movements of the rectum are increased, while voluntarily a deep breath is taken, the glottis is closed, and pressure is brought to bear upon the abdominal contents. The external sphincter ani is voluntarily relaxed, while the internal sphincter is inhibited. Both rectum and sphincters have a double nerve-supply, which in function are motor and inhibitory. It has been shown that section of the spinal cord of dogs in the lower thoracic region does not prevent normal defecation. The *centre* probably lies in the lumbar cord, but is connected with the brain so as to be under voluntary control.

MICTURITION.

The urine as it is formed in the kidney is periodically carried to the bladder by a peristaltic action of the ureters. Whether the peristalsis is due to the stimulus of the contained urine or whether the ureters are automatically rhythmic is not known. The urine is emptied into the bladder in a series of spurts, and is prevented from flowing through the urethra by the elasticity of the parts and perhaps also by a tonic contraction of the internal sphincter of the bladder. As it increases in amount and a desire to micturate arises, the sphincter of the urethra is voluntarily contracted to prevent the escape of urine, and the back-flow through the ureters is prevented by their oblique entrance. Micturition is *initiated voluntarily* by a relaxation of the sphincter urethræ. The walls of the bladder contract, driving the liquid out forcibly. This may be aided by a closure of the glottis and a contraction of the abdominal muscles. In the male the last portions are ejected in spurts by the contractions of the bulbocavernosus muscle. The *tone* of the bladder is continually undergoing changes, so that the pressure of the urine varies independently of the quantity present. This explains why a desire to micturate, if not satisfied, may pass off. The *centre* of micturition has been located in the lumbar portion of the cord, between the second and fifth lumbar spinal nerves. The bladder has a *double nerve-supply:*

1. From lumbar nerves passing through the inferior mesenteric ganglion and hypogastric nerves. Stimulation of these causes a feeble contraction.
2. From sacral spinal nerve-fibres contained in the nervus erigens. Stimulation of these causes a strong contraction.

PARTURITION.

This process is inaugurated by painless, rhythmical peristaltic waves that sweep over the upper segment of the uterus. These contractions increase in intensity and duration until they give pain, which is intensified by resistance ahead or may be absent altogether if the child is small and the canal large and free. The pain is at first confined to the uterus, but later spreads up into the abdomen and down into the thighs. Contractions in the human being involve only the upper portions of the uterus, the lower segment and cervix remaining passive. When the membrane which precedes the fœtus in its passage through the os uteri bursts, there is for a time a cessation of uterine contractions (owing to the considerable reduction in the bulk of the uterine contents), but they are soon renewed with increased vigor, aided by forcible contractions of the abdominal muscles and by forcible expirations with closed glottis. By these means the head of the fœtus is gradually pushed through the os into the vagina, followed by the more easily passing remainder of the body. After expulsion of the fœtus the contractions gradually diminish, becoming painless, and in about fifteen minutes the after-birth, consisting of placenta, amnion, chorion, decidua reflexa, and parts of the decidua vera appears. At this time the blood flows freely; the average loss, amounting to about 400 grammes, which can be and should be greatly reduced by a proper "following down"—*i. e.* intermittent massage—of the fundus. After parturition, by a process of involution lasting for several weeks, the uterus returns to its unimpregnated state. The entire process is a *reflex* act, the nervous *centre* being in the lumbar portion of the cord. The nerves reach the uterus in company with blood-vessels, and are derived from the pelvic plexus.

LOCOMOTOR MECHANISMS.

The two hundred or more bones of the body are joined together to form articulations of four types: *sutures*, *symphyses*, *syndesmoses*, and *diarthroses*.

A *suture* is formed when two bones gradually interlock immovably, leaving only a more or less distinct seam. The best examples are in the skull.

A *symphysis* is the union of two bones by fibrocartilage, as in the case of vertebræ. This allows a limited amount of movement.

A *syndesmosis* is a union of two bones by fibrous bands, which allows considerable movement as in the inferior tibiofibular articulation.

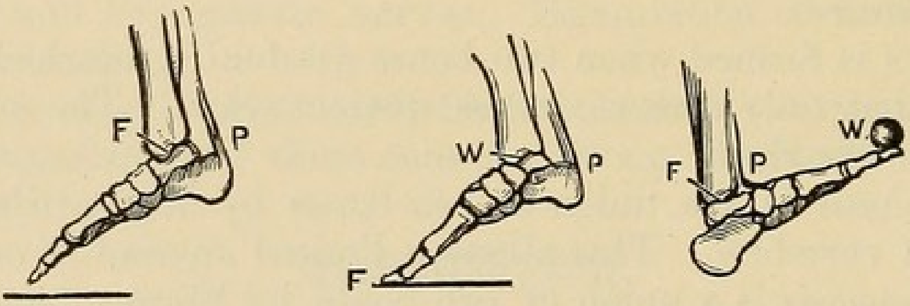
A *diarthrosis* is a union between two bones that allows the greatest movement, generally, however, only in a special direction. The parts in contact are lined with cartilage, and lubricated with a viscid synovial fluid. The union is made firm by guiding ligaments and fibrous capsules. In some cases, as in the head of the femur and acetabulum, the parts fit so well that they are kept in place, partially, at least, by atmospheric pressure.

The *movements between joints* may be: (1) *Angular*; (2) of *circumduction*; (3) of *rotation*; (4) *gliding*. In the first the angle between the long axis of the bones changes in value. In the second the longitudinal axis of the bone forms the sides of a cone whose apex is at the joint. In the third the bone moves about its longitudinal axis. In the fourth one bone slides over the other.

Many of the bones may be looked upon as levers, with the muscles attached as sources of power. *Levers* are divided into three classes, according to the relative position of the power, the weight to be moved, and the axis of motion or fulcrum. Different movements of the foot offer an illustration of the three kinds of levers. The *first* kind (Fig. 5), where the fulcrum (F) is between the source of power (P) and the weight of resistance (W), is shown when the foot is raised and the toe tapped upon the ground, the ankle-joint being the fulcrum. The *second* kind of lever, where W is between F and P, is illustrated when the body is raised upon the toes, which, resting upon the ground, are the fulcrum. The *third* kind of lever, where P is between F and W, is illustrated when a weight is held up by the toes, the ankle being the fulcrum and the anterior group of muscles of the leg the source of power.

Standing is a complex coördinated action in which the muscles are continually in play to keep the centre of gravity of the body

Fig. 5.



I II III

Illustration of levers of all three orders (Huxley): W. Weight of resistance. F. Fulcrum. P. Power.

over the base of support. In *walking* the centre of gravity is continually being put forward, but the body is kept from falling by the legs, which alternately move forward to sustain it. One foot or the other is continually on the ground. *Running* differs in that the body is more forcibly moved ahead by vigorous pushes. The body is more inclined, and both feet leave the ground at times.

VOICE.

The *larynx* is a closed cavity, except in its communications with the trachea below and the pharynx above. The walls are made up of cartilages, together with various muscles and membranes. Across the cavity in an anteroposterior direction are stretched the *vocal cords* by the vibration of which the voice is produced. Mere vibration of the cords held in a state of tension by muscular action produces in itself but a feeble sound. This is intensified by *reënforcement* of the vibrations by resonating cavities above and below the cords. It is necessary to consider three features of the voice—the *intensity*, the *pitch*, and the *quality*. The *intensity* depends upon the amplitude of vibrations of the cords. This is partly the result of their structure and partly of the energy with which the air passes between them. The *pitch* is determined by the thickness, tension, and length of the cords. The *quality* of the tone depends upon the character of the upper partial tones which are combined with the fundamental tone. These are varied by altering the shape and size of the buccal and nasal cavities. The voice is controlled by an exceedingly *complex nervous mechanism* of afferent and efferent fibres to various centres in the cerebral cortex. That relations between the hearing and speech centres, for instance, are very intimate is shown by the fact that dumbness is usually a defect of hearing which leaves the voice uncontrolled by the ear in pitch and quality. The pitch of the voice is elevated usually by the contraction of the crico-thyroid muscle, which stretches the vocal cords. There are numerous other methods of altering the pitch. Whenever there is a transition from one method to another, a break occurs in the musical scale. The range of voice between these breaks is known as a *register*. The lowest register is commonly designated as the *chest voice*, and the highest as the *head voice*. When a third division is made, it is by some called the *falsetto*. *Language* consists of short musical sounds produced by the vocal cords with other noises added by the mouth-parts, the whole being interrupted by different methods of obstruction. In *whispering* the musical component is greatly replaced by noisy vibrations.

QUESTIONS ON CHAPTER IV.

What is the function of the jaws and the teeth?
Give action of the muscles concerned in mastication.
What purpose do the tongue and cheeks serve?
Into what stages is deglutition divided?
Describe each stage in detail.
How does the deglutition of liquids differ from that of solids?
How long does it take food to pass from the pharynx to the stomach?
Is swallowing reflex or voluntary?
What is the effect of sectioning the œsophagus on peristalsis?
Give the nervous mechanism of deglutition.
Describe the movements of the stomach.
What is the function of the fundic end of the stomach?

Give the nerve-supply to the stomach and its function.
Describe vomiting. Is it a reflex act?
What experiment shows that food is ejected from the stomach mainly by abdominal muscles?
Give the nerves involved in vomiting.
Explain the movements of the intestines.
What is antiperistalsis?
What is the proof that normal peristalsis is due to a nervous mechanism?
What are the differences between the peristaltic and the rhythmic movements of the intestine?
How do rhythmic movements aid the circulation?
Discuss the nervous mechanism of the intestines.
Describe defecation. Give nerve-supply and locate centre.
Describe micturition.
Explain why a desire to micturate may pass off.
Locate centre and give nerve-supply involved in micturition.
Describe parturition.
What forms the after-birth?
How much blood is lost during parturition? Is this essential?
Give source of nerve-supply and locate centre involved in parturition.
Name the types of articulations between bones.
Define each type.
What kinds of movements may take place between joints?
Describe the three kinds of levers formed by bones.
Define standing, walking, and running.
How is the voice produced?
Define pitch, intensity, and quality of voice.
What is the relation of the centre of speech to other centres of the cerebral cortex?
What constitutes a register?
Define head voice, chest voice, and falsetto.
Define language. Define whispering.

CHAPTER V.

ABSORPTION.

General Principles.—When food in the intestinal canal has undergone its digestive changes, it is absorbed. The alimentary canal from œsophagus to rectum consists of a single layer of columnar epithelial cells placed on a basement membrane. The soluble diffusible constituents of the food on one side and the blood on the other side seem to offer favorable conditions for filtration and osmosis. But it has been proved that the *activity* of the *epithelial cells* is an important factor in absorption.

1. Substances are absorbed from the intestine having the same, less, or greater osmotic tension.

2. Sugar and peptones, which are less diffusible than sodium sulphate, are absorbed more rapidly.

3. Non-dializable substances like egg-albumen may be absorbed.

4. Some substances like peptone are changed in their passage through the intestinal wall.

There are *two paths* which absorbed products may take: they may pass directly into the blood of the capillaries and so into the portal system, in which case they are taken to the liver, or they may pass into the lacteals of the lymphatic system, forming chyle. In this case they pass through the thoracic duct to enter the general circulation at the junction of the left internal jugular and subclavian veins. *It will, therefore, be noted that the blood is the final objective point by each path.*

ABSORPTION FROM THE STOMACH.

The absorption of substances from the stomach is not very marked. Sugars, peptones, and proteoses may be absorbed with difficulty. The same is true of water, which is usually rapidly passed into the duodenum. Alcohol is absorbed more rapidly, salts slowly, and fats not at all. Some salts like sodium iodide are not absorbed at all in dilute solutions, but when the concentration of the solution reaches 3 per cent., absorption becomes pronounced. Normally, salts never reach this degree of concentration. It has been found that the absorption of sodium iodide is greatly increased by mustard, pepper, and alcohol, which act either by congesting the mucous membrane or by stimulating the epithelial cells to greater activity.

ABSORPTION FROM THE SMALL INTESTINE.

The food in its passage along the intestine moves slowly, requiring from nine to twenty-three hours after ingestion to appear at the end of the *small* intestine. The latter, moreover, presents a vast surface for absorption by reason of the *villi* and the *valvulæ conniventes.* Both of these conditions favor absorption. As a matter of fact, 85 per cent. of the proteid has been found to disappear. That *proteoses* and *peptones* are absorbed directly by the blood is shown in ligating the thoracic duct, which does not interfere with their disappearance. Nevertheless they do not appear in the blood as such, and if present, act as poisonous bodies which cannot be used by the tissues and are immediately excreted by the kidneys. It is probable that the epithelial cells convert them into *serum albumin*. *Carbohydrates* which are changed to diffusible sugars, dextrose, and levulose are also absorbed directly into the blood, and the portal vein has been found to show an increased percentage of sugar after meals. The lymph of the thoracic duct shows no such increase unless excessive quantities have been taken.

Fats, it is conceivable, may be absorbed in an emulsified condition or as glycerine, fatty acids, and soaps. Experimentally it has been found that the greater part of the fat (60 per cent.) is passed through the epithelial cells and through the stroma of the villi to the central lacteal, which is the beginning of the thoracic duct. The remainder, however, remains unaccounted for and may be absorbed by the blood as fatty acid and glycerine. There is very likely a *synthesis* of the latter substances in the body of the epithelial cells into neutral fat. The absorption of *water* and *salts* by the small intestine is very active, but there is also a secretion of water into the intestinal lumen, so that the contents remain of the same fluid consistency. Water and salts are absorbed directly by the blood unless excessive quantities are taken, when a portion passes through the lymphatic system, accelerating the rate of flow of the chyle.

ABSORPTION FROM THE LARGE INTESTINE.

The absorption from this part of the alimentary canal is considerable, as is shown by the changes in its contents, which, entering the ileocæcal valve in a fluid state, are converted into solid fæces. Of the 15 per cent. proteid present, some is absorbed and some is destroyed by bacterial action. *The results obtained from nutrient enemata consisting of egg-albumen, salt, and milk-fat, show the absorbing capacity of the large intestine.* Animals may be kept alive by this method of nourishment, although no enzymes are present to digest the food.

QUESTIONS ON CHAPTER V.

What conditions are present in the alimentary canal that favor filtration and osmosis?

Give proofs that epithelial cells are active during absorption.

What paths may absorbed products take in their passage into the blood?
Discuss the absorption that takes place in the stomach.
What conditions in the small intestine favor absorption?
What is the path taken by absorbed proteid?
In what form do proteids appear in the blood?
Where are they changed?
What is the fate of peptones and proteoses injected into the blood?
Give the path taken by absorbed carbohydrates.
How are fats absorbed?
Trace the path of fats from the intestinal lumen into the blood.
Discuss the absorption of water in the small intestine.
What paths do water and salts take in absorption?
Discuss the absorption that takes place from the large intestine.
What change in the consistency of the contents of large and small intestine is brought about by absorption?

CHAPTER VI.

METABOLISM.

HAVING traced the food to its reception in the blood, it will be proper to consider the facts that are known concerning its further history. The food-stuffs are rapidly taken to all portions of the body, and in the capillaries are transferred through their walls to the lymph, which in turn brings them into intimate contact with the tissue-cells. Each cell extracts from the lymph the substances that it needs for its nourishment. Then, under the influence of living matter, they undergo a series of changes, *anabolic* and *katabolic* in nature, which converts them finally to simple stable bodies possessing little energy. This is shown in the following tables. During twenty-four hours there are taken into the body:

Food (chemically dry)	16 ounces.
Water (as drink and as combined with solid food)	80 "
Oxygen (absorbed by lungs)	26 "
Total	122 ounces.

These substances are converted to relatively simple bodies, and leave through the ordinary excretory channels—lungs, skin, kidneys, and intestines.

From the lungs there are exhaled every twenty-four hours—

Of carbonic acid, about	30 ounces,	
Of water	10 "	40 ounces.
Traces of organic matter.		
From the skin—		
Water	23 ounces,	
Solid and gaseous matter	1 ounce.	24 "
From the kidneys—		
Water	50 ounces,	
Organic matter	$1\frac{1}{2}$ "	
Minerals and salines	$\frac{1}{2}$ ounce.	52 "
From the intestines—		
Water	4 ounces,	
Various organic and mineral substances	2 "	6 "
Total		122 ounces.

The income and expenditures of the *normal adult* body balance each other.

ENERGY OF FOOD.

The law of the *conservation of energy* teaches that the sum-total of energy of the universe is constant, and that it can be neither created nor destroyed, or, in other terms, increased or diminished. This law is as rigorously true for the body as for any physical system, so that the manifestations of living bodies must be the transformations of energy brought to them in some form or other. Of all the sources of energy to the body, the chemical energy of the food is the most important. It is in a potential form, and appears in kinetic form as *heat, electricity,* and *mechanical work.* By far the greatest amount appears as heat. An adult man in the course of twenty-four hours will liberate about 2,400,000 calories of heat—a *calorie* being equal to the amount of heat which is required to raise one cubic centimetre of water one degree Centigrade.

Since the energy of food-stuffs is set free by their physiological oxidation, it is obvious from the standpoint of the doctrine of the conservation of energy that it may be measured by burning the food-stuffs outside of the body. This is done by means of a *calorimeter*, and the number of calories of heat obtained is known as the *combustion equivalent.* This, in round numbers for proteids, has been found to be 4100 calories; for fats, 9300 calories; and for carbohydrates, 4100 calories. These food-stuffs, as far as their potential energy is concerned, are interchangeable, so that if carbohydrates are to take the place of fats, they must be furnished in the ratio of 9300 : 4100 or as 2.2 : 1. In other words, it takes more than twice as much carbohydrate material to render the same energy as any given amount of fat. This ratio of 1 : 2.2 is known as the *isodynamic equivalent.*

The energy produced by the body in twenty-four hours may be measured as heat in two ways:

1. It may be measured directly by placing the animal in a calorimeter.

2. It may be obtained by feeding on a given diet, determining from the excreta the amount of food destroyed, and multiplying by the proper combustion equivalent. These methods are known respectively as *direct* and *indirect calorimetry.* The nutritional value of food-stuffs cannot be estimated from their contained energy alone, and it is necessary to follow the changes they undergo in their metabolism as far as it is possible.

Proteid is taken by the blood to the tissues, and under the influence of living matter is oxidized to *carbon dioxide, water, urea, sulphates,* and *phosphates.* It is believed that a part of the proteid is built up into the structure of living matter and is designated as *tissue proteid,* while the other part is simply destroyed and is called *circulating proteid.* These terms do not imply that there are two varieties of proteid, but refer only to their ultimate fate. Any given proteid may fulfil either function. Since living matter is essentially nitrogenous in its composition, it must have some source of nitrogen. This it finds in proteid food-stuffs, which consequently are absolutely necessary to life. No animal can live for any length of time on fat and carbohydrate food alone, but these are, nevertheless, used and broken down in the body to furnish energy. The amount of proteid destroyed during any given time is indicated by the amount of nitrogen in the various excreta, and can easily be determined by *Kjeldahl's method.*

Place 5 c.c. of the substance to be tested in a Kjeldahl flask, and add 15 c.c. of sulphuric acid and ¼ gramme of copper sulphate and heat until foaming ceases. Then add 10 grammes of potassium sulphate, and finally a little potassium permanganate, continuing the boiling until the liquid is light-green in color. Allow to cool, and transfer the contents to an Erlenmeyer flask, adding about 500 c.c. of water. Add also a little talc on the point of a knife. Insert into the neck of the flask a thistle tube and Reitmaier bulb. Connect the latter with a condenser. In the receiving flask place 50 c.c. of decinormal oxalic acid solution, which will unite with the ammonia that is to be distilled off. When everything is ready, put into the flask strong sodium hydrate until the contents are alkaline; then heat and distil over about 200 c.c. of the liquid. Add to the distillate a few drops of an alcoholic solution of rosolic acid, and titrate with decinormal sodium hydrate solution to a deep pink color. When the nitrogen of the excreta equals the amount ingested as food, an animal is said to be in *nitrogenous equilibrium.* Likewise *carbon equilibrium* is a condition in which the total carbon of the excreta (CO_2, urea, etc.) is equal to that taken in the food. When, from the total carbon, there is subtracted the amount that belonged to proteids broken down, the remainder is an indication of the carbohydrates and fats that were used. An animal may be in both nitrogen and carbon equilibrium at the same time, or may be in either alone. If an animal is giving off more nitrogen in the excreta than it receives in the food, it must be losing the proteid of its body and so losing in weight, but if the nitrogen given off is less than that of the food, the animal must be storing up proteid and gaining in weight.

It would seem that if proteid fulfils two functions, enough might be given to an animal to cover the tissue waste and the balance of the food might be given as energy producing fats and carbohydrates, and still maintain nitrogen equilibrium. This is not the case, however. It requires more proteid than is theoretically necessary. *Part of it is always used as circulating proteid which carbohydrates cannot replace.* The fact that proteids are always taken in excess of what is necessary to just cover tissue waste has led to the designation of the excess as a *luxus consumption.* This is an inappropriate term, since animals which only receive enough nitrogen to cover tissue waste show nutritional disturbances for the reasons already given.

Albuminoids resemble proteids in percentage composition, but cannot be used to maintain nitrogen equilibrium nor for the formation of new tissue. They serve, however, as a source of energy, and can take the place of circulating proteids. The value of albuminoids as a food is limited because of the aversion that its continued use produces.

Carbohydrates are oxidized and furnish energy. They may be converted into fat, and stored as reserve material. Of the end-products, CO_2 and H_2O, the latter obtains its oxygen from the carbohydrate molecule, so that only enough additional oxygen is required to oxidize the carbon. The *respiratory quotient*, $\frac{CO_2}{O_2}\left(\frac{\text{carbonic acid}}{\text{oxygen}}\right)$, therefore approaches unity as the carbohydrates in the meal are increased. These food-stuffs, like proteids, are first split before undergoing oxidation. Dextrose in its passage through the liver is converted to *animal starch* or *glycogen*. It may be detected by the port-wine-red color which it gives with iodine. Microscopically, it can be seen to disappear during fasting and to increase after meals. The amount formed depends upon the character and quantity of the food, exercise, temperature, etc. It forms from 1.5 to 4 per cent. of the weight of the liver, and may be increased to 10 per cent. by a rich carbohydrate diet. Glycogen may also be produced from purely proteid food, but not from fats. It seems that the proteid molecule is split into a nitrogenous and a non-nitrogenous portion, and that the latter forms glycogen. Glycogen performs a useful function as a *temporary reserve store*, for, if the dextrose formed during digestion be passed directly into the general circulation, the percentage of sugar would be increased at too rapid a rate and would then be excreted by the kidneys. It is, therefore, stored up by the liver as glycogen, and from time to time, as the demand arises, is reconverted to dextrose and secreted into the blood, so that the sugar in the latter remains nearly constant (0.1 to 0.2 per cent.). It is found that after the liver is removed from the body its supply of glycogen quickly disappears, and dextrose is found instead. In this connection it is interesting to know that extracts of the liver yield an amylolytic enzyme which converts glycogen into dextrose. The dextrose that the liver gives to the blood is taken to the tissues, and in time is oxidized. It may, however, again be *stored in the muscles* as glycogen. These contain, when at rest, 0.5 to 0.9 per cent., and in the entire muscular system there is as much as is present in the liver. When a muscle is active, its store of glycogen quickly disappears. It has been shown that an isolated muscle when irrigated with blood containing dextrose can form glycogen; also that an active muscle will take up more sugar from an artificial supply of blood than a resting muscle.

Fats which reach the circulation as neutral fats are taken to the tissues, and in time are converted to CO_2 and H_2O. They contain more available energy, weight for weight, than carbohydrates. The body fat, particularly that of the *panniculus adiposus,* is a reserve supply, and is drawn upon whenever the need arises. The *origin of fat* was at first supposed to be simply that which was taken in as food, but the history of fat as seen microscopically showed that it was not simply deposited, and it was soon demonstrated that in cows and pigs an amount of fat might be formed out of all proportion to the amount ingested. In addition to this it was found that the fat of an animal differed in kind from that which was taken in as food. It has been definitely decided that only under special conditions, as when an animal is richly supplied with fats, are the latter stored directly. Usually the fat of the food is completely oxidized, and that which is stored is derived from carbohydrates and proteids. The latter is an important source; the theoretical maximum that it can yield is about 51.5 per cent. It has been shown that in a young pig the amount of fat laid on in a given time was greater than that obtained from the food directly, plus the theoretical maximum obtainable from proteids, so that it must have come from the ingested carbohydrate food. *It is of interest that the Banting diet for reducing obesity is characterized by the absence of carbohydrates and the excess of proteids.*

Water is lost through the skin, lungs, kidneys, and fæces. It is replaced in the food as such, and also as part of the structure of food-stuffs. *It is not a source of energy, but serves as a menstruum in which metabolism takes place.* Deprivation by changing the composition of the tissues leads to death.

Salts.—Sodium chloride is the only salt usually taken deliberately with the rest of the foods. *Salts are not a source of energy, and most of them are eliminated as they are taken in.* Sodium chloride in the formation of the acid of the gastric juice is an exception. Some of the sulphates and phosphates are formed in the body. The general function of salts is to preserve imbibition relations. Diets which are entirely lacking in saline constituents fail to preserve life at all, even when they are present in proper amount and kind separately—so that they seem to be ordinarily in organic combination with food-stuffs. *Carnivora do not crave salts as herbivora do.* This is explained by Bunge as being the result of the fact that plants contain an excess of potassium salts, which react with sodium chloride to form potassium chloride and a corresponding sodium salt, which are excreted by the kidneys when they reach above a normal limit. The following uses of *calcium salts* have been given:

1. They are necessary to the development of the bones, as a diet poor in calcium salts brings about a condition similar to rickets in children.

2. They are necessary to the coagulation of blood, lymph, and milk.

3. They are necessary to the rhythmic activity of the heart and to the normal activity of all protoplasm.

The calcium acquired and lost by the body normally is very small in amount, and is excreted mainly through the intestinal walls. The main portion of the calcium of the fæces, however, is that ingested with the food, and simply passes through the canal. It is probable that the calcium, in order to be absorbed, must be in organic combination. The *salts of iron* are of importance in their relation to hæmoglobin, which, being continually lost, must be replaced. Most of the iron of the food, including that of the hæmoglobin of meats, is passed out unchanged in the fæces, and to this is added a slight excretion of iron from the intestinal walls. The iron absorbed by the system is probably in the form of organic compounds.

DETERMINATION OF METABOLISM.

In determining body-metabolism the nitrogen of the excreta is multiplied by 6.25 to give the amount of proteid destroyed. The value 6.25 is obtained from the proportion—proteid molecule: nitrogen contained : : 100 : 16. It has been ascertained by numerous analyses that on an average the nitrogen forms about 16 per cent. of the proteid molecule. The metabolism of the body varies greatly with its condition. It has long been known that muscular work increases metabolism, and since the latter involves living matter, which is essentially nitrogenous, it was thought that there must be a simultaneous increase in the output of urea. But numerous experiments have shown that this is not usually the case.

During severe labor, however, upon a diet insufficient in carbohydrates and fats, the proteids of the body are drawn upon to furnish energy, and there is then an increase in the excretion of urea. The carbon dioxide is markedly increased by muscular activity, in intact organisms as well as in isolated muscles. Since nitrogenous components are not used up, the energy must come from non-nitrogenous food-stuffs, or from non-nitrogenous portions of the biogen. During sleep the excretion of urea is not diminished, but that of carbon dioxide is distinctly. In general the consumption of non-nitrogenous material increases with the fall of the outside temperature, providing that of the body remains constant, therefore while the excretion of carbon dioxide increases, that of urea is unchanged. In pathological cases with an excessively high or low body-temperature, the metabolism of both proteid and non-proteid is changed. High temperatures increase, and low temperatures decrease, the output of waste matters. In *starvation* an animal uses its reserve material, and then lives on its own tissues. During the first day or two of starvation the quantity of proteid destroyed is greater than on subsequent days, when the circulating proteids have been destroyed and only tissue-proteids and non-proteids remain. After the latter substances have disappeared, shortly before death, there is an increased excretion of urea, for the animal is then entirely dependent upon tissue proteids alone. In starvation the various tissues and organs are differently affected. Muscles suffer most absolutely, and fats most relatively, while organs in continuous activity, like the heart and central nervous system, lose practically nothing.

QUESTIONS ON CHAPTER VI.

How do the food-stuffs reach the tissue-cells?
Define "conservation of energy."
Does the law of the conservation of energy hold true for the body?
What is the source of energy of the body?
Into what forms of energy does the body convert the energy of the foods?
How much heat is given off by the body per day?
Define a calorie.
Discuss the "combustion equivalent" of foods.
How is the combustion equivalent obtained?
Into what simple bodies are proteids converted by the body?
Give the combustion equivalent of proteids, carbohydrates, and fats.
Discuss the isodynamic equivalent of fats to carbohydrates.
Discuss circulating and tissue proteids.
Why is proteid necessary to the animal economy?

Give the method of the determination of total nitrogen.
What is meant by nitrogen and carbon equilibrium?
How are the destroyed carbohydrates determined?
Discuss "luxus consumption."
What is the nutritive value of albuminoids?
Into what simple substances are carbohydrates converted?
What happens to the respiratory quotient as the result of a carbohydrate diet?
Are the various food-stuffs directly oxidized?
Give the history of glycogen.
Give the quantity of glycogen in liver and muscle.
What is the percentage of dextrose in the blood?
Into what simple bodies are fats changed?
What are the function and the origin of the body-fat?
Give proofs as to the origin of fat.
What values have water and salts to the animal?
What salt especially undergoes a change in the body?
Why do herbivora crave salts?
What are the sources of the salts of the body?
What are the uses of calcium salts?
How is the amount of proteid broken down by an animal determined from the nitrogen of the excreta?
How is metabolism varied under different conditions?
Is the excretion of urea increased by muscular work? Is the excretion of CO_2 increased?
Give changes in metabolism during starvation.
How are the different organs affected by starvation?

CHAPTER VII.

BLOOD AND LYMPH.

BLOOD.

THE blood, a chemically complex fluid contained within the vessels of the body, has been recognized from the earliest times as indispensable to the life of man. An *excessive hemorrhage* prostrates, enfeebles, and may cause death. This becomes evident when it is known that the blood carries to the tissues *material* for their *growth* and *repair*, and removes from them *matters* that have become *effete*. It equalizes the *temperature* of the body, and maintains uniform *imbibition relations* between the *cells*. It is an *internal medium* that bears the same relations to the *tissues* that the *outer world* does to the *entire body*. It forms in total nearly one-thirteenth of the *body-weight*, so that a man of *170 pounds* will possess over *13 pounds* of blood, or nearly *6 quarts*. In given individuals it does not vary through any wide limits. *Variations* that are brought about by *loss* of *water* as by *perspiration* or by a *gain* of *water*, as through the *ingestion* of excessive quantities of water, are *compensated* for by a passage of fluid from or to the tissues. In starvation the quantity and the quality of the blood are maintained at the expense of the other tissues. An *estimation* of the *amount* of blood of an animal is made by measuring directly as much as will escape from the vessels. The latter are then washed out with normal saline solution, and the tint of the washing is *matched* by diluting a given quantity of normal blood. This *process* is repeated after carefully *mincing* the entire body. The blood in the washings may be calculated by knowing the dilution of normal blood required to match it. This, added to the amount measured directly, gives the total quantity. It is distributed in the body as follows:

One-fourth in the heart, lungs, large arteries, and veins.
One-fourth in the liver.
One-fourth in the skeletal muscles.
One-fourth in the remainder of the body.

The blood consists of a fluid *plasma* (*liquor sanguinis*), in which are suspended cells called *blood-corpuscles. It may be regarded as a tissue of which the intercellular matrix is a fluid.* Freshly drawn, it is of a bright *scarlet* color when taken from the arteries or pulmonary veins, but *crimson* when taken from the systemic veins. This is the result of different *oxidation* stages of the pigment *hæmoglobin*, which is contained in the red corpuscles. The blood is *opaque*, caused by the fact that its solid elements *oppose* the *transmission* of *light* by *reflecting* it back from their surfaces. In various ways, as by the addition of ether, bile, excess of water, by freezing and thawing, etc., the coloring-matter may be driven from the corpuscles into solution in the plasma, leaving a delicate, *colorless cell-body*, through which the light passes readily. The blood is then *transparent*, and is known as *laky blood*. The *specific gravity* varies from *1041* to *1067*, according to age, sex, state of health, meals, exercise, and sleep. Its slightly *alkaline* reaction is due to the *phosphates* and *carbonates* of the *alkaline metals.* Estimated as sodium carbonate, it is equal to 0.35 per cent. Ordinary litmus-paper cannot be used in testing the reaction of the blood, owing to the fact that it stains. Soaking in saturated salt solution covers the paper with a layer of salt that holds the corpuscles, and which may then readily be washed off. *It never becomes acid.* Blood has a salty *taste*, and a peculiar, characteristic *odor*. The *temperature* is about 98.9° F., but probably is higher in the internal parts of the body.

Corpuscles.

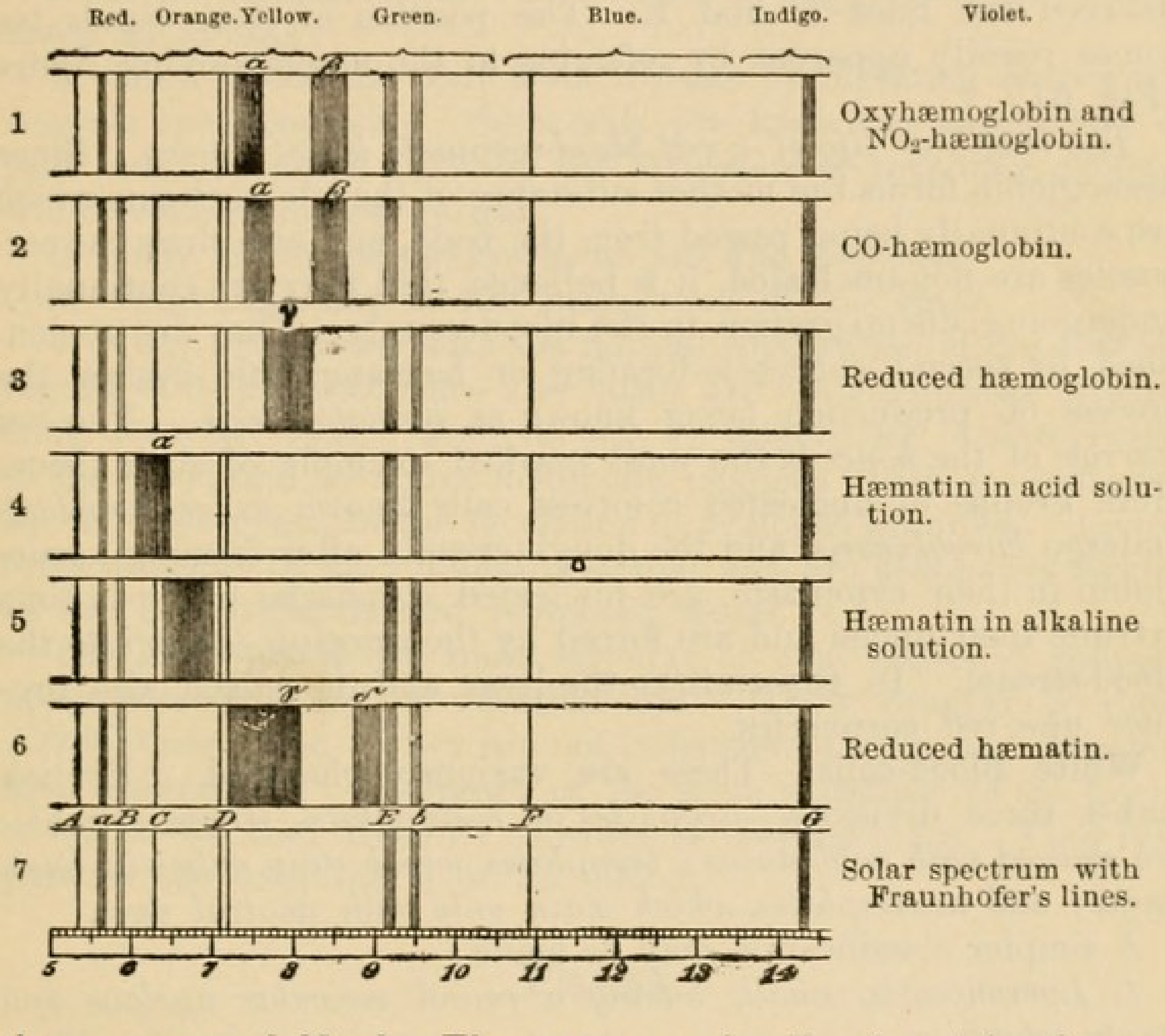
The corpuscles of the blood are of at least three kinds—*red corpuscles* (*erythrocytes*), *white corpuscles* (*leucocytes*), and *blood-plates* (*microcytes*). The **red cells** may be put at 5,000,000 per c.mm. for males, and at 4,500,000 for females, as an average number. Their number varies with the constitution, nutrition, manner of living, and age of the individual. They are most numerous in the embryo and young. In the adult their number is at a *minimum* after meals; it is *increased* during menstruation, and decreased during pregnancy. *Change of altitude* has been found to exert a most remarkable influence. A mountain life has been found to raise the average number to 8,000,000, and to increase the contained hæmoglobin as well. A return to a lower level brings back the blood to its normal state. A diminished *pressure of oxygen* in the blood, whether produced by high altitudes or by the actual loss of blood, stimulates to greater *activity* the *tissues* that form new corpuscles.

When viewed under the microscope *individually*, each corpuscle is of a *faint yellowish* color. Each consists of an extensible, protoplasmic material known as *stroma*, which gives shape to the corpuscle and holds the hæmoglobin. The latter, forming 90 per cent. of the solid matter of the corpuscle, is held in some weak chemical combination with the stroma, since its behavior within the corpuscle differs from that when separate.

Hæmoglobin is a member of the group of combined proteids. It may be separated in various ways into a proteid body, *globin* (96 per cent.), and a simpler pigment, *hæmatin* (4 per cent.), together with other bodies whose nature is unknown. If the decomposition takes place in the absence of oxygen, *hæmochromogen* is formed instead of hæmatin. It is the hæmochromogen that gives to hæmoglobin its peculiar power of taking up *oxygen* into loose chemical combination. *There are 14 grammes of hæmoglobin to every 100 grammes of blood, so that a man weighing 68 kilos has 750 grammes of hæmoglobin distributed among 25 trillions of cor-*

puscles, giving a superficial area of about 3200 square metres. This is important from a *respiratory* point of view, as the entire surface is practically exposed to the *absorption* of oxygen. Hæmoglobin will take 1.59 c.c. of oxygen to each gramme weight, and form in so doing a compound known as *oxyhæmoglobin.* The latter, if placed in an atmosphere which is *deficient* in *oxygen,* will be converted by the loss of oxygen to *reduced hæmoglobin.* Hæmoglobin has the power of combining with a number of other gases. With *carbon monoxide* it unites in the proportions of one volume to one of hæmoglobin, forming *carbomonoxide-hæmoglobin,* which is more stable than oxyhæmoglobin, so that it is not easily converted into ordinary hæmoglobin. *This explains the fatal effects produced by breathing illuminating gas, which contains carbon monoxide as a constituent.* The oxygen of the air is prevented from uniting with hæmoglobin and thus produces asphyxia. *Nitric oxide* (NO) produces a still more stable combination. Carbon dioxide (CO_2), however, which in its reaction with hæmoglobin produces *carbohæmoglobin,* unites with a different part of the hæmoglobin molecule since it does not interfere with the absorption of oxygen. *Thus is explained the action of this gas as an anæsthetic.* It has been suggested that the carbon dioxide unites with the proteid portion, and it makes possible the transportation of carbon dioxide by hæmoglobin from the tissues, where it is given off as a waste-product to the lungs, where it is removed from the body. The most characteristic feature of hæmoglobin is the presence of *iron,* which amounts to about 0.47 per cent., so that an estimation of the iron of the blood would be a method of determining the amount of hæmoglobin. This element remains a part of hæmatin when hæmoglobin is decomposed, and upon it depends the affinity of hæmoglobin for oxygen. One atom of iron will take up one molecule of oxygen. Both *oxy-* and *reduced hæmoglobin* are *crystallizable.* A good method is to shake the blood in a test-tube until it becomes laky, and then place it on ice until the crystals form. They have different forms in different animals—for example, those of man and most mammalia are *rhombic prisms;* of the squirrel, rhombic plates; and those of the guinea-pig, tetrahedra. These crystals are soluble in water, but do not dialize. Hæmatin unites with hydrochloric acid (HCl) to form *hæmin,* the crystals of which are of the greatest importance in the *identification of blood-stains.* Scrapings from the stain are placed on a glass slide, and a drop of a 1 per cent. solution of sodium chloride ($NaCl$) is added. Heat over a gentle flame, avoiding ebullition until the water has nearly evaporated. Then quickly add one or two drops of glacial acetic acid, cover with a cover-glass, and again warm until the acid has nearly disappeared. When cool, microscopic, characteristic, brown *crystals* are deposited. Together with the *spectroscopic test* they indicate positively

FIG. 6.



the presence of *blood.* The presence of cells of certain size and non-nucleated ones will exclude the blood of certain animals, but it is not sufficient evidence of human blood. *Mammals have non-nucleated cells.*

Solutions of hæmoglobin and compounds derived from it give characteristic absorption bands. The spectrum of a dilute solution of oxyhæmoglobin shows two dark bands, both between the lines D and E. That nearer the red end of the spectrum, or *alpha band* as it is called, is darker, narrower, and more distinct than the other or *beta band.* The distinctness and width of the band vary with the density of the solution. With very dilute solutions only a faint alpha band is present; with stronger solutions the bands grow wider, fuse, and finally shut off all light. The orange is the last to disappear. If a solution of oxyhæmoglobin is converted to reduced hæmoglobin by the addition of *Stokes' reagent* (an ammoniacal solution of a ferrous salt), only one absorption band is seen, called the *gamma band,* which lies between the lines D and E. The position of these bands becomes readily apparent by referring to the accompanying figure (Fig. 6).

The length of life of a red blood-corpuscle is not known. Since hæmoglobin forms the mother substance of the bile-pigments which are continually being passed from the body, and also since the corpuscles are non-nucleated, it is believed that they are continually undergoing disintegration in the blood-vessels. They are replenished by special corpuscle-forming or hæmatopoietic tissues, the process of production being known as *hæmatopoiesis.* The *red marrow* of the *bones* is the most marked example of such tissue. Here groups of nucleated colorless cells known as *erythroblasts* undergo *karyokinesis,* and the daughter-cells, after forming hæmoglobin in their cytoplasm, are nucleated corpuscles which in time extrude their nuclei and are forced by the growing tissue into the blood-stream. In the embryo the liver and the spleen also produce new red corpuscles.

White Blood-cells.—These are variously classified. Ehrlich makes three divisions—*oxyphiles* or *eosinophiles, whose granules are stained with acid stains; basophiles, which stain only with basic stains;* and *neutrophiles, which stain only with neutral dyes.*

A simpler classification may be made:

1. Lymphocytes, small, having a round vesicular nucleus and scanty cytoplasm.

2. Mononuclear leucocytes, large, having a vesicular nucleus and abundant cytoplasm.

3. Polynuclear leucocytes, large, with nucleus divided into lobes or into distinct parts.

4. Eosinophile cells, like the last, but with cytoplasm filled with coarse granules.

It is possible that the members of the last classification may be progressive stages in the growth of a single kind of cell, the lymphocyte forming the youngest, while the polynuclear cell forms the oldest stage. Leucocytes show amœboid movements which enables them to move from place to place (therefore called *wandering cells*), and even to pierce the walls of the blood-vessels and get into the lymph-spaces. This process is known as *diapedesis.* Their number is put at about 7500 per c.mm. A marked increase in number (*leucocytosis*) is seen in leukæmia.

Function of Leucocytes.—A number of suggestions have been made as to this:

1. They *protect* the body from *disease* by ingesting pathogenic *bacteria* (phagocytosis). Such cells are known as *phagocytes;* or they may *guard* the body by the formation of *protective proteids* which destroy disease-germs.

2. They aid in the *absorption* of *fats* and *peptones.*

3. They take part in the *coagulation* of the *blood.*

4. They help to *maintain* the normal *composition* of the *blood* in regard to its *proteids,* since the latter are not all formed directly from absorbed food. They do this by undergoing disintegration in the blood and by active metabolic changes which are indicated by their cytoplasm in the formation of zymogen granules. Leucocytes multiply by karyokinetic division, and are also newly formed in the lymph-glands and lymphoid tissue.

The **blood-plates** are small circular or oval bodies of homogeneous structure and of variable size. Their number is about 250,000 per c.mm. They are not independent cells, and therefore soon disintegrate. Composed of the same substance as the nuclei of leucocytes, they are often regarded as nothing more. They take part in the coagulation of the blood.

Plasma.

The plasma, which is an *alkaline, viscid, straw-colored fluid* of a *specific gravity* of 1030, may be obtained in a number of ways: The blood may be *cooled,* in which case *coagulation* takes place *slowly* and the corpuscles have time gradually to sink to the bottom of the vessel. The corpuscles having a specific gravity of 1088 are the heaviest components of the blood. When blood is received directly into neutral salt solutions, as *sodium* or *magnesium sulphate,* it will not clot. The corpuscles may then be allowed to sink, or they may be centrifugalized off. The method of action of the salt is not known.

Peptones and *albumoses,* when injected into an animal, will prevent the clotting of its blood for a long time. But peptone added to blood already shed has no such effect. The action of the peptone in the body is explained in that it causes a rapid destruction of leucocytes. This sets free two substances—a *nucleoproteid* and *histon.* The first takes part in the formation of *fibrin ferment,* which is destroyed by the liver, while the second, which is known to be antagonistic to the coagulation of the blood, is left in the blood-vessels. The addition of *oxalate solutions* by precipitating the soluble calcium salts will prevent coagulation.

Plasma consists of water, at least three kinds of simple proteids, combined proteids, extractives, and salts. The simple proteids are *serum-albumin*, *serum-globulin*, and *fibrinogen.* The *serum-albumin* is separated from the other two by saturation with magnesium sulphate, which leaves it in solution, while it precipitates the globulins. It may be brought down in a neutral or acid medium by heat, which gives three different coagulations: at 73°, 77°, and 84° C. respectively, indicating three kinds of serum-albumin. In man it forms about 4.52 per cent. of the solids. Its source is the absorbed food-stuffs. *Serum-globulin* (*paraglobulin*) is coagulated at 75° C. In man it forms about 3.1 per cent. of the solids present, and is more abundant in serum than in plasma, on account of the disintegration of the white blood-corpuscles, which takes place during coagulation. Whether this is its sole source is not known.

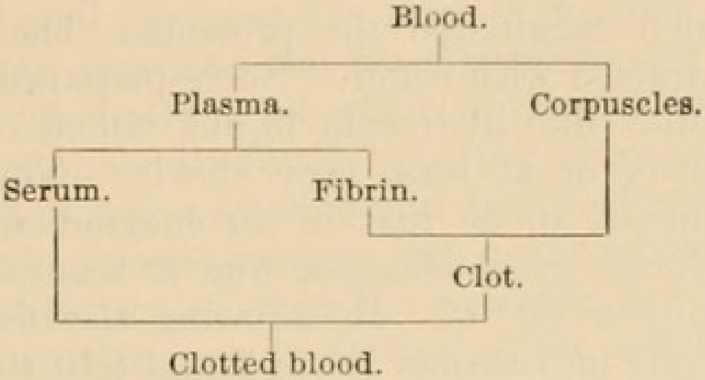
Fibrinogen is another globulin coagulating at from 56° to 60° C. It is present in human blood to the extent of 0.22 to 0.4 per cent. Its nutritive value to the body and its source are unknown. It is indispensable to the coagulation of the blood.

Combined Proteids.—These are *hæmoglobin* and *nucleo-albumins.*

Extractives.—Such include substances like fats, sugar, urea, lecithin, cholesterin, and gases.

Inorganic Salts.—These are peculiar in their distribution, inasmuch as the plasma contains an excess of sodium salts while the corpuscles contain an excess of potassium salts.

Coagulation or Clotting.—After the blood has escaped from the vessels of the body it exhibits its most peculiar property—that of *clotting.* If the blood is caught in a beaker, it is at first perfectly fluid, but soon becomes viscous and sets into a jelly. As the clot shrinks in size it presses out a clear, faint-yellow liquid called *blood-serum*, which increases in quantity until at the end of about an hour it is sufficient in amount to float the clot. The latter becomes separated from the sides of the vessel. The appearance of the clot or *crassamentum* is due to the formation in the plasma of fine fibrils which extend in every direction and which gradually contract and inclose in their meshes the various corpuscles. The process may be indicated by diagram as follows:



When coagulation has been retarded for some time, the red corpuscles have time to sink from the surface, producing after coagulation a yellow layer which is known as the *buffy coat.* Many leucocytes, owing to their amœboid movements, escape from the meshes of the clot. If the blood, while it is coagulating, is agitated with a bundle of rods, the fibrin is removed as quickly as it is formed, and appears as a stringy white mass on the rods. After this the blood appears normal, but it has lost its power to coagulate, and is known as *defibrinated blood.*

The **value of clotting** is that it stops hemorrhage. A serious condition is present in some pathological states where the blood will not clot. The *time of clotting* varies in different individuals and at different times. Normally the jelly-stage sets in in from three to ten minutes, while the formation of serum requires from ten to forty-eight hours.

Owing to the complexity of the blood, the investigations as to the *cause of clotting* have given rise to many different views. It seems to be well established, however, that the formation of *fibrin* depends upon the interaction of two factors—the *fibrin ferment* (*thrombin*) and *fibrinogen.* The latter is not entirely used up in the formation of fibrin (only 60 to 90 per cent.), but a portion appears in the serum as a new, globulin-like proteid called *fibrin-*

globulin. Calcium salts are absolutely essential in order that this reaction may take place. Their exact behavior is still under discussion. It has been stated that the *disintegration of leucocytes* and *blood-plates* in the blood sets free a *nucleo-albumin,* which may be considered the precursor of the ferment and called *prothrombin.* Prothrombin unites with calcium to form the ferment, which has the power of reacting with a portion of the fibrinogen molecule by transferring its calcium to it and so giving rise to fibrin. Fibrin ferment was originally prepared by subjecting serum to an excess of alcohol, which coagulated the proteids. The latter were removed and extracted with water. Such preparations were found to coagulate fluids like hydrocele liquid, which normally do not clot spontaneously or at least very slowly. The nature of the action was believed to be that of an enzyme, since very small quantities produced great changes, and it was destroyed permanently by heating to 60° C. By allowing the blood to run from the vessels directly into alcohol it was found that the *ferment* is *not present in normal blood;* that, moreover, it has its *origin* in the *leucocytes* is shown by the following facts:

1. In microscopic preparations of coagulating blood the fibrin fibrils radiate from broken-down leucocytes and from blood-plates.
2. Whatever prevents the disintegration of the white blood-cells retards the coagulation of the blood.

Clotting within the blood-vessels may be brought about by the presence of foreign bodies or by injury to the epithelial lining of the vessels. When the clot is confined to the injured area, it is called a *thrombus. General intravascular clotting* is brought about by the injection of fibrin ferment, nucleo-albumins, etc., but this is not accomplished easily, owing to a defensive function for the body exerted by the cells of the liver. Sometimes the blood is rendered less coagulable by the injection of the above substances, constituting the *negative phase* of the injection. This is explained by the assumption of the predominance of *histon* over *leuconuclein,* both of which are formed by the breaking down of leucocytes. Histon retards the coagulation, while leuconuclein favors it. Normally the blood of the body is prevented from clotting by the integrity of the lining epithelium of the vessels. In the *living test-tube experiment,* for example, the jugular vein with its contained blood are removed from the neck of the horse, and it is found that the blood under these conditions remains fluid until the epithelial cells of the blood-vessels undergo degenerative changes.

It is not known what percentage of blood may be lost by man through hemorrhage without fatal results, but judging from experiments upon lower animals, it may be put at about 3 per cent. of the body-weight, or one-fourth of the total blood.

Regeneration of the blood takes place rapidly and is completed in from twenty-four to forty-eight hours. After severe hemorrhage recovery is more certain if a solution of sodium chloride, isotonic with the blood (0.9 per cent.) in man, is injected into the veins. The *salt solution* increases the *blood-pressure* and makes *effective* the remaining *blood-corpuscles*, which in normal blood are always in *excess* of the number absolutely required for *respiratory* purposes.

The *injection of saline* solution into the blood-vessels of a normal animal raises the blood-pressure, but never above 180 mm. Hg. This limit holds true also when the pressure has previously been lowered by hemorrhage or by section of the cervical cord. The explanation of this fact lies in the manner in which the heart is affected. As soon as the arterial tension reaches its maximal height, the heart beats slower and less vigorously, and the residual blood in the left ventricle increases. This causes a diastolic rise of pressure in the ventricle, which is propagated back through the left auricle, pulmonary circuit, right heart, to the veins. There arises in this way a congestion of the veins and capillaries of the lungs and abdominal organs chiefly. An amount of salt solution equal to four times the normal quantity of blood of the animal may in this way be accommodated. The liver becomes hard, tense, and swollen, and other tissues become œdematous. Owing to the transudation of fluid, the body becomes dropsical. The bladder is distended with urine, and the stomach and intestines become filled out with fluid. These factors prevent the blood-pressure from rising much above the normal. After the injection the arterial and venous pressures return quickly to the normal, generally within an hour. Injection of saline solution differs from transfusion of blood in that in the former case the blood-flow is accelerated. The solution injected must be isotonic with the blood of the animal, of the same temperature, and every precaution taken to prevent the entrance of air. When injection of salt solution is maintained for some time, the work of the heart is increased, and cardiac failure sometimes results. In the endeavor to avoid the latter it has been found that blood-letting rapidly reduces arterial pressure, owing to a general paralysis of the vasomotor apparatus through overdistention, so that the animal is easily killed by the hemorrhage. One hundred and fifty per cent. of the normal quantity of blood of the animal is the maximal amount that can be injected without directly endangering the life of the animal.

Transfusion of blood is *dangerous* for two reasons:

1. Strange blood, even after defibrination, carries an excess of *fibrin ferment* liable to cause intravascular clotting.

2. The blood of one animal has a *globulicidal* action and *toxic* effect on the corpuscles of another. By *globulicidal action* is meant that property of the serum of an animal which causes it to destroy the red corpuscles of the blood of another, thereby rendering it laky. The white corpuscles may be destroyed as well. As an example it may be said that man's serum is globulicidal to rabbit's blood. Similarly the blood of one animal may be *poisonous* to that of another aside from its globulicidal action. Thus the injection of 10 c.c. of dog's serum will rapidly kill a rabbit. These properties are destroyed if the blood is heated to 60° F., and they may, as has been suggested, be the result of a proteid substance—an *alexine*—which is present in small quantities in the blood of every animal.

LYMPH.

Lymph is a pale, straw-colored liquid found in the *extravascular* spaces and *lymph-vessels* of the body, bathing every tissue-element. It is slightly *alkaline*, of a *salty taste*, and has *no odor*. It contains a number of leucocytes; after meals, fat-globules; accidentally, red corpuscles and blood-plates. Lymph contains the three *blood-proteids*, the *extractives*, and *the salts*. The last are in the same proportions as in the blood; the proteids, especially the fibrinogen, are in lesser amounts. Lymph coagulates more slowly and less firmly than blood. During *digestion* there is a marked *increase* of *fats* in the lymph of the intestines, making it resemble milk, and it becomes known as *chyle*. *The lymph derives substances from three sources—from the blood, from the tissues,* and *from the villi of the intestines.* It is first collected into capillary spaces, which open into definite lymphatic vessels which finally empty their contents into the blood-vessels at the junction of the subclavian and internal jugular veins. The continual formation of lymph, aided by subsidiary forces, leads to a relatively high pressure in the lymph-spaces, which drives the lymph to the veins or points of lowest pressure. Among the *subsidiary forces* may be mentioned the pump-action of the villi, the peristaltic movements of the intestine, and the action of the skeletal muscles in contracting and the pressure-changes in the chest during respiration.

The formation of lymph from the blood is brought about mainly by filtration and osmosis. The endeavor to prove the *participation* of the active *epithelial cell* has *not been successful.* The capillaries, however, in different regions of the body have a different structure, which is not optically recognizable, but which gives them different permeabilities, so that they influence the character of the lymph formed, particularly in regard to the percentage of proteids.

QUESTIONS ON CHAPTER VII.

How does excessive hemorrhage affect man?
What is the function of the blood?
What is the total quantity in the body of man?
How does the quantity vary?
How is the total quantity of an animal estimated?
How is the blood distributed in the body?
What are the components of the blood?
What is the cause of the difference in color in arterial and venous blood?
What makes the blood opaque?
What is laky blood?
Give the physical and chemical properties of blood.
Discuss the corpuscles of the blood.
What is hæmoglobin? How is it held in the corpuscle?
What is hæmochromogen?
What is the total area which the red corpuscles expose to the action of the air?
Discuss some of the compounds formed by hæmoglobin and various gases.
Explain why illuminating gas is dangerous when inhaled.
What is the percentage of iron in hæmoglobin?
Describe the crystals of hæmoglobin and their manner of preparation.
What are hæmin crystals? How prepared? Of what importance are they?
Discuss the absorption spectra of oxyhæmoglobin and of reduced hæmoglobin.
What facts indicate that red corpuscles remain in the vessels but a limited time?
What is hæmatopoiesis?
Where are red corpuscles formed? Describe the process.
How are the white blood-cells classified?

What is diapedesis?
What is the function of leucocytes?
Discuss the blood-plates.
Describe the plasma of the blood.
By what methods may plasma be obtained free from corpuscles?
Explain the effect of the injection of peptones into the blood of an animal.
Why do oxalate solutions affect coagulation?
What are the chemical constituents of plasma?
Give the percentage of serum-albumin in the blood of man. How is it separated from the globulins?
What facts indicate that there is more than one kind of serum-albumin.
What is the percentage of serum-globulin in the blood? Give its probable source.
What is the percentage of fibrinogen in the blood?
What substances are included under extractives?
What peculiarity in the distribution of salts in the corpuscles and in the plasma?
Describe the process of clotting.
How is the buffy coat produced?
Give the chemistry of clotting.
How is fibrin ferment obtained?
How has it been shown that fibrin ferment is normally not present in the blood?
Give proof as to the origin of the fibrin ferment.
How may intravascular clotting be produced?
Explain the "negative phase" produced by the injection of ferment into the vessels of an animal.
What experiment shows that the epithelial lining of the vessels normally prevents clotting of the blood?
How much blood may be lost without fatal results?
Why is the injection of sodium chloride solution beneficial after severe hemorrhage?
Why is the transfusion of blood dangerous?
What is meant by the globulicidal and toxic actions of the blood?
What is defibrinated blood?
Give the composition and the physical properties of the lymph.
What is chyle?
What is the source of lymph?
What forces cause the lymph to flow into the blood-vessels?
To what extent do the capillaries influence the composition of the lymph?

CHAPTER VIII.

CIRCULATION.

THE HEART.

THE blood is forced through the vessels that contain it mainly by the rhythmic contractions of the heart. Its *path*, in general, is as follows: Beginning with its exit from the left ventricle it passes into the aorta, and through its various branches is rapidly taken into the systemic capillaries of all portions of the body. From the capillaries it is passed into the veins, which lead it back to the right auricle, through which it passes to the right ventricle. The latter, in turn, forces it through the arteries, capillaries, and veins of the pulmonary system to the left auricle, and then to the left ventricle, thus reaching its starting-point. That portion of the blood which happens to pass into the capillaries of the stomach, intestines, spleen, or pancreas necessarily circulates through a second set of capillaries which are found in the liver, giving rise to what is known as the portal circulation. The kidney exhibits a somewhat similar arrangement.

Every particle of blood follows a path which, no matter how deviating it may be, finally returns into itself. The blood, moreover, is flowing always in a certain *definite direction.* This is the meaning of the expression "*circulation of the blood.*" The left side of the heart forces the blood through the systemic vessels, while the right side forces it through the vessels of the lungs. It is thus possible for the blood to carry the food-stuffs absorbed from the intestines and those brought to it by the thoracic duct, as well as the oxygen which is absorbed in the lungs to all the cells of the body. In addition it carries the waste-products of the cells, in order that they may be removed by the proper excretory organs.

The *energy* of the *contractions of the heart* is derived from the potential chemical energy of the food-stuffs, and is entirely converted into heat before it leaves the body. Each contraction is technically known as a *systole*, and each relaxation as a *diastole.* During the *systoles* of the *ventricles*, which occur simultaneously, the blood is forced into the arteries, because the cavity of the ventricles is diminished in size, and, as the *auriculo-ventricular valves* are *closed*, the blood must pass through the *open semilunar valves.* During *diastole* the *semilunar valves* are *closed*, preventing the *regurgitation* of the *blood* from the *arteries*, but the *auriculoventricular* valves are now open, so that the blood in the large veins and in the auricles can enter the ventricles.

By experiment on a dog it has been found that blood can pass from a point in the external jugular through the right cavities of the heart, aorta, arteries, capillaries, and veins of the head to the starting-point in fifteen to eighteen seconds. Each contraction and relaxation or beat of the heart consists of a regular sequence of events known as the *cardiac cycle.* The systoles of the two auricles occur together, as do those of the ventricles, and the same is true of their diastoles. While the auricles are contracting they shrink in size, and at this time the ventricles swell. Then follow immediately the systoles of the ventricles, during which the ventricles diminish in size, the auricles swell, and the injected arteries grow larger and longer. During the succeeding diastoles of the ventricles both ventricles and auricles swell until the next contraction of the auricles swells the ventricles still more. These changes

FIG. 7. DIASTOLE.

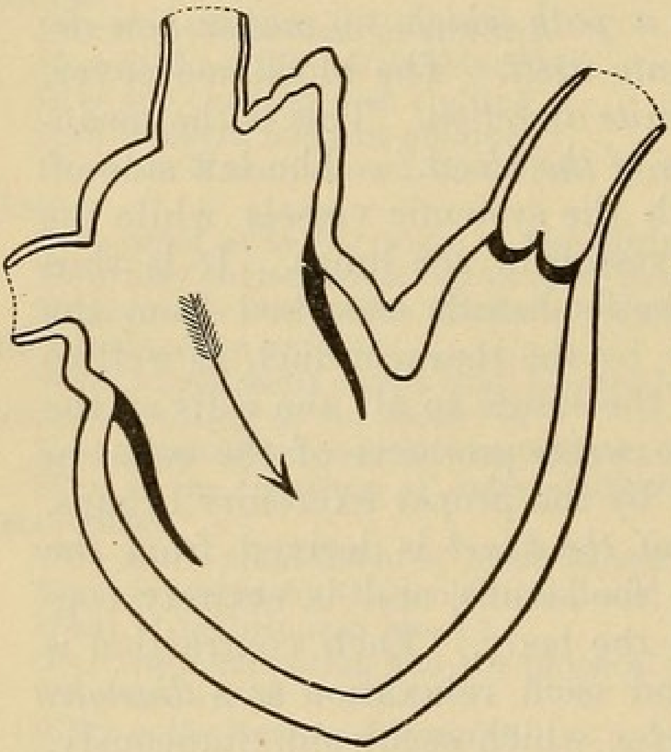
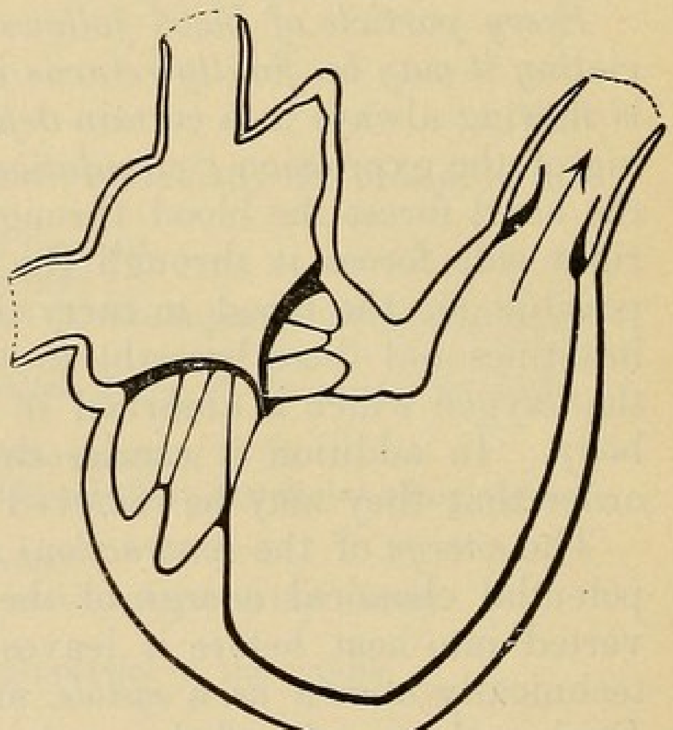


FIG. 8. SYSTOLE.



Diagrams of valves of the heart (after Dalton).

in the size of the heart are due entirely to the varying amounts of blood contained, and not to any variations in the *bulk* of the heart-muscle. In the relaxed condition the heart-walls are very soft and flaccid. Owing to this fact the *changes* of *form* that the *heart* undergoes are easily modified by gravity when the thorax is opened and the heart exposed, since it is then unsupported by the *lungs,* which normally have a *dilating influence.* In this condition in an animal lying on its back it is seen that during a contraction of the ventricle the long axis of the heart sweeps toward the median line, and also toward the head, so that the apex rises a little toward the observer. The heart twists so that the left ventricle moves nearer the breast, while the right turns toward the spine. There is no *change* of *color* in the *ventricle*, but the *auricles* being thin, *show the blood* within—the right, *bluish;* the left, *bright red.* As the auricles contract they become paler. A distinct *pulse* is present in the arteries, but none in the veins. In the unopened chest it is probable that the ventricles become smaller in girth during systole, and that they are always approximately circular and not elliptical. The ventricles shorten somewhat in length, but the apex does not leave the chest-wall, because the injected arteries at the base of the heart lengthen and push the entire heart forward thus fully compensating for the shortening of the ventricle. The apex of the heart as it contracts hardens, and protrudes the chest-wall in the intercostal space of the fourth and fifth ribs, midway between the left margin of the sternum and a vertical line let fall from the left nipple. This constitutes the *impulse* or *apex-beat*, and it coincides with the upstroke of the pulse. Around the protrusion caused by the apex-beat the soft parts of the chest-wall are drawn in slightly, which is due to the fact that the heart becomes smaller at that time, and is, therefore, in contact with the chest-wall over a smaller area. This drawing-in is called the *negative impulse.*

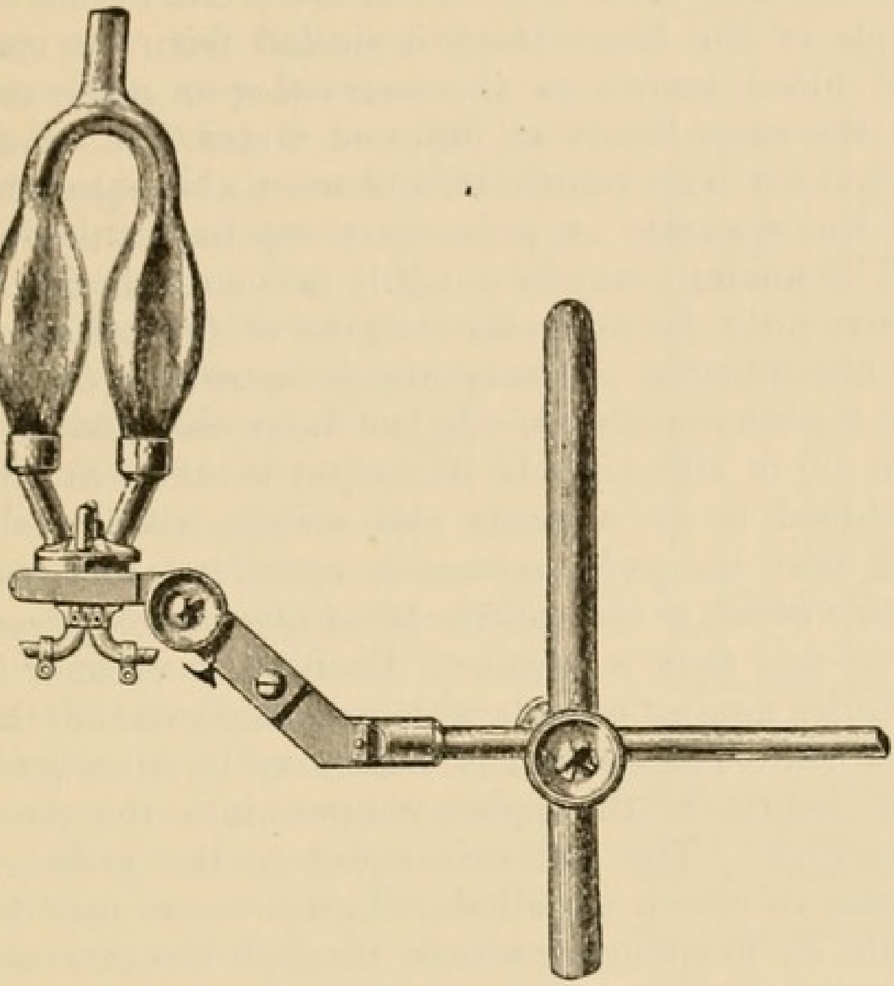
The heart during each cycle produces *two sounds.* The *first*, low-pitched and muffled, *coincides* with the *systoles* of the *ventricles*, and is therefore heard when the apex-beat is felt. The *second sound* is *shorter, higher*, and *clearer* than the other, and follows after a scarcely appreciable interval. It *coincides* with the early part of the *diastole* of the *ventricle. After* the *second sound* there is a period of *silence*, which is *coincident* with the *latter portion* of the *diastole* of the *ventricle* and the *systole* of the *auricles.* It has been proved that the *second sound is due* to the closure of the semilunar valves of the pulmonary artery and the aorta. When these are experimentally rendered incompetent, the second sound disappears and is replaced by a murmur. The *first sound* is believed to be *due* to the combined action of the closure of the tricuspid and mitral valves, and by the muscle sound produced by the ventricles in contracting. The first sound is heard best over the apex of the heart. The closure of the tricuspid valve can be listened to best at the lower end of the sternum. The second sound is heard best at each side of the sternum, between the first and second ribs, being propagated upward along the great vessels to which the semilunar valves are attached.

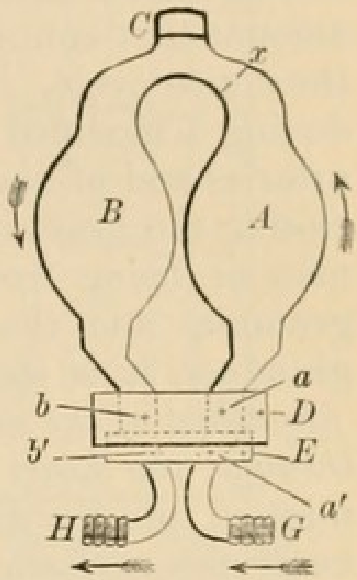
The *average rate* of heart-beat in an adult man is about 72 a minute, and is somewhat faster in women. It varies, however, so that in some individuals it may be 40 or 100 a minute. Shortly before and after birth it averages from 120 to 140. During extreme age its frequency is increased. It is *influenced* by many conditions of *bodily health* and *environment*, such as *sleep, position, temperature, meals,* and *emotions*. *Exercise* may increase it to 200 or more.

The auricular systole is rapid, and forces the blood into the still quiescent ventricles. On completion of the auricular systole the auricles expand and remain quiet during the systole of the ventricles, which begins the moment the auricles cease contracting. The ventricular systole is more forcible than that of the auricles, and they remain longer in a contracted state. During ventricular systole the blood is forced into the arteries. At the close of the ventricular systole the ventricles dilate. The auricles do not take up the work again at once, but there is a period during which the entire heart is in repose. After this a new cycle is begun. If we assume the average number oi heart-beats to be 72 a minute, each cardiac cycle occupies 0.8 of a second. The contraction of the auricles lasts 0.1 of a second; that of the ventricles, 0.3 of a second; and the repose of the entire heart, 0.4 of a second. If the heart-rate be increased, the ventricular systole remains about 0.3 of a second, and the increase in rate is made at the expense of the time occupied by the diastole.

It is the function of the heart to force the blood in one direction only, and this is effected by means of the *valves*. As the ventricle fills, the auriculoventricular valves are floated up from the sides of the ventricle in such a manner that their edges are brought into contact. As the ventricle contracts more forcibly pressure is brought upon the valves, so that not only are the edges in contact, but also portions of the surfaces of the cusps. These valves are of considerable area, and are held in position by the *chordæ tendinæ*, which arise from the *papillary muscles*, so that eversion of the valve into the auricle is impossible. The semilunar valves form a guard against the return of the blood to the ventricle at the pulmonary and aortic openings. These valves are forced open during the ventricular contraction by the blood which passes through them to distend the elastic walls of the large arteries. The pressure of the blood under the *elastic recoil* is sufficient to throw the cusps of the valves into action. The *corpora Arantii* are useful in making a perfect closure of the valve, although not

FIG. 9.





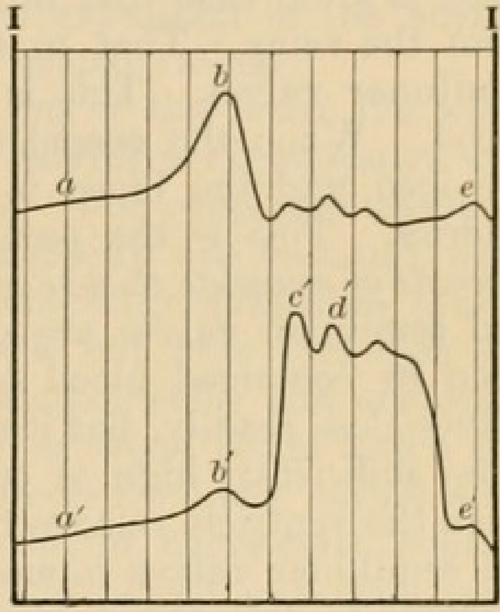
Ludwig's stromuhr and a diagrammatic representation of the same. This consists of two glass bulbs, *A* and *B*, communicating above with each other and with the common tube *C*, by which they may be filled. Their lower ends are fixed in the metal disc *D*, which may be made to rotate, through two right angles, around the lower disc *E*. In the upper disc are two holes, *a* and *b*, continuous with *A* and *B* respectively, and in the lower disc are two similar holes, *a'* and *b'*, similarly continuous with the tubes *G* and *H*. Hence, in the position of the discs shown in the figure, the tube *G* is continuous with the bulb *A*, and the tube *H* with the bulb *B*. On turning the disc *D* through two right angles, the tube *G* becomes continuous with *B* instead of *A*, and the tube *H* with *A* instead of *B* (Foster).

absolutely essential. A part of the weight of this pressure is borne by the thick ventricular wall, which forms a ring from the outer edge of which the arteries spring, while the valves are attached to the inner edge. Under some circumstances the tricuspid valve does not entirely close, but allows a certain amount of regurgitation of blood. This occurs in conditions of disease or of violent exercise, when the lung capillaries are overcharged with blood. The leakage of the valve is conservative, and relieves the pressure upon the delicate capillaries of the pulmonary system. *Pulsation in the jugular veins indicates this regurgitation.* The condition is not pathological, and with altered conditions disappears.

During each cycle of the heart there is ejected from the ventricles a quantity of blood known as the *contraction* or *pulse volume.* It varies in the same heart at different times, but on an average must be equal for both ventricles, and must also equal the amount that enters the systemic or pulmonary capillaries during the entire cycle. The amount may be roughly measured by introducing a modified stromuhr between the origins of the coronary arteries and of the innominates. It may also be measured by enclosing the heart in a *plethysmograph.* It has been estimated for man as being from 50 to 190 c.c. If its weight is taken at 100 grammes and the blood in an average man weighs about 5300 grammes, it is seen that *the pulse volume is equal to about one-fifty-third of the entire blood, so that all the blood of a person passes through the heart in less than a minute.* Each pulse volume is injected into the arteries against considerable resistance, so that the ventricles perform work. The *amount of work* may be calculated by multiplying the weight of the pulse volume into the force exerted by the ventricles. The latter is equal to the pressure under which the pulse volume is expelled. This *pressure* may be measured in animals by introducing a tube through the external jugular into the ventricle, and connecting with a mercury manometer provided with a valve, so that the maximum pressure may be recorded. The left ventricle exerts more than twice as much power as the right. The exact *intraventricular pressure* in man has *not been determined.* The *expansion* of the *heart* exerts a *negative pressure* which *aids* the *onflow* of the blood especially from the lungs to the left auricle and ventricle. The intra-auricular pressure is very much less than the intra-ventricular, and there is a negative pressure during the diastole of the auricles. It has been estimated that each ventricular contraction equals 3½ to 4½ foot-pounds. In twenty-four hours this is equal to more than 120 foot-tons. Practically all the energy of the heart's contractions is converted into heat by the friction of the blood in the vessels.

By a slight alteration of the "maximum manometer" it may be converted into one that records minimum pressures. By the employment of such manometers it has been ascertained upon a dog in one case that the maximum pressure in the ventricle rose as high as 234 mm. Hg., while that in the aorta reached 212 mm. Hg. The minimum of the left ventricle was minus 38 mm. Hg., while that of the aorta did not get lower than 120 mm. Hg. These values vary, but their relations to one another may be taken as an example of what is true of both ventricles. It is seen that the *pressure in the artery is always high*, fluctuating but little, while that of the ventricles rises above the highest arterial pressure and falls much below. The pressure of the blood in the ventricle must overcome that within the artery to open the semilunar valves and force the blood into the artery. As the pressure falls in the ventricle the semilunar valves close as soon as it is less than that of the artery, and prevent regurgitation. When the pressure in the ventricles is at its lowest, the blood streams in from the large veins and from the auricles, because the pressure in the latter, although low, is higher than that in the ventricle.

FIG. 10.



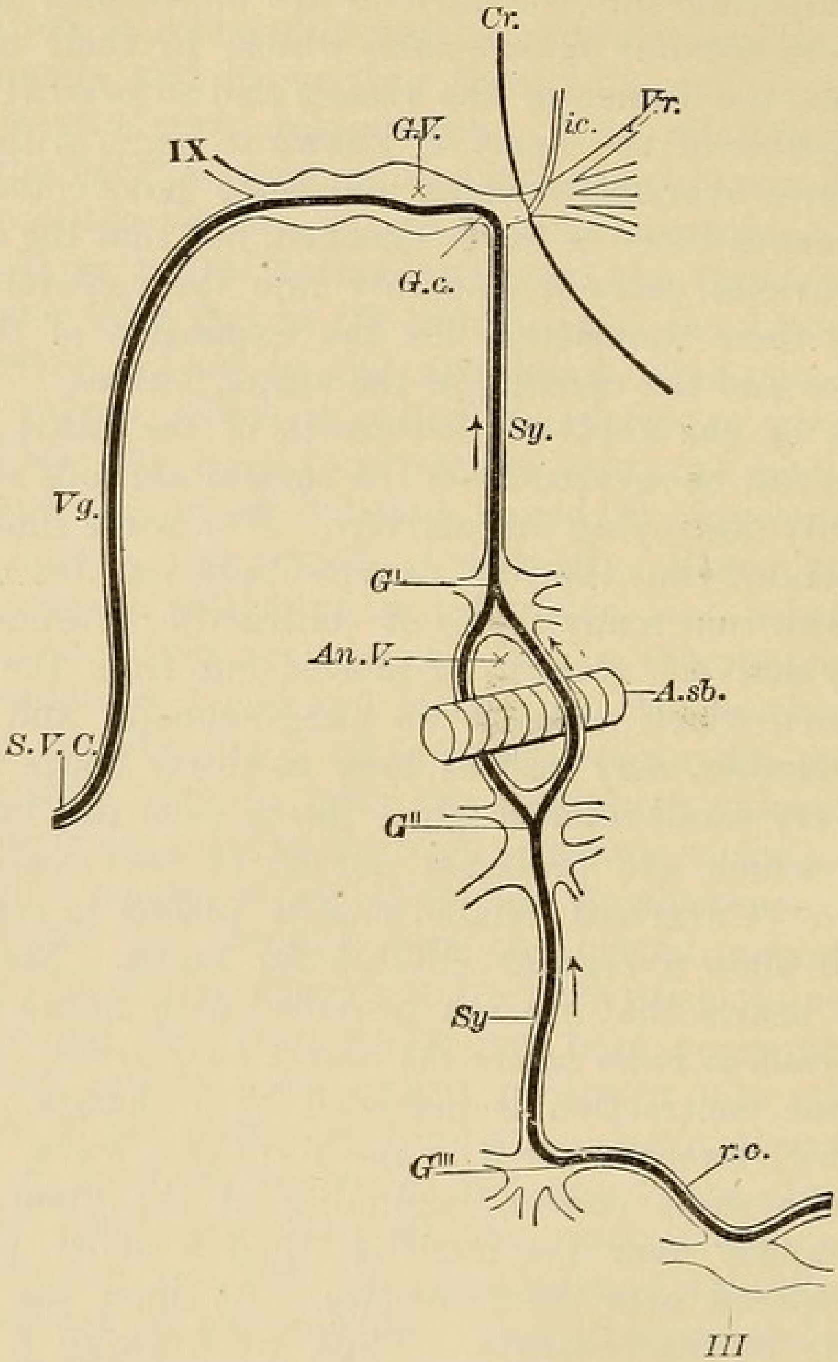
Simultaneous tracings from the right auricle and ventricle of the horse (after Chauveau and Marey): *a*, *a′*, beginning of cardiac cycle; *b*, *b′*, rise of pressure due to auricular systole; *c′*, pressure due to ventricular systole; *d′*, oscillations due to inertia: *e*, *e′*, close of cardiac cycle.

Curves of endocardiac pressure which are obtained by inserting a hollow probe into the various chambers of the heart differ in their form as the method is by air or by liquid. Pressure-curves from the ventricle transmitted by air are peaked, the pressure rising swiftly to a maximum, and then as rapidly falling to or below atmospheric pressure. There follows then a slow gradual rise until the next systole of the ventricle. Transmission by water gives the same curve, with the exception that the peak is replaced by a *plateau*—*i. e.*, the pressure instead of falling after reaching a maximum is sustained for some time. The latter is probably the truer form of the pressure change. The fluctuations of the plateau are due to oscillations produced by inertia. An endocardiac pressure-curve very rarely shows any indication as to the *play of valves.* These must be obtained by carefully graduating two elastic manometers and connecting them with auricle and ventricle, or ventricle and aorta respectively. The relative pressures are given by the heights to which the recording levers rise, and thus the closure of the various valves may be ascertained. As long as the tricuspid or mitral valves are open the pressure in the ventricle is lower than that in the auricle, and the blood is entering from the veins. That in the arteries is shut out by the closed semilunar valves. This is called the *period of reception* of the blood. When the cuspid valves are shut, the semilunar valves are open, and the blood is being forced by the *ventricle* into the arteries. This is the *period of ejection.* There are two brief *periods of complete closure* of the ventricles—*i. e.*, when both cuspid and semilunar valves are closed. When the ventricle contracts upon its contained blood and thus raises the pressure, the cuspid valves close readily, but it takes some time for the pressure to become sufficiently high to open the semilunar valves. Similarly when the ventricle relaxes the high pressure in the arteries closes the semilunar valves immediately, but it takes some time for the pressure to fall low enough that the cuspid valves can open. During the ventricular diastole at the time when the cuspid valves are just opening the blood which has been accumulating in the auricles flows, and to some extent is drawn into the ventricles. This *force* of slight *suction* is due to the *elastic fibres* of the *lung*, which tend to open the ventricles and also to the elasticity of the heart-muscle itself, especially of the auriculo-ventricular ring. The *ventricles* can *maintain* the *circulation* of the *blood* for a *time* at least, unaided by the auricles. The latter form a storehouse for the blood which accumulates during the ventricular systole. The pressure in them in the dog, for instance, seldom rises above 10 mm. Hg. They form, therefore, but a feeble force-pump which completes the filling of the ventricles. Their value in this respect becomes important when the *heart-rate increases,* for then the *ventricular pause* is *shortened* and the auricles form an efficient *mechanism for quickly charging* the ventricles. The *negative pressure* of the auricles has been found to be as low as minus 10 mm. Hg. This is *caused* by the *elasticity* of the *lung*, which just at this moment is *heightened* because the *contracting ventricle* *increases* the *negative pressure* in the *chest*. The mouths of the *great veins* emptying into the auricles are *unprovided* with *valves*, but are *rich* in *circular muscle-fibres* which, by their contraction, may obliterate the lumen of the vessels and so *prevent regurgitation*. The systole of the heart is known to begin with the veins, and sweep down over the auricles, and some have contended that the flow of venous blood is never checked, but that the contracting veins and auricles carry it smoothly into the ventricles by compensating by their contraction for the expansion of the auricles and ventricles and the opening of the cuspid valves.

The *cause of the rhythmic movements* of the heart lies within itself, since it can be severed from the central nervous system without necessarily destroying its activity. For some time many observers contended that the rich nerve-supply was essential, but it has been shown that many forms of contractile substance may be rhythmically active. A strip of muscle cut from the apex of a tortoise's heart, which contains no ganglion-cells, and suspended in a moist chamber, may beat as long as thirty hours with a slow rhythm. Very small microscopical pieces from the bulbus aortæ of the frog, which are probably devoid of nerve-cells, contract rhythmically. Curarized striated muscle placed in certain saline solutions will show a regular rhythm for hours. Many invertebrates have hearts that are not provided with nerve-cells. *The heart of the embryo beats before the nerves have grown into it.*

The cardiac contraction is preceded by a change of electrical potential, which sweeps over it in the form of a wave. Both normally take the same course, beginning at the great veins and spreading rapidly over the auricles, then a short pause, after which they spread over the ventricles. At times the contraction may originate in the ventricle. Thus, by drawing a tight ligature about the heart at the junction of the auricles and ventricles, the rhythm of the heart is disturbed and the ventricle beats with an independent slower rhythm. If the *electrical changes* of the beating heart are investigated, it is found that the base becomes negative before the apex, and that this condition of negative potential passes along in the form of a wave to the apex. Its speed has been found to average at least 50 mm. a second. The *latent period* of frog's heart-muscle is about 0.08 of a second, but the change of potential takes place instantly after the application of the stimulus. The *excitation wave* can be made to pass

FIG. 11.



Diagrammatic representation of the course of cardiac augmentor fibres in the frog (Foster): *V.r.*, roots of vagus (and ninth) nerve. *G.V.*, ganglion of same. *Cr.*, line of cranial wall. *Vg.*, vagus trunk. IX., ninth, glossopharyngeal nerve. *S.V.C.*, superior vena cava. *Sy.*, sympathetic nerve in neck. *G.c.*, junction of sympathetic ganglion with vagus ganglion sending *i.c.*, intra-cranial fibres, passing to Gasserian ganglion. The rest of the fibres pass along the vagus trunk. G^1, splanchnic ganglion connected with the first spinal nerve. G^{11}, splanchnic ganglion of the second spinal nerve. *An.V.*, annulus of Vieussens. *A.sb.*, subclavian artery. G^{111}, splanchnic ganglion of the third spinal nerve. *III.*, third spinal nerve. *r.c.*, ramus communicans.

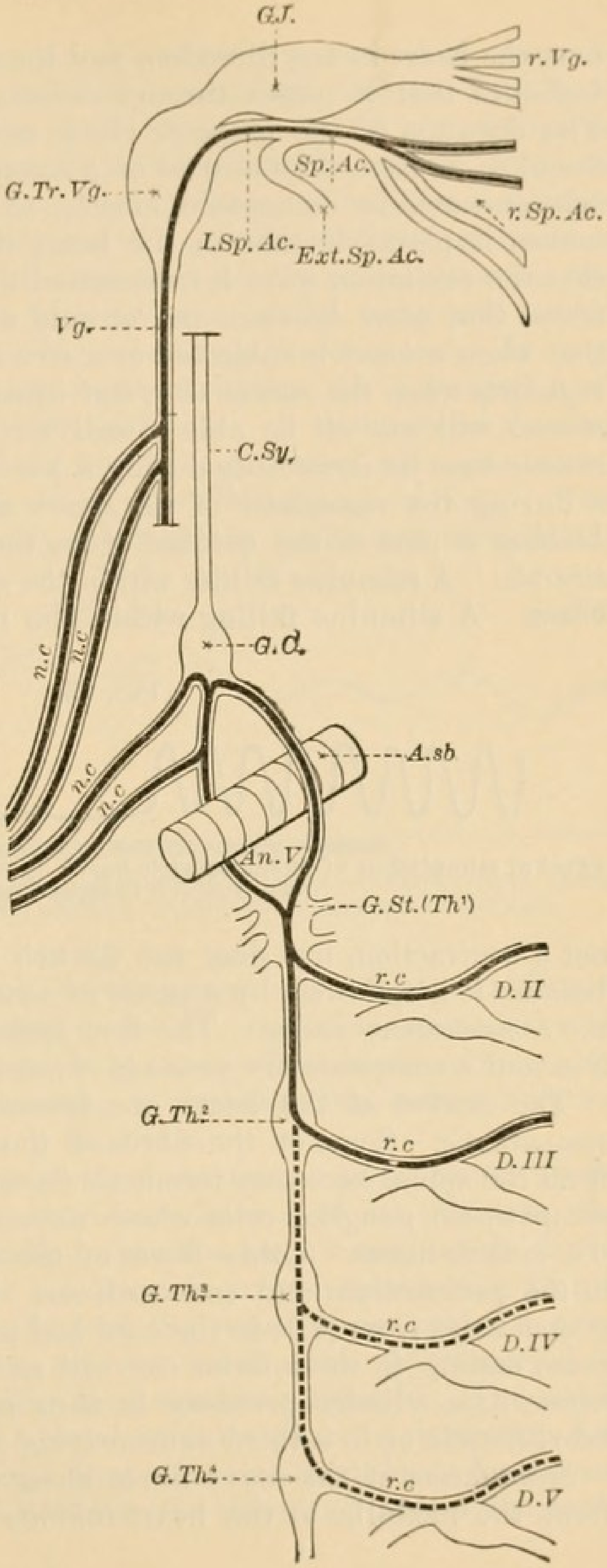
The course of the augmentor fibres is shown by the thick black line. They may be traced from the spinal cord by the anterior root of the third spinal nerve, through the ramus communicans to the corresponding splanchnic ganglion G^{111}. and thence by the second ganglion G^{11}, the annulus of Vieussens, and the first ganglion G^1, to the cervical sympathetic *Sy*, and so by the vagus trunk to the superior vena cava *S. V. C.*

Fig. 12.

Diagrammatic representation of the cardial inhibitory and augmentor fibres in the dog. The upper portion of the figure represents the inhibitory, the lower the augmentor, fibres (Foster): *r. Vg.*, roots of the vagus. *r.Sp.Ac.*, roots of spinal accessory; both drawn very diagrammatically. *G.J.*, ganglion jugulare. *G. Tr. VG.*, ganglion trunci vagi. *Sp.Ac.*, spinal accessory trunk. *ext. Sp.Ac.*, external spinal accessory. *i.Sp.Ac.*, internal spinal accessory. *V.g.*, trunk of vagus nerve. *n.c.*, branches going to heart. *C.Sy.*, cervical sympathetic. *G.C.*, lower cervical ganglion. *A.sb.*, subclavian artery. *An.V.*, annulus of Vieussens. *G.St.* ($Th.^1$). ganglion stellatum or first thoracic ganglion. *G.Th.*^{2}, *G.Th.*^{3}, *G.Th.*^{4}, second, third, and fourth thoracic ganglia. *D.II.*, *D.III.*, *D.IV.*, *D.V.*, second, third, fourth, and fifth thoracic spinal nerves. *r.c.*, ramus communicans. *n.c.*, nerves (cardiac) passing to heart (superior vena cava) from cervical ganglion and from the annulus of Vieussens.

The inhibitory fibres, shown by black line, run in the upper (medullary roots) of the spinal accessory, by the internal branch of the spinal accessory, past the ganglion trunci vagi, along the trunk of the vagus, and so by branches to the superior vena cava and the heart.

The augmentor fibres, also shown by black line, pass from the spinal cord by the anterior roots of the second and third thoracic nerves (possibly also from fourth and fifth as indicated by broken black line), pass the second and first (stellate) thoracic ganglia by the annulus of Vieussens to the lower cervical ganglion, from whence, as also from the annulus itself, they pass along the cardiac nerves to the superior vena cava.



over the heart in any direction, and the *speed* with which it travels *indicates* that it passes through *muscle* and not through *nerve*. The duration of the pause or block in the frog's heart has been found to be from 0.15 to 0.30 of a second. The speed of the excitation-wave in embryonic muscle (3 to 11 meters a second) makes it plausible that in the heart the block is due to the fact that the excitation-wave is transmitted through embryonic muscle-fibres that exist between the auricle and ventricle. It is found that when a *heart* is subjected to a *series* of *stimuli* it will *respond regularly* when the *rate* is *slow*, but when it becomes too *rapid*, the *stimuli* will *not all* be able to call forth a *response*. The *heart-muscle loses* its *irritability* during a *part* of its *systole*, and *regains* it during the *remainder* of the *systole* and the following *diastole*. During a part of the cardiac cycle, therefore, it is refractory to stimuli. A stimulus falling within the *refractory period* is without effect. A stimulus falling within the non-refractory period calls

FIG. 13.

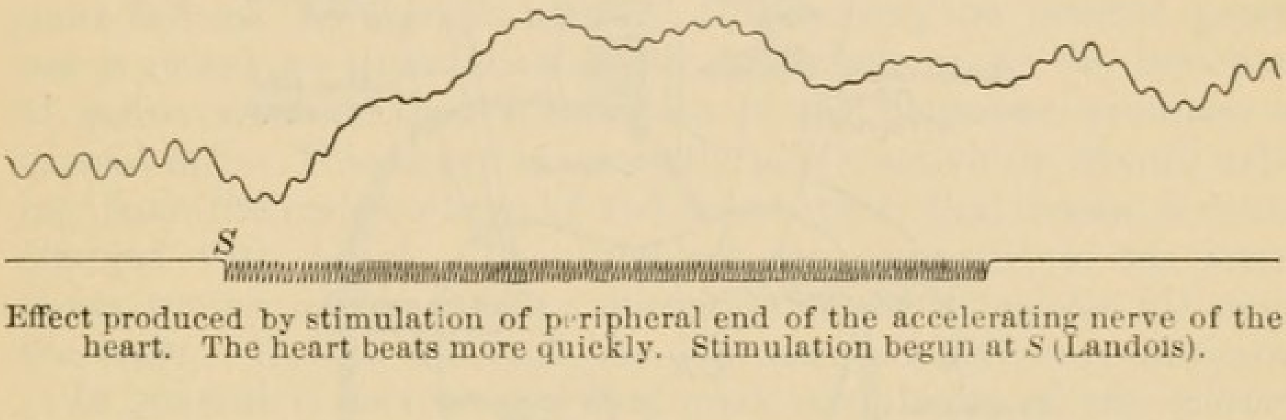
Effect of stimulation of pneumogastric nerve upon action of heart in frog. To be read from left to right (Chapman).

out a contraction, but does not disturb the rhythm of the heart, because it is followed by a pause of extra length. This is called the *compensatory pause*. The first systole after an extra contraction and a compensatory pause is of marked strength.

The **nerves of the heart** are branches of the *vagus* and the *sympathetic*. Some of the fibres of the *vagus* which are derived from the spinal accessory terminate in end-baskets which surround sympathetic ganglion-cells whose axis-cylinder processes end on the muscle-fibres. Other fibres of the vagus end in end-brushes in the pericardium and endocardium. Fibres of the *sympathetic* system arise from cells in the cord and pass out through the white rami, ending in the inferior cervical and stellate ganglia on cells whose axis-cylinder processes in turn pass either directly to the heart-muscle or to a third neuron lying in the heart.

Stimulation of the *vagus* fibres along any portion of their path from the medulla to the heart *inhibits* the heart's action. The effect is not immediate, but follows a latent period which extends over a beat or two. The *inhibition* manifests itself at first by a lengthening of the duration of the diastole without any change in the systole. A stronger stimulation lengthens the systole also, and may stop the beat of the heart altogether. *Inhibition* is further *shown* by a *lessening* of the *force* of the *contraction;* by an *increase* of *pressure* in the *heart* during *diastole;* by *an increase* in the *amount* of *residual blood;* by a *decrease* in the *input* and *output* of the *ventricle*, and by *diminished ventricular tonus.* It may further be said that during vagus excitation the propagation of the cardiac excitation is more difficult. A *demarcation current* derived from a portion of the *auricle* is *increased* by *vagus excitation*, although the auricle shows no visible change of form. The heart cannot be continuously inhibited by prolonged stimulation.

FIG. 14.

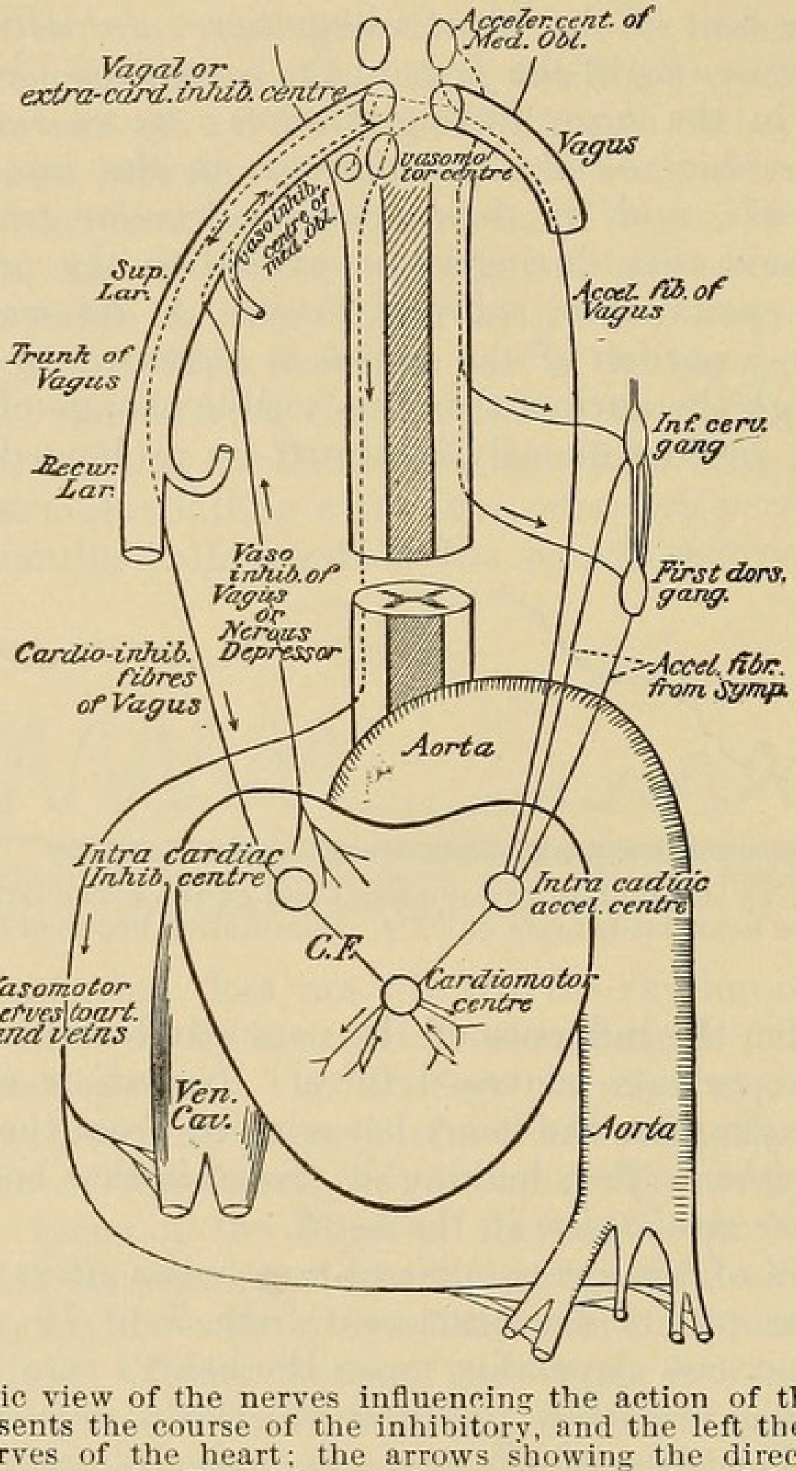


Effect produced by stimulation of peripheral end of the accelerating nerve of the heart. The heart beats more quickly. Stimulation begun at *S* (Landois).

It *escapes* from the influence of the vagus and resumes its former rhythm with perhaps increased force. *Immediate stimulation* of the *second vagus* after the heart has escaped from the influence of the first is *without effect*, making it probable that both nerves act upon the *same mechanism* in the heart.

Stimulation of the *sympathetic* or *augmentor fibres* causes an increase in the rate of the heart-beat from 7 to 70 per cent., the amount of increase depending upon the heart's rate before stimulation. A *long excitation* produces *no greater acceleration* than a *short one.* The *force* of the *beat*, the *pulse-volume*, and the *speed* of the *excitation-wave* are all *increased.* The *latent* period is usually a *long one*, extending from two to ten seconds. The acceleration may continue for several minutes after the excitation has ceased. It has been found that pressure brought to bear upon the human heart where a defect in the chest-wall makes it accessible can be felt by the subject, and direct stimulation of the surface of the heart in animals may cause movements of the limbs.

FIG. 15.



Diagrammatic view of the nerves influencing the action of the heart. The right half represents the course of the inhibitory, and the left the course of the accelerating nerves of the heart; the arrows showing the direction in which impressions are conveyed. The ellipse at the upper extremity of the vagus looking like the section of the nerve is intended to represent the vagal nucleus or centre. In this diagram the nerves are incorrectly made to cross, instead of passing behind, the aorta (Chapman).

The latter event is absent when the vagi are cut, so that it is thought the vagus carries afferent fibres to the brain. Stimulation of the central end of the cut vagus when the other is intact slows the heart-rate. This effect disappears when both vagi are cut.

The *depressor* is a nerve whose fibres pass from the heart to the central nervous system. *Section* and *stimulation* of the *peripheral end* cause no appreciable change. *Stimulation* of the *central end* causes a general fall of blood-pressure to one-half or one-third its former height, and lessens also the pulse-rate. Both are restored after stimulation ceases. When both vagi are cut there is a fall of blood-pressure upon stimulation of the depressor, but no change in the pulse-rate. This shows that the impulses from the depressor may spread to the cardio-inhibitory centre and through the vagi slow the heart. It shows, moreover, that the fall in pressure is not dependent upon the vagi. Section of the *splanchnic nerve* causes dilatation of the abdominal vessels and a fall of the general blood-pressure. If, now, the depressor is stimulated, no effect is produced, because the blood-pressure is already so low that little more fall can be brought about. If, however, the general pressure is raised by stimulation of the splanchnic or by the injection of saline solution, then stimulation of the depressor produces a typical fall. This nerve is normally made active by stimuli arising from the endocardium of the heart when that organ is overcharged with blood. The impulses are conveyed to the vasomotor centre, which causes a dilatation of the arterioles all over the body. Unlike the vagi, the depressor is active only at times.

In general it may be said that weak stimulation of any *sensory nerve* like the sciatic produces augmentor effects, while a strong stimulation produces inhibitory effects. Stimulation of the central end of the abdominal sympathetic produces through the vagi a reflex inhibition of the heart. *Dilatation* of the *stomach* has experimentally been shown to *inhibit* the *heart.*

The *cardio-inhibitory* centre is situated in the bulb at the level of a mass of cells known as the accessory nucleus of the twelfth and the nuclei of origin of the ninth, tenth, and eleventh nerves. The centre is probably always in action, since section of the vagi, which removes the influence of the centre, is followed by an increase in the rate of the heart-beat. The continuous activity of the centre is due to a stream of impulses that come from all portions of the body. After cutting off most of these by dividing the spinal cord near the bulb, section of the vagi no longer increases the heart-rate. The *augmentor centre* is situated somewhere in the bulb and is also *continuously active.* This is shown by sectioning the vagi and then extirpating the inferior cervical and first thoracic ganglia on both sides, which causes a slowing of the heart. Dividing the cord in the cervical region after the vagi have been cut has the same effect. *Inhibition* of the heart through the vagi is more *easily obtained* when the *augmentor fibres* have been *severed.* Whenever sensory nerves are stimulated, producing an accelerated heart-beat, it is probable that both the augmentors and the cardio-inhibitory centres are stimulated, but the first more strongly, so that its effects prevail. There are a few cases on record where the heart-centres in the medulla were apparently influenced by impulses from the cerebral cortex, but these are extremely unusual.

The heart of the higher animals has a distinct arterial and venous system, upon which its nourishment depends. The *arteries* in the human heart each supply a given area of the muscle, not invading the area of its neighbors, and *no collateral circulation can be established between them.* If, therefore, an artery is plugged by *embolism* or *thrombosis,* the part of the heart-wall that it supplies dies, becoming dull-white or faintly yellow in color, granular in cross-section, and is soon replaced by connective tissue. Such an area is known as an *infarct.* The result of closure of the arteries of the heart depends upon the size of the vessel operated upon. Sometimes no effect is produced, or the ventricles may stop beating and fall into fluttering, twitching movements known as *fibrillary* contractions. The auricles will, perhaps, continue beating for a short time. As the arrest of the heart draws near the force of the ventricular beat becomes irregular, but the pressure in the heart gradually lessens during systole and becomes greater during diastole. The cause of the arrest is not the mechanical injury done to the heart, but to the sudden anæmia produced. *Anæmia* brought about by *hemorrhage* produces a different series of symptoms because the heart works against *decreasing resistance* in the arteries, which is not the case when a branch of the coronary artery is ligated, for then the peripheral resistance continues to be high. *Closure* of the *coronary veins* produces fibrillary contractions in a rabbit in from fifteen to twenty minutes, but is without effect upon the dog, owing to the fact that some of the blood passes into the cavities of the heart through the *venæ Thebesii,* and is sufficient in amount to maintain the *nutrition* of the heart.

The contractions of the heart favor the entrance of the blood into the coronary arteries in two ways:

1. By the pressure produced in the aorta.
2. By directly compressing the walls of the bloodvessels in the heart muscle.

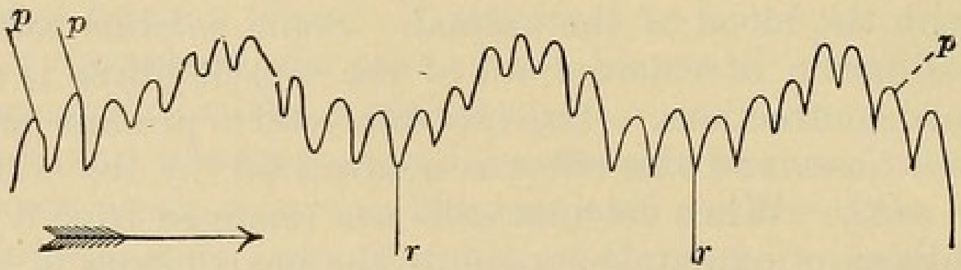
It has been found that the volume of the blood passing through the coronary circulation, unless it varies very much, does not influence the rate of the beat, but does modify the force of the contraction.

The various constituents of the complex fluid, blood, have different values in maintaining the activity of the heart. This has been investigated by the use of nutrient solutions of definitely known composition. The results obtained are briefly as follows: *Nutrient fluids* for the heart must be *alkaline* in reaction. *Sodium carbonate* is the alkali generally used. It has no specific action, but neutralizes the carbon dioxide and acids formed by the activity of the heart muscle. *Sodium chloride* must be present of a strength isotonic with the blood of the animal. Some *calcium salt* to prevent the diffusion of calcium out of the muscle-fibres is essential to continued contractions. *Calcium salts* tend to produce prolonged *tonic contractions*, and this effect is neutralized by the addition of *potassium salts.* When calcium salts are removed from a solution by the addition of oxalate compounds, the heart ceases to beat, but spontaneous contractions return when calcium is again added. A well-known nutrient solution is *Ringer's*, which is a mixture of 100 c.c. of a 0.6 per cent. sodium chloride solution saturated with tribasic calcium phosphate and 2 c.c. of a 1 per cent. solution of potassium chloride. *Oxygen* is essential to the prolonged activity of the heart. *Carbon dioxide* is injurious when present in large quantities. A heart poisoned with the latter substance shows an *irregular series of contractions.* It has not been satisfactorily demonstrated that organic substances are immediately necessary to the rhythmic activity of the heart.

ARTERIES, CAPILLARIES AND VEINS.

The continuously high *pressure* that exists in the *aorta* causes the blood to move to points of lower pressure, and it is thus kept in constant movement from the arteries through the capillaries to the veins, and so back to the heart, where, by the action of this organ it is again transferred into the artery and put under high pressure. *Blood-pressure* is usually measured by an instrument called a *mercurial manometer.* It consists of a U-shaped glass tube, the bend of which is filled with mercury. One limb of the tube, filled with an anti-coagulation fluid, is put in connection with the bloodvessel of the animal, while the surface of the mercury in the other limb carries a small float to which is attached a delicate pen that bears against a horizontally moving surface. Such an arrangement is a *kymograph.* *Variations* of the blood-pressure within the vessel are transmitted through the fluids to the mercury, which moves up and down, carrying the float and pen with it, and are thus recorded. By this method it is found that the blood in an artery exhibits at least two regularly recurring *changes of pressure,* which take the form of smaller waves superimposed upon

FIG. 16.



Tracing of arterial pressure with a mercury manometer (Foster). The smaller curves, *p p*, are the pulse-curves. The space from *r* to *r* embraces a respiratory undulation. The tracing is taken from a dog, and the irregularities visible in it are those frequently met with in this animal.

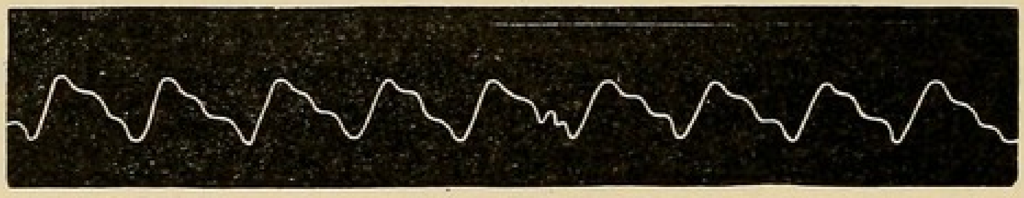
larger ones. The *latter* are due to *respiratory movements,* while the former are due to *heart-beats.* The *mean blood-pressure* is the average pressure during any arbitrarily chosen length of time. This in man is about 200 mm. of mercury (Hg.) or more in the aorta; from 30 to 50 mm. Hg. in the capillaries; about 20 mm. of Hg. In the external jugular and in the *veins near* the *heart* the *pressure* becomes *negative.* From the aorta through the capillaries and veins back to the heart there is a continuous decline in pressure.

The *cause* of the *high pressure* in the aorta is the intermittent entrance into it of jets of blood, the *resistance* offered by the *peripheral capillaries* and the *elasticity* of the *vessel-walls.* Each volume of blood forced into the aorta from the heart extends the wall of the vessel, which, through its elasticity, tends gradually to return to its normal size during every diastole of the heart. It is at all times, however, stretched, and therefore always exerts a pressure upon the blood within. Under normal conditions the amount of blood accommodated by the yielding artery during each systole is equal to the amount that passes from the arteries and to the capillaries during the diastole of the heart. Each increase of pressure caused by the heart-beat is propagated in the form of a wave through the arterial system, and constitutes what is called the *pulse*.

The pressure in the capillaries and veins is caused by the same factors that are present in the aorta—power of the *heart*, *resistance* of *friction*, and *elasticity* of *bloodvessel-walls*. But in the *capillaries* and *veins* their is *no pulse* and the *pressure* is *low*. The cause of the latter becomes obvious when it is taken into consideration that a part of the force of the heart has been lost in overcoming the friction of the bloodvessels. In addition, the friction which the blood has yet to overcome in its passage back to the heart is but a fraction of the total friction which it encountered at first. Diminished resistance ahead means lowered pressure. The blood in the capillaries has become pulseless, because the elasticity of the arteries displaces the blood in the capillaries at the same rate that the systole of the heart does.

There are *subsidiary forces* that assist the heart in propelling the blood. Among these may be mentioned the *contractions* of the *skeletal muscles*, the constant *pull* of the *fibres* of the *lung*, and the *movements* of *respiration*. The muscles, in contracting, press upon the veins moving the contained blood onward, since the valves prevent all back-flow. The fibres of the lungs, through their elasticity, are constantly pulling upon the walls of the heart and the large veins, which tends to draw the blood into them. This effect is increased with each inspiration, and the blood then rushes in at a quicker rate; during the following expiration the blood flows more slowly again. There may in this way arise a *distinct pulse* in the large *venous vessels* of the *chest*, which may extend along the *veins* to the *root* of the *neck*. In this region, in deep respirations, there may be an intermittent flow of blood from a cut vein. The bleeding occurs during each expiration and ceases during each inspiration, when the blood is sucked past the wound and not pressed out of it. Owing to this reason *air* may be *drawn* into the *vein*, an event which causes *immediate death.* This region is, therefore, known as the *dangerous region.*

Fig. 17.



Trace of the radial pulse taken by the sphygmograph (Dalton).

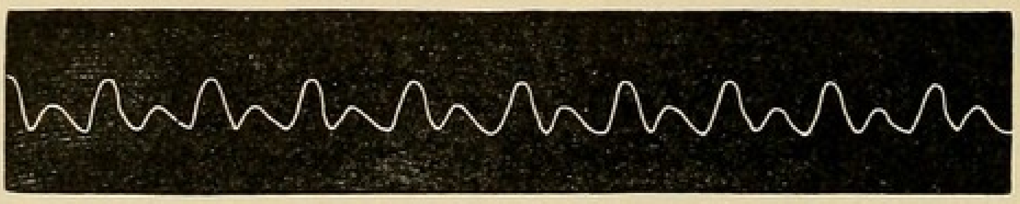
By the term *arterial pulse* is meant the fluctuations of arterial pressure that correspond to the beats of the heart. The pulse is dependent upon :

1. The contractions of the heart.

2. Upon the resistance produced by the friction of the blood in the vessels.

3. Upon the elasticity of the bloodvessel-walls. An abnormal change in either of the three will modify its character. An artery not only increases in its girth as the pulse-wave sweeps over it, but also in its length, which can readily be seen when the vessel has a sinuous course. The increase in girth can be felt with the finger, and forms a constant means of diagnosis. The *rate* of the pulse-wave is from 3 to 9 metres a second. As the blood moves on an average in the arteries only a half metre in the same time, it is clear that it is not the travelling of the blood that produces

Fig. 18.



Dicrotic pulse of typhoid fever (Marey).

the pulse, but a wave of pressure. A number of terms describe the *character* of the *pulse.* In regard to its *tension* it may be :

Of high tension or of low tension.
Incompressible or compressible.
Hard or soft.
Very hard (wiry) or very soft (gaseous).

High tension is indicative of *high blood-pressure*, and can be measured by a sphygmometer. In regard to its *size* the pulse may be:

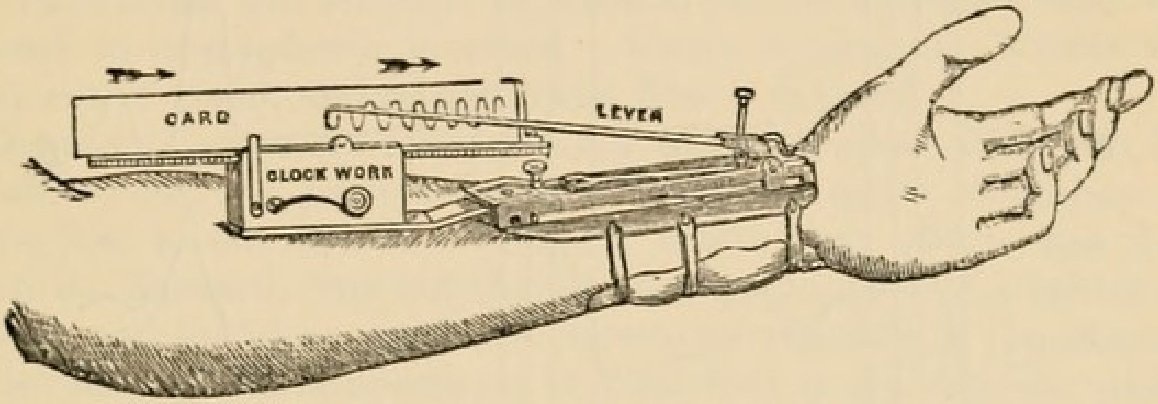
Large or small.

Very large (bounding) or very small (thready).

A large pulse often indicates a low mean blood-pressure. Finally, the pulse may be short or long. It is long when the upstroke takes place slowly.

While an experienced physician can appreciate slight variations in the character of the pulse, it is only by means of the graphic method that different kinds of pulse can be investigated successfully and records kept. The *sphygmograph* is an instrument which measures the succession of alternate dilatations and contractions of an artery, magnifying them, and registering them on

FIG. 19.

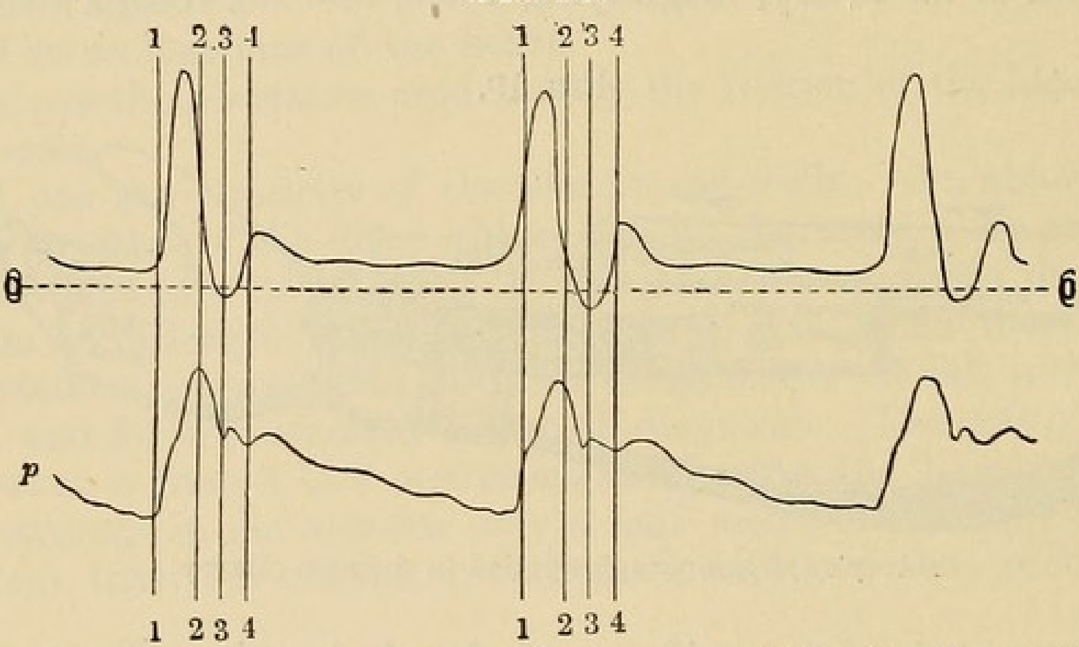


Marey's sphygmograph applied to the arm (Marey).

a surface moving at a uniform rate by clockwork. The tracings show variations of the pulse too slight to be appreciated by the most experienced fingers. The record of a sphygmograph is called a *sphygmogram.* Each pulsation of the artery is seen to be made up of a sudden and direct upstroke and a gradual oscillating downstroke. The latter in typical tracings is made up of three waves, of which the middle one is the most pronounced, and is known as the *dicrotic wave.* When the dicrotic wave can be felt with the finger, the pulse is spoken of as a *dicrotic pulse.* This is apt to *accompany* a low *blood-pressure. The dicrotic wave is caused by the sudden closure of the semilunar valves.*

The blood moves through the arteries in a series of pulses which grow less and less pronounced, until they are extinguished in the capillary district. Here the blood flows toward the veins with much friction, slowly and under comparatively low pressure. Instruments have been devised to measure rapid fluctuations of speed. They consist essentially of a needle, which is thrust through the wall of the vessel. The amount that it is deflected from the perpendicular by the movement of the blood is read on a graduated semicircle which is placed under the free end of the needle. It has been ascertained that the blood in the large arteries flows at a rate of from 250 to over 500 mm. a second. The *speed* in the veins is somewhat slower. In the capillaries it has been measured directly under the microscope, and some physiologists have observed it in the retinal capillaries of their own eyes. It flows from 0.6 to

Fig. 20.



Tracings of variations of rapidity and of pressure of blood in the carotid of a horse, obtained by Chauveau and Lortet. The line *v* represents the curve of the rapidity of the blood; and *p* the curve of arterial pressure. The figures and vertical lines represent corresponding periods in the tracings (McKendrick).

0.9 mm. a second. The speed and pressure of the blood rise and fall together in the arteries, but whereas the pressure falls continuously from arteries to veins, the speed falls from arteries to capillaries, but is increased again as it approaches the heart. The speed does not depend upon the pressure alone, but also upon the width of the blood-path. Whenever a vessel divides, the cross-sectional area of its branches is greater than that of the vessel itself. The *collective sectional area* of the capillaries is several hundred times that of the aorta, while the latter is half that of the venæ cavæ. The blood then flows swiftly through the arteries to the capillaries, where it performs its functions and is returned almost as quickly to the heart by the veins. It has been estimated that the blood remains about 0.6 of a second in a capillary ½ mm. long.

The **pulmonary circulation** differs in minor respects from the *systemic.* The total *friction* is *less,* in correspondence with which the right ventricular walls are far thinner than those of the left ventricle. Owing to the fact that the *pulmonary system* lies entirely within the thorax, it is *subjected* to the *negative pressure* which exists there, and the veins and arteries are opened by the elastic pull of the lungs. This tends to favor the flow in the veins and to hinder it in the arteries. The flow in the latter, however, is not affected much on account of the thickness of the arterial walls, so that, on the whole, the *negative pressure* in the *thorax,* increased with each *inspiration,* helps the *pulmonary circulation.* The capillaries are situated so close to the surface that they are exposed to atmospheric pressure. Every expiration presses the blood out of them, and so again the flow is favored.

The heart pumps the blood through all parts of the body, but the amount in any one portion depends upon the active dilatation or contraction of the vessels. That an *artery* may *dilate* was first shown by Bernard, who cut the *cervical sympathetic* of a rabbit on *one side* and found an *increased redness* of the skin of the ear and an elevation of the temperature of from four to six degrees, which persisted for months. If the peripheral end of the cut nerve is stimulated with a galvanic current, normal conditions are resumed, and which last only as long as the stimulus is applied. The existence of *dilator nerves* is placed beyond doubt by the results obtained upon the chorda tympani of the submaxillary gland. Nerves that bring about a dilatation of bloodvessels are called *vasodilator nerves*; those that cause a constriction are called *vasoconstrictor nerves. Both are present in the nerves of the sympathetic system, as well as in the cerebrospinal* and *spinal nerves. They also supply veins.* The *portal vein,* for instance, may be made to contract by stimulation of the peripheral end of the cut splanchnic. The changes in the capacity of the bloodvessels may be studied by direct inspection in many cases, but often it is more satisfactory to place a manometer in a branch of the artery that supplies the portion of the animal under observation. The principle underlying this is that the pressure in an artery depends upon the resistance to be overcome in its distal capillaries. Another method of studying vasomotor phenomena is to inclose a portion within an air-tight cylinder, which usually is filled with a liquid and is connected with a tambour. Changes in volume of the parts inclosed, due to variations in the amounts of blood, are transmitted to a tambour. Such an instrument is called a *plethysmograph.*

Vasoconstrictor and *vasodilator* nerves are usually found in the *same nerve-trunk.* Upon stimulation the effects of one may be entirely masked by the effects of the other, so that it becomes necessary to learn the differences between the two.

1. The vasoconstrictors are excited less easily than the vasodilators.

2. The after-effect of stimulation of the constrictors is shorter than that of the dilators.

3. Warming increases the excitability, and cooling decreases it, more in the constrictors than in the dilators.

4. The maximum effect of stimulation is reached more quickly in the constrictors than in the dilators.

5. The constrictors have a latent period of 1.5 seconds; that of the dilators is 3.5 seconds.

There is in the *medulla* in the anterior part of the *lateral columns* on each side of the median line a group of cells known as the *anterolateral nucleus* of *Clarke.* This is the situation of the *vasomotor centre.* It is *bilateral*, and occupies an area caudal to the corpora quadrigemina. When sections are made through successive levels of the bulb, the pressure of the blood begins to fall when a point is reached about 1 mm. caudal to the quadrigemina, and continues to fall until an area extending over the fourth millimetre has been reached. There is then no further fall. The *centre* continually sends impulses along fibres that extend to the nuclei of various cranial nerves, and also down the lateral columns of the cord to small cells situated at various levels in the anterior horn and lateral gray substances. From these cells axis-cylinders pass out through the anterior roots of the cranial and spinal nerves and enter the sympathetic ganglia. Here cells in turn send out processes that end on the muscle-fibres of the bloodvessels. *The evidence for the existence of subsidiary spinal centres is conclusive* It has been found that in a dog whose cord is severed at the junction of the dorsal and lumbar regions mechanical stimulation of the skin of the abdomen and penis will cause erections. This is a vasomotor reflex due to dilatation of bloodvessels of the penis through the *nervi erigentes.* Again, section of the cord in the dorsal region of a dog is followed by a vasodilatation of the arteries of the hind limbs. If the animal continues to live, the limbs are in time restored to their normal condition. Destruction of the lumbar cord now brings on a second dilatation. It must be assumed, therefore, that centres exist in the cord which normally are controlled by the bulbar centre, and that when severed from the latter will become gradually independent. There are, in addition to the vasomotor centres already mentioned, *centres* in the *sympathetic ganglia. Destruction of both bulbar and spinal centres does not destroy arterial tone completely.* For example, the lower portion of the spinal cord of a dog was removed for about 80 mm. The dilatation of the vessels of the hind limbs which followed was succeeded in time by a constriction, leaving the temperature of the limbs even cooler than normally

Long *oscillations* in blood-pressure curves due to vasomotor changes are called *Traube-Hering* waves. They *indicate* alterations in the *tonus* of the bloodvessels, and are caused by irradiations of impulses from other centres to the vasomotor centre. *Vasomotor reflexes* arise by impulses which come either from the bloodvessels or from the end-organs of sensory nerves. In the latter case the dilatation affects not only the portion from which the impulses come, but also parts functionally

FIG. 21.

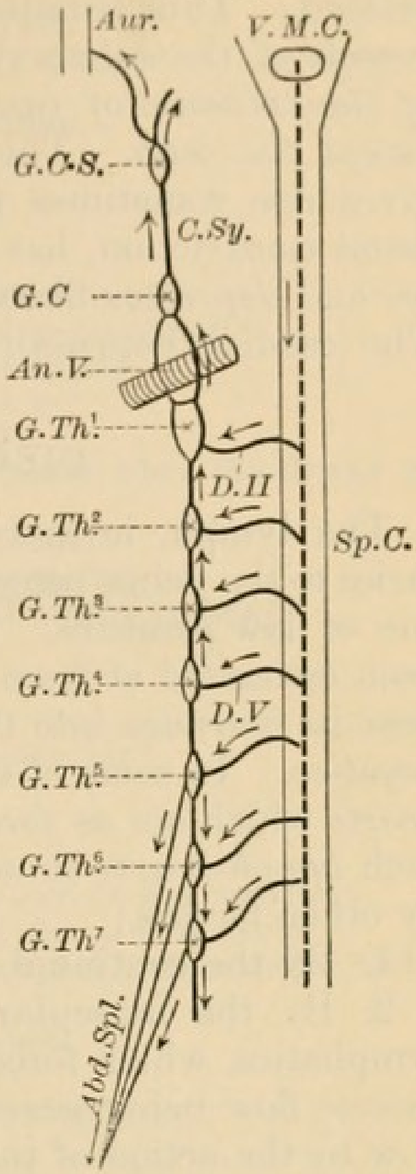


Diagram illustrating the paths of vasoconstrictor fibres along the cervical sympathetic and (part of) the abdominal splanchnic (Foster): *Aur.*, artery of ear; *G. C. S.*, superior cervical ganglion; *Abd. Spl.*, upper roots of and part of abdominal splanchnic nerve; *V. M. C.*, vasomotor centre in medulla; *C. Sy.* cervical sympathetic; *G. C.*, lower cervical ganglion; *G. Th.*1 to *G. Th.*7, the thoracic ganglia, first to seventh both inclusive; *D. II.* and *D. V.*, respectively the second and fifth dorsal nerve; *An. V.*, annulus of Vieussens. The paths of the constrictor fibres are shown by the arrows The dotted line in the spinal cord, *Sp. C.*, is to indicate the passage of constrictor impulses down the cord from the vasomotor centre in the medulla.

related. Thus stimulation of the tongue causes dilatation of the vessels of the submaxillary gland. *There is no sufficient evidence of the existence of vasomotor centres in any portion of the brain except the bulb.* The fact that stimulation of the same nerve gives rise sometimes to a reflex dilatation instead of the more usual constriction, has given rise to the conception of special *pressor* and *depressor* fibres. The former constrict, the latter dilate. The cardiac depressor nerve is a good example.

CIRCULATION OF LYMPH.

The lymph, in moving from the tissue-gaps and lymph-capillaries to the veins, passes from a point of relatively high pressure to one of low pressure. The *pressure* in the lymph-capillaries has been estimated at from 12 to 25 mm. of Hg.; in the *thoracic duct*, near its entrance into the veins, it is very near to *zero*, and often is *negative*. In some of the lower animals there are separate *lymph-hearts* which act as *force-pumps* to drive the lymph on. In *man* such *lymph-hearts* do *not exist*, but the movement is brought about by other factors:

1. By the continual formation of new lymph.
2. By the muscular movements of the body compressing the lymphatics, which force the lymph on in the proper direction, the *reverse* flow being *prevented* by *valves*. The *chyle* is aided in its flow by the action of the muscular fibres of the small intestine and also by the contractions of the villi. In the mouse the chyle has been seen to flow with the intermittent movements corresponding to the peristaltic waves. The *contractility* of the *walls* of the lymph-vessels themselves probably aid the flow.
3. The thoracic aspiration of the chest on inspiration draws the lymph into the thoracic cavity in the same manner as it draws the venous blood. The movement of the lymph is, without doubt, irregular, but in the course of a day a considerable amount is poured into the veins. An accumulation of lymph in the gaps of the tissues constitutes *dropsy*, and such tissue is said to be *œdematous*. A substance in solution injected into the blood can be detected at the mouth of the thoracic duct in from four to seven minutes.

QUESTIONS ON CHAPTER VIII.

Give the path of the blood through the body.
Give the path of the blood through the portal system.
What is meant by "circulation of the blood"?
What function is fulfilled by the circulation?
Whence does the heart derive its energy?
Define systole and diastole.
By what means is the blood forced in one direction only?
How much time is required by the blood to complete its circuit?
What different events take place during a cardiac cycle?
What are the changes in the size of the heart due to?
What is the condition of the heart when relaxed?
What changes take place in the heart during systole when the thorax is open?
How are these changes modified in the unopened chest?
Give the changes of color of the heart during contraction.
Why does the heart not move from the chest-wall during systole?
Where is the apex-beat felt?
What is meant by "negative impulse"?
Describe the sounds of the heart.
With what portions of the cardiac cycle do they coincide?
What is the cause of the heart-sounds?
Where can the sounds be best heard?
Discuss the rate of the heart-beat.
Describe the character of the contractions of the auricle and ventricle.
Give the times involved by the various events of the cardiac cycle.
What changes take place in regard to the time occupied by the cardiac cycle events when the heart-rate is quickened?
Describe the action of the valves during a heart-beat.
What is the pulse-volume?
How is the pulse-volume obtained? What is its value?
How is the work of the heart calculated?
How are intraventricular pressures determined?
How much work does the heart do in a day?
What are the relative pressures in ventricle and aorta?
Discuss endocardiac pressure curves obtained from ventricle with different methods.
What are the oscillations of the plateau due to?
In what way may the times of closure and opening of the valves be ascertained on intracardiac pressure-curves?
Define "period of reception" and "period of ejection."
Discuss periods of complete closure of the ventricles.
Can the ventricles alone maintain circulation?
What is the function of the auricles?
What variations in pressure are there in the auricles?
Discuss the entrance of the blood into the auricles from the veins.
Discuss the cause of the rhythmic activity of the heart.
What is the "cardiac excitation wave"?
Where does the contraction of the heart begin?
What is the effect of tying a ligature about the auriculoventricular groove?
What is the speed of the cardiac excitation wave?
What is the latent period of the frog's heart-muscle?
What is the time-value of the block of the heart's contraction?

What is the cause of the block? Give evidence.
What is meant by the refractory period of the heart-beat?
Define compensatory pause.
What are the sources of the nerve-fibres to the heart? Describe their course.
Discuss the effect of stimulation of the vagus on the heart-beat.
How does stimulation of the vagus affect a demarcation current from the auricle?
Discuss the end-apparatus by means of which the vagi inhibit the heart.
What is the effect of stimulation of the augmentor fibres on the heart-beat?
Give the lengths of the latent periods of inhibition and acceleration.
What evidence that afferent fibres run from the heart to the central nervous system?
Discuss the function and the effects of stimulation of the central cut end of the depressor nerve.
Are the vagi and depressor nerves continuously active?
How do weak and strong stimulation of sensory nerves affect the heart?
What effect has dilatation of the stomach on the heart?
Discuss the situation and action of the cardio-inhibitory centre.
Discuss the action of the accelerator centre.
Where are the ligatures of Stannius placed, and what effect do they produce?
What is the peculiarity in the distribution of bloodvessels to the heart?
What is an infarct?
How does the anæmia resulting from hemorrhage differ in its action from that caused by ligating the coronary artery?
How do the contractions of the heart favor the entrance of blood into the coronary arteries?
In what ways does the blood-supply to the heart affect its beat?
Discuss the constituents of the blood that cause the rhythmic activity of the heart.
How do the actions of potassium and calcium salts differ?
What is Ringer's solution?
What effect has carbon dioxide on the heart?
Why does the blood move from the arteries to the veins?
How is blood-pressure measured?
Describe a mercurial manometer.
What is the form of blood-pressure curves obtained from an artery?
What is meant by mean blood-pressure?
What are the mean blood-pressures in arteries, capillaries, and veins?
What is the cause of the high pressures in the arteries?
What are the causes of blood-pressure in capillaries and veins?
Why does the pressure decline from arteries to veins?
Why is there no pulse in the veins?
Discuss the action of subsidiary forces that aid the heart in circulation.
What is the pulse? Its cause?
How does the character of the pulse vary?
What is a sphygmogram?
What is the dicrotic wave? Its cause?
How are rapid changes in the velocity of the blood measured?
Give the rate of flow of the blood and the causes for its variations.
How long does the blood remain in the capillaries?
How does the pulmonary differ from the systemic circulation?
What governs the distribution of the blood in the body?

What are vasomotor fibres? Give proofs that they exist.
Are vasomotor fibres present in veins?
Give the means of distinguishing between dilator and constrictor fibres.
Discuss the location of the vasomotor centre and its communications.
What is the evidence that spinal and sympathetic vasomotor centres exist?
What are Traube-Hering waves and their cause?
How do vasomotor reflexes arise?
What are pressor and depressor fibres?
Discuss the factors that cause the flow of the lymph.
What constitutes dropsy?
What is the rapidity of the lymph circulation?

CHAPTER IX.

RESPIRATION.

THE expression *respiration* embraces two distinct ideas. It may mean the *entrance* of *oxygen* into and the exit of *carbon dioxide* from an animal, or it may have *reference* to the *visceral*—muscular and pulmonary, etc.—*movements* by which these *gases* are *caused* to *flow* in and out of the *lungs*. The lungs of man are of vital importance in the interchange of oxygen and carbon dioxide, while the *skin* is of but *subsidiary importance.* This condition of affairs is reversed in the frog. The *lungs* consist of an enormous number of *air-vesicles* or *alveoli* which communicate by means of a series of passages with the trachea and the external air, Their total *area* is more than one hundred times the superficial area of the skin, and their walls form a delicate partition in intimate *relation* to the *blood-capillaries* of the *lung.* Before *birth* the *lungs* are airless (*atelectatic*), but after having once been expanded, they never regain their atelectatic condition, because during *collapse* the *passages close first* and so imprison some air in the alveoli. The lungs are enclosed in the air-tight thorax, and separated from its walls by a double layer of *pleura.* The *thorax* of the *child* grows *faster* than the *lungs*, so that the *latter* become *distended* in an *air-tight* cavity. Whenever the thorax is opened, the lungs, owing to the *elasticity* of their structure, immediately shrink together. It follows, therefore, that the lungs are always tending to shrink and thus pulling away from the thoracic walls and *diaphragm.* This produces a *pressure* in the pleural cavity below that of the *atmosphere*, and it is called a *negative pressure* whenever atmospheric pressure is regarded as a standard. The negative pressure has been found to vary greatly under different conditions, but may be put at minus 6 mm. of Hg at the end of a quiet expiration, and at minus 9 mm. of Hg at the end of a quiet inspiration. During forced inspiration the value may reach minus 40 mm. of Hg. The pressure in the pleural cavity—*i. e.*, outside of the lungs and within the thorax—is known as *intrathoracic* pressure, while that within the lungs and respiratory passages is called the *intrapulmonary* pressure. The *variations* in pressure are caused by *changes* in the *capacity* of the *thorax*, which may enlarge in all directions. It is obvious that when the thorax increases in size the decreased pressure within causes the entrance of air from the outside, where it is at a higher pressure. The air rushes through the trachea and inflates the lungs. This constitutes an *inspiration.* The opposite process, or an expulsion of air by a decrease in the size of the thorax, is *expiration*, and both together form respiration. The lungs during respiration are entirely passive, and merely follow the thoracic walls because the atmospheric pressure acting on their inner surfaces is greater than that between the lungs and the thoracic walls. The pleuræ are moistened with lymph, and slide over each other without friction.

Inspiration is an active process brought about by certain muscles which, by their action, enlarge the thorax in a vertical, anteroposterior, and lateral direction. The upper part of the thoracic cage being fixed, the vertical diameter is increased by the descent of the diaphragm in contracting. Other muscles act on the ribs, so that they turn on their axes, with the result that their sternal ends are raised up and carried forward, enlarging the *anteroposterior diameter ;* at the same time the direction of the axes of the ribs causes them to rotate outward and upward, so increasing the *lateral diameter.* The chief *muscles of inspiration* are the diaphragm, the scaleni, the serrati postici superiores et inferiores, the levatores costarum breves et longi, and the external intercostals and interchondrals. The *diaphragm* projects into the thoracic cavity in the form of a flattened dome. During contraction it descends from 5.5 to 11.5 mm. in quiet respiration, and about 42 mm. in deep inspiration. There is a tendency for the diaphragm to pull in its points of attachments—the lower ribs, with their cartilages, and the lower portion of the sternum, but usually this is counterbalanced by the pressure of the abdominal viscera. The serrati postici inferiores assist the diaphragm by fixing the ninth, tenth, eleventh, and twelfth ribs. The scaleni fix the first and second ribs. The serrati postici superiores help to fix the second rib, and raise the third, fourth, and fifth ribs. The external intercostals and interchondrals and the levatores costarum elevate and evert the first to the tenth ribs. They serve also to give the intercostal tissue a proper tension.

During *forced inspiration* additional muscles are brought into play to permit a more powerful inspiratory act. Besides the muscles already enumerated, the following are brought into play: The trapezei and rhomboidei fix the shoulders; the pectorales majores and minores, acting from the fixed shoulders, draw the sternum and ribs upward; the sternomastoidea fix the upper part of the chest; the erectores spinæ stiffen the vertebral column; the serrati postici inferiores, quadrati lumborum, and sacrolumbales draw the lower ribs downward and backward.

At the close of inspiration the various muscles that raised the thorax gradually relax, and by its weight the thorax compresses the lungs and expels the air. In addition there is an active recoil of the elastic tissue in the substance of the lung, which has been put on the stretch during inspiration. Also during inspiration the interosseous portions of the internal intercostal muscles were put on a stretch; when *expiration* begins these muscles contract, but their contraction is not sufficiently forcible to pull the ribs down, and the only purpose of this contraction seems to be to keep the intercostal tissues tense and thus prevent bulging of the intercostal spaces. During inspiration each costal cartilage is twisted in the direction of its long axis by the eversion of the ribs. During expiration the costal cartilage tends to untwist itself. It may be said there are *no muscles* of *quiet expiration. Forced expiration* is accomplished by the intervention of many muscles.

The interosseous internal intercostals act forcibly in drawing down the ribs when the lower part of the thorax is fixed; the abdominal muscles fix the lower part of the thorax and press the abdominal contents upward; the levatores ani and perineal muscles hold the floor of the pelvis rigid against abdominal pressure; the triangularis sterni draws the costal cartilages down.

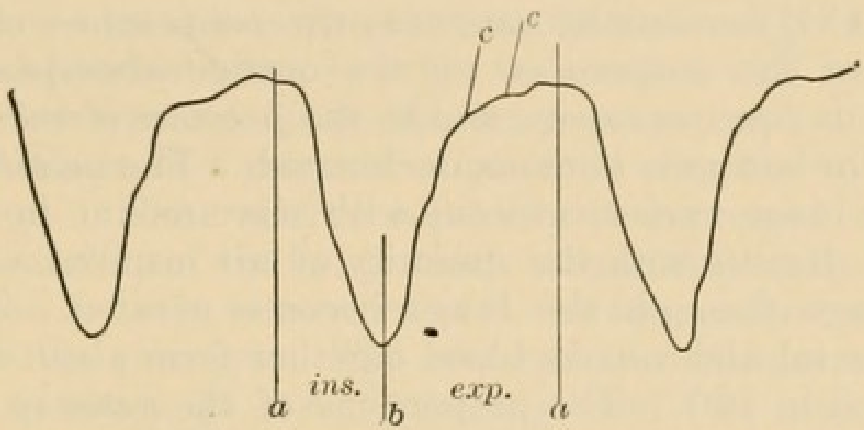
A number of movements which take place in connection with the ingress and egress of air to the lungs are known as *associated respiratory movements.* The nostrils may dilate with inspiration and return to their passive condition with expiration. The soft palate moves to and fro; the glottis is widened and narrowed. During labored breathing the mouth is opened and the muscles of the face become active; the soft palate is raised and the larynx is lowered.

It is stated that of the two types of respiration, "thoracic" and "abdominal," the former is more marked in women and the latter in men. This is true in the sense that women increase the antero-posterior and the lateral diameters of the chest more than do men, owing not so much to functional differences between the sexes, as to habits of dress, etc. Adult males and children of both sexes use the diaphragm almost exclusively in quiet inspiration.

When the ear is placed in contact with the chest-wall or a stethoscope is used, a *respiratory murmur* will be heard—fairly marked during inspiration; short and faint during expiration. It varies in different parts of the chest-wall, being loudest over the large bronchi. The changes in these murmurs incident to disease of the respiratory tract are characteristic of different pathological changes, and it is upon the recognition of these alterations that the value of auscultation depends. The force of the inspiratory muscles is greatest in people of medium height, being equivalent on the average to a column of mercury three inches high. It diminishes in people above and below this height. The force of expiration is about one-third greater; but the variations are not so regular, since the expiratory muscles are used for other purposes, so becoming stronger. The value of *breathing* through the *nose* instead of the mouth consists in that it warms the air and moistens it; foreign particles are partially removed and noxious odors detected.

Normal respirations may be studied in man by means of the stethograph or the pneumograph of Marey. It is found that *inspiration* and *expiration* follow each other *without pause;* that *inspiration* is *shorter*, and that the *curves* of each differ in minor respects only. In *pathological cases* there may be *expiratory* or *inspiratory* pauses. The *Cheyne-Stokes* respiration consists of groups of ten to thirty respiratory movements, which are shallow at first, but become deeper and deeper until a maximum is reached, after which they gradually become shallow again. The intervals between the groups last from thirty to forty-five seconds. The time-ratio of inspiration to expiration may be put at 5 : 6. In infants the ratio is 1 : 2 or 3. The *rate* of respiration varies with the most diverse internal and external conditions. In the normal adult the rate is about 18 cycles a minute when the body is in repose. The ratio to the pulse-rate may be put at 1 : 4. During quiet respiration the inflow and outflow of air, which amounts to about 500 c.c., or 30 cubic inches, is known as the *tidal air*. It does not go lower than the large bronchi. The volume of expired air, owing to its increased temperature, is greater than that inspired, but the actual quantity is less. *Complemental air* (about 1500 c.c.) is the amount that can be inspired after an ordinary inspiration.

FIG. 22.



Tracing of thoracic respiratory movements obtained by means of Marey's pneumograph (Foster). A whole respiratory phase is comprised between *a* and *a*; inspiration, during which the lever *descends*, extending from *a* to *b*, and expiration from *b* to *a*. The undulations at *c* are caused by the heart's beat.

The *supplemental* or *reserve* air (about 1500 c.c.) is the amount that can be expelled after an ordinary expiration. *Residual air* is the volume that remains in the lungs after the most forcible expiration (1500 c.c.). *Vital capacity* is equal to the sum of the complemental, tidal, and supplemental air. *Stationary air* is the amount that remains after the ordinary expiration, and is equal to the sum of the reserve and the residual air. The *lung capacity* is the total quantity of air that can be held after the most forcible inspiration, and is equal to the sum of the vital capacity and residual air (4500 c.c.).

It may easily be calculated that man in twenty-four hours respires about 10,800 litres of air, which is equal to a space $7\frac{1}{3}$ *feet in three dimensions.* The ratio of the quantity of oxygen absorbed to the carbon dioxide given off is known as the respiratory quotient. While in the lungs the air loses 4.78 volumes of O_2 in 100, and gains 4.34 volumes of CO_2 in 100, so that the value of the *respiratory quotient*, $\frac{4.34}{4.78}$, is equal to 0.901. This value is subject to great variations, because the production of carbon dioxide is to some extent independent of the amount of oxygen absorbed. This is so for several reasons:

1. CO_2 may result not only from *oxidation* changes, but from *intramolecular* splitting, so that the *elimination* of CO_2 in normal quantity may *continue* when *absorption* of O_2 has entirely *ceased.*

2. Some food-stuffs require more O_2 for their complete oxidation than others.

The *air* during its sojourn in the *lungs* is *altered* in addition to its O_2 and CO_2 contents by *assuming* the *temperature* of the body, *regardless* of the *temperature* of the outside *atmosphere;* by an *increase* of its aqueous *vapor;* and by the *presence* of *volatile organic* bodies. The *nitrogen* remains unchanged. The *quantity* of *water* lost by the lungs varies *inversely* with the amount in the atmosphere, and *directly* with the quantity of air inspired. The blood in its passage through the lungs becomes aërated. The O_2 and CO_2 in arterial and venous blood together form about 60 volumes of the blood in 100. The proportions of the gases to each other are constant in the arterial blood, but vary in the venous blood in different localities.

The *oxygen* of the air enters the alveoli of the lung, passes into the blood through the delicate epithelial walls, and is carried to the tissues, where it is taken up by the cells. Very little is used up in the blood. The CO_2 given off by the cells is carried to the alveoli of the lungs by the blood, and is there given off. But the *air* that is inspired does not reach the *alveoli* directly, because the *lungs* are *never completely emptied* of air. It becomes necessary, therefore, to consider the methods by means of which the *interchange* of *gases* is brought about. The *air-currents* that are set up *mechanically* probably help to equalize the composition of the air in the lungs. Besides, the heart with each contraction as it shrinks in size expands the lungs slightly and causes a movement of air into the chest synchronous with its beat. These are known as *cardiopneumatic movements.* In addition to the mechanical factors, the physical process of *diffusion* is of great importance.

The rapidity of diffusion depends, among other things, upon the differences of the partial pressures of the gases in various regions. If the total atmospheric pressure is 760 mm. Hg and O_2 forms $\frac{1}{5}$ of the gaseous constituents of the air, then it will exert a pressure of its own equal to $\frac{1}{5}$ of 760, or 152 mm. Hg; and carbon dioxide, forming 0.04 volume in 100 of the air, will exert a pressure of $\frac{0.04}{100}$ of 760, or about 0.30 mm. Hg. It has been estimated that the partial pressures of O_2 and CO_2 in alveolar air are equal to 100 and 23 mm. Hg, respectively. The differences in partial pressures, therefore, will cause O_2 to diffuse toward the alveoli, and CO_2 from the alveoli to the outside air.

The *gases* in the blood are not only in *solution*, but also in weak *chemical combination*, so that diffusion from the alveoli into the blood and *vice versâ* is somewhat complicated. The amount of a gas that is absorbed when brought in contact with water depends upon the relative *solubility*, the *temperature*, and the *barometric* pressure. Each, of a mixture of gases, is absorbed independently of the others. The relative solubility is expressed by the *coefficient of absorption* of the fluid, which is experimentally determined, and is found to be in *inverse* ratio to the *temperature* and in *direct* relation to the *pressure*. The absorption-coefficient of water for O_2, as an example, at zero Centigrade and 760 mm. pressure, is equal to 0.0489. This means that under the given conditions of temperature and pressure 1 volume of water will take up 0.0489 volume of O_2. Since, however, the O_2 forms but $\frac{1}{5}$ of the quantity of the air, water will absorb from the atmosphere only $\frac{1}{5}$ of 0.0489 volume, which is equal to 0.009+, or nearly 0.01 volume. As the partial pressure of O_2 is raised or lowered, O_2 will leave or enter the water, so that the gas in solution is said to be under *tension*. The absorption-coefficient of blood for O_2 is about that of water, but at the bodily temperature is decreased to less than $\frac{1}{2}$. Every volume of blood should, therefore, contain $\frac{1}{2}$ volume of oxygen in 100; but experiment shows that there is much more present. Upon subjecting blood to a vacuum, O_2 is given off according to the laws of partial pressures and tensions until the pressure is lowered to $\frac{1}{10}$ of an atmosphere. From $\frac{1}{10}$ to $\frac{1}{30}$ of an atmosphere the great bulk of O_2 is given off. Below $\frac{1}{30}$, physical laws, as given above, again prevail. The explanation of this is that the O_2 is held in chemical combination with the hæmoglobin, and is set free at $\frac{1}{10}$ to $\frac{1}{30}$ of an atmosphere. This pressure is termed the *tension of dissociation.*

Venous blood contains 45 volumes of CO_2 in 100. Of this, 5 per cent. is in simple solution; 10 to 20 per cent., in firm chemical combination; and 75 to 80 per cent., in loose chemical combination. The largest amount is connected with the red blood-cells. While the CO_2 absorbed by water increases regularly with the increase of pressure, that absorbed by solutions of hæmoglobin is relatively large for low pressures and small for high pressures. The quantity in the blood is in excess of what physical laws will permit. It is found that the partial pressures of O_2 and CO_2 in venous blood are about 22 and 41 mm. Hg, respectively. Comparing the pressures of O_2 in the lung, alveoli, blood, and tissues (152, 100, 22, 0), with those of CO_2 (0.3, 23, 41, 58), it is seen that O_2 and CO_2 will diffuse in opposite directions. Pure oxygen at a pressure of 1 atmosphere may be breathed without injury. At higher pressures it acts as an irritant and produces inflammation. When less than 13 volumes of oxygen are present in the air in 100, it is insufficient to maintain the life of man. Pure CO_2 is fatal in from two to three minutes. N, H, and CH_4 cause no inconvenience if sufficient O_2 is present. Nitrous oxide and ozone produce anæsthesia, and finally death. Air containing 2 volumes of CO_2 in 100 is rapidly fatal.

Eupnœa is normal, easy breathing. *Apnœa* is a condition of suspended breathing. *Hyperpnœa* is increased respiratory activity. *Polypnœa* is a condition of deep, labored breathing. *Asphyxia* is characterized by convulsive breathing, followed finally by infrequent and feeble respirations. Apnœa can be induced in man or animals by rapid, deep respiratory movements or by forcing air into the lungs with a bellows. It is brought about by using pure O_2 or H_2; lasting for a longer time when the former is used. But the fact that it can be produced with H_2 shows that the condition cannot be due to a superabundance of O_2 in the blood. When the vagi are cut, H_2 no longer brings about apnœa. It is believed that in the violent inflation of the lungs the sensory endings of the pneumogastric in the lungs are stimulated, which produces a temporary paralysis of the respiratory centre. The increased amount of O_2 in the alveoli and blood, however, prolongs the condition. Hyperpnœa is produced usually by the products of muscular activity which excite the respiratory centre. The nature of these products is unknown, but the decreased alkalinity of the blood indicates that they may be of an acid character. Polypnœa is due to direct stimulation of the respiratory centre through the temperature of the blood or through reflex excitation of cutaneous nerves. Dyspnœa may be the result of a deficiency of O_2, or due to an excess of CO_2, in the blood. Oxygen dyspnœa is characterized by frequent deep inspirations; carbon dioxide dyspnœa, by infrequent, vigorous expirations. In the former, death is severe; there is a marked rise of blood-pressure and violent convulsions. In the latter, death takes place more quietly, the blood-pressure rises less, and no motor disturbances are present. Cardiac and hemorrhagic dyspnœas are due to a lack of O_2 chiefly.

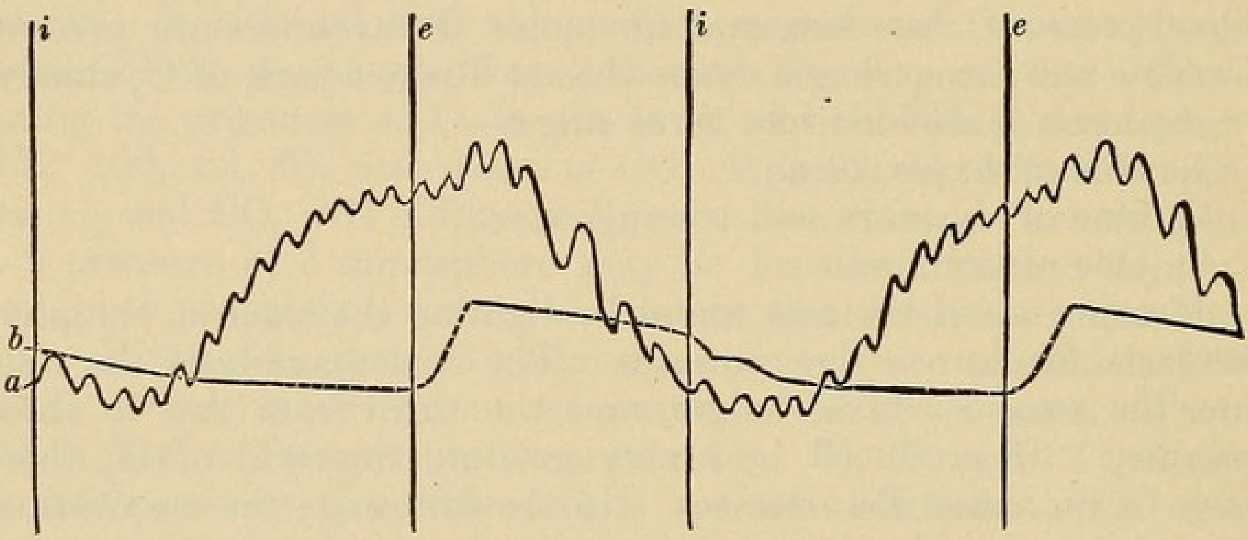
Asphyxia is divided into three stages—

1. One of hyperpnœa;
2. One of dyspnœa and convulsions;
3. One of collapse.

If asphyxia is brought about by ligating the trachea, the process lasts for four or five minutes. The first stage lasts one minute, the second a little longer, and the third from two to three minutes. If produced by a very gradual deprival of O_2, there may be no motor disturbances. In the first stage the respirations are increased in depth and frequency. Inspiration is pronounced. During the second stage expirations become violent and convulsive. During the third stage respirations are shallow, the pupils dilated, motor reflexes disappear, consciousness is lost, convulsive twitches are present, the limbs are stretched and rigid, the head and body arched backward, and finally the heart ceases beating. During the first and second stages the gums, lips, and skin become blue, the heart-beats are less frequent, and the blood-pressure is increased. During the third stage a general depression ensues. After death the blood is almost black, the arteries empty, and the veins and lungs congested. Death from drowning is due usually to asphyxia, but sometimes is due to a cessation of the activity of the heart.

The respiratory movements have a marked effect upon the blood-pressure. In the carotid artery with every inspiration it rises, and with every expiration it falls (Fig. 23). The two events are, however, not exactly synchronous, the pressure-changes lagging a little behind the respiratory changes. The effects are readily understood when it is remembered that the thoracic cavity is an air-tight chamber, and that the elastic fibres of the lung which fill it are constantly pulling on the heart and bloodvessels. This effect is increased during inspiration when the thorax is enlarged. The pressure of the blood is consequently lowered in the intrathoracic vessels, and the blood rushes in from extrathoracic regions, where it exists under atmospheric pressure. The effect of the pull of the lungs is greater upon the flaccid walls of the veins than upon the more rigid walls of the arteries, so that the inflow through the

FIG. 23.



Comparison of blood-pressure curve with curve of intrathoracic pressure (Foster) (dog): *a* is the blood-pressure curve taken by means of a mercury manometer; it shows the respiratory undulation, the slower beats on the descent being very marked. *b* is the curve of intrathoracic pressure obtained by connecting one limb of a manometer with the pleural cavity. Inspiration begins at *i*, expiration at *e*. With the beginning of inspiration (*i*) the expansion of the chest causes a marked fall of the mercury in the intrathoracic manometer; but the effect soon diminishes, since the lessening of intrathoracic pressure does not bear on the manometer alone, but on the lungs also; and as the lungs expand more and more the fall in the mercury becomes less and less until toward the end of inspiration the curve becomes very nearly a straight line. Conversely, the return of the chest at the beginning of expiration (*e*) produces at first a marked rise of the mercury in the manometer; but this soon ceases as the air leaves the chest and the lungs shrink, whereupon the mercury falls slowly.

veins is favored more than the outflow through the arteries is hindered. The pulmonary circulation is favored also by the increased negative pressure during inspiration, since the lung fibres pull with greater effect on the pulmonary veins than on the pulmonary artery, which produces a greater difference in pressure in the two vessels, so accelerating the flow of blood. During expiration there is not only a return to the former condition, but the intrapulmonary capillaries are actively squeezed between the air in the lungs and the thoracic walls. This again aids the flow in its passage from the right to the left side of the heart. The pressure which inspiration through the descent of the diaphragm exerts on the abdominal organs will force the blood along the arteries toward the limbs and check somewhat its exit from the thorax. In like manner the pressure on the veins will force the blood into the thorax and momentarily check its flow from the lower extremities. Finally, the heart-rate is increased distinctly during inspiration. The combined action of the above factors is to draw an increased amount of blood into the thorax and to the left ventricle, which, having more blood to pump, raises the blood-pressure.

Respiration continues after the destruction of the entire brain except the bulb. The location of the *centre* would therefore seem to be in the *medulla*, but its exact location is still in doubt. It is somewhere in the lower *portion* of the *bulb*. The area described by Flourens as the *nœud vital*, or vital knot, consists of a *collection* of *nerve-fibres* which arise from the roots of the tenth, eleventh, ninth, and fifth nerves. The *centre* is *bilateral*, one-half being situated on each side of the median line. The two parts are intimately *connected* by *commissural* fibres, but may be separated by a section in the median line, after which they act more or less independently of each other. Each half is connected with the *lung* and *muscles* of *respiration* of the *corresponding side*, so that, if destroyed, the movements on its own side cease. If one *pneumogastric nerve*, after a median section of the respiratory centre, is cut, the *respirations* on that side are *slower* and *inspirations* become *vigorous*. When, however, the *commissural fibres* are *intact*, *excitation* or *inhibition* of one side *affects* the *other* as well. After section of one *vagus*, for instance, the *respirations* are *slower* and the *inspirations stronger* on *both sides*. *Excitation* of the *central* end of the cut nerve *increases* the *respiratory* rate of *both sides*. Each half of the centre is divided into an *inspiratory* and an *expiratory* portion. *Weak stimulation* of the *inspiratory part increases* the rate of breathing, while a *strong stimulation arrests* respiration in the *inspiratory* phase. Stimulation in like manner of the expiratory part of the centre diminishes the rate, and finally causes an arrest in the expiratory phase. *Other respiratory centres* have been described. One in the *tuber cinereum*, known as the *polypnœic centre*, is *excited* by a *high external temperature*, and causes a very rapid rate of breathing. *Destruction* of the tuber cinereum *stops* all *acceleration* by *heat*. A *centre* in the *optic thalamus* in the *floor* of the *third ventricle* is excited by impulses from the nerves of sight and hearing. It is an *accelerator* centre. *Centres* have also been described in the *anterior* and *posterior corpora quadrigemina* and in the *brain-cortex*. The *existence* of these, as well as of those described in the *cord*, is *doubtful*.

After *section* of the *cord* in the *cervical region*, of the *posterior roots* of the *cervical spinal nerves*, of the *medulla* from all parts lying above it, of the *vagi* and *glossopharyngeal* nerves, the respiratory movements still continue, which indicates that the centre is *automatically active*. The *rhythm* may be affected by the *will* and by the *emotions*, by the *quality* and the *temperature* of the blood, and by *afferent impulses* coming over *various nerves*, but particularly the tenth. Section of *one vagus slows* and *deepens* the *respiration*. *Stimulation* of the *central* cut end with stimuli of proper strength *restores* the *rate*, if it does not further increase it. It is believed, therefore, that while the blood alone may bring about rhythmical discharges, these are controlled by impulses coming over afferent nerves. Among the latter are the fifth, ninth, tenth, and various cutaneous nerves. *Excitation* of the *superior laryngeal* fibres causes increased expiratory movements, and perhaps an arrest in the expiratory phase. Excitation of the glossopharyngeal nerves has a similar effect, but the inhibitory influence lasts for three or four successive respiratory acts. *Irritating* gases affect the *trigeminal* nerve-endings in the *nose* or the *endings* of the *tenth nerve* in the larynx and lungs. The effect of the excitation of the cutaneous nerves may be seen in a *cold douche*, which primarily *increases* the respiratory rate and *may cause* its *cessation*.

The *efferent* respiratory nerves are the *phrenics*, which supply the *diaphragm;* certain *spinal nerves* supplying respiratory muscles, as the *pneumogastrics*. Section of *one phrenic* causes *paralysis* of the diaphragm on the *corresponding* side. Section of the *cord* just below the fifth cervical nerve stops the costal movements, but does not affect the diaphragm, because the *nuclei* of *origin* of the phrenics lie just above the section. If the section had been placed somewhat higher, respiration ceases entirely, but the associated movements of the larynx and face continue. During *forced breathing* the *facial*, *hypoglossal*, and *spinal accessory* nerves are called into action. During *uterine life* the *respiratory centre* is in an *apnœic* condition, on account of a *low irritability* of the *respiratory centre* and the large amount, relatively, of oxygen in the blood. Cases have been seen in which the child has made respiratory efforts while within the intact fœtal membranes. Such an attempt draws some of the amniotic fluid into the nose, causing inhibition of all further efforts. *After birth, when spontaneous respiration is about to take place, it is well to remove all mucus or other matter from the nose, to avoid inspiration of them.*

The *nerves* which are distributed to the *lung tissue* are the *pneumogastrics, sympathetic,* and *dorsal* nerves. Among the pneumogastric fibres are *bronchoconstrictors* and *bronchodilators. Excitation* of *one vagus* causes a *constriction* of the bronchi of both lungs; *section* of the nerve causes a *dilatation* of the *bronchi* in the *corresponding* lung; *stimulation* of both *peripheral* and *central* ends of the cut nerve causes *constriction* of the bronchi of both lungs, which is more *pronounced* with the stimulation of the *peripheral* end. *Asphyxia* causes *bronchoconstriction*, but not after the vagi are sectioned. The *sympathetic* fibres are *trophic* and *vasomotor* in *function.*

There are a number of involuntary and voluntary special respiratory acts, largely reflex, which result from modifications of inspiration and expiration.

Sighing.—This results from a prolonged inspiration, the air passing noiselessly through the larynx and being expelled rather suddenly.

Hiccough.—This resembles sighing, but the inspiration is sudden, due to a spasmodic action of the diaphragm.

Cough.—This results from a deep inspiration followed by a forced and sudden expiration, during which the glottis is closed momentarily by the spasmodic action of the vocal cords.

Sneezing.—In this case after a deep inspiration the air is directed through the nasal passages by a sudden and forced expiration.

Speaking.—In this case there is a voluntary expiration, and the vocal cords being rendered tense by their muscles vibrate as the air passes over them, producing sound.

Singing.—This varies from speaking only in the differing tension and position of the vocal cords, and the consequently different sounds produced.

Sniffing.—This results from rapid repeated but incomplete nasal inspirations.

Sobbing.—This consists of a series of convulsive inspirations, during which the glottis is more or less closed.

Laughing.—This results from a series of short and rapid expirations.

Yawning.—This is an act of inspiration more or less involuntary accompanied by a stretching of various facial muscles.

Sucking.—This is caused chiefly by the depressor muscles of the os hyoides, which, by drawing down and back the floor of the mouth, produces a partial vacuum in it..

QUESTIONS ON CHAPTER IX.

What two different meanings are included in the term respiration?
What purpose do the lungs of man serve?
What is the total area of the alveoli of the lung?
What is the condition of the lungs before birth?
What are inspiration and expiration?
Why do the lungs follow the walls of the thorax?
In what directions is the thorax enlarged in inspiration?
Why does the air enter the lungs in inspiration?
Tell in detail by what mechanism the thorax is enlarged in inspiration.
What are the chief muscles of inspiration?
Give the action of each.
How is expiration brought about?
Give the action of the muscles of forced expiration.
What are associated respiratory movements?
Describe the character and significance of respiratory sounds.
What is the force of the respiratory muscles equal to?
What is the value of nasal breathing?
Describe a respiratory tracing.
Describe the Cheyne-Stokes respiration.
What are the relative lengths of inspiration and expiration?
What is the rate of breathing, and how is it varied?
Define and give values of tidal air; complemental and supplemental air; residual air and vital capacity.
What is the stationary air equal to?
What is the lung capacity?
What volume of air passes through the lungs of man in a day?
What is the respiratory quotient? Explain why it varies.
How is the air altered in the lungs?
How does the quantity of water vapor given off by the lungs vary?
How is the carbon dioxide held in the blood?
What is the evidence that CO_2 is held in chemical combination?
Compare the partial pressures of O_2 and CO_2 in the external air, alveoli, blood, and tissues.
What is the effect of breathing pure oxygen?
Give the effects of breathing other gases.

Define the terms—eupnœa, apnœa, hyperpnœa, polypnœa, dyspnœa, and asphyxia.

Discuss apnœa and its causes.

How is hyperpnœa produced?

How is polypnœa produced?

What is dyspnœa due to?

Discuss asphyxia in detail.

What is death by drowning due to?

Give the time-relations of the respiratory movements to the respiratory blood-pressure changes.

Explain in detail how respiratory movements produce changes in blood-pressure.

What are the changes in the heart-rate during respiration?

Discuss the respiratory centre in the medulla.

What can be said of other respiratory centres?

What is the proof that the bulbar respiratory centre is automatically rhythmic?

What happens to the blood in its passage through the lungs?

What is the amount of O_2 and CO_2 in the blood?

What factors bring the O_2 of the air to the alveoli of the lung?

What are cardiopneumatic movements?

Explain what is meant by the partial pressure of a gas.

Explain in detail the diffusion of O_2 from the outer air into the alveoli.

In what ways are the gases of the blood held?

What factors govern the amount of a gas absorbed by a liquid?

What is meant by the coefficient of absorption?

What is the absorption-coefficient of serum?

In what way is the gas in the blood under tension?

How much oxygen should the blood take up according to physical laws? Does it in reality hold more or less?

How is the discrepancy explained?

What is meant by tension of dissociation?

How may the respiratory rhythm be affected?

What is the effect upon the respiration of sectioning the vagi? Of stimulation of the central end?

What are the afferent nerves that control the activity of the respiratory centre?

What is the effect of excitation of the superior laryngeal and glossopharyngeal nerves?

Through what nerves do irritating gases affect respiration?

What afferent nerves are involved in respiration?

What is the effect of sectioning a phrenic nerve?

Give the effect of sectioning the cord just below the fifth spinal nerve.

Discuss the condition of the respiratory centre in the fœtus.

What nerves are distributed to the lung tissue?

Discuss the kinds of fibres in the vagus which are supplied to the bronchi.

What does stimulation of the central and peripheral ends of the fibres bring about?

Define—sighing, hiccough, cough, sneezing, speaking, singing, sniffing, sobbing, laughing, yawning, and sucking.

CHAPTER X.

ANIMAL HEAT.

Warm-blooded and cold-blooded animals are respectively designated as *homothermous* and *poikilothermous.* The former have a body-temperature that varies very little from a certain *normal* which is *characteristic* for the *species*, while the *temperature* of the *latter varies* directly with the *medium* in which they live, although usually from a *fraction* to *several degrees higher.* Man is warm-blooded—the *normal temperature* being about 98.5° F. (37° C.). The *temperature* is *not invariable,* and in the *internal organs* may be as *high* as *100° F.* under *normal* conditions. In the *rectum* the temperature is about 1 degree F. higher than in the *mouth* or *armpit.* The *warmest blood* in the body is that coming from the *liver* during *digestion*, and the *coolest* is that *coming* from *exposed* parts, such as the *tips* of the *ears* and the *nose.* In *health* the *temperature varies slightly* with the *external temperature, age, exercise, sex, constitution,* etc. The temperature of a newborn child is about 37.86° C. *In the adult there is a diurnal variation of 1 to 1.5 degrees F.; being lowest in the morning and highest late in the afternoon.* This *corresponds* to the usual temperature-ranges in *fever.* In ordinary pathological conditions the temperature does not remain long at a point below 95° F. nor above 105° F. without fatal results. Under conditions of prolonged exposure to cold and the algid stage of cholera, recovery has occurred after a bodily temperature as low as 75° F. On the other hand, in some cases of extreme fever, as from sunstroke, recovery has been noted after a temperature of 110° to 112° F.

It has been proved that the *source* of *animal heat* is the *potential energy* of the *foods.* The latter is converted into heat either directly as the result of chemical decompositions or indirectly through muscular movements, friction, etc. About 90 per cent. is formed directly. The *heat* liberated by an animal may be *measured* by calculating the *potential* energy from the *food* ingested or from the *amounts* of *oxygen* absorbed and *carbon dioxide* given off. This is *indirect calorimetry. Direct calorimetry* consists in measuring the heat directly by means of a *calorimeter.* A calorimeter is an apparatus by means of which the amount of heat given off by an animal may be measured. It usually consists of two concentric cases separated by ice, air, or water, and provided with thermometers and gasometers so arranged as to insure proper ventilation to the animal which is placed in the inner case. The object of calorimetry is to determine the quantity of heat that is dissipated in a definite time. A certain amount of the heat is taken up by the apparatus, some is given to the air that passes through the calorimeter, and finally some is lost in the evaporation of water.

To determine the amount imparted to the apparatus, it is necessary before using to determine its *calorimetric equivalent*, which is done by burning alcohol within it until the temperature has been raised 1 degree C. One gramme of alcohol will yield about 7000 calories of heat, so that if 5 grammes of alcohol are required to raise the temperature of the calorimeter 1 degree C., then the quantity of heat absorbed would be equal to 5 times 7000, or 35,000 calories. This is the *calorimetric equivalent*. If an animal has raised the temperature of the calorimeter 10 degrees C., the quantity of heat that it has given off would be equal to 10 times the calorimetric equivalent, or to 350 kilogramme-degrees. The quantity of heat given to the air is determined by measuring the amount of air passing through the calorimeter, and its temperature on its entrance and exit. The volume of the air must be corrected for the increased temperature and then reduced to weight, after which it is multiplied by the specific heat of air at 0° C., and then by the number of degrees of the increase of temperature. By *specific heat* is meant the heat required to raise the temperature of any substance 1 degree C., and is usually compared to water as a standard. The specific heat of the animal body is about 0.8. The formula for the correction of the volume of air is:

$$V = \frac{V' P}{760\ (1 + 0.003665t)}.$$

V' is *observed* volume at 0° C. and 760 mm. Hg; V, *desired* volume at 0° C. and 760 mm. Hg; P, *observed* pressure; and t, *mean* temperature. The value of 760 (1 + 0.003665) is obtained from standard tables, while the barometric pressure and aqueous tension are omitted, being too small to produce appreciable error. A litre of dry air at 0° C. weighs 0.001293 kilogramme.

The measurement of the aqueous vapor of the air before entering and after leaving the calorimeter gives the data for the estimation of the heat lost through evaporation. If it is found that the total quantity of water evaporated from the animal is 100 grammes, it is only necessary to multiply by 582 (since it requires this number of calories to evaporate 1 gramme of water), in order to obtain the heat in kilogramme-degrees that is lost by evaporation. The principal part of the total heat produced by the body is generated by muscular activity.

Subsidiary sources are the chemical action going on during digestion, friction of muscles, blood, warm foods, sun's rays, etc. In calorimetric determinations these are neglected.

Throughout life the body maintains a constant temperature, so that there is a regulation of heat produced and heat dissipated. The production of heat is known technically as *thermogenesis;* the dissipation of heat, as *thermolysis;* and the regulation of the relations between them, as *thermotaxis.* It is evident that if thermogenesis and thermolysis vary together, the body-temperature will remain unchanged; but an increase in thermogenesis with a constant or decreased thermolysis will raise the body-temperature. Further, a decrease in thermogenesis with constant or increased thermolysis will lower the body-temperature. The production of heat probably takes place in all the tissues of the body, since they all undergo oxidative changes, but the muscles are the main source of the heat not only when active, but when at rest. During activity the greater part of their chemical energy is liberated as heat, only one-fifth appearing as mechanical energy. The work of the heart is entirely converted to heat, forming about 5 to 10 per cent. of the total amount produced in the body. It is known that when a muscle is separated from the central nervous system it continues to produce heat, but much less than before. *Specific thermogenic fibres* have not been isolated. It has been claimed that the act of *shivering* has as its only purpose the production of heat, so that if the muscular contractions of shivering are brought about by impulses passing over ordinary motor nerves, they must have a specific thermogenic function. The proofs of thermogenic *centres* are the following:

1. Excitation of the skin by heat or cold brings about changes in heat-production entirely independent of vasomotor changes.

2. Injury or excitation of certain parts of the brain is followed

by increased heat-production; excitation of other parts of the brain, by a decrease of heat-production.

3. Injury to the spinal cord brings about changes in thermogenesis without vasomotor disturbances.

4. Operations upon certain parts of the cerebrospinal axis lead to an increase or decrease in the carbon dioxide excreted.

Of these centres, those that increase thermogenesis are called *thermo-accelerator* centres, while those that diminish thermogenesis are called *thermo-inhibitory* centres. These two kinds act upon and govern a third kind of centre, called *general* or *automatic centres.* The *latter* are located in the *spinal cord.* The *thermo-accelerator* centres probably exist in the *caudate nuclei, pons,* and *bulb.* The *inhibitory* centres have been located in the dog in the *sulcus cruciatus* and at the junction of the *suprasylvian* and *post-sylvian fissures.* Changes in the external temperature or in the temperature of the blood affect the centres in the brain, which in turn act upon the general centres in the anterior cornu of the gray matter of the cord. Heat influences the thermo-inhibitory, and cold the thermo-accelerator centres.

Heat is lost by an organism through radiation and conduction from the skin, by the evaporation of water from the skin and lungs, and in warming food and inspired air. *Thermolysis* is brought about by complex mechanisms. If the *temperature* of the body becomes too *high*, the *activity* of the *heart* is *increased*, *peripheral vascular dilatation* takes place, there are increased *respiratory activity* and *secretion* of *sweat.* These *processes* all tend to *increase* the *loss* of *heat.* When the external temperature becomes excessive, *thermotaxis* fails. Cold, for instance, may cause heat-dissipation to take place more rapidly than heat-production, so that the temperature of the body continually decreases until death ensues. The post-mortem rise of temperature is due to the fact that chemical activity will continue in the tissues for some time after the mechanisms of thermolysis have been rendered incompetent.

QUESTIONS ON CHAPTER X.

Define the terms homothermous and poikilothermous.
Give the body-temperature of man.
In what ways does it vary?
Where are the warmest and the coldest blood of the body to be found?
What factors influence body-temperature?
What is the source of the energy of heat?

What percentage of heat is directly formed from the chemical energy of the food?

What are direct and indirect calorimetry?

Describe a calorimeter.

Describe fully how the calorimetric equivalent is obtained.

Why is it necessary to obtain the calorimetric equivalent in calorimetry?

Explain in detail how the heat lost to the air is calculated.

What is the specific heat of a body?

Explain how the heat lost by evaporation of water is obtained.

What organs are principally concerned in heat-production?

What subsidiary sources of heat are there?

How much heat does the heart produce?

Define thermogenesis, thermolysis, and thermotaxis.

Discuss thermotaxis.

What is the effect upon heat-production when a muscle is separated from the central nervous system?

Discuss the phenomenon of shivering.

What is the proof that thermogenic centres exist?

What classes of thermogenic centres are there, and where are they located?

How is thermolysis brought about?

Explain the post-mortem rise of temperature.

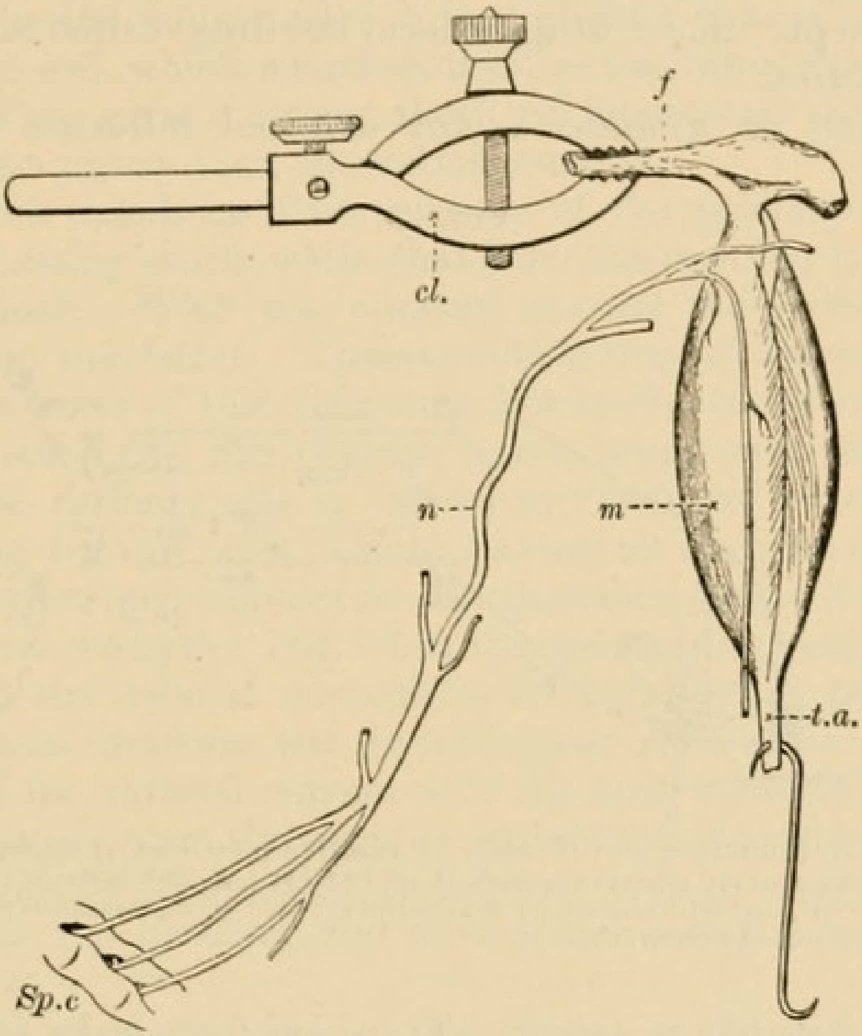
CHAPTER XI.

NERVE AND MUSCLE.

MOST of the cells of the body in the division of labor have developed preëminently some one or other of the fundamental properties of protoplasm. Thus, *muscle* is characterized by *contractility*, but has not entirely lost the properties of *nutrition*, *conductivity*, and *irritability*. *Nerves* are characterized by their *conductivity*, but possess also *nutrition* and *irritability*. *Both muscle and nerve in the adult condition have lost the power of reproduction.* The *properties* that they possess in common are *irritability*, *conductivity*, and *nutrition*. The phenomena of muscle and nerve can best be studied in cold-blooded animals. The frog's gastrocnemius (Fig. 24) is usually the most convenient, and when the sciatic nerve supplying the muscle is dissected out carefully at the same time there results a *nerve-muscle preparation*. If the *nerve* of such a preparation is in any manner *excited*, the *muscle* responds by a sharp and quick *contraction* or *twitch*. The *excitation* of the nerve has given rise to a *disturbance* of unknown nature in the substance of the nerve, which passes rapidly along its length to the *motor end-plate* and *excites* the *muscle-fibre*, which responds by its characteristic *function, contraction.* That muscle is *irritable* independently of nerves is shown in a number of ways:

1. *By the Curare Experiment.*—This is made as follows: Destroy the *brain* of a frog, by pithing, and tie off all the structures of the left leg with the exception of the sciatic nerve. Inject a

Fig. 24.



A muscle-nerve preparation (Foster): *m*, the muscle, gastrocnemius of frog; *n*, the sciatic nerve, all the branches being cut away except that supplying the muscle; *f*. femur; *cl.*, clamp; *t. a.*, tendo Achilles; *sp. c.*, end of spinal canal.

sufficient amount of curare solution to destroy the *reflex* movements of the right leg when the toe is pinched. Upon trial it will be found that *stimulation* of the *right sciatic* nerve when severed from the cord calls forth no movements, while *excitation* of the *left sciatic* does cause movements of the corresponding leg. *When the stimulus is applied directly to the muscles, they both respond.* The drug curare has destroyed the motor end-plates, so that nervous excitation of the muscle can no longer take place and the muscle-substance is stimulated directly.

2. *The sartorius muscle of the frog contains no nerve-fibres at its tips, which nevertheless are excitable.*

3. The *heart* of the *embryo* beats rhythmically before nerve-fibres are developed.

4. Muscle whose motor nerve has degenerated as the result of previous section is excitable. When such a muscle, when dying, is struck sharply, there arises a local swelling, called an *idiomuscular contraction.*

An *irritant* or *stimulus* is any external influence which can

FIG. 25.

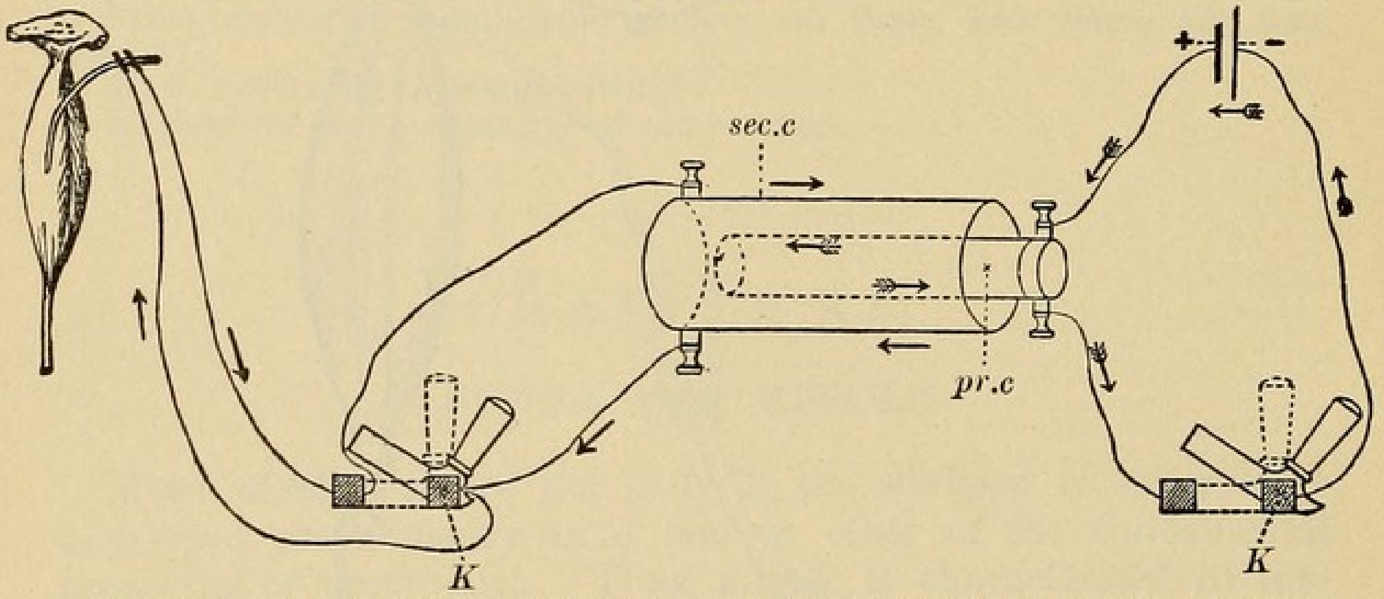


Diagram of an induction coil (Foster): + positive pole, end of negative element; — negative pole, end of positive element of battery; *K*, Du Bois-Reymond's key; *pr. c.*, primary coil, current shown by feathered arrow; *sc. c.*, secondary coil, current shown by unfeathered arrow.

excite living matter to action. There are five classes of irritants: *mechanical, thermal, electrical, chemical,* and *physiological.* The effect they produce upon living matter depends not only upon their efficiency, but also upon the irritability of the living material on which they act. The most desirable stimulus for experimental purposes is the electrical current, which produces very little injury and may be finely graded as to *strength, time,* and *place* of application. It may be either a *constant* or an *induced* current. The former, also called a *voltaic current,* is such as is furnished by any cell like the Grove or Daniell. The latter is obtained by the use of an induction coil (Fig. 25). This instrument consists essentially of two coils of copper wire, one of which is placed within the other, but *between which there is no metallic connection.* The inner coil of heavy wire (*primary coil*) is connected with a source of electricity, like a cell. The ends of the outer coil (*secondary coil*), which consists of many turns of fine wire carefully insulated, are connected with electrodes, by means of which the induced current is applied to the tissues to be stimulated, Any change in the strength of the *primary current*—*i. e.*, the current furnished by the voltaic cell—brings about a change of potential in the outer coil, which manifests itself as the *induced* or *secondary current.* This gives a strong shock of momentary duration and produces less injury than the voltaic current.

The shock resulting from closure of the primary current is called the *closing shock*, while that from the opening is called the *opening shock.* With the *constant current* the *former* is more *effective* than the latter. The *opposite* is true of the *induced* current. The cause of this difference lies in the construction of the induction coil. As the current passes along each turn of wire forming the primary coil it excites an "induced" current in the neighboring turn of wire, which, having an opposite direction to the primary current, opposes it, and therefore delays it in reaching its maximum strength; but, when the primary current is broken, both it and the induced currents in the neighboring turns of wire have the same direction and do not oppose each other. Since the *intensity* of the induced current with the same strength of primary current depends upon the rapidity with which the primary reaches its maximum, it follows that the *closing induced* current must be *weaker* than the *opening*, and have consequently a *smaller stimulating effect.*

The effect of a stimulus is proportional to the *rate* with which it reaches its maximum. This is true only within limits, for a stimulus may be applied both too slowly and too quickly to produce any effect. This has been expressed in Du Bois-Reymond's law: "It is not the absolute value of the current at each instant to which the motor nerve replies by a contraction of its muscle, but the alteration of this value from one moment to another; and, indeed, the excitation to movement which results from this change is greater the more rapidly it occurs by equal amounts, or the greater it is in a given time." This law is not strictly true.

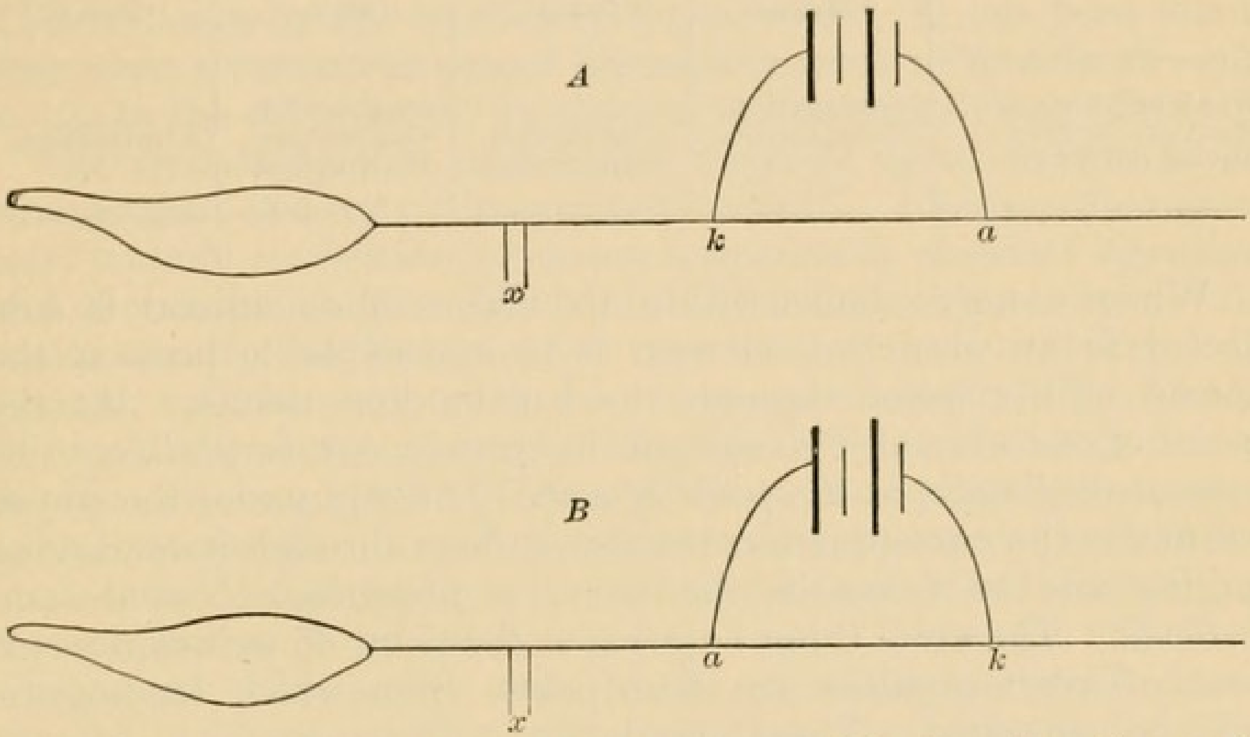
The *denser* the current the greater is its stimulating effect. This is well illustrated by the phenomena of unipolar action. Usually, in order to stimulate a preparation with an electrical current, it is necessary that there shall be a complete circuit; but under certain circumstances one wire of a secondary coil leading to the nerve is sufficient to excite it when the primary circuit is opened. This may be explained by the assumption of an electrical charge generated in the secondary coil and passing through the nerve to the muscle. In its *transit* through the nerve it arouses a *nerve-impulse.* If the electrode represented by the wire on which the nerve rests be replaced by a sheet of gold foil which is made to touch the nerve and muscle along their entire length, the charge from the induction coil will reach all points of the preparation at practically the same instant and will not excite it. The *charge* remains of the same *strength,* but the *electrodes* alter the *density.*

The *duration* of a stimulus must be of sufficient length to produce an effect. *In the experiments of Tesla, where powerful alternating currents are passed through the body without injury, it is the exceedingly small duration of the changes that prevents harmful effects.* It has been found that the results obtained by applying a constant current to a nerve depend upon the *direction* in which the current flows through the preparation.

A current, for instance, which in passing through the nerve from the *anode* (*positive electrode*) to the *kathode* (*negative electrode*) flows in the direction of the muscle, is called a *descending current;* while one flowing in a direction away from the muscle, is an *ascending current.* If a current of such strength is chosen that the closing shocks only are effective, its direction is of no consequence. This is true also when the current is increased in strength, so that both opening and closing shocks are capable of causing the muscle to contract. *With a strong current, however, it is found that the closing shock in an ascending current and the opening shock of a descending current cause no contraction.* In order to understand these results, it is necessary to consider the changes that a constant current produces in a nerve to which it is applied. These are known as *electrotonic changes,* and they differ in character at the anode and the kathode, so that the condition at the former has been named *anelectrotonus,* while that at the latter electrode is known as *katelectrotonus.* While the current is flowing, the *irritability* of the *nerve* is *raised* at the *kathode* and is *lowered* at the *anode*, and this condition is *reversed* immediately when the *current ceases* to *flow*. A rise of irritability and an excitation are inseparable. The underlying causes of both are the same. It may be accepted then that the rise of irritability of the nerve at the kathode when the stimulating current is closed, and at the anode when the current is opened, indicate the generation of nerve-impulses.

Closing excitations arise at the *kathode*, while *opening excitations* arise at the anode. Moreover, during *electrotonus* the *con-*

FIG. 26.



Muscle-nerve preparations: with the nerve exposed in *A* to a *descending* and in *B* to an *ascending* constant current (Foster). In each, *a* is the anode, *k* the kathode of the constant current; *x* represents the spot where the induction-shocks, used to test the irritability of the nerve, are sent in.

ductivity is *increased* slightly at the *kathode*, and *decreased* greatly at the *anode*. When the current ceases to flow, the conductivity is greatly lowered at the kathode and is raised at the anode. Reflection will make clear that with an ascending current the closing contraction fails to appear because the conductivity is so lowered at the region of the anode that the excitation which arises at the kathode cannot reach the muscle. With a descending current the opening contraction fails to appear because the conductivity is so lowered at the kathode that the nerve-impulse generated at the anode cannot reach the muscle. The impulses that originate at the electrode nearest the muscle are the only ones that are effective. At some point between the electrodes the region of increased irritability merges into that of decreased irritability. This point is nearer the anode, but with increase of strength of current it approaches the kathode. The facts relating to the effect of direction of current on the resulting contraction constitute what is known as *Pflüger's law.*

Current-strength.	Ascending current.		Descending current.	
	"Make."	"Break."	"Make."	"Break."
Weak current	Contraction.	. . . .	Contraction.	
Medium current . .	Contraction.	Contraction.	Contraction.	Contraction.
Strong current . . .	. . . .	Contraction.	Contraction.	

When a nerve intact within the tissues of an animal is subjected to an electrical current, it is impossible to prevent the spread of the latter through the surrounding tissues. At the *point* of *entrance* of the current it spreads out *brush-like*, to be *concentrated* again at the *point of exit.* Directly under the physical anode the current enters the nerve, flows through it at varying angles, and so forms in the nerve a *physiological anode* and *kathode.* The same thing happens at the point of exit of the current. Therefore there are four points from which an impulse may be generated. There may be:

1. An *anodic closing contraction*, which is the result of an impulse generated at the *physiological kathode* under the *physical anode.*

2. An *anodic opening contraction*, which is the result of a change developed at the *physiological anode* under the *physical anode.*

3. A *kathodic closing contraction*, which is the result of an impulse generated at the *physiological kathode* under the *physical kathode.*

4. A *kathodic opening contraction*, which is the result of an impulse generated at the *physiological anode* under the *physical kathode.*

These are abbreviated, respectively, ACC, AOC, KCC, KOC. When the stimulating current is increased gradually in strength, they appear in the following order: KCC, ACC, AOC, and KOC. This order of appearance is explained by three facts:

1. When the current is closed, the impulse is generated at the kathode; and when it is opened, at the physiological anode.

2. The impulse developed at the kathode is more effective than the one developed at the anode.

3. The effect of the current is greatest where the density is greatest.

When nerve and muscle are diseased, the ACC and KOC are obtained respectively with weaker currents than KCC and AOC. This is known as the *reaction of degeneration.* It has been found that when a current is passed through a nerve or muscle at *right angles* to the *direction* of its fibres it has no stimulating effect.

The *irritability* of a preparation depends upon changes in its environment and upon changes within itself. *Changes* of *environment* include *mechanical* agencies, *temperature*, *chemical* agencies, and *electrical* currents. Mechanical agencies acting on living substance usually first increase; but later destroy the irritability. In general, *cold decreases*, while *heat increases* the irritability, but in this case it is necessary to take into consideration the character of the stimulus employed. Tissues differ normally in their response to various stimuli. A *medullated nerve*, for instance, responds better to an induced current than to mechanical or chemical stimuli, but the application of cold makes it more susceptible to the effects of mechanical stimulation than to the exceedingly short induced current. Chemicals first raise and then lower the irritability. Deprivation of the blood-supply is equivalent to a change in the chemical environment of a tissue. That the normal irritability is dependent upon the blood-supply is shown by *Stenson's experiment* on the rabbit, in which the abdominal aorta was closed by compression. The paralysis which follows this procedure is due successively to the loss of function of nerve-cells in the cord, then of the motor end-plates, and finally of muscle- and nerve-fibres.

That the irritability of a preparation depends upon changes that may take place within itself, is shown by the separation of a nerve-fibre from its cell-body and by the effects of functional activity. The metabolism of a cell depends upon the presence of nuclear matter, so that if a nerve-fibre is cut off from its cell-body, it will *degenerate.* During this process there are first an increase and then a decrease of irritability. A *muscle* separated from the *central nervous system* by section of its *motor nerve* will also *degenerate.* After a period of two weeks or so, it responds better to stimuli of long duration than to those of short duration, and gradually becomes less and less irritable to the end of the seventh or eighth month. *Functional activity* leads first to an *increase* of *irritability,* but *later* in this case also to a *decrease.* This is attributable to both the consumption of its store of *nutriment* and to the *accumulation* of *waste products.* Some physiologists have drawn a distinction between the results of these two processes. Waste products if formed faster than they can be gotten rid of, give rise to *fatigue,* while the consumption of stored or available nutriment gives rise to *exhaustion.* That waste products are formed during activity, is shown by an experiment of Mosso. Having found the injection of a definite amount of blood from a rested dog into the veins of another to be without effect, he repeated the injection by using the blood of a dog completely tired out by a hard day's work. *The dog receiving the blood showed all the signs of extreme fatigue.*

It is said that in order that protoplasm may conduct, it must be continuous. A break in the physiological continuity of protoplasm, as when a nerve is crushed at one point, completely bars the *conduction process.* The cut ends of the nerve when placed in contact will not transmit a nerve-impulse, which distinguishes the latter from an electrical current, which passes readily from one part to the other. A conduction process having reached the boundaries of the cell in which it has originated, may cause the generation of a similar process in a contiguous protoplasmic mass. This, for instance, is shown by the relations of the end-brush of one cell to the dendrites of another. But fibres of muscles and nerves do not stimulate their neighbors normally as they lie side by side, since their sheaths prevent even contiguity. That the *conduction process* passes in *both directions* along the length of the fibre, may readily be seen in muscle, where it is accompanied by a change of form. In nerves it may be demonstrated by Kuehne's experiment on the sartorius of the frog. The end of the muscle after being slit longitudinally for a small distance, is stimulated at one tip, which causes contraction of both tips. Cross-conduction between muscle-fibres being impossible, the impulse generated in the nerve-fibres of one tip must pass back to other branches of the same nerve-fibre, and thus excite the other tip. A similar experiment may be made on the electrical organ of *Malapterurus*. The anterior roots of spinal nerves which contain fibres transmitting normally in only one direction may be shown to transmit also in the opposite direction by means of the electrical change accompanying a nerve-impulse.

The *rate* of conduction varies in different tissues, and is roughly related to the function. In muscles all gradations are to be found, from the 0.02 to 0.03 metre per second of the smooth muscle-fibres of the rabbit's ureters, to the 10 or 13 metres per second in human muscles. The rate in nerves may be put at 27 metres per second in frogs and 35 metres per second in man. The conduction process

Fig. 27.

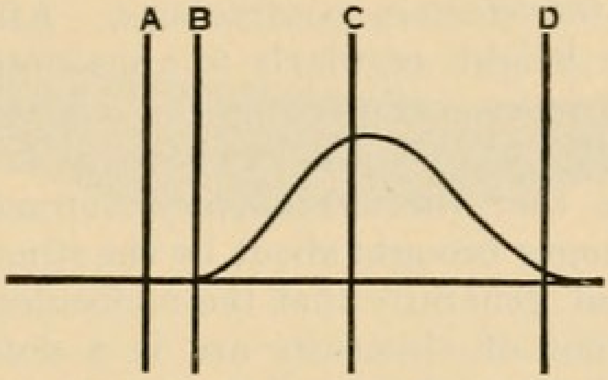


Diagram of muscle-curve (Collins and Rockwell): *a*, point of application of current; *b*, point of beginning contraction; *c*, maximum; *d*, return to normal.

sweeps over irritable tissue in the form of a wave, which in muscle is about 300 mm. long, while in nerve it is about 18 mm. long. *Conduction* is influenced by the same factors that affect *contractility*. The nature of the process has not been determined, but must be either of *physical* or *chemical* character. It is intimately dependent upon *metabolism*, yet all attempts to show its chemical nature have, in nerves, resulted negatively.

The movements made by striated muscles are too quick to be followed accurately by the eye, so that resource is had to what is known as the *graphic method*. The muscle, by means of a mechanism, is made to write its contractions and relaxations on a surface moving at a uniform rate. The entire arrangement constitutes a *myograph*, and the record thus obtained is a *myogram* (Fig. 27). The myogram of a simple muscle-contraction consists of three distinct portions. Immediately succeeding the stimulation is an interval (*latent period*) of about $\frac{1}{100}$ of a second, during which the muscle makes no apparent change. During the next $\frac{4}{100}$ of a second the muscle shortens, and during the last $\frac{5}{100}$ of a second it lengthens again. Contraction and relaxation take place at first slowly, then faster, and finally slowly again. The *entire time involved may be put at an average of $\frac{1}{10}$ of a second.* The time-relations vary with the nature of the muscle and the conditions under which it works. Finer methods of determination have reduced the *latent period* to a mechanical and an electrical latent period of 0.004 and 0.001 seconds, respectively. The latent period of the motor end-plates is about 0.002 to 0.003 of a second. When the striated muscle of a frog is submitted to a series of equal induction shocks at a regular rate, a series of contractions are recorded, of which the first four or five fall in height, and are known as the *introductory* contractions. After this there is an increase in the height regularly to a maximum which forms the "*treppe*" or *staircase.* Following this again, the contractions lose in height until they disappear, which is known as fatigue. It is very probable that the *introductory contractions* are caused by polarization changes brought about by the stimulating current.[1]

It is now assumed generally that the molecules of any solution which is a conductor of electricity are in a *state of dissociation* —*i. e.*, the molecules are divided into two or more parts, called *ions.* Thus sodium chloride in water becomes separated into a sodium ion charged positively with electricity and into a chlorine ion charged negatively. The passage of a galvanic current through such a solution is accomplished by means of the ions, and gives rise to electrolytic phenomena consisting of a migration of the positively charged ions or *kations* to the negative pole of the galvanic circuit. In like manner the negatively charged ions or *anions* move toward the positive. This effect is brought about in any moist tissue that will conduct, and is then said to be *polarized.* The difference of potential between the kations and anions sets up a current (polarization current) in a direction opposite to that of the inducing current.

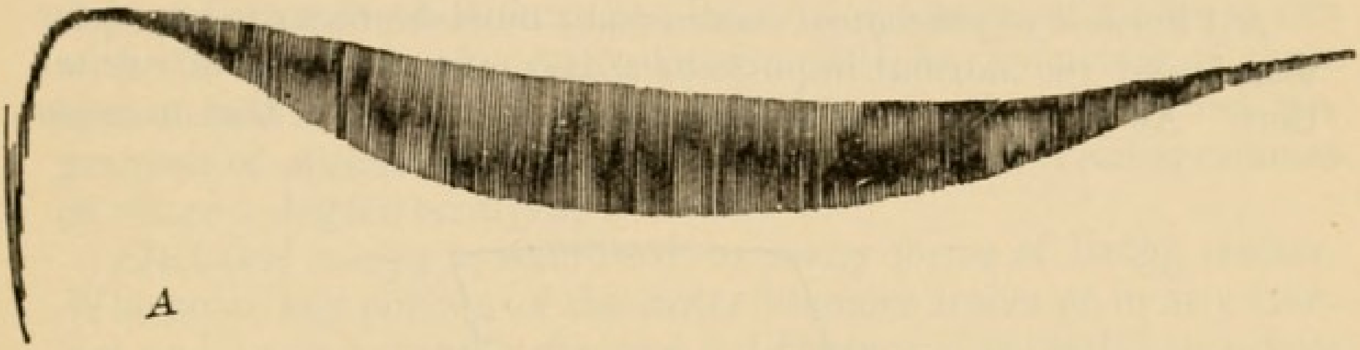
It happens thus that a polarization current produced in any

[1] From unpublished experiments made in the Physiological Laboratory of the University of Michigan.

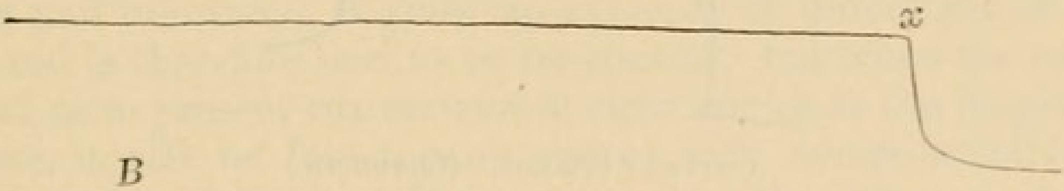
tissue—frog's muscle, for instance—will weaken the stimulating current and consequently the effect which the latter produces. In a series of stimulations the polarization effects should theoretically become greater as the excitation progresses, but this is not shown in serial muscular contractions, since the polarization effects are disguised entirely by the staircase.

The *staircase contractions* result from the fact that each stimulation occasions a heightened irritability, so that the succeeding stimuli become more effective. *Fatigue* is caused by the accumulation of waste products and to the consumption of available nutriment. When the rate of stimulation is increased, the separate muscular contractions may not come down to the base-line, giving rise to the phenomena of *contracture.* This condition may

FIG. 28.



Serial contractions of gastrocnemius of frog, showing double contracture, introductory contraction, staircase, and fatigue. Two stimuli per second, maximal induced current. Muscle weighted with 10 grammes and used three days after pithing frog.



Final portion of curve *A*, showing gradual relaxation due to fatigue; *x*, cessation of stimulation.

be explained by the fact that as the muscle contracts it becomes fatigued, resulting in a prolongation of the relaxation. A second stimulus reaches the muscle before the contraction resulting from the first is over. There is a summation of contractions. *Double contractures* are given by muscles composed of two distinct kinds of fibres, which react differently to the same stimulus.

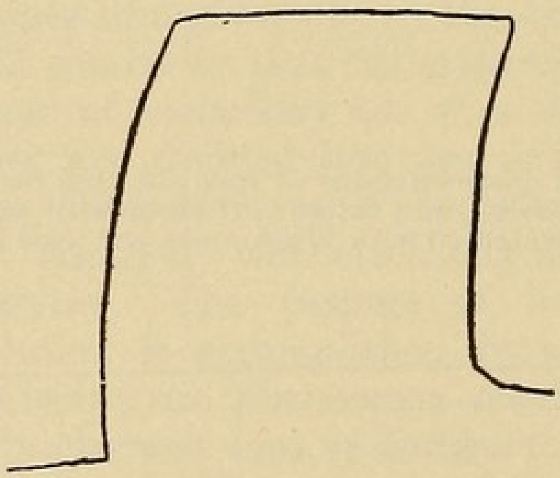
The *pale fibres* react quickly and soon are fatigued, while the *dark fibres* have greater endurance. The summation of contractions of the pale fibres occurs first and quickly raises the base-line. As they become fatigued, the base-line gradually sinks until the dark fibres in a similar manner raise it again. When both dark and pale fibres are fatigued, separate contractions, and relaxations no longer take place, and the base-line gradually sinks. With still more frequent rates of stimulation the staircase and contracture effects are merged into one another, giving rise to a very great height of contraction. As the curve is wavy or unbroken, it is known as an incomplete or complete *tetanus*.

Tetanus is the result of three factors:

1. Increase of irritability.
2. Summation of contractions.
3. Support offered by contracture.

All *normal physiological contractions* must be regarded as short tetani and the normal impulse as a discontinuous form of excitation. As the evidence of this may be cited the fact that muscles

FIG. 29.



Curve of tetanus. (Chapman.)

give out a *sound* when contracting, implying that their finest particles are in a state of *vibration*. Wollasten determined the rate to be from 36 to 40 per second. By means of vibrating reeds Helmholtz reduced the rate to 18 to 20 per second, which gives a tone imperceptible to the ear. Lately the rate has been made still slower, being placed at an average of about 10 per second. *Tremors* also give evidence that voluntary movements are not continuous.

The *energy* liberated by muscle appears in *mechanical, thermal,* and *electrical* form. The last is so small that in quantitative determinations it is negligible. Only one-fourth to one-twentieth of the chemical energy liberated by the muscle appears as mechanical energy. The work done by a muscle depends upon its nature and condition, the stimulus applied, and the mechanical conditions under which the work is done. *Work* is calculated by multiplying the load into the height to which it is lifted. The *absolute muscular force* of a muscle is the maximum weight that it can lift per unit cross-section. This for the frog is 3 kilogrammes per square centimeter. The heat liberated by active tissue is measured by a *thermopile* or a *bolometer.* The first consists of a certain number of junctions of two dissimilar metals like antimony and bismuth, which develop an electrical current whenever any two of the junctions are at a different temperature. The action of a *bolometer* depends upon the fact that the electrical resistance of a wire varies with the temperature. An isolated muscle has by means of these instruments been found to produce by a single contraction per gramme of muscle substance sufficient heat to raise 3 milligrammes of water 1 degree centigrade.

Electrical energy is exhibited by many forms of living matter. Whenever any portion of the latter becomes active or in any manner undergoes katabolic changes, a difference of potential manifests itself in that the active portion becomes negative to the rest. The difference of potential is generally small, requiring a sensitive galvanometer or electrometer to measure it, but in some electrical fishes becomes as high as 200 volts. When a muscle or nerve is intact and uninjured, it gives no evidence of differences of potential, and is therefore said to be *iso-electric;* but when the ends are cut, so as to present two sections at right angles to the longitudinal surface, it will be found upon testing with non-polarizable electrodes and a suitable galvanometer that the cut and therefore dying ends are negative to the uninjured longitudinal surface.

The current flows from the injured tissue through the muscle or nerve to the electrode on the longitudinal surface, thence through the galvanometer back to the starting-point. Points equidistant from the centre on the cross-section and from the equator on the longitudinal surface are at the same potential. A current obtained by mutilation of the tissue is known as a *current of injury,* of *rest,* or of *demarcation.* In a cat's nerve it has been found to equal

0.01 and in an ape's nerve 0.005 of a Daniell cell. *Dead tissue gives no current.*

It has been found that when living tissue is stimulated, the activity accompanied by katabolic changes sweeps over it in the form of a wave. As the latter, in muscle or nerve, passes by the electrodes it brings about differences of potential which are indicated by a galvanometer. These differences of potential give rise

Fig. 30.

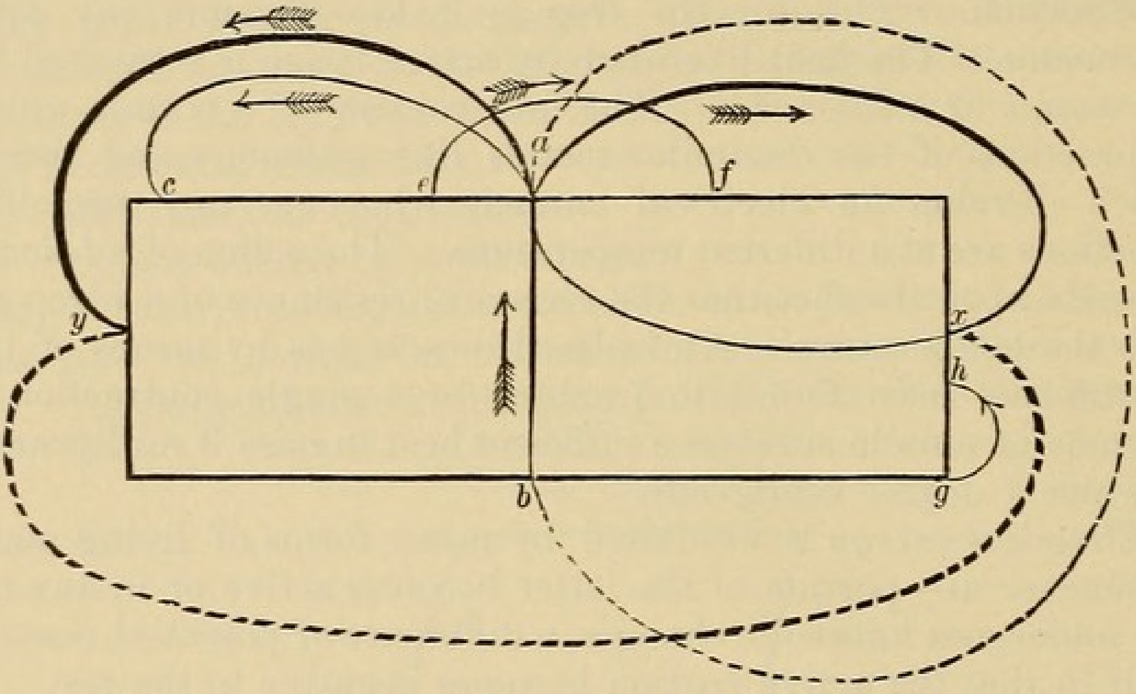


Diagram illustrating the electric currents of nerve and muscle: being purely diagrammatic, it may serve for a piece either of nerve or of muscle, except that the currents at the transverse section cannot be shown in a nerve. The arrows show the direction of the current through the galvanometer (Foster): *ab*, the equator. The strongest currents are those shown by the dark lines, as from *a*, at equator, to *x* or to *y* at the cut ends. The current from *a* to *c* is weaker than from *a* to *y*, though both, as shown by the arrows, have the same direction. A current is shown from *e*, which is near the equator, to *f*, which is further from the equator. The current (in muscle) from a point in the circumference to a point nearer the centre of the transverse section is shown at *gh*. From *a* to *b*, or from *z* to *y*, there is no current, as indicated by the dotted lines.

to *currents* of *action*. When a current of action is superimposed upon a *current* of *rest*, the needle of the *galvanometer* having been deflected to a certain extent by the latter, is made to move back toward the zero point, giving rise to a *negative variation*. When the nerve of one (A) of two nerve-muscle preparations is laid lengthwise over the muscle of the other preparation (B), and the nerve of B is stimulated with an interrupted current, both muscles are thrown into tetanus. That this phenomenon is not due to a spread of the exciting current through the preparations is shown by ligating the nerve of B between the electrodes and the muscle, when all contractions cease. As a matter of fact, the muscle-fibres of B give rise to currents of action that are circuited through the fibres of nerve resting on its surface. The nerve-fibres of A are thus stimulated and cause the muscle to contract. *This phenomenon is known as secondary tetanus.* As the wave of a nerve-impulse sweeps by the electrodes, it changes the potential successively of one and then of the other, so that the needle of the galvanometer is deflected at one instant in a positive direction and in the next in a negative direction. Currents of action are therefore *diphasic.* Changes of irritability due to the passage of a constant current have been alluded to under electrotonic changes. There are to be observed at the same time variations in the electrical currents of the nerve itself—*i. e.,* variations in the currents of rest. The constant current causes in the nerve outside of the electrodes the appearance of another current that has the same direction as itself, and is called the *electrotonic current.* The electrotonic current adds to or takes away from the currents of rest according as they are flowing in the same direction or in an opposite direction. The strength of the electrotonic current is dependent upon the strength of the polarizing current, the length of the region between the electrodes, and the condition of the nerve. A *dead nerve* does not manifest electrotonic currents, and they may be stopped by a ligature or by crushing the nerve.

Whenever a muscle dies, it undergoes a change manifesting itself in a loss of *translucency,* of *extensibility* and *elasticity,* by the development of a gradual *contraction,* of increased *heat-production* and *acidity.* This change is called *rigor mortis.* It usually affects the body in regular order, the *jaw, neck, trunk, arms,* and *legs* being influenced one after the other. In general, the more *active* the *protoplasm* the sooner does it pass into rigor. During life the central nervous system is continually sending impulses to the muscles, keeping them in a slight state of tension called *muscle-tonus.* If the muscles are severed from the central nervous system by curare, the development of rigor is delayed. Cold delays and warmth (38° to 40° C.) favors rigor. *The cause of rigor is the coagulation of the semifluid muscle-substance.* Muscle-plasma which can be expressed from frozen muscle contains two proteids, *paramyosinogen* and *myosinogen.* By the action of a *myosin ferment* they are converted into *myosin*. *Rigor caloris* is caused by the precipitation of various proteids of the muscle by heat.

QUESTIONS ON CHAPTER XI.

What properties characterize muscle and nerve?
What properties have they in common?
Which ones have they entirely lost?
What is a nerve-muscle preparation?
Give proofs that muscle is irritable independently of nerves.
Define a stimulus. How many classes are there?
Upon what factors do the results of stimulation depend?
Why is an electrical stimulus usually a desirable one?
Distinguish between voltaic and induced currents.
Define opening and closing shocks. Which is the stronger?
Tell why the breaking induced current is stronger than the making.
What are subminimal and supermaximal stimuli?
What changes take place in the contraction of a muscle as the excitation increases in strength?
What is Du Bois-Reymond's law?
Illustrate how density of current affects its exciting power.
Discuss the results of duration of stimulus.
What are ascending and descending currents?
Discuss changes in irritability and conductivity of a nerve during electrotonus.
What are anelectrotonus and katelectrotonus?
What is the relation of rise of irritability to excitation?
Discuss in detail Pflüger's law.
At what points may an impulse be generated when a nerve *in situ* is subjected to a constant current?
In what order do the contractions occur as the strength of current is increased? Give reasons.
What is meant by the "reaction of degeneration?"
Upon what factors does the irritability of a preparation depend?
Discuss the effect of changes in environment upon the irritability of tissue.
Discuss the effect of severing a nerve-fibre from its cell-body.
How does functional activity alter irritability?
Distinguish between fatigue and exhaustion.
Give proof that waste products are formed during activity.
What distinguishes between an electrical current and a nerve-impulse?
Give proof that conduction may pass in all directions in protoplasm.
Give rates of conduction in various tissues.
What factors affect conductivity?
What are the lengths of the conduction-waves in muscle and nerve?
By what method are muscle-movements studied?
Describe a simple myogram.
What is the latent period of the motor end-plates?
Discuss the introductory contractions, staircase contractions, and fatigue.
What is the cause of contracture?
What factors cause tetanus?
What is the nature of voluntary contractions?
Discuss the reasons for thinking voluntary contractions tetani.

How is the chemical energy of muscle liberated?
What proportion appears as mechanical energy?
Upon what factors does the work of a muscle depend?
How is work estimated?
What is absolute muscular force? Give its value in frog's muscle.
How is the heat liberated by tissue measured?
How is the electricity liberated by tissue measured?
When are muscles isoelectric?
What is a current of rest? Trace its path.
What are currents of action?
What causes a negative variation?
Explain secondary tetanus.
Explain why a current of action is diphasic.
Discuss electrotonic currents.
How does rigor mortis manifest itself?
In what order does it affect the various portions of the body?
What is the cause of rigor mortis?
What is the cause of rigor caloris?
What factors influence the onset of rigor?
What is muscle-tonus, and to what is it due?

CHAPTER XII.

CENTRAL NERVOUS SYSTEM.

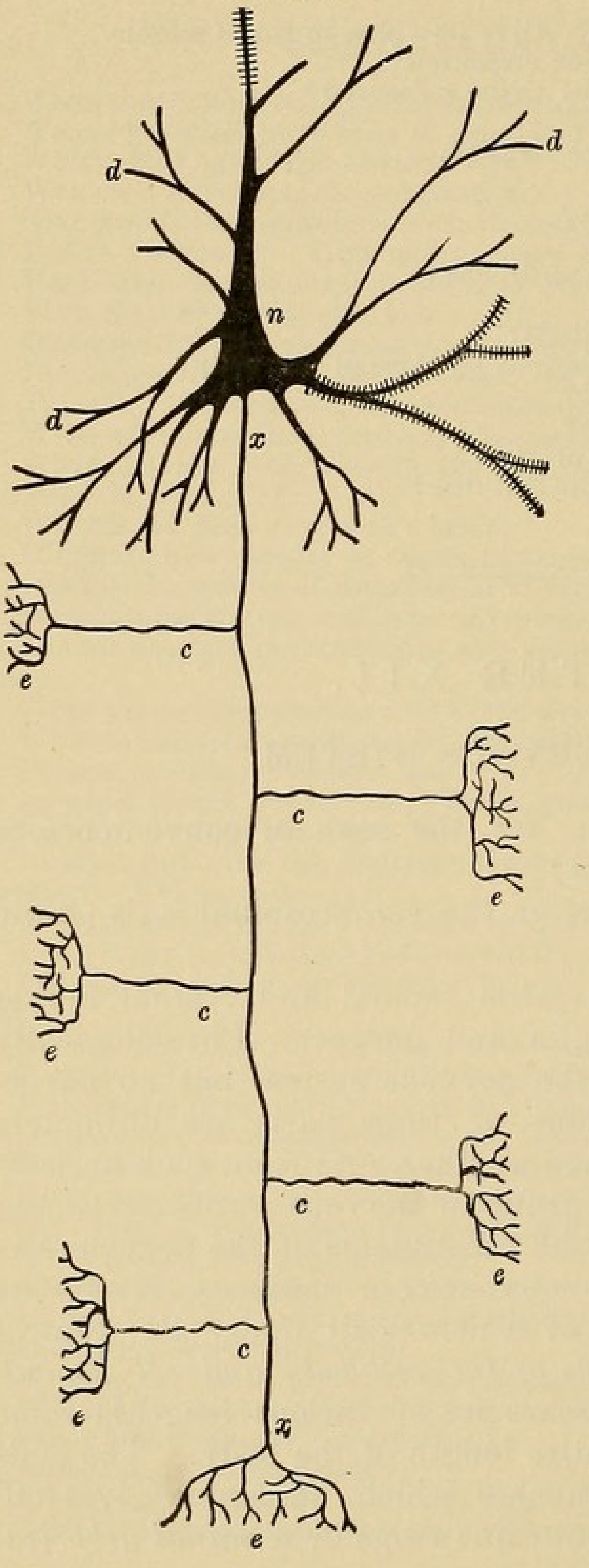
THE entire nervous system, for the sake of convenience, is divided into a number of parts:

1. *The central nervous system* or the cerebrospinal axis (brain and spinal cord).

2. *The peripheral nervous system* (spinal and cranial nerves and ganglia, sympathetic ganglia and nerves). Physiologically considered, such a division of the nervous system has no particular significance; the functions of these parts are intimately related and dependent upon one another, and form such an indivisible unit that any detached group of nervous structures would have no meaning. The essential constituents of the nervous system are *separate* but *contiguous nerve-cells* or *neurones*. A *neurone* is meant to include every part of a nerve-cell under the control of a given nucleus. *It consists of the cell-body and all its outgrowths.* Of the latter, the *axones* are of various lengths; some in man spanning almost the entire length of the body. The ends of the axones and of the branches which an axone gives off along its length are divided into fine twigs or *terminal arboriza-*

tions. The remaining branches of the nerve-cell do not attain the length of the axone, but very soon divide dichotomously, so that they also form finely divided terminal arborizations. The arrangement of neurones is such that the end-brush of the axone of one cell is in intimate relaiton to the end-brushes of the *dendrite* of another cell. Therefore an impulse generated in any one neurone is transmitted to its neighbor, which in turn passes it on to the next neurone. *It must be understood, of course, that it is not the impulse that is transmitted, but that an impulse reaching the end-brush of one axone has the power to generate another impulse in the dendrites of the contiguous neurone.* The general plan of a nerve-cell and its prolongations is shown in Fig. 31.

FIG. 31.



It is the *function of the nervous system* to bring the body into relation with changes in its environment and to preserve the harmonious working of all its organs. All parts of an or-

FIG. 31.—Neurone with long axone proceeding as the axis-cylinder of a nerve-fibre: *n c*, nerve-cell proper; *d*, dendrites; *x*, axon; *d g*, dendrite showing gemmulæ; *a d g*, apical dendrite with gemmulæ; *c*, collaterals; *e*, end-tufts, pyramidal cell of the cerebral cortex. (S. Ramón y Cajal.)

ganism are, therefore, bound together by nerve-structures. From the cerebrospinal axis the axones of nerve-cells, called nerve-fibres, pass to all portions of the body. They do not pass out indiscriminately, but are grouped together into nerve-trunks to form *the cranial, spinal,* and *sympathetic systems,* as is indicated in Figs. 32, 33, and 34.

Neurones whose fibres begin in *sensory* structures in the skin, muscles, or tendons, carry impulses into the central nervous system, and are known as *afferent* neurones. Those whose fibres carry impulses from the central system to the structures which the central nervous system controls are known as *efferent* fibres.

FIG. 32.

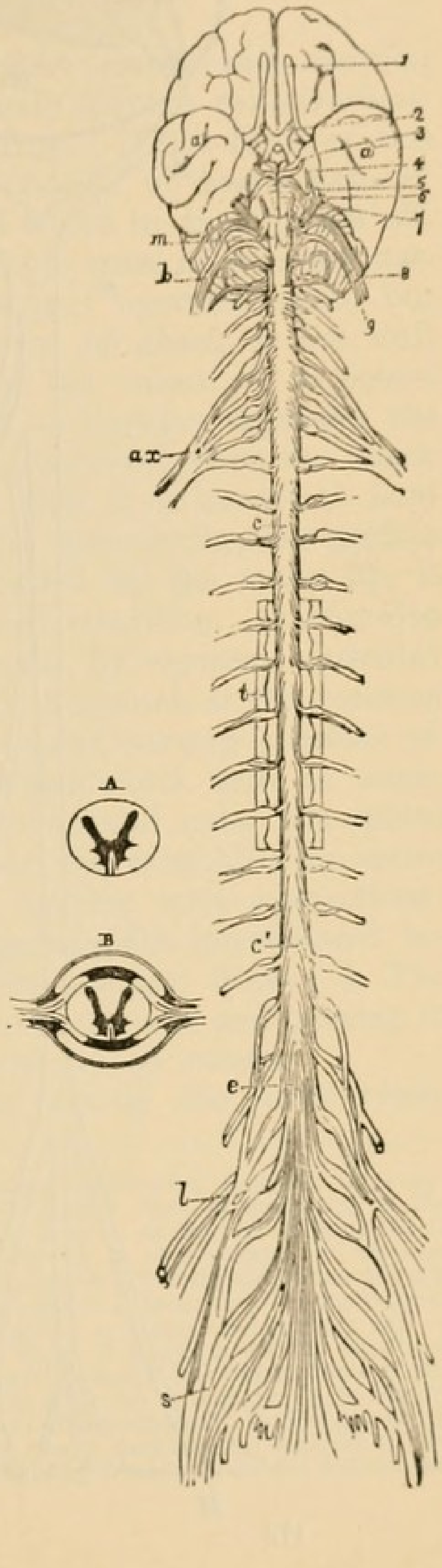
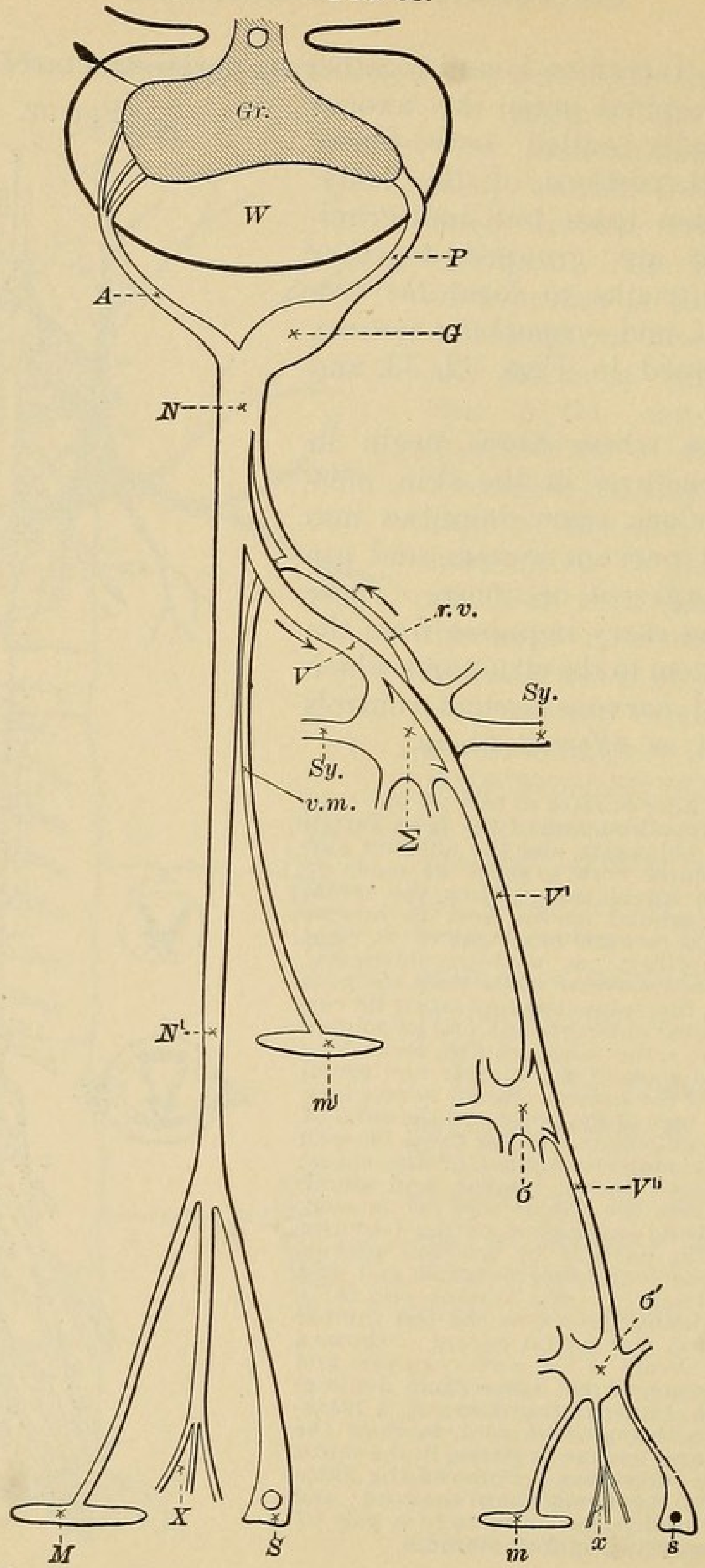


FIG. 32.—Under surface or base of the cerebrum and cerebellum, and of the pons Varolii and medulla oblongata, also the anterior surface of the spinal cord, to show the mode of origin of the spinal nerves from the spinal cord, and the cranial nerves from the base of the brain: *a, a,* cerebral hemispheres; *b,* right half of cerebellum: *m,* medulla oblongata; above this is a transverse white mass, the pons Varolii; *c, c',* the spinal cord, showing its cervical and lumbar enlargements, and its pointed terminations; *e,* the cauda equina, formed by the elongated roots of the lumbar and sacral nerves; 1 to 9, the several cranial nerves arising from the base of the brain and the sides of the medulla oblongata. Below these, on each side, are the roots or origins of the spinal nerves, cervical, dorsal, lumbar, and sacral. In some of these the double root can be seen, and the swelling or ganglion on the posterior root; *a, x,* the axillary or brachial plexus, formed by the four lower cervical and first dorsal spinal nerves; *l,* the lumbar plexus; *s,* the sacral plexus, formed by the last lumbar nerve and first four sacral nerves; *t* shows a piece of the sheath of the cord cut open, and with it a portion of the ligamentum denticulatum which supports the cord; *A,* a transverse section through the cord, to show the form of the gray cornua or horns, in the midst of the white substance. *B* shows the same parts, and also the membrane of the cord; and the anterior and posterior roots of a pair of spinal nerves springing from its sides.

Fig. 33.



In addition, there are cells whose branches do not leave the central nervous system, and whose function it is to convey impulses from one portion of the cerebrospinal axis to another. These are *central* neurones.

A *reflex act* (Fig. 35) is the simplest *coördinated reaction* which may take place, and not necessarily involve *consciousness*, as may be easily demonstrated in the frog. If the brain of this animal is completely destroyed, there results at first a state of collapse, which is known as *shock*, and which in time passes off. The removal or injury of any considerable mass of nervous matter affects the activity not only of the part operated upon, but also of distant structures. The *nature* of *shock* is not well known, but it may be explained as the result of a potent stimulus which through *inhibition* and *exhaustion depresses* the normal *functions*. After the frog has recovered from the shock it appears normal, with the exception that it is unable to hold itself up with its front limbs, so that the nose touches the surface of support. When the frog is suspended by the lower lip, it hangs with body and limbs in a relaxed condition. A stimulus applied to the skin of the leg is followed by vigorous muscular responses, which seem to be purposeful, inasmuch as the reaction tends to remove the irritant. The *essential nervous portions* of such a preparation are: 1. Afferent fibres which arise in sense-organs in the skin, muscles, and tendons; and enter the spinal cord by way of the posterior roots, perhaps stretching its entire length and by means of collaterals making wide connections; 2. The spinal cord with numerous central cells interpolated between the terminals of the afferent and efferent fibres; 3. The efferent fibres leaving by way of the ventral roots and passing to the muscles or to the ganglia of the sympathetic system.

The *sensory* stimuli that are received pass up the nerve-trunks

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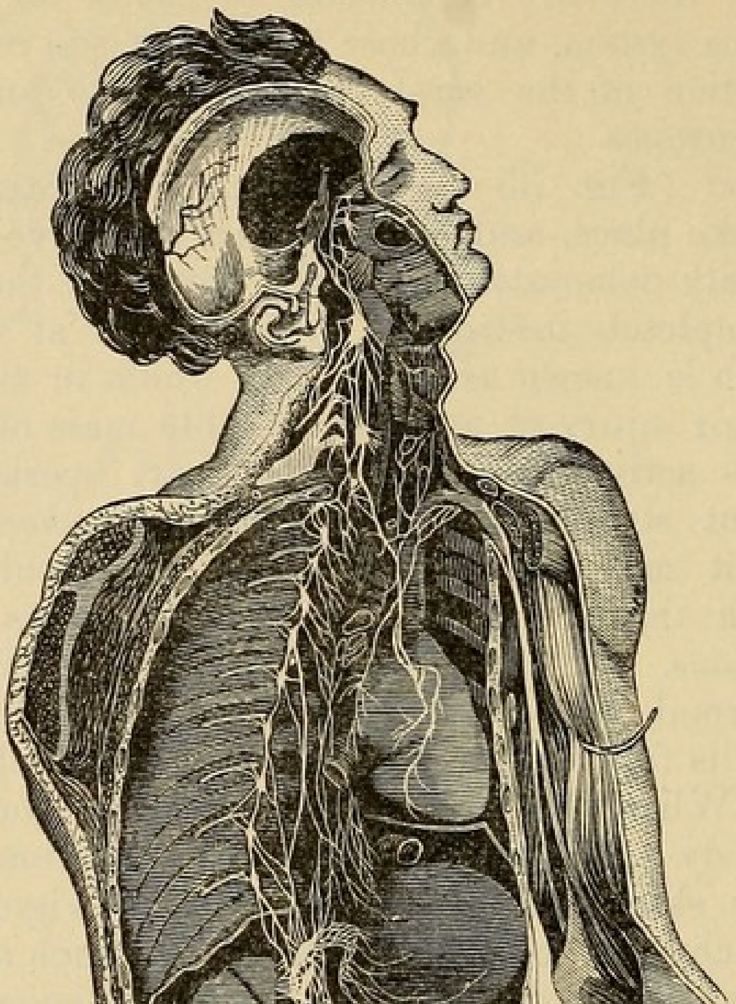
FIG. 33.—Scheme of the nerves of a segment of the spinal cord (Foster): *Gr*, gray; *W*, white matter of spinal cord; *A*, anterior; *P*, posterior root; *G*, ganglion on the posterior root; *N*, whole nerve; *N'*, spinal nerve proper, ending in *M*, skeletal or somatic muscle; *S*, somatic sensory cell or surface; *X*, in other ways; *V*, visceral nerve (white ramus communicans) passing to a ganglion of the sympathetic chain Σ, and passing on as *V'* to supply the more distant ganglion σ, then as *V''* to the peripheral ganglion σ' and ending in *m*, splanchnic muscle; *s*, splanchnic sensory cell or surface; *x*, other possible splanchnic endings. From Σ is given off the revehent nerve *r. v.* (gray ramus communicans), which partly passes backward toward the spinal cord, and partly runs as *v. m.* in connection with the spinal nerve, to supply vasomotor (constrictor) fibres to the muscles (*m'*) of bloodvessels in certain parts, for example, in the limbs; *Sy*, the sympathetic chain uniting the ganglia of the series Σ. The terminations of the other nerves arising from Σ, σ, σ', are not shown.

FIG. 34.



Ganglia and nerves of the sympathetic system. (Dalton.)

to the *posterior* nerve-roots, and thus to the spinal cord. In the *cord* the impulse may be sent to the *brain*, producing *consciousness*, etc.; or else the *impulse* in the cord may be transmitted directly to some *motor* cell in the *anterior horn*, stirring it to activity, with the result that there is *muscular* action. A person, for example, may be tickled with a feather, and the subject brushes away the offending object either with or without consciousness of what he is doing. If he does it *unconsciously*, the *reflex* act takes place in the cord; if he brushes away the feather as a result of the *impression* received in his *brain*, the *reflex* act took place in the *brain*. Furthermore, a person may perform a reflex act through the *reflex centres* in the cord, and yet after the act is completed he may receive the sensory impulse in the brain. Such an act may be *simple* and involve a *single muscle*, or *complex* and involve many; thus, a ray of *light* falling upon the *retina* causes a *simple reflex* contraction of a single muscle, and the *iris contracts*. As an illustration of a *complex* reflex action, however, *irritation* of the *larynx* causes not only a *closing* of the *glottis*, but also a *contraction* of all the *muscles* involved in forced *expiration* or *coughing*. The *spinal cord* in man is so much under the control of the higher centres that its *capabilities* for *reflex* action are often overlooked. After *injury* to the spinal cord the reflex acts are apt to be purposeless and fruitless. In many lower animals reflex actions, after the cord has been divided, are extensive and well coördinated. This is well marked in the frog. Yet the difference is one of degree only. *In man many acts are accomplished as reflex movements occurring in the cord, although it is incapable of initiating them itself.*

FIG. 35.

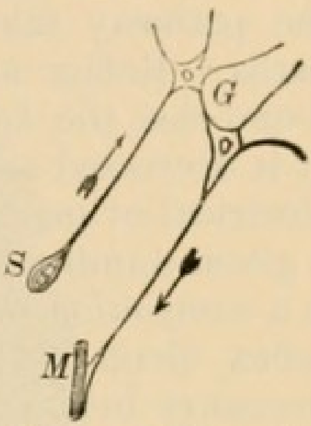
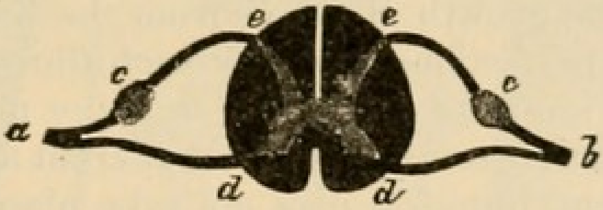


Diagram illustrating simplest form of reflex apparatus. (Foster.)

FIG. 36.



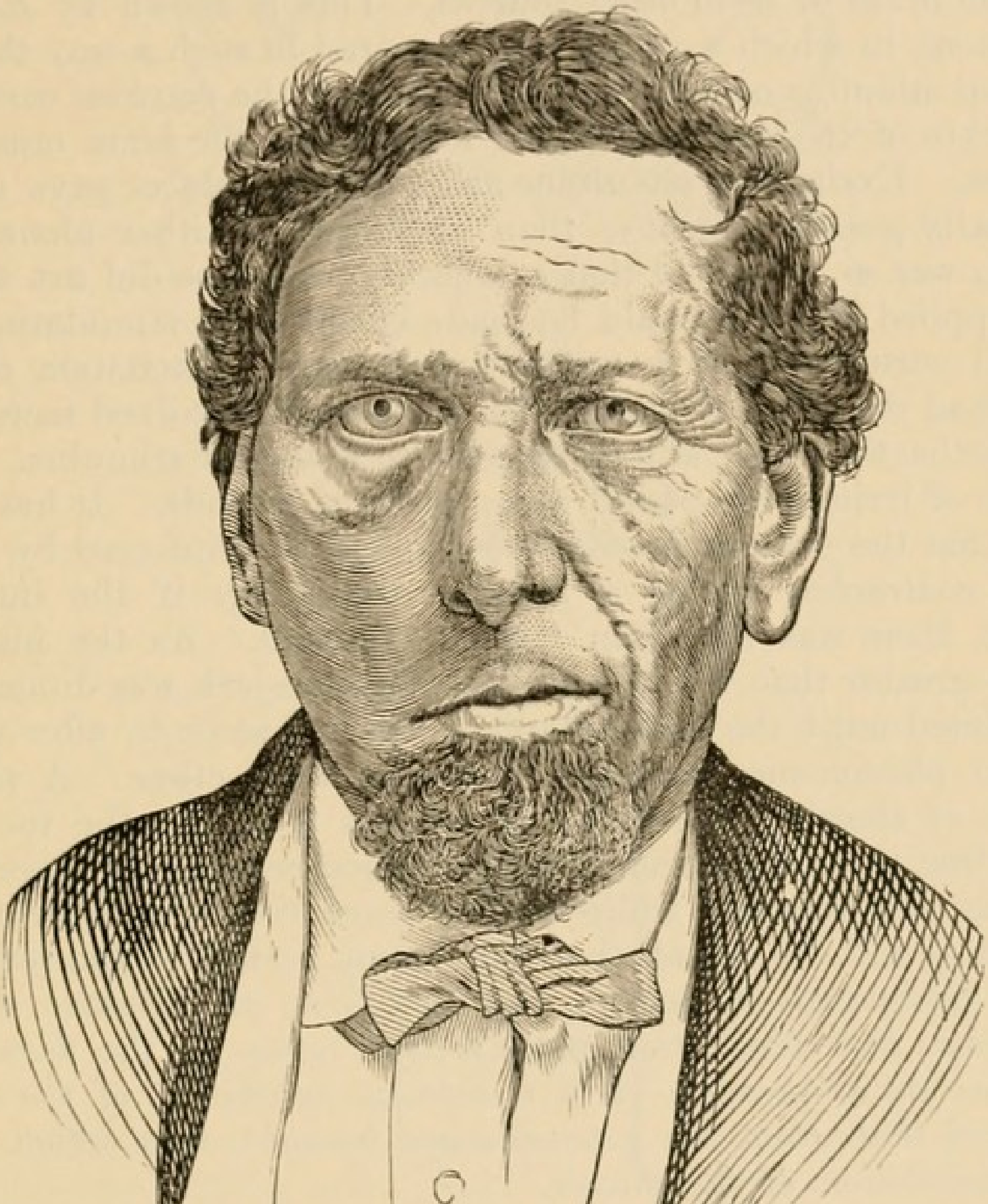
Transverse section of the spinal cord: *a*, *b*, spinal nerves of the right and left sides; *d*, origin of the anterior root; *e*, origin of the posterior root; *c*, ganglion of the posterior root.

Stimulation of afferent fibres brings about a response, usually, of those muscles innervated from the *same segment* of the cord, but the reflex may involve corresponding muscles of the other side of the body or muscles innervated from segments of a lower or higher level. It may be accepted as a *general rule*, that an afferent impulse when it passes through the cord tends to die out, and that it reaches more cells than actually are discharged. Further, that the pathway taken by an impulse is but one of many possible paths. Reflex acts, like all others, involve time. It has been found that the *latent period* varies from 0.05 to 0.40 of a second. It is decreased as the strength of the stimulus is increased. With electrical or mechanical stimuli the response often occurs only after a given number of stimuli have been applied. In such cases there is a *summation* of the effects of the stimuli in certain parts of the reflex chain. It has been found that three segments only are necessary in the frog to produce the reflex clasping movement that the male develops during the breeding season. The higher the animal stands in the scale of development, the more complicated does the structure of the cord become, but the less are the segments capable of acting independently. Most of the *reflexes of man* are those that involve *unstriped muscle* or *glands*. These and others are: *deglutition*, *peristalsis of the intestine*, *defecation*, *micturition*, *emission*, *vaginal peristalsis*, *parturition*, *coughing*, *sneezing*, the *tendon-reflexes*, the *reactions* of the *vascular* system, and the action of *glands*. Many reflexes which in the young are uncontrolled are later brought under the action of the will. This is due probably to the growth of fibres from the brain into the cord, or rather to more perfections made by such fibres.

The spread of impulses from one to many neurones, which is termed *diffusion*, differs somewhat along afferent and efferent paths. Diffusion of afferent impulses does not take place until they have reached the cord, while diffusion of efferent impulses takes place in the peripheral ganglia. Fibres passing from the cord to the sympathetic ganglia are termed *preganglionic fibres*, while those passing from the ganglia to the peripheral structures are termed *postganglionic fibres*. It is found that each preganglionic fibre is distributed to more than one cell in the ganglion, so that an impulse passes out of the ganglion over a number of paths.

Normally, impulses are always coming into the cord from all parts of the body; are diffused throughout the central nervous system to a greater or less extent; and are the cause of efferent impulses that continually are leaving the cord to be transmitted to the various structures of the body, keeping them in a *state of tone.* This is noticeable in many pathological cases, especially in the

Fig. 37.



Facial paralysis of the right side. (Dalton.)

insane, where phases of mental exaltation and depression are depicted in the expression of the face, so that they appear like different persons. The legs of a pithed frog do not hang in a perfectly relaxed position unless the sciatic nerve is severed. Rigor mortis usually sets in, in both legs of the frog at the same time, but when the sciatic nerve of one limb is cut immediately after the killing rigor mortis is delayed in that leg. This is accounted for by the fact that the *impulses* from the cord *hasten* the onset of *rigor mortis.*

Spinal reflexes are more or less modified by impulses coming from the brain or from other sources. This is shown by *Exner's experiment,* in which a rabbit was prepared in such a way that an electrical stimulus could be applied either to the cerebral cortex or to the skin of the foot, both being followed by the same muscular response. Excitation, simultaneously, of both places gave a proportionally greater response than excitation of either alone. If the skin was so weakened that a muscular response did not follow when applied alone, it could be made effective by stimulating the cerebral cortex 0.6 of a second previously. Excitation of the cortex had the effect of making the nerve-cells involved more irritable, so that they were able to respond to a weaker stimulus. The increase of irritability passed away in three seconds. It has been shown that the *patellar tendon-reflex* could be reinforced by a *voluntary contraction* or by a *sensory stimulation* if the interval between them was less than 0.4 of a second. As the interval became greater than 0.4 of a second, the knee-jerk was diminished or inhibited until the time-difference was 1.7 seconds, after which the two phenomena ceased to influence each other. A simple method of showing *inhibition* of *reflexes* is to dip the toe of a pithed frog into dilute acid. A contraction results. If the experiment is now repeated while at the same time the other toe is pinched, it will be found that the latent period of the reflex is greatly prolonged, or that no contraction at all follows. *It has been shown that stimulation of the cortical areas for the flexors of the arms simultaneously gives rise to an inhibition of the extensors, and that when the extensors are brought into action there is an inhibition of the flexors.*

Voluntary responses differ from reflexes in that they are less predictable, more variable, and that instead of following in a very short interval they may be delayed for a long while—possibly for years. The most complex voluntary reactions involve the entire central nervous system, and especially the cerebral cortex. The path taken by the impulse is longer and involves more neurones, so that in its course it may become much more modified.

Impulses over afferent fibres pass along the posterior spinal nerve-roots and enter the cord. Their *path* is then along fibres

FIG. 38.

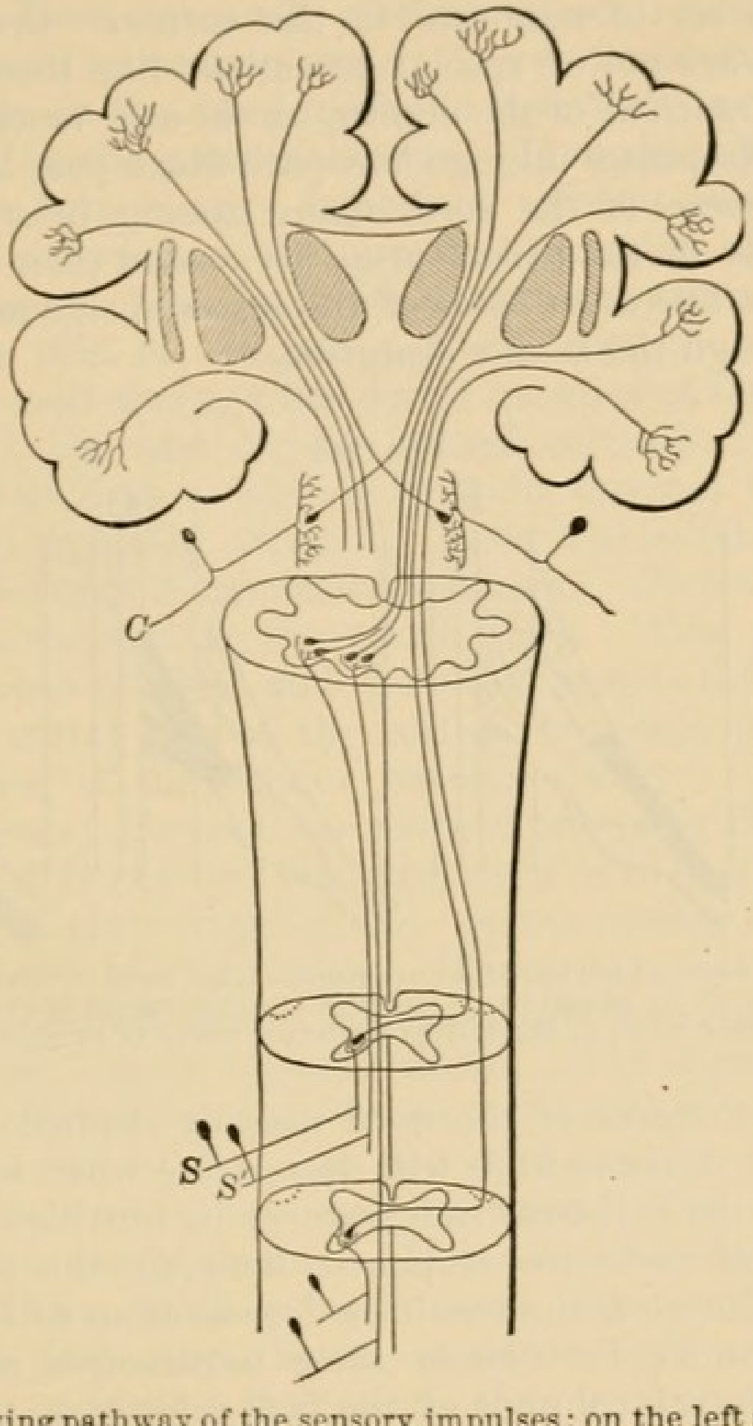
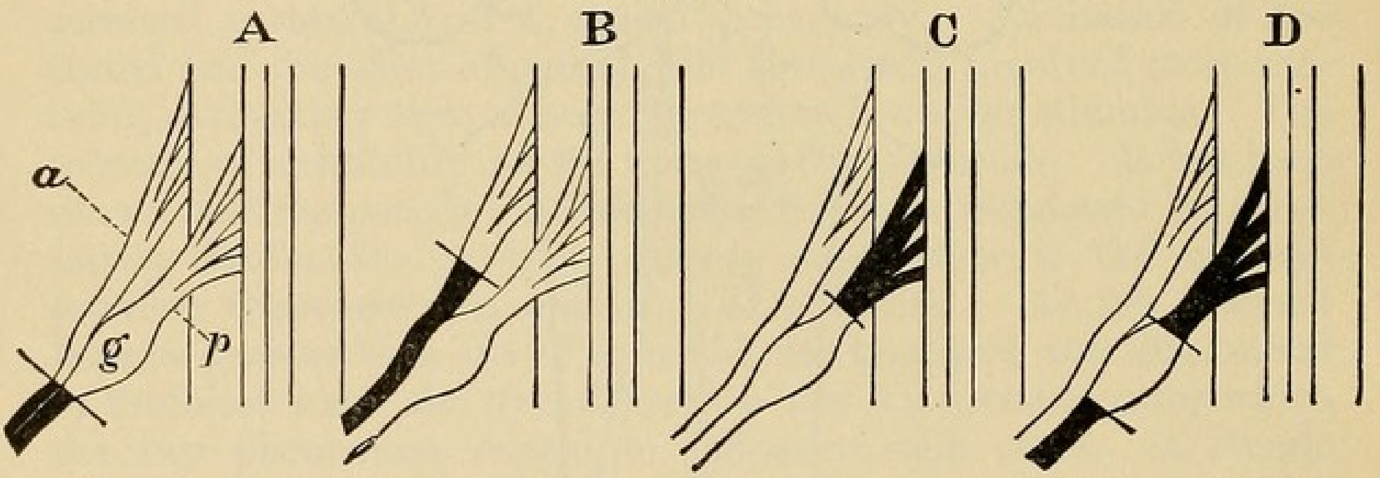


Diagram showing pathway of the sensory impulses: on the left side *S S'* represent afferent spinal nerve-fibres; *C*, an afferent cranial nerve-fibre. These fibres terminate near central cells, the neurone *S* of which crosses the middle line and ends in the opposite hemisphere. (Van Gehuchten.)

that ascend the posterior columns, and may be either along a *short-path* or a *long-path* fibre. If it is the *latter*, they are carried to the dorsal funiculi, to terminate about cells in the *nuclei* of the *gracilus* and *cuneatus.* Here the impulse is taken up by a second set of *neurones,* which *decussate,* and then go forward in the *medial lemniscus,* to end either in the *ventral* portion of the *thalamus* or in the *cerebral cortex.* From the *thalamus* the impulse may pass along a third set of neurones to the cortex. *Cranial afferent* nerves, which are not of special sensation, like those of the fifth, the *vestibular portion* of the eighth, ninth, and tenth, have a similar course. Impulses taking short-path fibres pass largely to cells in the *dorsal cornu* of the *cord,* many passing by way of the *collaterals.* Cells of the *dorsal gray horn* send their *axones across* the *cord* to the *lateral columns* of the opposite side and pass to the *thalamus* through the *medial lemniscus.*

Fig. 39.



Degeneration of spinal nerves and nerve-roots after section (Dalton): *a*, anterior root; *p*, posterior root; *g*, ganglion; A, section of nerve-trunk beyond the ganglion; B, section of anterior root; C, section of posterior root; D, excision of ganglion.

Pathways or tracts of the cord may be studied by means of *degenerations.* A nerve-fibre will degenerate when by section it is removed from the cell-body that governs its nutrition.

If the *dorsal roots* are sectioned between the *posterior root-ganglion* and the *cord,* the resulting *degeneration* will extend down the *dorsal* columns for two or three centimetres, and up to the *nuclei* in the dorsal columns of the *bulb* mainly on the same side as the section. On passing upward, however, the *area* of degeneration constantly becomes less, owing to the fact that fibres continually are leaving the posterior columns and passing into the gray matter of the cord. When the *cord* is *hemisected,* the *ascending* fibres that *degenerate* are in the *dorsal* columns, in the *dorso-lateral ascending* tract, and in the *ventrolateral descending-*

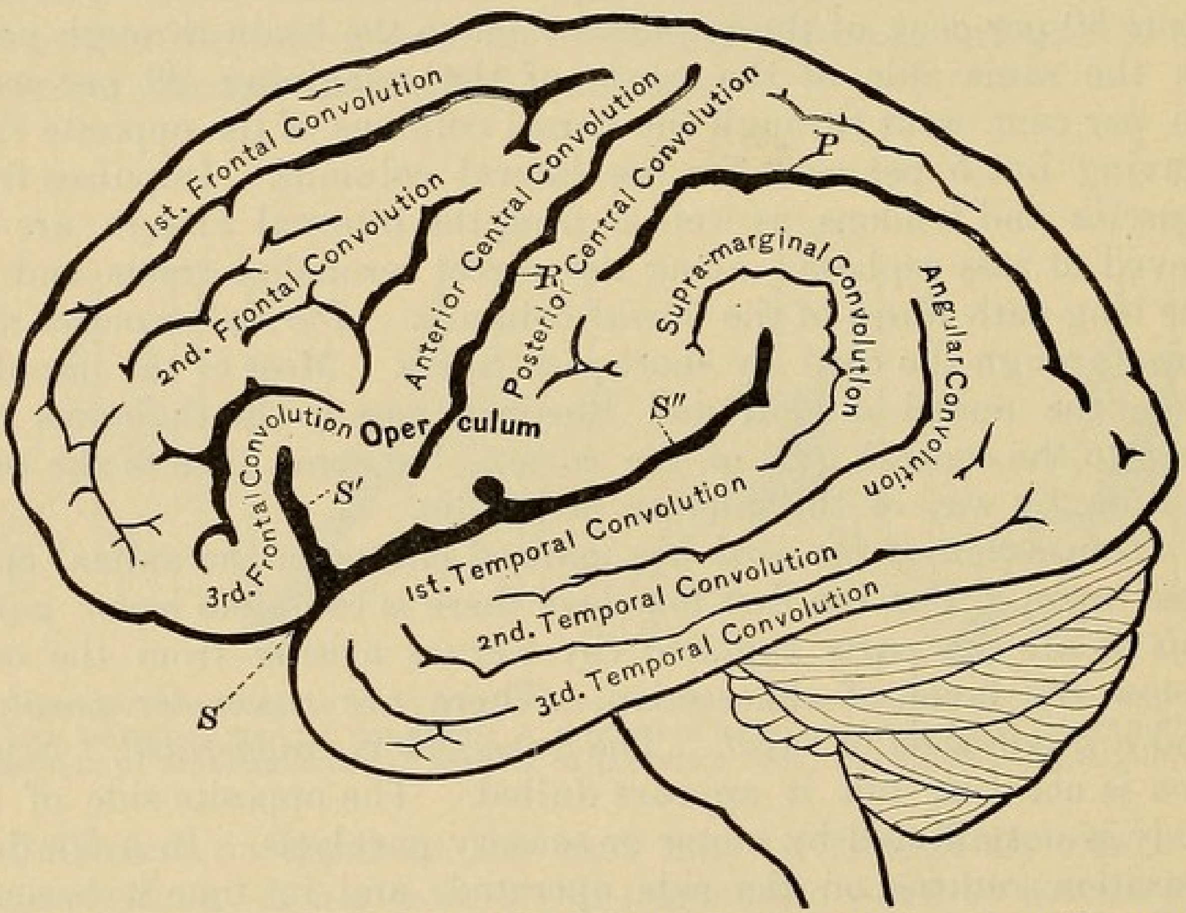
ascending tract. Most of the degenerated fibres are to be found on the same side as the section, although a few are on the opposite side. Strong *stimulation* of *sensory* nerves like the *sciatic* causes a *rise* in the *blood-pressure.* One investigator has, therefore, attempted to block the path of the vasomotor impulses by sectioning the cord in various ways. It was found that cutting the lateral column on the side opposite to that of the nerve stimulated was followed by the greatest success. It seems then that the *lateral columns* form a very important *afferent pathway.* Gotch and Horsely determined that upon stimulation of the posterior roots 80 per cent. of the impulses went to the brain through paths on the same side of the cord; of the remaining 20 per cent., 15 per cent. went through the dorsal columns of the opposite side, leaving but 5 per cent. for the lateral columns. Impulses from muscles and tendons, as well as from the internal viscera, are believed to pass cephalad along the direct cerebellar tracts and by the long-path fibres of the dorsal columns. *Dermal impulses* may pass through the cord by short-path fibres. Most of the impulses from the nuclei of Goll and Burdach pass to the thalamus and then to the central gyri of the cortex, but some pass to the cerebellum by way of the inferior peduncles.

Hemisection of the cord has marked effects on the animal operated upon. For the first few days there is complete *motor paralysis* of all the parts supplied by nerves arising from the cord below the level of the section. There are *vasomotor paralysis* and a *diminution* of *sweat.* The *knee-jerk* is *exaggerated. Sensation* is not lost, but it appears dulled. The opposite side of the body is not affected by motor or sensory paralysis. In a few days sensation returns on the side operated, and in time it becomes difficult to determine that paralysis exists. The limb, however, remains permanently thinner. If the *hemisection* is made above the level of the *eighth cervical nerve,* the *pupils* are *contracted* permanently, but, nevertheless, react to *light* and *shade.* The *dilator* and *pilomotor nerves* of the *cervical sympathetic* are unaltered.

Impulses reaching the cortex give rise to others that pass out of the central system and cause a response in various peripheral structures of the body, just as was the case in pure reflexes. To determine the *descending* paths of these impulses, it is customary to investigate the cerebral cortex by means of *electrical* or *mechanical* excitation, or by means of lesions.

An *electrical* stimulus, if of proper strength, will usually bring out *well-coördinated movements*, which last longer than the stimulus. As the *excitation* becomes too great the movements become *convulsive*. It has been found by this method of investigation that the *cerebral cortex* can be divided into *areas* which are connected with definite *portions* of the *body*. These *areas* are either

FIG. 40.

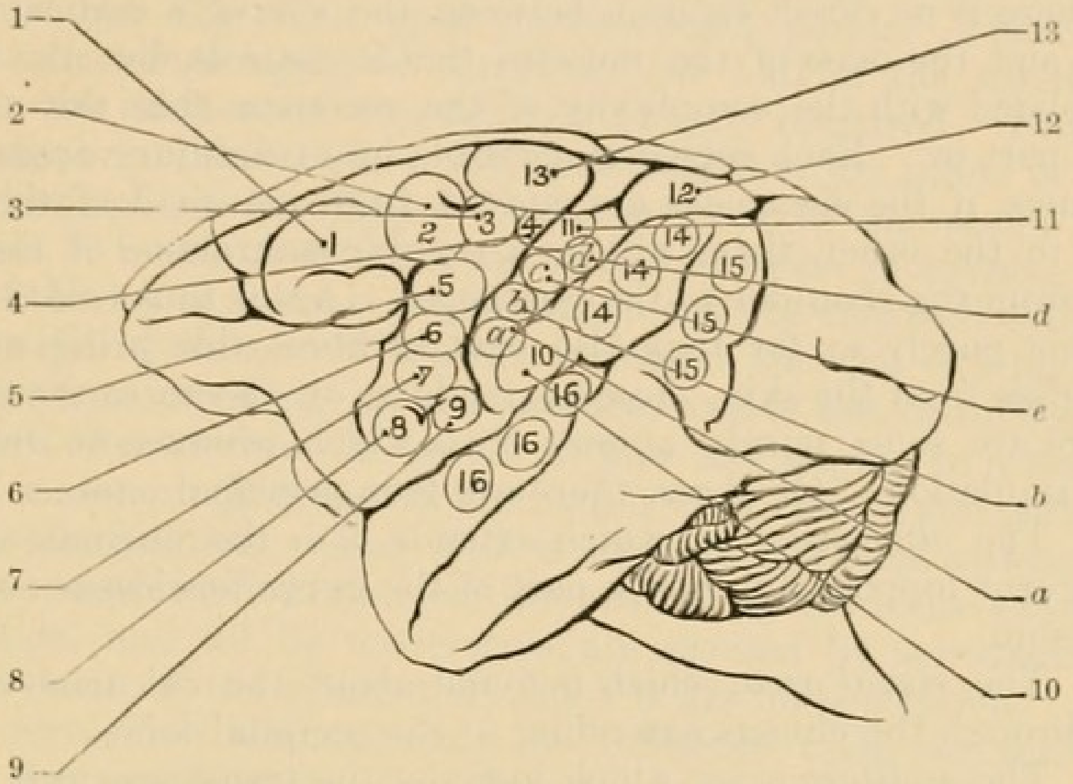


Plan of the human brain in profile (Dalton), showing its fissures and convolutions: *S*, Fissure of Sylvius; *S'*, anterior branch; *S''*, posterior branch; *R*, fissure of Rolando; *P*, parietal fissure.

sensory or *motor*. Each *motor region* upon *stimulation* will call out *movements* of certain *muscles*.

The *fibres* from the *motor* cells of the *cortex* pass directly into the substance of the brain, which is shown by making *circular incisions* about various areas, when their usual responses to excitation are not altered. A cut *parallel* to the surface of the *cortex*, however, renders *stimulation* of the area *ineffective*. The paths of the fibres from the cortex are investigated by destroying the cortical cells, when the fibres with which they were in connection degenerate. By this method it has been found that the *axones* of the *motor cells* extend through the *internal capsule*, through the *crusta*, and the *pyramids* to the *bulb-cord*. It is found that some fibres of the *callosum* also *degenerate*, and may be traced down through the *internal capsule* and *crusta* of the *other side*.

FIG. 41.



Brain of monkey, showing the position of the motor and sensory centres as ascertained by Ferrier. The actions all occur on the side of the body opposite to the part of the brain irritated: 1, the eyes open widely, the pupils dilate, and head and eyes turn toward opposite side; 2, extension forward of the opposite arm and hand, as if to reach something in front; 3, movements of tail (and trunk); 4, retraction with adduction of opposite arm; 5, supination and flexion of the forearm, by which the arm is raised toward the mouth; 6, action of zygomatics, by which the angle of mouth is retracted and elevated; 7, elevation of ala of nose and upper lip; 8, opening of mouth with protrusion of tongue; 9, retraction of tongue; 10, retraction of opposite angle of mouth; *a*, *b*, *c*, *d*, prehensile movements; 11, retraction and adduction of opposite arm; 12, advance of the opposite hind limb; 13, complex movements of thigh, leg, and foot; 14, 15, vision (sensory); 16, hearing (sensory).

At the *decussation* of the *pyramids* the greater number of the fibres from the internal capsule of each side cross to the opposite side, and when they reach the cord are grouped together to form the *crossed pyramidal tract* of the *lateral columns*. A lesser number of the fibres pass down into the cord on the same side and form the *direct pyramidal tracts* of the *anterior columns*.

Injury to the *cortex* of one hemisphere will produce *degenera-*

tion of the *cross-pyramidal* tracts of both sides, but that on the side opposite the lesion is much more marked. The *direct pyramidal* tracts are well defined in man and monkeys, but extend only to the *mid-dorsal* region. Before their termination they cross to the other side of the cord in the gray commissure. The motor fibres of both pyramidal tracts end in relation with motor cells in the anterior horns of the spinal cord, which cells in turn send their axones to the muscles by way of the anterior spinal nerve-roots.

There is no direct *relation* between the size of a cortical motor area and the mass of the muscles that it controls, but the size is correlated with the complexity of the reactions that the muscles take part in. Each region is divisible into subsidiary areas. For instance, if the electrodes are moved from one limit of the arm-area to the other, there will be a regular contraction of the muscles from the shoulder to the phalanges. Areas thus called motor are not purely so, for they also contain fibres that bring afferent impulses from the skin, muscles, tendons, or viscera to the cortex. There are some purely *sensory areas* which produce no response on stimulation. Of these, there are four principal ones:

1. The *olfactory area*, which extends over the uncinate gyrus, the gyrus hippocampi, and a part of the gyrus fornicatus near the callosum.

2. The *visual area*, which is found about the calcarine fissure, all through the cuneus extending to the occipital lobe.

3. The *auditory area*, which includes the transverse gyri in the Sylvian fissure and the first temporal gyrus.

4. The *body-sense area*, which is found about the two central gyri and extends forward to the frontal gyri, and from the precuneus over one-half of the mesial surface of the hemisphere.

As the result of common experience it is known that a motor response may follow any sensory stimulation whatsoever, so that motor and sensory areas must be connected. The fibres that bring this about are called *association-fibres*. Their function is to furnish pathways which are more or less intricate between different areas, and to retain previous impressions as memories which modify any other impulses passing over them. When the motor and sensory areas are contrasted with the surface that remains of the cortex, it is found that extensive areas give no response upon direct stimulation. They may be designated as *latent areas.* They include the ventral surface of the hemisphere, a considerable portion of the mesial surface, and parts of the frontal, parietal, and temporal lobes. The frontal region is connected by fibres with the pons and cerebellum. Removal of this portion of the brain is followed by transient sensory and motor disturbances. *Removal* of both lobes causes the animal to lose all curiosity, affection, pleasure, and capacity to learn. It is in this portion of the brain that the intelligence is centred; it is the organ of the mind. Memory, reason, emotions, and all the other attributes of the mind are dependent upon its functional power. There are instances in which injury or disease of one half of the cerebrum has left the intellectual faculties not gravely impaired. From a consideration of such cases it has been held that the action of one of the hemispheres is sufficient for the purposes of the mind; but, as a rule, it is safe to say that the *hemispheres* act in *unison*. In some of the lower animals the cerebrum may be removed entirely without killing them. When this is done in the case of a pigeon, the bird remains quietly in one position, and is not disturbed by noises; if thrown from its perch, it flies and alights in a nearly normal manner. If a foot be pinched, it withdraws it and perhaps changes its position. The bird is capable of reflex actions of various complicated kinds, but there is no spontaneous exercise of volition, and all its movements are excited by nerve-stimuli *from without*, of the moment of which it has no perception.

The *cerebellum* seems to exert no influence upon the sensory nerves, for sensibility is not affected by its injury. The *motor system* of the body is, however, entirely disorganized by lesions of this organ, giving rise to extreme *incoördination*. The two halves of the cerebellum are united by commissural fibres, division of which is followed by a transitory disturbance in the *gait*. The *cerebellum* is *not concerned* with *psychical functions*. When small portions are removed, the animals become feeble and uncertain in their movements, but are able to move about for ordinary purposes. As the amount removed is increased, the want of coördination of the voluntary muscles becomes greater. With the entire cerebellum gone, the condition is absolute—animals cannot stand or walk, or bring any of the muscles into orderly action. If the animal is laid upon the back, it cannot recover itself, but struggles in vain. The senses are normal and the will is present, for if a blow is threatened an attempt is made to avoid it. When the lesion is confined to one hemisphere, the lack of coördination is noticed in the opposite side of the body. Under these circumstances the animals fall to the opposite side and roll over, giving rise to what are known as *forced movements.* Pigeons from which the cerebellum is removed may live sometimes for months, and in some cases after partial removal there is a return of the power to coördinate at the end of some days.

The function of the *thalamus* is not well understood. Fibres reach its ventral portion from the cord, and the cells in relation

FIG. 42.

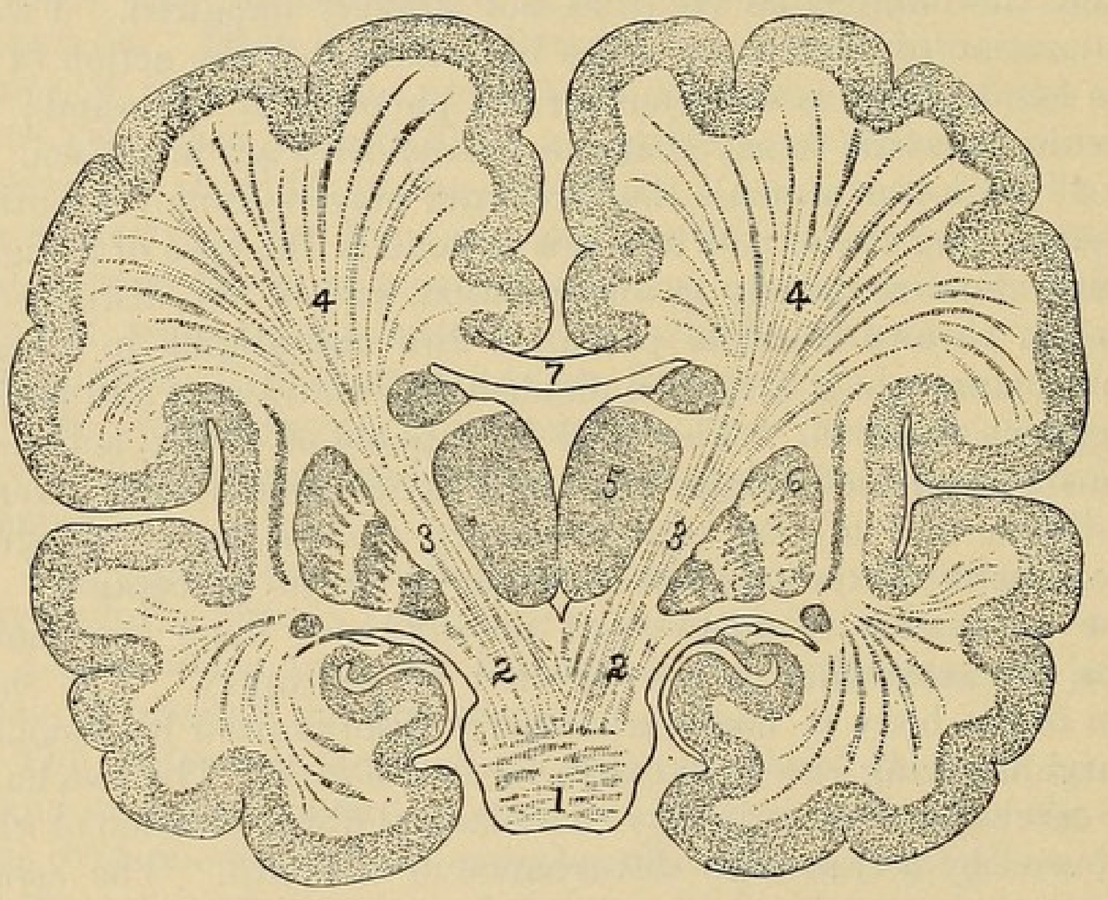


Diagram of human brain in transverse vertical section (Dalton): 1, tuber annulare; 2, 2, crura cerebri; 3, 3, internal capsule; 4, 4, corona radiata; 5, 6, cerebral ganglia; 7, corpus callosum.

with which they end send their axones to the cerebral cortex. Some cells in the cortex, in turn, send axones back to the thalamus. Cell-groups which increase the responsiveness of the central system are probably located here. Lesions are accompanied by a loss of power to express the emotions through the muscles of the face. When they extend to the internal capsule and to the crura cerebri, paralysis results.

Lesions in the *crura* lead to paralysis of the opposite side of the body, both of sensation and of motion, of a degree depending upon the extent of the lesions; and, besides, result in a paralysis of the motor oculi nerve of the same side as the lesions. There is a derangement of the coördination of movements, shown in rotary movements when the subject attempts to walk. It is inferred that coördinating impulses pass through the crura.

The *anterior corpora quadrigemina* are the homologues of the optic lobes in some of the lower animals, and the anterior pair may be regarded as important centres for the *visual* and *motor functions* of the *eyes*. The *posterior pair* are associated more intimately with the *sense of hearing*. Not only does *blindness* follow lesions of the anterior pair, but often they are *atrophied* when the eyes are destroyed. Crossed paralysis may follow lesions in the lower portion of the pons, which is more or less complete, together with a paralysis of the facial muscles on the same side as the lesions.

As the *medulla* is the sole connecting link between the upper part of the brain and the cord, it necessarily contains all fibres passing between these limits, so that it conducts all impulses. It resembles the spinal cord in being the seat of reflex acts; the only difference between them being in the fact that many of the reflexes performed by the bulb are of much greater importance to life. There is a considerable number of centres in the medulla which control important and complicated coördinated muscular actions. These are centres for reflex action for the most part, which are called upon to act in response to stimuli derived from an afferent impulse or to a voluntary effort. As examples, may be mentioned: the *cardiac centre*, the *vasomotor centre*, the *thermotactic centre*, and the *respiratory centre*. The latter may be easily demonstrated in the frog, If the spinal cord be removed up to the medulla, the respirations will continue, and in the same way they will not cease if the hemispheres also are removed. If the medulla is then injured at the origin of the pneumogastric nerve, the movements of respiration cease. The same occurs when the medulla is broken in man near the axis in executions by hanging.

Division of the spinal cord results in a complete loss of conductivity between the two segments. There are a loss of sensation and a paralysis of the parts supplied by nerves emerging from the cord below the section. Both segments of the cord may suffice for certain reflex movements. If the section be made above the point of origin of the *phrenic* nerves, death from *asphyxia* results. In the frog, whose spinal cord has been cut close to the medulla and the medulla destroyed, the following results are noticed: the animal does not respire through its lungs and lies prone on its belly. If dropped into a basin of water, it sinks, making no attempt to swim; it does not swallow food. If the section is made anterior to the bulb, the frog breathes, sits in a normal position, swims in a basin of water, crawls out if it can and then sits still. It makes no motion unless irritated, then hops away. It swallows food placed upon the tongue.

Cranial Nerves.

The cranial nerves are varied in their functions, and all arise from ganglia of gray matter in the brain and medulla. The floor of the fourth ventricle is distinguished particularly by the abundance of nuclei from which the cranial nerves arise.

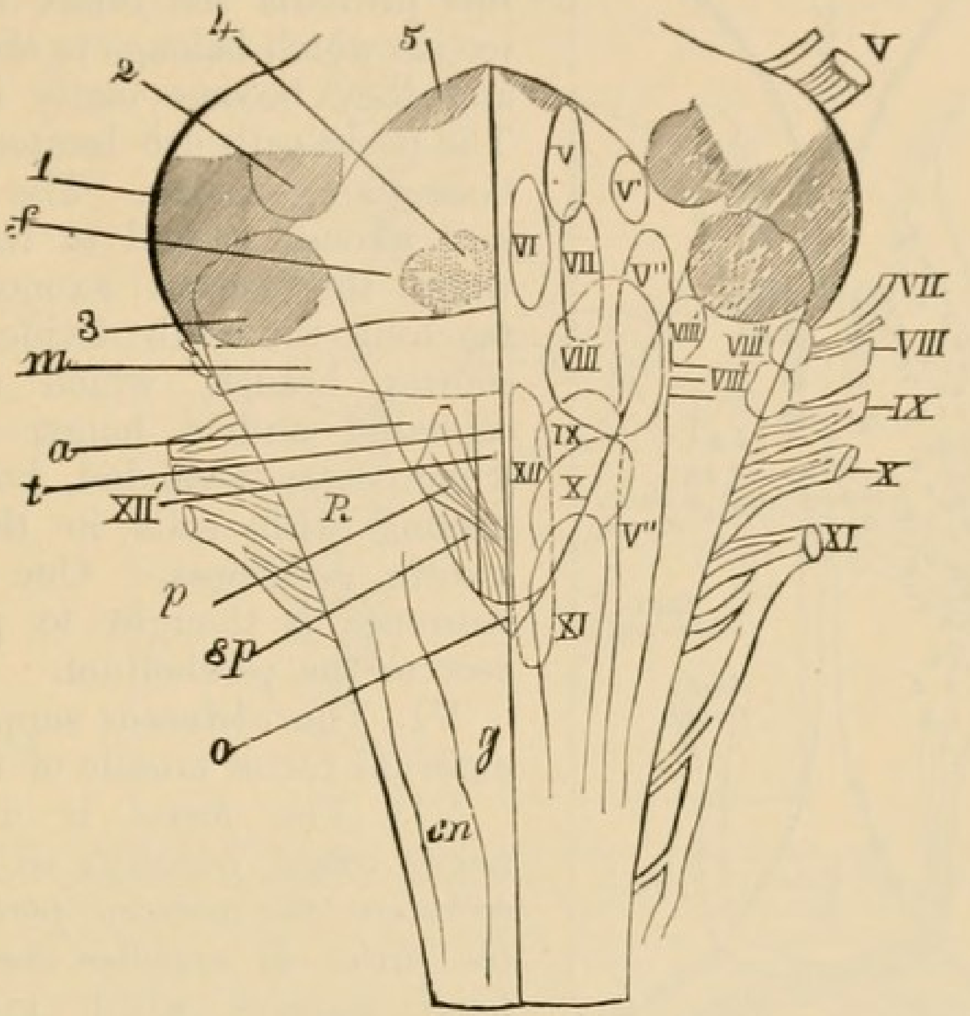
I. The *olfactory nerve* forms the pathway for the impulses giving rise to smell. The fibres pass from the sense-endings of the nose to the olfactory bulb on the same side, and then by way of the olfactory tract to the gyrus fornicatus or to the temporal end of the gyrus hippocampi.

II. The *optic nerve* conducts impulses from the retina to the pulvinar, the corpora quadrigemina, and the external geniculate bodies. In man the fibres for the greater part cross in the chiasma. From the primary centres they are continued to the occipital cortex of the same side, passing through the occipital end of the internal capsule. The location of the centres is probably in the cuneus and surrounding parts. The calcarine fissure has been indicated by some as the most important ending.

III. The *motor oculi* is a purely motor nerve. Section paralyzes the elevator of the upper eyelid, giving rise to *ptosis;* paralysis of the muscles of the eyeball results in inability to move the eye up, down, or inward, while the unopposed action of the external rectus produces external strabismus; paralysis of the muscle of the iris causes the pupil to remain dilated, so that it does not respond to light; paralysis of the ciliary muscle prevents accommodation. The control of the pupil through a strong voluntary effort exerted through the third nerve shows itself in a contraction, as when the eyeball is turned strongly upward and inward.

IV. The *patheticus* supplies the superior oblique muscle. Its section results in double vision, and the image seen by the affected eye appears obliquely and below that of the other eye. This may be corrected by inclining the head to the opposite side.

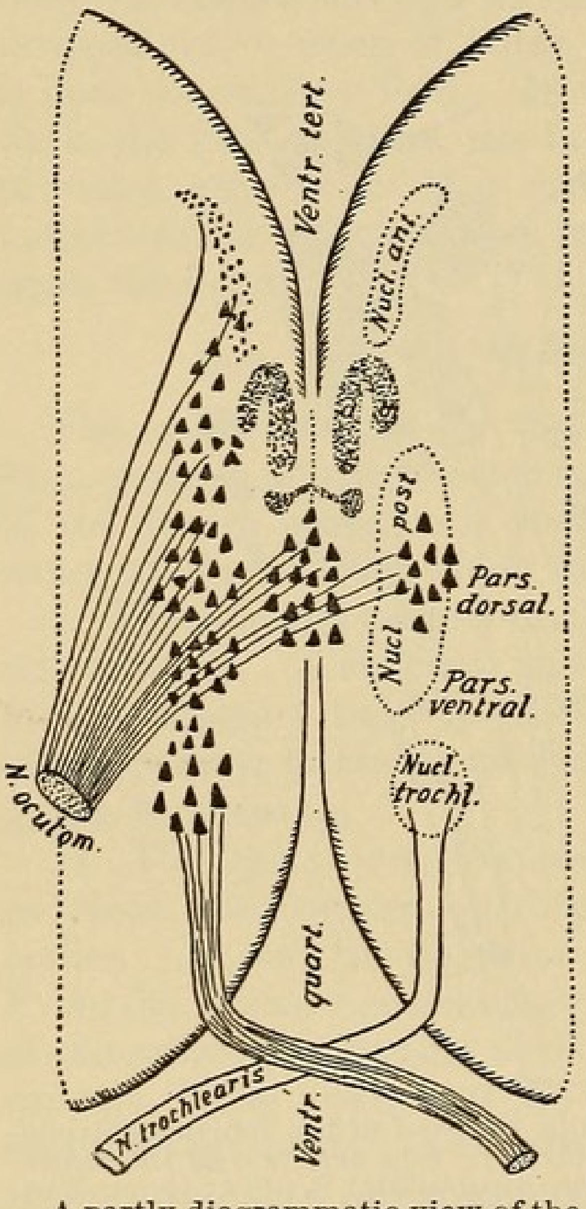
FIG. 43.



View of the posterior surface of the medulla, the roof of the fourth ventricle being removed to show the rhomboid sinus clearly. The left half of the figure represents: *Cn*, funiculus cuneatus and, *g*, funiculus gracilis; *O*, obex; *sp*, nucleus of the spinal accessory; *p*, nucleus of the pneumogastric; *p* + *sp*, ala cinera; *R*, restiform body; *XII'*, nucleus of the hypoglossal; *t*, funiculus teres; *a*, nucleus of the acusticus; *m*, striæ medullares; 1, 2, and 3, middle, superior, and inferior cerebellar peduncle, respectively; *f*, fovea anterior; 4, eminentia teres (genu nervi facialis); 5, locus cœruleus. The right half of the figure represents the nerve-nuclei diagrammatically; *V*, motor trigeminal nucleus; *V'*, median, and *V''*, inferior sensory trigeminal nuclei; *VI*, nucleus of abducens; *VII*, facial nucleus; *VIII*, posterior median acoustic nucleus; *VIII'*, anterior median; *VIII''*, posterior lateral; *VIII'''*, anterior lateral acoustic nuclei; *IX*, glossopharyngeal nucleus; *X*, *XI*, and *XII*, nuclei of vagus, spinal accessory, and hypoglossal nerves, respectively. The Roman numerals at the side of the figure, from *V* to *XII*, represent the corresponding nerve-roots (Erb).

V. The *trigeminus nerve* breaks up into three branches: of these, the *first* and *second* are entirely sensory, while the *third* is motor. Section of the motor root of the nerve results in a paralysis of the muscles of mastication. Destruction of the sensory root results in complete anæsthesia of the skin of the face and the mucous membrane of the mouth. The anæsthesia of the conjunctiva, of the nostrils, and of the lips prevents the reflex self-protection which belongs to the parts, and they become easily injured. The nerve-cells are located in the Gasserian ganglion. The peripheral axones extend to the skin, while the central axones upon reaching the bulb divide into a shorter branch, which extends cephalad and a longer branch which extends caudad, both connecting with cells in the substantia gelatinosa. One set of neurones is thought to pass direct to the cerebellum.

Fig. 44.



A partly diagrammatic view of the floor of the aqueduct, looking upward (dorsally), nuclei of the third and fourth nerves, and the decussating fibres of the latter all shown; the third nerve nuclei are subdivided into an anterior nucleus, the Edinger-Westphal nucleus (*a* and *b*), and a posterior nucleus; the posterior nucleus has a dorsal, a ventral, and a mesial portion; the decussation of the fibres from the dorsal portion of the posterior nucleus of the third nerve is shown. (Edinger.)

VI. The *abducens* supplies the external rectus muscle of the eye.

VII. The *facial* is a motor nerve *which parallels in its distribution the sensory portion of the fifth.* It supplies the superficial muscles which give the power to the features reflecting the emotions. If the nerve is sectioned, the face on that side is devoid of motion and becomes smooth and expressionless. The eyelids do not close and the lips do not oppose properly on account of the defective action of the orbicularis muscle. There is difficulty in drinking and in speaking for the same reason.

VIII. The *cochlear portion* of the auditory is the nerve of hearing. The cell-bodies of these fibres are situated in the spiral ganglion of the cochlea, which is homologous with the dorsal root-ganglia of spinal nerves. One axone reaches the organ of Corti, and the other passes to the bulb, where it terminates either in the dorsal or ventral nucleus of the eighth nerve. The fibres entering

FIG. 45.

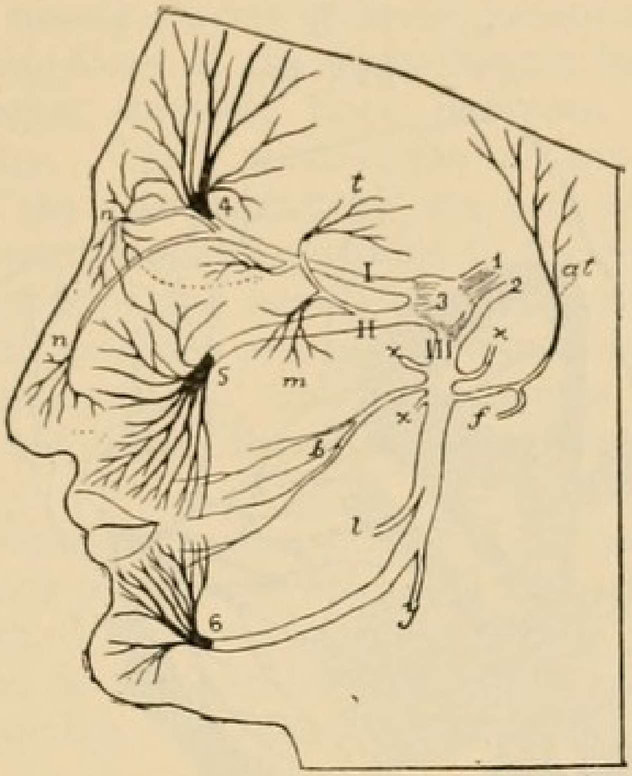


Diagram of the fifth nerve and its distribution: 1, sensitive root; 2, motor root; 3, Gasserian ganglion; I, ophthalmic division; II, superior maxillary division; III, inferior maxillary division; 4, supraorbital nerve, distributed to the skin of the forehead, inner angle of the eye, and root of the nose; 5, infraorbital nerve, to the skin of the lower eyelid, side of the nose, and skin and mucous membrane of the upper lip; 6, mental nerve, to the integument of the chin and edge of the lower jaw, and skin and mucous membrane of the lower lip; *n*, *n*, external terminations of the nasal branch of the ophthalmic division, to the mucous membrane of the inner part of the eye and the nasal passages, and to the base, tip, and wing of the nose; *t*, temporal branch of the superior maxillary division, to the skin of the temporal region; *m*, malar branch of the superior maxillary division, to the skin of the cheek and neighboring parts; *b*, buccal branch of the inferior maxillary division, passing along the surface of the buccinator muscle, and distributed to the mucous membrane of the cheek and to the mucous membrane and skin of the lips; *l*, lingual nerve, to the mucous membrane of the anterior two-thirds of the tongue; *at*, auriculotemporal branch of the inferior maxillary division, to the skin of the anterior part of the external ear and adjacent temporal region; *x*, *x*, *x*, muscular branches, to the temporal, masseter, and internal and external pterygoid muscles; *y*, muscular branch, to the mylohyoid and anterior belly of the digastric; *f*, sensitive branch of communication to the facial nerve.

the ventral nucleus may be continued to the superior quadrigemina, passing by way of the trapezium, the superior olive, the lateral lemniscus, and the inferior collicus. They may give collaterals to each, or may end in any of these gray masses. Cells of the dorsal nucleus send their axones across the floor of the fourth ventricle, forming the striæ acusticæ.

The *vestibular portion* of the eighth nerve transmits impulses from the ampullæ of the semicircular canals, and therefore serves the sense of equilibrium. The cell-bodies of these fibres are located in the vestibular ganglion, and their central axones are

FIG. 46.

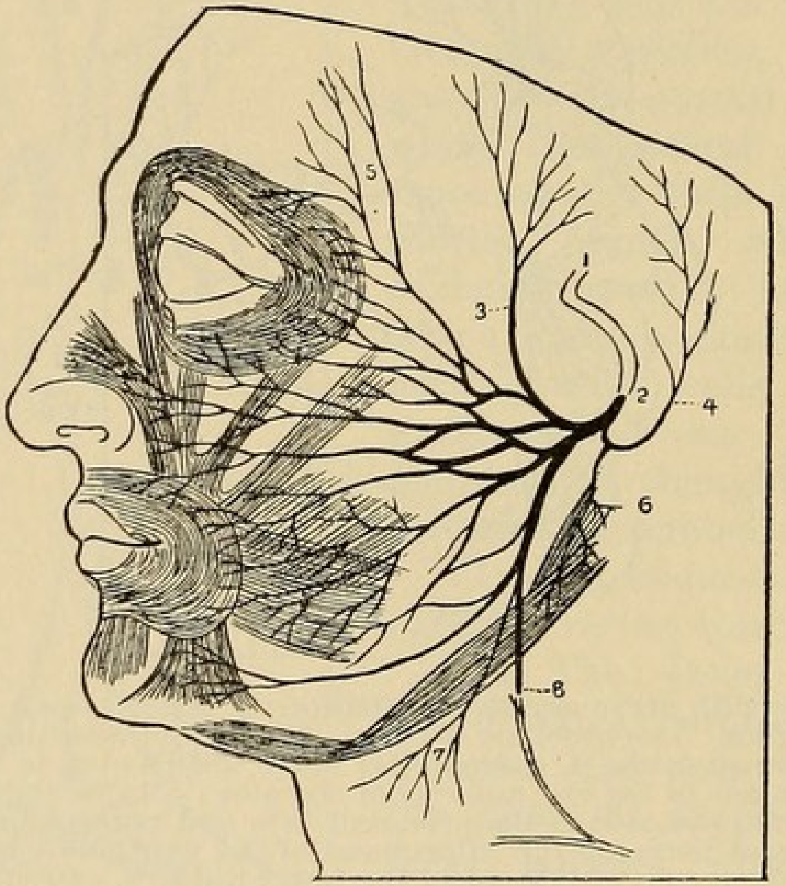


Diagram of the facial nerve and its distribution: 1, facial nerve at its entrance into the internal auditory meatus; 2, its exit at the stylomastoid foramen; 3, 4, temporal and posterior auricular branches, distributed to the muscles of the external ear and to the occipitalis; 5, branches to the frontalis muscle; 6, branches to the stylohyoid and digastric muscles; 7, branches to the upper part of the platysma myoides; 8, branch of communication with the superficial cervical nerve of the cervical plexus.

divided into a branch passing cephalad and one passing caudad, which terminate with various nuclei, and also pass to the cerebellum.

IX. The *glossopharyngeal* nerve is the nerve of taste and of deglutition. It is motor as well as sensory in function. Its distribution is to all the muscles of deglutition, and stimulation contracts, while section paralyzes them. The very numerous connections of the nerve complicate its origin and interfere with a clear comprehension of the unaided function of the nerve. The cells of the fibres lie in the bulb on the medial side of the tractus solitarius. Their axones are sent cephalad through the medial lemniscus. *Latest investigations have shown that the chief path of the taste-sense is over the chorda tympani nerve, which leaves the glossopharyngeal mainly a nerve of motor function.*

X. The *afferent fibres* of the *vagus* convey impulses from the pharynx, œsophagus, stomach, liver, pancreas, spleen, larynx, bronchi, and lungs. Their termination is near the *nœud vital.* The functions of the pneumogastrics are very numerous indeed. It is involved in respiration, deglutition, in the movements of the stomach, in the action of the heart, lungs, and viscera.

XI. The *spinal accessory* is a motor nerve essentially, but it contains some sensory fibres. Section produces paralysis of the voice, but does not affect the glottis. Forced respiration is impaired.

XII. The *hypoglossal* is a motor nerve, but possesses some sensory fibres which it derives from the cervical spinal nerves and from the fifth. This nerve is important in mastication. In animals its section is followed by inability to drink on account of difficulty in lapping. In man section of the nerve prevents articulation.

WEIGHT AND GROWTH OF THE BRAIN.

Weight.—Roughly it is three pounds or about one-fortieth of the total body-weight, and this ratio is greater than in the lower animals, with a few exceptions among the smaller birds and monkeys.

Weight of Brain in Grammes (Topinard).

Classes.	Males.	Females.
Macrocephalic	1925 to 1701	1743 to 1501
Large	1700 " 1451	1500 " 1351
Medium	1450 " 1251	1350 " 1151
Small	1250 " 1001	1150 " 901
Microcephalic	1000 " 300	900 " 283

In comparing brain-weights, the method of removal of the encephalon should always be considered, since retention of pia and the fluids of the ventricles affects the result.

In *Boyd's method*, after the skullcap has been removed but the pia left intact, the hemispheres are sliced away in horizontal sections as far down as the tentorium. By means of a section passing in front of the corpora quadrigemina the remainder of the hemispheres is removed. The cerebellum, including the quadrigemina, pons, and bulb, is finally removed. Each portion is weighed separately. Sometimes the pia and the fluid within the ventricles are included in the weight of the brain, and sometimes not. Broca gives the following table for the *weight of the pia*, for normal males:

20 to 30 years	45 grammes.
31 " 41 "	50 "
60 "	60 "

The ventricles have a capacity of 26 c.c. of water.

In considering the weights of different brains, it is assumed that the *proportion* of *nervous* to *non-nervous* tissue is constant, so that different weighings may be compared. If this be the case, then the variations in weight may be due to greater size of the individual nerve-elements, indicating a greater potential energy, or they may be due to a greater number of nerve-elements giving rise to more possible pathways. A minute study of the proportional weights of different parts of the brain shows that *variations* due to sex, age, and stature are very constant, which is in harmony with the view that weight-differences are due to the size of the nerve-elements rather than to variations in their number. In the latter case brain-weights would show independent variations in different parts of the encephalon.

All parts of the central nervous system of males are heavier than corresponding parts of females. The weight varies, in each, directly with the stature and inversely with old age. The brains of *criminals* do not differ in any marked way from those of ordinary hospital patients. *Insane* (excluding microcephalics) have no characteristic brain-weight, except in such cases where a congestion of the brain has occurred, when the weight is markedly increased; on the other hand, insanity due to destructive changes of brain-tissue is marked by a low brain-weight. As a whole, individuals whose brains during the years of growth have been under favorable circumstances possess the heavier brains. In some degree the size of the brain bears a direct relation to the *intellect* of the individual, but this is not absolute. The depth of the sulci and the consequent size and complexity of the convolutions are a more efficient measure of the brain power. In the largest of the apes the brain of an adult animal is about the same in weight as that of a human infant at birth.

Weight of Cord.—The average weight of the spinal cord is about 26.27 grammes, without the nerve-roots, but the pia intact. It is probable that this weight varies, like that of the brain, with age, sex, and stature.

Growth of Brain.—At birth the brain-weight is about one-third of what it will be at maturity. The increase is very rapid during the first year; quite rapid during the next seven or eight years; after this it becomes very slow. The maximum weight is attained in men between the fiftieth and sixtieth years; in women, between the fortieth and fiftieth years. A "*premaximum*" at thirteen to fifteen for males and at about fourteen for females, indicating a too vigorous growth, seems to be an important cause of death at this age. The encephalon reaches maturity much sooner than the body as a whole. At the end of the eighth year, when the brain has almost completed its growth, the body has reached but a third of its mature weight. At birth the brain forms 12 per cent. of the total weight of the body, while in the adult it forms but 2 per cent., or even less.

It has been estimated that the cortex alone contains 9200 million cell-bodies, and that the entire nervous system must contain at least 13,000 million cells. It is generally *agreed that in the human being the number is not increased after the third month of fœtal life.* All subsequent increase in the mass of the brain is therefore due to an enlargement of individual cells. There is very little direct evidence for this in man. Kaiser has measured the diameters of the cells of the anterior horns of the spinal cord, and in this manner has determined an increase in size. In the frog there is a gradual increase in the number of fibres of the ventral and dorsal spinal nerve-roots. The rate of increase is about 50 fibres for the ventral roots and 70 fibres for the dorsal roots for each gramme increase in the weight of the frog. Moreover, the greatest number of medullated fibres is to be found in the ventral roots near the cord, and in the dorsal roots near the ganglion. This is explained by assuming undeveloped cells which gradually become mature, and in so doing push out their processes.

The *area* of the *cerebral cortex* which is exposed has about one-half the extent of that which forms the walls of the sulci. It has been shown that the fibres of the cortex are greater in number in middle age than in youth or old age. The *association-fibres*, moreover, form three parallel systems. The deepest of these is first to become medullated, and the middle layer last.

The average *specific gravity* of the brain for males is about 1036.3, and for females 1036. The gray matter has about 81 per cent. of water, and the white matter about 70 per cent. The amount diminishes from birth to maturity. Between the fiftieth and sixtieth years the brain loses in weight in all parts, but the loss in the cerebral hemispheres is slightly greater than in other portions. The entire cerebral cortex diminishes in thickness with *age*, but more in motor than in sensory areas. In the cerebellum the branches of the arbor vitæ decrease in number and size; some of the cells are found to be shrunken, while the cells of Purkinje disappear altogether. In the cord, especially in the lumbar region, the cells become shrunken, pigmented, and degenerate; the supporting tissue is increased, and the walls of the bloodvessels are thickened. In paralysis agitans similar but more marked changes occur. With the advance of age the entire central nervous system breaks down into groups of elements, so that its powers are lost in an irregular and disjointed manner.

Fatigue.—When by voluntary contractions of the muscles of the index finger a moderately heavy weight is raised at regular intervals, it is found that the height of the contractions gradually decreases, so that in time the weight can no longer be lifted. If the effort is continued, it is found, in some people at least, that the power of contraction returns periodically to nearly its normal strength, so that a record of the contractions presents a series of waves. The *local feeling of fatigue* in this case is probably due, to a great extent, to the organs of muscular sense. An explanation of the *general fatigue* which may result is to be found in Mosso's experiment, in which he injected the blood of a fatigued animal into the circulation of a normal one, giving rise in the latter to all the symptoms of fatigue. It cannot be doubted that muscular activity gives rise to products, most of them as yet unknown, which are carried to the brain in the circulation. *Lactic acid* and the monophosphates of alkali metals circulated through a muscle produce in it all the characters of typical fatigue.

Lactic acid, although formed in muscle, is, however, not alone responsible.

Blood-supply of Brain.—In general, the capillary network is closest in the gray matter or wherever any aggregation of cell-bodies is to be found. Huber has demonstrated nerve-fibres in the walls of the vessels of the pia, and Kölliker claims to have traced them to vessels of the nervous substance proper. But, nevertheless, *vasomotor phenomena* of the brain are not very marked, so that the quantity of blood flowing through the brain varies but slightly.

A general rise of arterial pressure causes the blood to flow more rapidly in the cerebral vessels, raises the venous pressure and also the *intracranial pressure.* To some extent the latter is compensated for by a flow of cerebrospinal fluid through the foramen magnum into the vertebral canal. If the pressure continues to rise, the distention of the brain shuts off that outlet. Increase of pressure from now on impedes the circulation through the brain. It follows, therefore, that in pathological cases where trephining of the skull results beneficially the explanation may lie in a better blood-flow.

The *metabolism* of the central nervous system is not very intense. This is readily understood when it is known that the cell-bodies equal only 2 per cent. of the entire mass of the brain. The relative metabolism is less than that of muscles. During mental activity blood passes from the limbs to the head, as shown in cases where a defect of the cranial wall exists. During fatigue the brain becomes anæmic, coinciding with a decrease in the force of the heart-beat and of the tone of the abdominal vessels.

Sleep.—This phenomenon is one of many instances of the *rhythmic activities* of the central nervous system. From time to time all animals with a well-developed nervous system go to sleep, during which psychical activity is at its lowest point. To reach this condition, the most important *favoring factor* is an exclusion of all or most of the impulses from the central nervous system. In a well-known case of Strümpell, in which, from a complicated anæsthesia, all sensory impulses were limited in their entrance to a single eye and a single ear, the patient could be put to sleep at will by closing the eye and stopping the ear. In addition, sleep has been attributed to the following influences:

1. Chemical influences;

2. Circulatory influences;
3. Histological influences.

Those who hold to *chemical influences* in the production of sleep, maintain that during normal activity of the body various substances are formed which are circulated in the blood and directly lessen the activity of the nerve-cells or indirectly diminish the supply of blood to the brain. In the theories of *circulatorg influences* a fatigue of the vasomotor centre is looked upon as the cause of the anæmia of the brain resulting in sleep. In the *third set of theories* sleep is supposed to be due to a separation of the dendrites of the brain-cells due to a shrinkage of the nerve-cell bodies or to an intrusion of neuroglia-cells between them.

During sleep the capability of the nervous system to transmit impulses is not entirely lost. The cerebral cortex is most affected, the spinal cord least. The close relation between dreams and external stimuli is well known, and it has been proved experimentally that vasomotor changes, induced by external stimuli, may take place without awakening the sleeper.

The period of *deep sleep* is short and falls within the first two hours after its onset. During this time the pulse and breathing are slower, the intestines and bladder are at rest, the output of carbon dioxide is lessened, and the consumption of oxygen still more so; metabolism is less vigorous and the temperature falls. The respiration is said to become thoracic in type and to take on a more or less pronounced Cheyne-Stokes rhythm. The visual axes are probably parallel and directed to a distance, but the *pupils are contracted.* The latter is peculiar, since an absence of light should bring about dilatation. This is connected perhaps with important actions taking place in lower levels of the brain.

Loss of sleep is more injurious than starvation. Dogs have recovered from a period of starvation of twenty days, but a loss of sleep of five days proved fatal. The body-temperature fell 8° C. below normal and the reflexes disappeared. The red blood-corpuscles first were diminished, but later increased in number. Post-mortem examination revealed widespread fatty degeneration and cerebral hemorrhage.

In experiments made by Patrick and Gilbert, three subjects were observed for ninety hours while being deprived of sleep. The gain in weight which resulted was lost during the first sleep after the experiment. A decreased pulse-rate and a lowered body-temperature were observed. In general, there was a loss of all powers except in acuteness of vision, which was increased.

Hibernation.—This is connected closely with sleep, occurring periodically in many groups of animals and in a few mammals. It is characterized by a lessened metabolism resulting from a fall of the external temperature, and may be produced artificially in summer by cold. The heart beats very slowly and not very vigorously, while respiration is very slow and feeble. Nevertheless, the blood, arterial as well as venous, is bright scarlet in color, owing to the little oxygen consumed by the tissues. A hibernating dormouse has been observed to gain in weight, which was due entirely to an excess of oxygen taken in. Muscles and nerves remained irritable, and stimulation of the vagus produces a still further slowing of the heart-beat.

Hypnotism.—This state is analogous to, but by no means identical with, sleep. It differs in a peculiar loss of control over the muscular powers; in frequent anæsthesia and hyperæsthesia; in the great clearness of psychical images, which may be forgotten, but are remembered in subsequent trances. In the lighter stages the mind sees clearly what is going on about it, which is not true in sleep. Finally, hypnosis is characterized by an extraordinary obedience to suggestions. The power of inhibition residing in the cerebrum, by which the mind is constantly controlling and arresting reflex movements, seems to be diminished if not absent. Verworn has shown that the so-called hypnotism in animals is not due to an inhibition from the cortex, since the phenomena are obtained easily in decerebrate individuals.

Knee-jerk.—If the leg is placed in an easy position, as when it rests on the other leg, and a sharp blow is directed against the patellar tendon, the foot will be brought forward with a sudden jerk. This is known as the knee-jerk, and is caused by the sudden contraction of the quadriceps femoris. Physiologists are divided in the explanation of this phenomenon: some regarding it as a *true reflex*, while others maintain that the contraction of the muscle is due to a *direct stimulation* of the muscle by vibrations set up in the tense tendon.

Considered as a reflex, the afferent path of the impulses is over fibres starting in the patellar tendon, running in the anterior crural nerve, and reaching the cord by the posterior root of the fourth lumbar nerve in man. The centre for the knee-jerk lies in the third and fourth lumbar segments of the cord. The efferent path is over fibres in the anterior crural nerve which leave the cord by way of the anterior roots of the third and fourth lumbar nerves. If any portion of this reflex arc is destroyed, the knee-jerk is no longer to be obtained. It may be augmented or depressed by nervous impulses from many parts of the central nervous system. It is reënforced by cutting the nerves of the antagonistic muscles, and depressed by stimulating the central ends of these nerves. This is explained by the fact that flexor muscles send impulses to the spinal centre, and according to their condition influence the contractions of the extensors.

It is found that a deficiency of the knee-jerk exists usually, but not always, with a subnormal tension of the tendon, while a hypertonic state gives rise to an exaggerated jerk. Thus section of any portion of the reflex arc, by lessening the tonus of the muscle, extinguishes the reflex. It has been claimed that the time involved, 0.03 of a second, is characteristic of a simple muscular twitch, but too short for a reflex, the briefest of which requires more than one-fourth again as much time.

The *variations* found in the tendon-reflexes are very considerable. In some perfectly healthy individuals no knee-jerk at all can be obtained. Local fatigue of the extensor muscles diminishes it, while general fatigue at first increases but later diminishes it too. Shutting off the blood-supply will cause the knee-jerk to disappear in a quarter of an hour. *Stimuli* applied to the skin, a cold bath or friction, increase it if applied not more than 0.2 to 0.4 second before the tendon is struck. If applied sooner, they cause an inhibition which reaches its maximum about 1 second after the stimulus is applied. Sound always reënforces the jerk, while light causes very little if any inhibition. Inhalation of anæsthetics (chloroform, ether) extinguishes the reflex. It has been found in man that the knee-jerk was present immediately after decapitation, but usually injury to the cord permanently abolishes it. Lombard has shown that all the ordinary events of daily life are portrayed faithfully in changes in the knee-jerk. In deep sleep the knee-jerk is absent, but sensory stimuli too feeble to awaken the sleeper are manifested in an exaggeration of the tendon-reflexes. An increased knee-jerk is a symptom of some spinal diseases. After removal of the right half of the cerebellum the knee-jerk on the homonymous side is more vigorous. A similar result follows section of the cerebellar peduncles.

Time Involved in Nervous Processes.—Whenever a nerve-impulse passes from one neurone to another, there is a delay in its transmission. In the frog, for example, it takes twice as long for an impulse to pass from the middle of the cerebral hemispheres to the optic lobes as from the bulb to the lumbar enlargement, although the distance is much less. If one eyelid be stimulated electrically, both lids wink. The total time required for this reflex is from 0.066 to 0.057 second. Deducting the time required for the impulse to pass to and from the brain along the fifth and seventh nerves, and also the latent period of the orbicularis muscle, there remains 0.05 to 0.04 second for the time required in the bulb. This time-value may be regarded as an *average* of *simple reflex actions*. The individual values vary greatly. In general the time is shorter the stronger the stimulus. It is shorter when the reflex is confined to one side of the body than in cases where the impulse crosses to the other side, even if allowance is made for the difference in the length of the nervous path. The time depends, of course, on the condition of the cord, becoming greater during exhaustion and disease. The time becomes longer the greater the number of neurones involved. When the afferent impulse arouses sensation and consciousness, and the ensuing response is the result of a volitional effort, then the neurones involved are indefinite in number. The action is now a *reaction*, and the time is known as the *reaction-time*. This time is shorter when the right hand makes a response to a stimulus to the left than when the response is to either auditory or visual sensations. But the shortest reaction-time follows a visual excitation produced by direct electrical stimulation of the retina. Roughly, reaction-times for cutaneous sensations are one-seventh of a second; for auditory sensations, one-sixth of a second; for visual sensations, one-fifth of a second.

A reaction-period consists of *three stages*, corresponding to the times required by the impulse on its afferent path, its efferent path, and in the central nervous system. All three stages may vary independently. The time involved in the central stage is known as the *reduced reaction-time*. It varies in different persons, and is known as the *personal equation*. When the subject is required to react to one of two or more possible signals, the reaction-time may be prolonged from 0.016 to 0.062 second, the time varying with the sensation employed. It is shortened by practice, so that in time it becomes more of the reflex type.

Nerve-centres.—It is very difficult to give a satisfactory definition of what is meant by a centre. In general, any portion of the central nervous system where impulses originate or undergo modification is a centre. The modification of the impulse may be in strength, in direction, or in time. There is no doubt that many of the so-called centres of the central nervous system are not really such, and of the remainder all are not equivalent in power, which depends mainly upon the number of paths by which impulses may reach them.

By *association-centres* are meant portions of the cerebral cortex that lie between sensory centres and whose function it is to retain previous impressions as memories. Flechsig calls the association-centres "organs of thought." The conception of association-fibres and -centres gives an explanation of many pathological phenomena.

In order to do this, it is necessary to assume association-paths between most or all motor and sensory areas. These are better organized in some cases than in others, so that the communication, for example, between visual, auditory, and motor centres is more complicated and complete than that between auditory, gustatory, and motor centres. There exist, besides, differences in the two hemispheres. Broca first showed that a lesion of the third frontal convolution of the left hemisphere resulted in a loss of the power of speech. It was soon found that lesions of the corresponding area of the right hemisphere do not produce so great a disturbance, particularly in right-handed persons. It is concluded, therefore, that in most persons the speech-centre is developed more highly on the left side. A greater perfection of the right eye and ear, involving corresponding changes in motor areas, sustains the idea that in these respects at least the hemispheres differ.

Speech involves both *sensory* and *motor areas* of the cortex. Nerve-impulses, reaching the sensory areas, affect consciousness. Through the senses of hearing, sight, or touch, certain disturbances in the medium external to the nervous system are able to arouse in the sensory areas the idea of words. Any permanent interruption of impulses to the sensory areas will result in deafness, blindness, or touch-anæsthesia. The portion of the brain where the perception of words occurs is connected with an association-centre, in this case the *speech-centre* located in the posterior portion of the third frontal convolution of the left hemisphere. From this region paths run to various motor areas of the brain, to the corpus callosum, and thus to the opposite hemisphere, and to the internal capsule. Lesions of purely motor areas or paths result in a loss of expression through paralysis of the necessary muscles. The effects produced by an interruption of the impulse along its incoming or outgoing path are easily understood. When, however, a lesion occurs within the central nervous system involving any of the paths required in speech, the results are more complicated. Lesions of sensory areas give rise to *sensory aphasia.* When these are situated in the occipital region, there results an inability to form a comprehension of written language. Words are seen, but are not understood. This is known as *alexia* or *word-blindness.* In this case spoken language is readily understood. Similarly there may be *word-deafness*, when written language is understood, but spoken language becomes a mere series of noises without meaning. The lesions in this case exist in the first and second temporal gyri and in the gyrus supramarginalis. A destruction of the paths connecting the auditory centre with the speech-centre would cause word-deafness. In alexia there is always an inability to write.

Motor aphasia may consist in loss of the power to speak words or to write words intelligently. When the lesion involves Broca's centre the muscles of articulation are not paralyzed. Such patients may laugh, smile, and vary their voice so as to indicate their emotions. They may understand what they hear and read. Memory is not necessarily affected. The perception of words is not lost, but there is an inability to express words. This is known as *aphemia.* The loss of the power to write words is called *agraphia.* Both may exist together or aphemia may exist without agraphia. In the latter condition the patient cannot speak intelligently, owing to a lesion involving fibres which connect the speech-centre with the motor apparatus. Writing is possible, however, because the paths connecting the speech-centre with the centre governing the movements of the hand are not injured.

An inability to recall words is known as *amnesia.* Such patients can repeat, upon hearing them, words which before they had forgotten, which is not true in motor aphasia.

QUESTIONS ON CHAPTER XII.

How may the central nervous system be divided?
What is a neurone?
What is the length of the longest axones?
What are collaterals?
How do the branches of nerve-cells and collaterals end?
By what means are impulses transmitted from one neurone to another?
What is the function of the nervous system?
What are afferent, efferent, and central neurones?
What is a reflex act?
What is shock? How is it produced?
Describe the path of a simple reflex.
Discuss a reflex act involving consciousness.
Discuss the spread of an impulse in the cord.
What is the latent period of a reflex act?
How is it affected by an increase in the strength of the stimulus?
Discuss the summation of stimuli in the cord.
What is the smallest number of segments that can produce a reflex in the frog?
How is the cord modified as the animal ascends in the scale of development?
Name some of the reflexes found in man.
Why is it that many reflexes uncontrolled in children are brought under the will later in life?
Discuss the diffusion of impulses in the cord.
What are preganglionic and postganglionic fibres?
Discuss the cause of tone of the body.
How are spinal reflexes normally modified? Give experimental proof.
Stimulation of the cortical areas controlling the flexors produce what effect upon the extensors?
How do voluntary responses differ from reflexes?
Give in detail the afferent path of impulses from the skin to the cortex.
What cranial fibres have the same course?
How are pathways in the nervous system determined?
Describe the degeneration following section of the posterior spinal nerve-roots.
What proof is there that vasomotor impulses pass through the lateral tracts of the cord?
Give the percentage of impulses passing over the posterior and lateral columns.
What path do impulses from muscles and tendons take?
What is the path of dermal impulses?
Describe the effects of hemisection of the cord.
What effect in general have impulses when they reach the cortex?
What is the result of stimulating certain areas of the cortex?
What is the direction of the fibres that leave the cortex? Give proof.
Give in detail the path taken by motor fibres from the cortex to the muscles.
What degeneration follows unilateral lesion of the motor areas of the cortex?
What is the relation of the size of the cortical motor areas to the muscles they control?
How may each motor area be divided?
Are motor areas purely motor?
Name the principal sensory areas. Give their location.

What are association-fibres?
What is the function of association-fibres?
What are latent areas? Where located?
What symptoms follow lesions of the frontal areas?
What is the function of the cerebrum?
Give the results of the removal of the cerebrum.
What is the function of the cerebellum?
Give the results of removal of the cerebellum.
What symptoms follow section of the commissural fibres of the cerebellum?
What are the forced movements that follow injury to the cerebellum?
Discuss the function of the thalamus. Name fibres that connect it with other parts of the brain.
What symptoms follow lesions of the crura?
What are the functions of the quadrigemina?
What symptoms follow lesions of the quadrigemina?
What are the functions of the medulla?
Discuss the results of division of the spinal cord.
What is the behavior of a frog whose brain has been destroyed with the cord left intact?
What is the behavior of such an animal when only the hemispheres have been removed?
Discuss the function of each of the cranial nerves.
What is the path of the fibres of the first cranial nerve?
What is the path of the fibres of the second cranial nerve?
What symptoms result from paralysis of the third nerve?
What symptoms result from paralysis of the fourth?
Discuss the path of the fibres of the fifth.
What is the result of section of the seventh?
Discuss the path of the fibres of the cochlear portion of the eighth nerve.
What is the path of the vestibular fibres of the eighth?
Where are the cells of the fibres of the ninth located?
Discuss the functions of the tenth.
What symptoms result from section of the twelfth?
Explain general fatigue.
How is the intracranial pressure regulated?
What can be said of the metabolism of brain-cells?
What is the cause of sleep? Discuss sleep.
Discuss hypnotism.
What is meant by the knee-jerk?
Give the evidence for regarding the knee-jerk a reflex act.
Give the evidence that knee-jerk is not a reflex act.
Define nerve-centre and association-centre.
What is meant by alexia and agraphia?
In what ways are aphemia and agraphia produced?
What is amnesia?
Distinguish amnesia from motor aphasia.

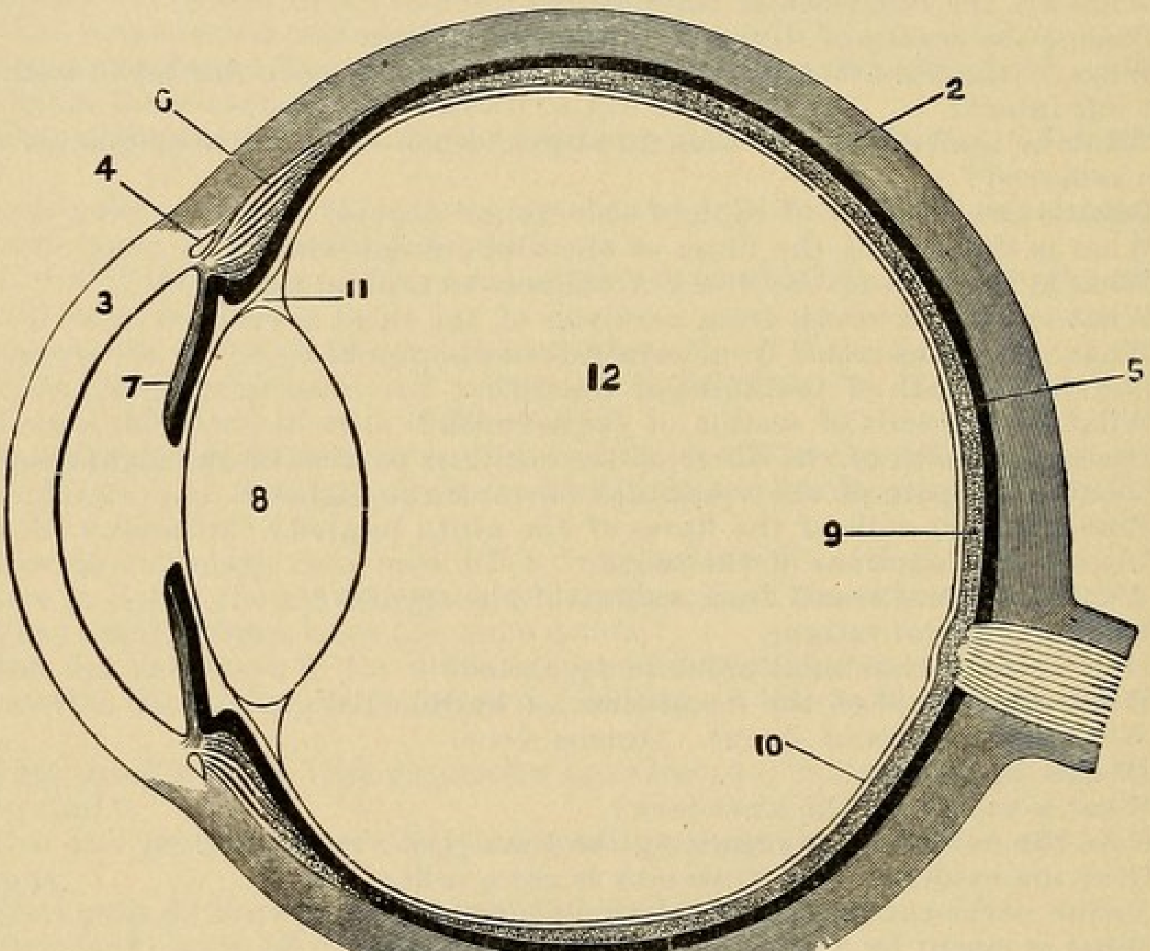
CHAPTER XIII.

THE SPECIAL SENSES.

SIGHT.

THE eye is a special organ by means of which certain rhythmic disturbances of the ether affect consciousness and produce the sensation of light. Among other *functions* that the eye serves are the determination of color, of distance, and of form. It consists of

FIG. 47.

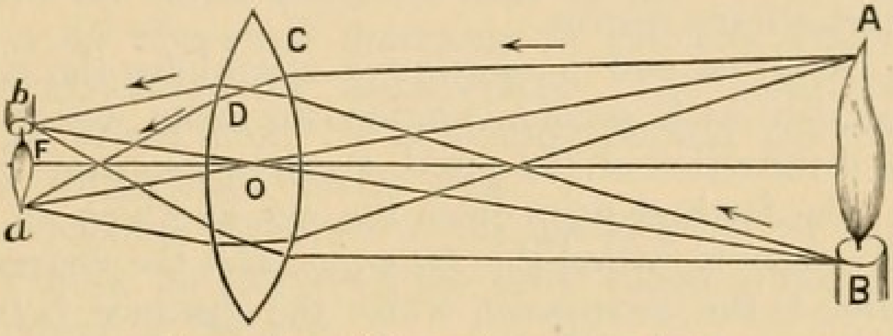


Horizontal section of the right eyeball (Collins and Rockwell): 1, optic nerve; 2, sclerotic coat; 3, cornea; 4, canal of Schlemm; 5, choroid coat; 6, ciliary muscle; 7, iris; 8, crystalline lens; 9, retina; 10, hyaloid membrane; 11, canal of Petit; 12, vitreous body.

various adjustable refracting media, by means of which the rays of light are focused properly on the retina, and of various muscles and accessory structures by means of which the eye is moved in different directions and is protected.

The muscles of the eye serve to move the eyeball through wide angles in all directions. When the *axis* of *vision* points straight ahead, the eye is in the *primary* position. If it moves from this position, so that the axis of vision rotates either about the transverse or vertical axis, then the eye is in a *secondary* position. All other positions are called *tertiary*. In order to understand clearly the nature of the image received by the eye, it is only necessary to review the images cast by a convex lens. If a double-convex lens is taken and the image formed by a luminous object is noted, it is seen that it is an inverted image at the point of focus of the lens if the luminous object is placed at a distance. Referring to this figure, it will be seen that the rays originating at A will be twice refracted, once by the lens as they enter it and again as they leave it, so that all rays from A reaching the lens are joined at *a*. The

FIG. 48.



Formation of image by convex lens.

same is true for B and *b*. Therefore a screen placed at focus, F, will receive an inverted image, *ab*, of the luminous object AB. If the lens were more convex, the image would be formed nearer the lens; if the lens were flatter, the image would fall further from the lens. Again, on the other hand, if the image is to be formed at a definite spot, the further the object is from the lens the flatter the lens must be; and *vice versâ*, the nearer the object the more curved the lens must be. With a double-convex lens the image formed is real, inverted, and on the opposite side of the lens from the object. The *crystalline lens* is a double-convex lens, and obeys the laws just described for other lenses. In addition, there are other refracting media in the eye—the *cornea*, the *aqueous*, and the *vitreous humors*. The crystalline lens is, however, the most important, as it possesses the power by virtue of the *ciliary muscles* of increasing or diminishing its *curvature*.

By *accommodation* is meant the power of the crystalline lens to change its amount of curvature so as to throw the image of an object in exact focus on the retina whether the object be near or far from the lens. At the same time the pupil is expanded or contracted to admit the necessary amount of light. Thus, if an object be near the eye, in order to produce a sharp image the lens is more curved, owing to the contraction of the ciliary muscle, and the *pupil* is *contracted*. If, on the other hand, the object be on the horizon, the ciliary muscle relaxes, the lens is flatter, and the *pupil* is *dilated*. Accommodation is an example of a voluntary act brought about by the action of the unstriped fibres of the ciliary muscle. The fact that most people must be assisted by visual sensations does not alter the fact that it is the result of the will. The *nervous path* of accommodation is through the anterior part of the nucleus of the third nerve in the floor in the third ventricle, the anterior bundle of the nerve-root, the third nerve, the lenticular ganglion, and the short ciliary nerves.

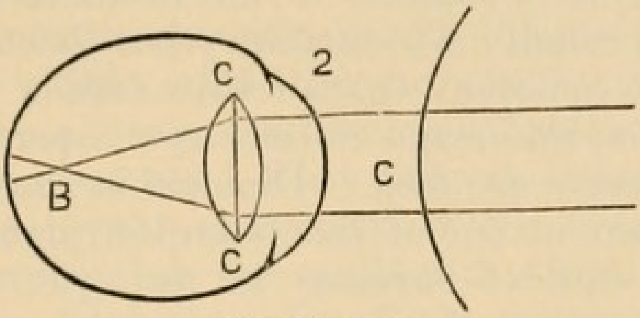
Atropin paralyzes and *physostigmin* stimulates the ciliary muscle. Associated with accommodation for near vision there is, besides the contraction of the pupil, a convergence of the axes of the eyes. The farthest point from the eye at which an object can be distinctly seen is called the *far-point*, and the nearest point of distinct vision is the *near-point*, while the distance between near-point and far-point is the *range* of accommodation. The near-point is the shortest focus of the crystalline, and is usually about five or six inches.

Emmetropia is the normal eye—that is, an eye in which parallel rays or rays from objects at a distance are focused upon the retina without an effort of accommodation. Such a distance for practical purposes is considered to be any point beyond twenty feet. Absolutely emmetropic eyes are not common.

Myopia, or near-sight, is the term applied to an eye in which the rays from a distance are focused in front of the retina and the image is blurred. Such an eye is permanently focused for near objects (Fig. 49).

Myopia is produced in two ways—by the *anteroposterior diameter* of the eye being too *great*, or by the *convexity* of the *lens* being *exaggerated*. In either case the focus of the lens will fall in front of the retina. The first condition is essentially a congenital defect, whereas too great a convexity of the lens may be either congenital or the result of disease. Myopia is corrected by the use of a concave lens, which diverges the rays and in this way prevents their coming to a focus too soon.

FIG. 49.

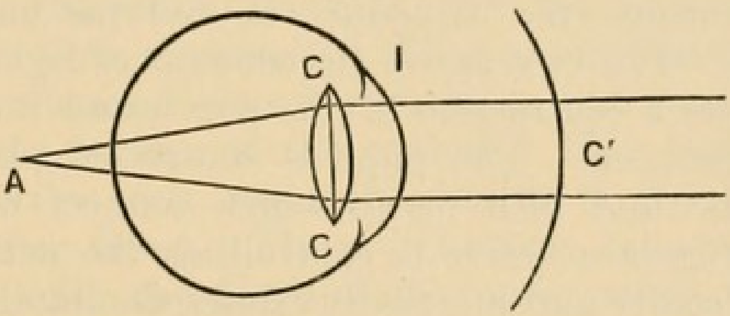


Myopic eye.

Hypermetropia, or far-sight, is the reverse of myopia (Fig. 50). In this case the anteroposterior axis of the eye is too short, or else there is an abnormal flattening of the lens which does not allow accommodation for near vision. The result is that the image of an object near by is focused behind the retina; but objects at a distance are clearly seen.

Hypermetropia is corrected by the use of a convex lens, and the convexity cannot be increased for near vision which adds to the refractive power of the eye.

FIG. 50.



Hypermetropic eye.

Presbyopia is defective vision due to the loss of power in advanced years. The *elasticity* of the *lens* becomes less, and the convexity cannot be increased for near vision. The ciliary muscle may also be weaker and aid in the production of the error.

Astigmatism is a defect in the vision due to irregularity in the globe of the eye whereby the diameter in one plane is greater than in another. Thus the cornea or the retina may be an uneven surface and the image focus definitely in one part and falsely in another. In this condition vertical, variously oblique, and horizontal lines are not seen with equal distinctness. Astigmatism is corrected by the use of cylindrical or prismatic glasses, which have to be accurately adapted to the needs of each case. This error, if serious, usually accompanies other defects of vision.

Diplopia is the condition which results from a want of *harmony* in the eyes, so that the image of each eye is perceived separately—that is, two images are seen. Diplopia is caused commonly by paralysis or spasm in one of the lateral straight muscles, which results from a want of harmony in the eyes. If the eyes are turned so that the axes of vision separate, the condition is known as *external strabismus,* or *squint;* if the axes are crossed, the result is *internal strabismus,* or *cross-eye.*

When a pencil of rays falls on a spherical, refracting surface, those at the periphery of the surface will be refracted more than those which lie near the axis, and will come to a focus sooner. This phenomenon is known as *spherical aberration,* and exists also as an imperfection in the eye, where it is corrected largely by the greater refractive index of the centre of the lens, and partly as well by the fact that the iris cuts off the peripheral rays.

Contraction or dilatation of the pupil is a reflex act, and the *afferent impulse* is carried through the optic nerve, while the motor impulse comes through the third cranial nerve, acting from a centre just beneath the aqueduct of Sylvius and the corpora quadrigemina. The increase in the amount of light that comes to the retina causes a contraction of the pupil, and a decrease is followed by a dilatation. The pupil is controlled also by fibres of the sympathetic and fifth nerve which connect with the ciliary ganglion. Drugs are active in controlling the action of the iris, *Atropin* both locally and internally dilates the pupil ; *opium* taken internally, and *eserin* applied locally, contract it.

If in obtaining an image of an object through a double convex lens the lens be too large, there will be seen around the image formed a halo of prismatic colors. This is called *achromatism,* and is produced by an *unequal refraction* of light-rays by the peripheral portions of the lens. The unequal refraction results in a dispersion of the light, so that it is broken up into the primary colors. This defect is remedied by putting a shutter in front of the lens, and so limiting the entrance of light to the central portions of the lens, where the index of refraction is constant. In the eye the iris acts as a shutter, thus making the image achromatic, but in some defective eyes where there is considerable fault in the focus of the image on the retina a visible band of color appears.

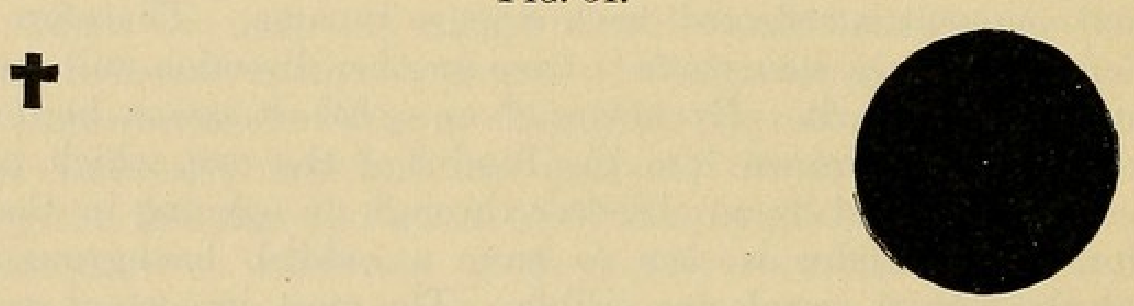
Under certain conditions a number of objects lying within the eye itself become visible. Of these *intraocular* images, the most common are known as *muscæ volitantes.* These are in the form of beads, streaks, or patches. They have an independent motion, which is increased by the movements of the eye. They are of greater specific gravity than the medium in which they are found, and are supposed to be the remains of the *embryonic* structure of the *vitreous* body.

Under normal conditions the *pupil appears* as a *black* spot. The reason for this is that the source of light and the retina lie in conjugate foci, so that any light which escapes absorption by the retinal pigment is reflected back whence it came. Therefore the eye of an observer who views it from another direction will see no light coming from it. By means of an *ophthalmoscope,* however, a strong light is thrown into the fundus of the eye, which upon reflection is viewed by an observer through an opening in the reflector. The fundus is seen to have a reddish background in which the retinal vessels are visible. The most important structures are the *rods and cones.* They are closely packed on the outer surface of the retina, the rods over the greater part of the retina being the more numerous. They are cylindrical bodies of a transparent substance placed parallel to one another and perpendicular to the surface of the eyeball. The cones, which are modifications of the rods, are very similar to the latter, but do not reach the same level. These structures are connected more or less directly with the fibres of the optic nerve. Where this nerve enters the retina, a little to the inner side of the most posterior point of the eyeball, there are no rods or cones, so that an image focused at this point will be followed by no perception. This point is called the *blind spot.* If the left eye is covered and the right directed steadily upon the cross in Fig. 51, the circular spot will be visible at the same time, though less distinctly. As the book is moved slowly backward and forward, a point will be found at which the round spot disappears, reappearing as the book is held nearer or farther, or as it is inclined in either direction and the image is carried from the blind spot.

At the exact centre of the retina—that is, the most posterior point of the eye—there is a small yellow area (*macula lutea*) with a central depression (*fovea centralis*). Here none of the fibres of the optic nerve are to be found, but a great increase in the number of cones as well as an increase in their size. If the object looked at is focused directly upon the macula lutea, the image is seen with greatest clearness. In everyday life images are received upon the macula lutea, and rays of light entering the eye at an angle are focussed on some other part of the retina, and are not defined so clearly.

A retina which has been protected from the light for a time has a purplish-red color, due to a coloring-matter termed *visual purple.* This is confined to the outer portions of the rods and does not

FIG. 51.

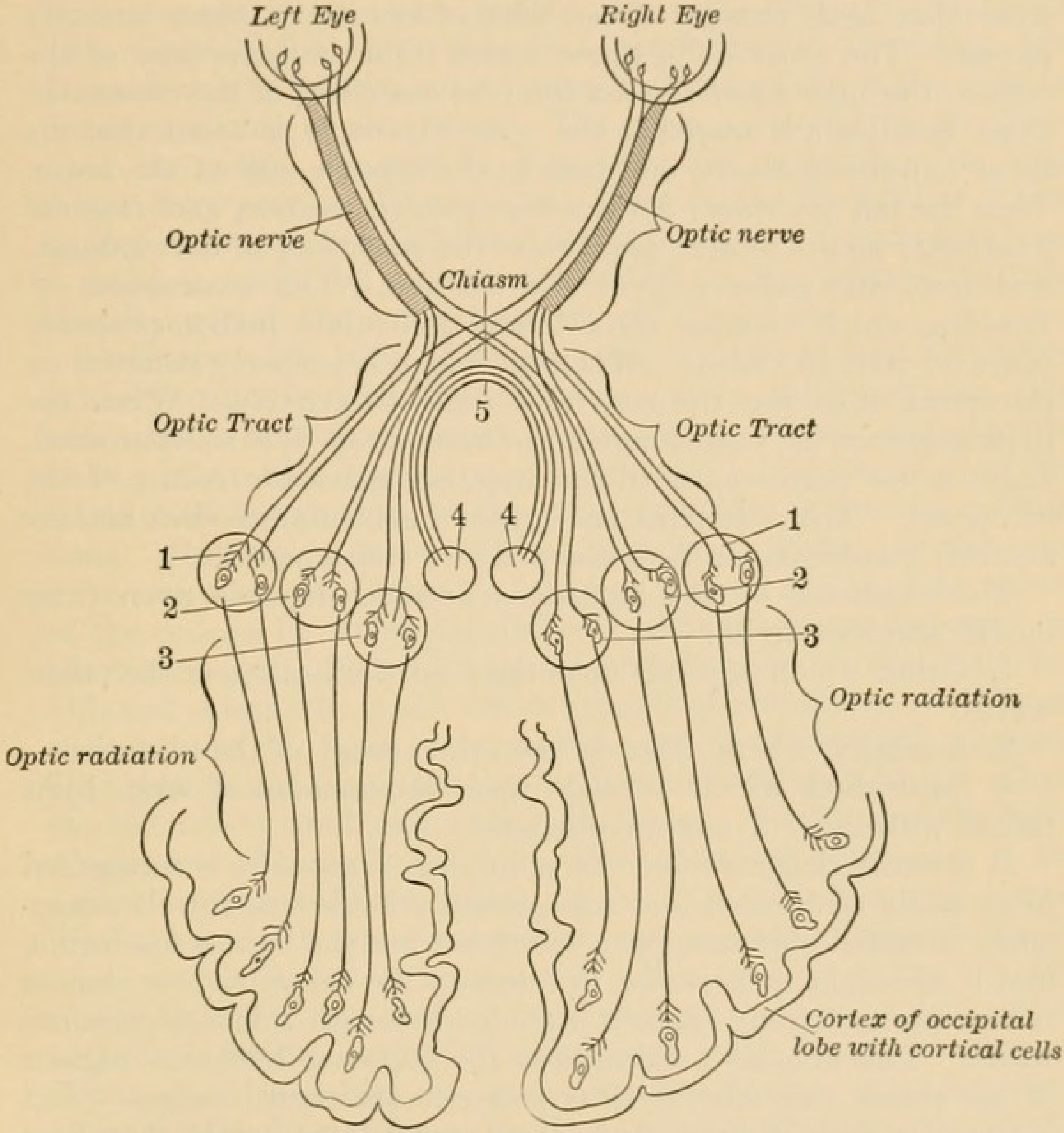


reach the cones. It is bleached by light, but restored by the pigment epithelium. The retina of a rabbit may be impressed with an image focused upon it and then treated with a 4 per cent. solution of alum, which "fixes" it and prevents the restoration of the visual purple. Such a picture is called an *optogram.*

Vibrations of the ether form the normal stimulus for the retina, the rods and cones of which form, perhaps, the only structures of man that can supply the necessary conditions for the transformation of radiant energy into the energy of a nerve-impulse. The ether-vibrations vary widely in their frequency, and only certain ones are capable of affecting the eye. The impulses they generate pass to the brain by way of the *optic nerves,* giving the *sensation* of light.

If the optic nerves are examined in a superficial manner, they will be seen to leave each eye and pass backward through the optic foramina until they reach the body of the sphenoids. Here they cross one another in the form of an X (optic chiasm), the fibres intermingling, and the right nerve apparently passing over

Fig. 52.



1, external geniculate body; 2, pulvinar; 3, anterior quadrigeminate body; 4, internal geniculate body; 5, commissure of Gudden. (Collins and Rockwell.)

to the left side and the left nerve to the right side. The posterior limbs of the X pass backward, and are called the optic tracts. The optic tracts in their course curve around the crura cerebri to terminate in the ganglion-cells of the pulvinar, *anterior* quadrigemina, and *external* geniculate bodies. From these, ganglion-cell fibres, called the *optic radiations*, pass backward to terminate in the ganglion-cells of the cortex of the posterior part of the occipital lobes. A closer examination of the optic nerves will show that each consists of *two distinct bundles* of *fibres* laterally placed. The *inner set* of fibres comes from the *inner half* of the *retina*; the *outer bundle* comes from the *outer half* of the *retina*. If these bundles are traced to the *optic chiasm*, it is noted that the inner bundles *decussate* and pass to the *opposite side* of the *brain*. Thus the left *pulvinar*, *left anterior quadrigeminate*, and *external geniculate* bodies receive *fibres* from the *inner half* of the *right eye*, and from the *outer half* of the *left eye*. The *commissure of Gudden*, which connects the internal geniculate bodies, probably plays no part in vision. When an image is properly received on the retina, it excites the rods and cones to activity. When the impulses reach the *basal ganglia*, the *sensation of light* is not aroused. Light is not perceived until the impulses reach the cortex of the cerebrum. The pulvinars, the external geniculate bodies, and the anterior quadrigemina form the *primary vision centre*.

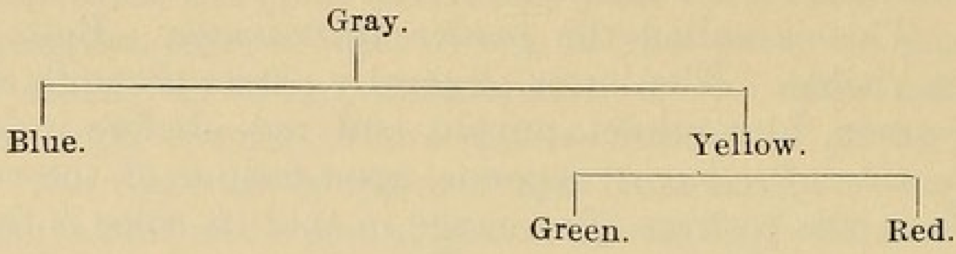
The character of the sensations aroused depends upon three modifications of light:

1. Color, which depends upon the rate of vibration of the ether-waves.
2. Intensity, which depends upon the energy of the vibrations.
3. Saturation, which depends upon the amount of white light mixed with light of one wave-length.

It is easily demonstrated for man that *luminosity* is recognized more easily than *color*, and this probably holds true for all organisms. Colored objects appear colorless when the light is too feeble, and if the light is increased in intensity the colors appear, but as it becomes too strong there is a tendency for all colors to pass into white. This is most noticeable in the yellow. Different regions of the retina vary also in their power to distinguish colors. Red is lost at a short distance from the macula lutea, while the violet is lost only at the borders of the retina.

Stimulation of the *retina* is followed normally by a latent period, then by a period during which the effect of the excitation reaches a maximum; from the maximum there is a slow decline in the effect, which is analogous to fatigue, and when the stimulation has ceased there is an after-effect which slowly passes away. When a very bright object is looked at for some time, the impression upon the retina lasts for a considerable interval after the excitation has ceased. This is called the *positive after-image*. Both form and color are visible. The latter generally passes through a series of colors—green, blue, violet, purple, and red—before it disappears. The *negative after-image* depends upon fatigue of the retina, and differs from the positive after-image in that its color is the complementary of that of the object. The effect produced by an object upon the retina depends in part upon the amount it has been fatigued by previous impressions. This makes the field of vision appear darker near a light area and lighter near a dark area than it really is, while the color is so modified by the neighboring field that it appears the complementary of the latter.

Ordinary *white light*, if decomposed, is resolved into the seven primary colors—violet, indigo, blue, green, yellow, orange, and red. Each of these primary colors has a different wave-length. Colors other than the seven primary colors are the result of the mixture of two or more of the primary colors in various proportions. Nothing is known of the manner in which the rods and cones are made to vibrate by ordinary images, nor as to the nature of the process by which the different color-effects are conveyed by the optic nerve. The different *color theories* assume that there are different substances in the retina capable of responding to different wave-lengths of light (comparable to a photochemical process). Red, green, and violet are the fundamental colors and all others can be made by combinations of these three. Working on this basis, *Young and Helmholtz* assumed three chemical substances in the retina capable of responding to the three fundamental colors. *Hering* assumed three substances corresponding respectively to white or black, red or green, and yellow or blue light. In this theory the white, red, and yellow rays are katabolic in their effects on their individual recipient substances, while black (absence of light), green, and blue are anabolic, thus having an antagonistic effect. *Mrs. Franklin* assumes in her theory that in early life the eye possesses no color-perception, but merely the power of perceiving luminosity—*i. e.*, distinguishing between white or black. The substance responding to luminosity is called gray-perceiving. As the development progresses, some of the gray is differentiated into a blue and a yellow-perceiving substance. The yellow-perceiving substance is still further differentiated in the course of development into a red- and a green-perceiving substance; thus—



Many objections have been raised against each of these theories, but Mrs. Franklin's is so far the best, and explains more readily the causes of *color-blindness.* According to the theories of *Helmholtz* and *Hering*, color-blindness is due to an *absence* of one or more of the *fundamental color-perceiving substances. Mrs. Franklin's* theory assumes a *lack* of full *development* or *complete absence* of *development* of *gray substance.* If the development should cease after the blue- and yellow-perceiving substances have been formed, the individuals would be capable of distinguishing the blues and yellows, but could not recognize reds and greens. Clinically such cases often are met with. Males are far more likely to be color-

FIG. 53.

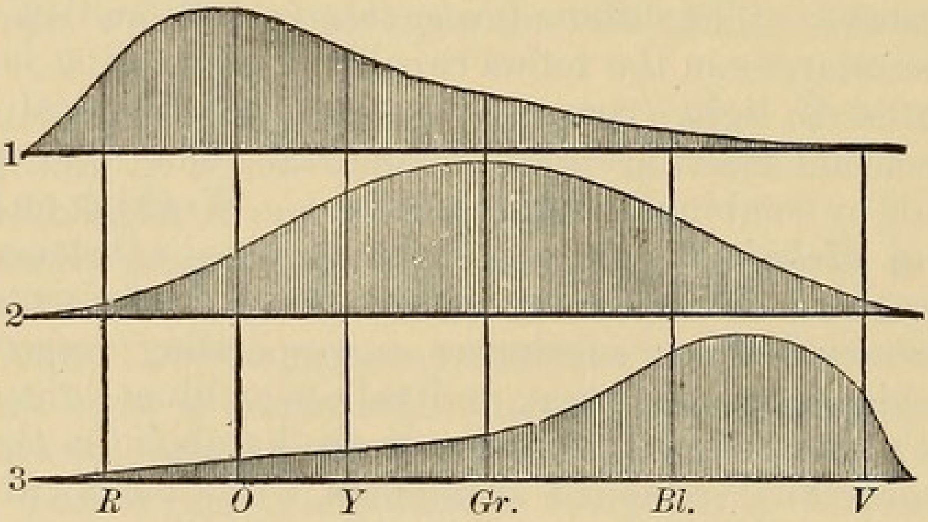


Diagram of three primary color sensations (Foster): 1 is the so-called "red," 2, "green," and 3, "violet" primary color sensation. *R, O, Y*, etc., represent the red, orange, yellow, etc., color of the spectrum, and the diagram shows by the height of the curve in each case, to what extent the several primary color sensations are respectively excited by vibrations of different wave-lengths.

blind than females (16 to 1). Only 1 woman in 400 is color-blind. The reason for this is partly at least that the development of the gray-perceiving substance is favored by practice and color education. Such an education is often neglected in boys, but girls receive sufficient practice often in matching colors for doll's clothing, etc.

The retina is capable of judging the *size of objects* in two dimensions only—*i. e.*, in the plane perpendicular to the axis of vision. The *perception of distance* is closely connected with the fact that the size of the image formed upon the retina varies with the distance. Besides, the distinctness with which objects are seen influences the judgment of distance because when indistinctly seen, objects are supposed to be farther away. Again, the judgment of distance is further aided by the sense of effort required in accommodation and also by the change of position of an image on the retina when the eye is moved. The latter depends upon the fact that the change in the position of the image is inversely proportional to the distance

Fig. 54.

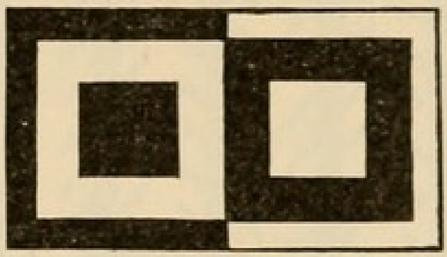


Illustration of irradiation. (McKendrick.)

of the objects. Many circumstances affect the accuracy of the spatial judgment of the retina. One of these is *irradiation*. All brightly illuminated objects appear larger than others of the same size.

The illusion of *Zöllner's lines* is due to the fact that through early association with right angles as seen in all parts of our houses, etc., and which are viewed from different directions so that they appear acute or obtuse. The tendency of the mind is therefore to make such angles right angles, so that acute angles are overestimated while obtuse angles are underestimated. In Fig. 55 the heavy lines are consequently made more perpendicular to the short cross-lines than is absolutely the case, which brings the alternate ends of the heavy lines closer together.

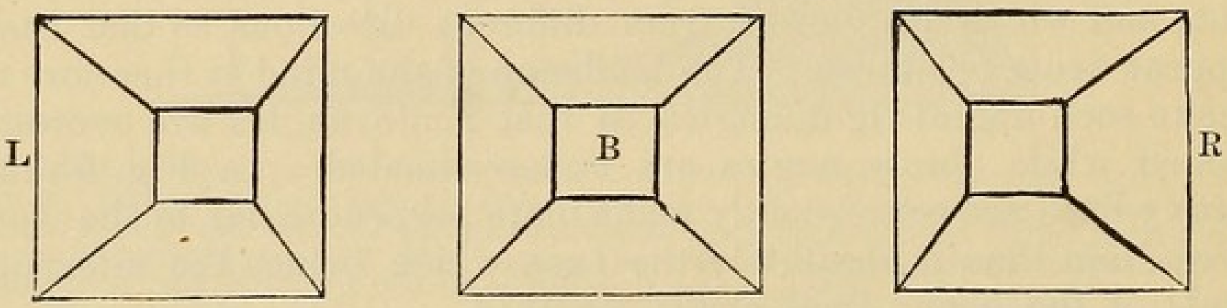
Although there are two eyes, each of which furnishes an impression, only one object is perceived. In abnormal positions of the eye the two impressions can be made recognizable. Ordinarily, therefore, the images of objects fall on *corresponding points* of the *retina*. A point on the right side of one retina has its cor-

FIG. 55.

Zöllner's figure showing an illusion of direction. (McKendrick.)

responding point on the left side of the retina of the other eye. When the images fall on corresponding points, they are blended

FIG. 56.



Illustrating the principle of the stereoscope and binocular vision.

into one perception. *Binocular vision* affords a method of judging the solidity of objects, since the image of any object falling on one eye cannot be exactly like that which falls on the other. Thus the perceptive faculties can judge more correctly of the form and distance of an object.

From the laws of optics it is known that the image formed on the retina is an *inverted image* of the object. Yet, it is perceived in its upright position. This is the result of lifelong habit. A baby sees an object; the next step is to touch it; by practice the child finds out which is the top of the object through the touch perception. Very speedily the brain learns to make the correction. It is an act of mental and not physical origin. Thus, objects which are projected upon the left of the retinal surface look to be, as they really are, on the right of the body; and so with all the directions.

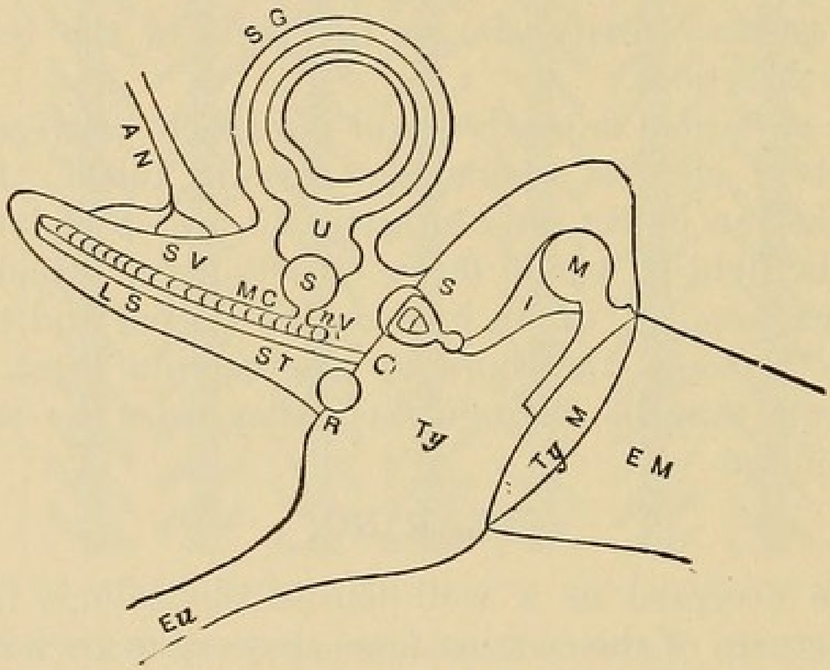
Clearness of vision depends upon the space between the cones in the point of clearest vision, the macula lutea. It has been calculated that an object must subtend an arc of at least 60 to 70 seconds in the field of vision to be clearly seen. Such an object makes an image $\frac{1}{12000}$ of an inch on the retina, and this is about the distance between the cones at the macula lutea. In order that two points may be distinguished, they must be separated at least this amount.

HEARING.

It may be accepted as a well-defined physiologic fact that the nervous structures of the cochlea form that organ by which musical sound and noise of all kinds are converted into nerve-impulses. The sound-waves of the air, which originate in vibrating bodies, are gathered together by the concha, carried into the external auditory canal, and vibrate against the membrana tympani. The latter takes up the vibrations and transmits them through the chain of ossicles to the stapes in the fenestra ovalis. The stapes imparts its motion to the perilymph of the vestibule (Fig. 57). There is now set up in the perilymph a fluid wave that travels in all directions. It passes along the scala vestibuli to the apex of the cochlea, then through the aperture of communication with the scala tympani down the latter until it expends itself against the membrane of the fenestra rotunda. In its passage the fluid vibrates against the membrane of Reissner and the basilar membrane, and this sets up similar vibrations in the endolymph of the canalis cochlearis. The fluid wave in the canalis cochlearis is in a position to irritate the hair-cells of the *organ of Corti*. These cells seem to be able to respond to particular tones by their sensitiveness to certain rates of vibration. But the fact that the organs of Corti are absent in birds which evidently are capable of appreciating musical tones shows that they are accessory and not absolutely essential.

The branch of the eighth nerve, having received its impulses from the cells of the organ of Corti, transmits them to the centre under the acoustic tubercle in the floor of the fourth ventricle;

FIG. 57.



Diagrammatic view of the relative position of the parts of the ear (Chapman): EM, external meatus; *Ty*M, tympanic membrane; *Ty*, tympanum; M, malleus; I, incus; S, stapes; R, round window; O, oval window; SG, semicircular canal; U, utriculus; S, sacculus; V, vestibule; SV, scala vestibula; ST, scala tympani; MC, membranous cochlea; LS, lamina ossea; *Eu*, Eustachian tube; AN, auditory nerve.

thence fibres pass by means of the trapezium in the pons to the opposite side, and through the lower fillet of that side to the posterior quadrigeminal body, whence by means of the brachium, internal geniculate body, optic thalamus, and internal capsule, they proceed to the cortex of the first and second temporal convolutions.

By *subjective hearing* is meant sounds that are heard distinctly and yet are not produced by physical sound-waves from the exterior, nor are they hallucinations. They may be due to disturbances of the auditory apparatus or to abnormal conditions of surrounding organs. Thus buzzing or ringing in the ears may result from the hyperæmia of the parts and the increased rush of blood, or from disease in the auditory nerve or some other portion of the apparatus. Hallucinations are purely creations of a disordered brain.

Musical sounds are distinguished by the mind by three factors —loudness, pitch, and quality. Every musical tone is produced by a succession of regular alternate rarefactions and condensations of the air. It is their *periodicity* which makes them musical, otherwise they are known as noises. The range of musical notes that can be appreciated by the human ear is about seven octaves. There are about 3000 hair-cells in the organ of Corti, and it is easily seen that this would allow an enormous capability to differentiate sounds and musical tones. This corresponds to a range of from 40 to about 4000 vibrations per second. The range of *audibility*, on the other hand, is about eleven octaves, or from 16 to 38,000 vibrations per second. With less than 16 vibrations per second the ear perceives only separate shocks, while with more than the larger number the sensation of sound is not produced.

The *distance* and *direction of sounds* are not perceived directly, but are estimated by their loudness and quality combined with reasoning from past experience. When one ear is totally deaf, all sounds seem to originate from the side of the healthy ear. When the eyes are closed, a sound directly overhead is imperfectly localized, but seems to come from a point ahead and above the person. The quality as well as the loudness of the sound varies with the distance from its source, because the lower tones die away first, making the overtones more prominent. This is taken advantage of by *ventriloquists*, who, by modifying the intensity and quality of the voice, produce an imitation of the effect of distance. The ear is capable of appreciating very small intervals of time; 132 auditory impulses per second are heard separately, while in the eye all above 24 per second are fused together.

SENSE OF EQUILIBRIUM.

By sense of equilibrium or equipoise is meant a state of the body in which all the muscles are under the control of nerve-centres so as to resist the effect of gravity whenever necessary. It is of the greatest importance to animals, and therefore several mechanisms share in its performance. It is brought about by sensory impulses coming from many sources, and the sum-total of the sensations involved constitutes the *sense of equilibrium.* Every known sensation probably contributes to the maintenance of equilibrium, but certain structures in the ear, known as the semicircular canals, form the main source. When the canals are injured in any way, the animal sprawls on the ground, holds its head in an unnatural position, makes peculiar forced movements, etc. The effect varies with the number and the position of the canals operated upon, and ranges from simple unsteadiness of gait to complete incoördination. These results are explained as being due to increased or decreased pressure of the endolymph on the cristæ acusticæ of the ampullæ of the semicircular canals. The latter are situated in the three dimensions of space, and rotation of the body in any direction can be judged quite accurately as to direction and amount. Rapid rotation in one direction is, after its cessation, often followed by a sensation of rotation in the opposite direction. Excessive rotation leads to dizziness, but in deaf-mutes dizziness is difficult to produce on account of the imperfect development of the ears. Diseases which alter the pressure in the canals lead to vertigo and incoördination. The semicircular canals in themselves, however, are not sufficient to preserve complete equilibrium.

SMELL AND TASTE.

The special olfactory mucous membrane is situated in the upper part of the nasal cavity, away from the direct current of the inspired air. The rod-cells which it contains are connected with fibres that are part of the olfactory nerve and constitute the sensory nerve-endings. Substances that excite the sense of smell are in a *fine state of division* or in a gaseous state, and are brought into contact with the rod-cells by rapid but short inspiratory movements. They are perceived best when the air is at the body-temperature. The substance producing smell is probably taken into solution in the moisture covering the olfactory membrane. In the lower animals the sense of smell plays a very important part, and it is probable that all animals give out characteristic odors by which they recognize one another. The sense of smell is therefore highly developed, which is not the case in man. The distribution of the olfactory nerves is much wider and the cerebral development correspondingly greater in some animals than is the case in man, where, however, the range of susceptibility is wider. The variety of odors and the very minute quantity of the substance required to produce smell are wonderful. The most delicate analysis may fail to show traces of the substances which can be appreciated by the sense of smell. For instance, 0.000000005 of a gramme of oil of peppermint in 1 litre of water can be detected. Some odors, like musk, are pleasant perfume to some, while to others they are unendurable. The *acuteness* of the sense of smell varies in different persons, and this may apply to certain odors only. Like the sense of touch and other senses, it can be developed by practice. Often in cases of mental disease there are hallucinations of smell.

The *olfactory nerves* arise from a mass of gray matter lying beneath the anterior lobe of the brain upon the cribiform plate of the ethmoid bone. This is the olfactory bulb, and is connected by the olfactory tract with the cerebrum. Each *olfactory tract* arises from the cerebrum by three roots, two of which are composed of white matter, and the third of gray matter. By these it is connected with the olfactory centres. The perceptions of the olfactory nerve and of the nerves of touch of the nose often resemble each other, and some stimuli affect both nerves. The *common sensibility* is evoked by such substances as are irritating or acrid—ammonia gas has no odor, but it stimulates the mucous membrane of the nose. The relation between the two kinds of perception is lost, and the smell of ammonia or of alcohol is spoken of when it is not olfactory, but a sensory perception.

Taste.—The sense-organs concerned in taste, the taste-buds, are located on the upper surface and sides of the tongue, the anterior surface of the palate and of the anterior pillars of the fauces. Those of the posterior third of the tongue are connected with the *glossopharyngeal nerve*, while those of the anterior part of the tongue are connected with the *lingual* and *chorda tympani* nerves. Taste-perceptions are modified by simultaneous olfactory sensations, so that it is difficult to distinguish between an apple and an onion when the nostrils are closed. The *intensity* of taste increases with the area stimulated, and is greatest when the stimulating substance is at the temperature of the body. Taste depends upon the concentration of the solution. There is evidence that the sensation may be divided into *four primary ones*—bitter, sweet, sour, and salt, with *special nerves and end-organs* for each. Thus, the tip of the tongue perceives acids acutely, sweets less, and bitter substances hardly at all. Saccharin appears sweet at the tip of the tongue and bitter at the base. The fungiform papillæ scattered over the surface of the tongue were tested with succinic acid, quinine, and sugar. Out of 125, 27 did not respond at all, showing that they were devoid of taste-endings; 12 reacted to succinic acid alone; 3 to sugar alone; while quinine affected them all. An extract of a tropical plant has been found to paralyze the sense-endings for sweet and bitter substances. *Cocaine* abolishes the sensibility of the tongue in the following order: (1) general feeling; (2) bitter taste; (3) sweet taste; (4) salt taste; (5) acid taste; (6) tactile perception.

The tongue has a highly developed sense of touch, temperature, pressure, and pain, which aid the accuracy of speech, mastication, and deglutition. Some aromatic substances leave an impression of their taste, called an *after-taste*, and when tasted in rapid succession a number of times the appreciation of their flavor is lost.

CUTANEOUS SENSATIONS.

A specialized peripheral organ for the reception of an external impression, an afferent nerve, and the brain for the perception of the sensation, constitute the organs for sensation. It is by means of impressions so received and conducted to it that the mind is able to control the body and to take cognizance of the external world. Cutaneous sensations include the sense of touch, temperature, and pain. *Touch* is due to sensory nerve-endings in the skin and mucous membrane. The nails and teeth are peculiarly involved in the sense of touch, and also the hair in certain regions—*e. g.*, the eyelashes. The relation between the strength of the stimulus and the resulting sensation is expressed by *Weber's law:* "*The amount of stimulus necessary to provoke a perceptible increase of sensation always bears the same ratio to the amount of stimulus already applied.*" This law is only approximately correct for small and for large weights. Fechner's "*psychophysical*" *law* attempts to express the relation more exactly: "*The intensity of sensation varies with the logarithm of the stimulus*"—*i. e.*, the sensation increases in arithmetical, while the stimulus increases in geometrical proportion.

Different areas of the body vary in their power of discriminating pressure-differences. The forehead, lips, and temples appreciate an increase of $\frac{1}{40}$ to $\frac{1}{30}$; but the head, fingers, and forearm can appreciate a stimulus only when increased from $\frac{1}{20}$ to $\frac{1}{10}$ of its previous intensity. When two equal weights of different expanse press upon the skin, the larger appears the heavier. A weight pressing upon the skin leaves an *after-sensation*, so that the intervals between successive applications of stimuli to touch-endings cannot be less than $\frac{1}{610}$ of a second if they are to give separate sensations. If the impressions follow at a more rapid rate, they will be fused together into a continuous sensation.

Touch-sensations are *localized—i. e.*, they are referred to the right portion of the body where the stimulus is applied. This power is acquired early in life and the sensations of touch are correlated with those of sight and those arising from muscles, so that each area of the skin acquires a "*local sign.*" The power and fineness of localization differ greatly for different portions of the skin. The following table is taken from Kirke's *Handbook:*

TABLE OF VARIATIONS IN THE TACTILE SENSIBILITY OF THE DIFFERENT PARTS.[1]

Tip of tongue	$\frac{1}{24}$	inch.
Palmar surface of third phalanx of forefinger	$\frac{1}{12}$	"
Palmar surface of second phalanges of fingers	$\frac{1}{6}$	"
Red surface of under lip	$\frac{1}{6}$	"
Tip of the nose	$\frac{1}{4}$	"
Middle of dorsum of tongue	$\frac{1}{3}$	"
Palm of hand	$\frac{5}{12}$	"
Centre of hard palate	$\frac{1}{2}$	"
Dorsal surface of first phalanges of fingers	$\frac{7}{12}$	"
Back of hand	$1\frac{1}{6}$	"
Dorsum of foot near toes	$1\frac{1}{2}$	"
Gluteal region	$1\frac{1}{2}$	"
Sacral region	$1\frac{1}{2}$	"
Upper and lower parts of forearm	$1\frac{1}{2}$	"
Back of neck near occiput	2	"
Upper dorsal and mid-lumbar regions	2	"
Middle part of forearm	$2\frac{1}{2}$	"
Middle of thigh	$2\frac{1}{2}$	"
Mid-cervical region	$2\frac{1}{2}$	"
Mid-dorsal region	$2\frac{1}{2}$	"

Tactile areas have, in general, an oval form with the long axis parallel to the long axis of the portion of the body investigated.

[1] The measurement indicates the least distance at which the two blunted points of a pair of compasses could be separately distinguished.—E. H. Weber.

These areas are not indicative of the distribution of certain nerves. The important factor in the separation of two points that are stimulated is not that two different nerves shall be stimulated, but that there must be a certain number of unstimulated points between those stimulated.

The sense of touch can be greatly educated and specialized. The reading of raised letters by the blind is an example. Improved touch-discrimination, attained by practice upon the skin of one arm, is accompanied by an improvement in the corresponding area of the other arm, but not of any other areas of the body. This shows that the *localizing power* lies within the central system.

The skin is an organ for the detection of temperature-changes, and its power in this respect varies in different portions of the body. The *intensity* of the sensation depends upon the area stimulated. There is very little doubt that there are two *distinct temperature-nerves,* which serve, respectively, for the appreciation of heat and cold. The areas to which the nerves are distributed can be located in the skin as cold and heat points. *That this sensation is distinct from ordinary tactile sensation has been inferred from the fact that when the ordinary touch is blunted the temperature-sense remains unimpaired.* Temperature-sensations are not accurate; they are only relative—that is, the temperature of various things is inferred from the temperature of the skin and its habitual surroundings. It is related that Arctic explorers have found the water warm when swimming in pools on icebergs, and a drop of mercury at 80° F. is said to feel cold in the tropics. A more simple illustration is that of immersing one hand in water at 40° F. and the other in water at 120° F., and then plunging both into water at 80° F., when one hand will feel hot and the other cold. During a chill the temperature of the body is often very high, and yet the sensation is that of cold.

COMMON SENSATION.

By *common sensation* is meant that state of mind, more or less definite, by which the condition and position of the body at any moment are known. Such perceptions cannot be located distinctly in any organ or set of organs, as, for instance, hunger, thirst, etc. Besides these there are some sensations which involve certain organs which must be classed under this head; thus inclinations to cough or to sneeze, to vomit, defecate, and urinate. Many of these sensations occupy the border-line between common sensibility and the special sense of touch, such as tickling and itching. *Pain* is a common sensation, but is allied very closely to touch. It is the sensation which results from intensifying any common sensation, and differs from the special sensations in not being well localized and in the long latent period that precedes its development. According to one investigator, pain-points are separate from pressure-points and are more numerous. *More than 100 are found to every square centimeter of the skin, and they require 1000 times as great a stimulus for their excitation as do the pressure-points.*

Hunger and *thirst* are peculiar sensations, which ordinarily depend partly on local and partly on general causes. Local causes of hunger and thirst are an empty stomach and certain conditions of the mucous membrane. These sensations are felt largely as the result of habit, and depend thus upon the condition of secreting and absorbing mechanisms.

By taking a body in the hand and raising it, a sense of resistance is felt in the muscles, by the intensity of which the weight of the body can be determined more accurately than by the pressure-sense alone. This is called the *muscular sense.* It is developed to an exceedingly fine degree in some occupations; for example, postal clerks detect overweight letters with wonderful accuracy and quickness. Muscular sensation is allied closely to common sensation. It may be due to a consciousness of the amount of energy sent to motor cells or to the inflow of sensory impulses which indicate the tension to which the muscle has been subjected. The latter view is corroborated by the existence of sensory endings, the *muscle-spindles,* in muscles and tendons. The *centre* for the muscular sense is in the upper part of the quadrate lobule on the mesial surface of the hemisphere. Its involvement by pressure brings about inability to locate the position, say, of the hand or foot without the aid of sight.

QUESTIONS ON CHAPTER XIII.

What are the functions of the eye?
Give the essential parts of the eye.
What are primary, secondary, and tertiary positions of the eye?
How is an image formed on the retina?
Discuss accommodation.

Discuss the effect of drugs on accommodation.
Give the nervous mechanisms of accommodations.
Define near- and far-points and the range of accommodation.
What is an emmetropic eye?
Discuss myopia and hypermetropia.
What are presbyopia and astigmatism?
Discuss diplopia of the eye.
Define spherical aberration and achromatism.
Give the nervous mechanisms that control the iris.
Discuss intraocular images.
Why does the pupil appear black?
What is an ophthalmoscope?
What are the most important structures of the retina?
What are the blind spot, macula lutea, and fovea centralis?
How may the blind spot be demonstrated?
What is the visual purple?
How may an optogram be obtained?
What supplies the normal stimulus to the retina?
Give the course of the optic fibres.
What constitutes the primary vision centre?
Upon what physical conditions does the sensation of light depend?
How can it be shown that luminosity is recognized more easily by the eye than color?
How do different portions of the retina vary in their power to distinguish color?
Give the various phases of the activity of the retina when stimulated.
Distinguish between positive and negative after-images.
What is irradiation?
What is the relation of color to white light?
Discuss the color theories.
How is color-blindness explained?
What is the proportion of color-blind in men and women? What reason can be given for this?
Discuss the perception of distance.
Discuss the illusion produced by Zöllner's lines.
Discuss binocular vision.
Discuss the correction for the inversion of the retinal image.
What does clearness of vision depend upon?
Where are the physical vibrations of sound transformed into nervous impulses?
How do the sound-waves of the air reach the organ of Corti?
Are the organs of Corti absolutely essential to the appreciation of musical tones?
How are the impulses conveyed from the ear to the brain?
What is subjective hearing and its causes?
Upon what factors do musical sounds depend?
How do noises differ from musical sounds?
What is the musical range of the ear?
What is the range of audibility of the ear?
How is the distance of sounds estimated?
Discuss the power of the ear to appreciate small intervals of time.
What is meant by equilibrium of the body?
How is the sense of equilibrium brought about?
What is the effect of injury to the semicircular canals of an animal?

What proof is there that the semicircular canals aid in preserving equilibrium?
What is the situation of the olfactory mucous membrane?
What is the condition of substances that excite smell?
What is the importance of smell in the lower animals?
Give instances of the delicacy of the power of smell?
Give the course of the olfactory fibres.
Discuss the relation of common sensibility and smell.
What is the location of the sense-organs of taste?
What are the nerves of taste?
What is the relation of smell to taste?
Does taste depend upon concentration or on the quantity of the stimulating substance?
How is taste divided?
Give evidence of special end-organs for each division.
How does cocaine affect the sensibility of the tongue?
What is the function of the tongue?
What is an after-taste?
What are the organs of cutaneous sensation?
What sensations are included in cutaneous sensations?
Give Weber's and Fechner's laws.
Discuss the discriminating power of different parts of the body to pressure.
What interval must elapse between touch-stimuli in order that they may give separate impressions?
Discuss the localization of touch-sensations.
What factor determines the recognition of two points of the skin stimulated simultaneously?
Discuss the situation of touch-areas.
What fact shows that improved touch-discrimination is a central phenomenon?
Discuss temperature-sensations.
What is a common sensation?
Discuss the sensations of hunger and thirst.
What sensations are on the border-line between common sensation and special sensation?
What evidence is there for separate pain-points in the skin?
What is meant by the muscular sense?
What is muscular sense due to? Locate centre and give effects of injury.

CHAPTER XIV.

REPRODUCTION.

Reproduction is a process by means of which life is perpetuated because the existence of individuals is limited. There are *two methods* of reproduction—the *asexual* and the *sexual*. The former is the more primitive form, and is restricted to the lower organisms. It is not difficult to conceive a reason for reproduction in cells, for as the mass of living matter increases, its volume increases as the cube, while its surface increases only as the square. There will finally result therefore a condition when the absorptive surface is too small for the amount of living matter, and a division will cause a relative increase of surface. *Sexual reproduction* is derived probably from the asexual method, and consists in the union of male and female elements. The most primitive examples are to be found in some of the unicellular organisms where there is a fusion of the two sexes, known as *conjugation.* The resultant mass divides and so produces its offspring. In somewhat more highly differentiated forms there are simply an exchange and a fusion of nuclear matter. In the higher animals there is a fusion of nuclear matter of two individuals brought about by the production of two kinds of sexual cells—*ova* and *spermatozoa.* In some animals, like the worms, both *sexual elements* exist in the *same individual,* but this condition is found only abnormally in the highest animals. Here the sexes present wide anatomical, physiological, and psychological differences. These differences fall into two groups—*primary* and *secondary.* The *primary sexual characters* are the most pronounced, and consist of those pertaining to the sexual organs and their functions. The secondary sexual characters are accessory to the primary ones, and include the differences in voice, growth of hair on the face, the mammary glands, etc., in man and woman.

The *sexual cells* differ widely in appearance. The *spermatozoön* consists of an elliptical head, a short middle piece, and a tapering tail. It is undoubtedly a cell which arises from a testicular cell known as the *spermatocyte.* The latter divides into four *spermatids* which grow directly into *spermatozoa.* It is important as well as interesting to know that the number of *chromosomes* in the head of the spermatozoön are one-half the number normally present in the body-cells of the individual. The spermatozoön is adapted to vigorous activity. It seeks the ovum by means of the movements of its tail, which is lashed from side to side, causing it to progress and at the same time to rotate. The *rapidity* with which it moves is from 1.2 to 3.6 mm. per second. Spermatozoa will live in the male genital passages for months, and they probably will live in the female for a long while, but the exact time is not known. They are produced in large numbers. One estimate puts the production at 226,257,000 per week. The spermatozoa are contained in a fluid which comes from the *testes* partly, but chiefly from *accessory sexual glands*—the *seminal vesicles*, the *prostate gland*, and *Cowper's glands*. Together these constituents form the *semen*, which may be described as a whitish viscid fluid with a characteristic odor. The amount passed at a time is from 0.5 to 6 c.c. In some animals it contains *fibrinogen*, which enables it to clot within the female passages, thus preventing escape of the spermatozoa.

The *ovum* in its perfected state as it leaves the *Graafian follicle* is found to be a minute globular cell containing a nucleus and nucleolus as well as a cell-membrane. It undergoes a process analogous to what takes place in the formation of a spermatozoön, which is known as *maturation*. It begins as the ovum is leaving the ovary, and consists of a *karyokinetic* division of the nucleus twice in succession. With each division half of the nucleus is extruded together with a small amount of protoplasm as the *polar bodies*. The first polar body usually divides into two parts, making three polar bodies, all of which degenerate. As the result of these divisions the ovum has left one-half of the number of chromosomes of a body-cell. The union of the nuclei of ovum and spermatozoön restores to their original number the chromosomes of the species. Ova are developed within specialized cavities of the ovary lined by epithelial cells known as Graafian follicles. A Graafian follicle moves toward the surface of the ovary, ruptures, and discharges the ovum, giving rise to the process of *ovulation*. This is in most animals a periodic phenomenon, and in woman probably begins at puberty with the first menstruation and continues until the climacteric. Cases of pregnancy at the ages of seven, eight, and nine years show that it may occur very early. After the ovum has been set free from the ovary it in some unknown manner reaches the Fallopian tubes. It is possible that in woman, as has been observed in some animals, the fimbriated ends of the tubes clasp the ovaries when the eggs are discharged. The cilia lining the tubes gradually carry the egg toward the uterus, which it reaches in from four to eight days.

Impregnation or *fertilization* usually takes place in the tubes because the cilia, while they carry the ovum in one direction, act as a guiding stimulus to the spermatozoa, which move in the opposite direction to meet the ovum. In case the ovum is fertilized, it passes on to the uterus, where it is retained and develops to the end of the embryonic period.

The uterus is active monthly in that it discharges a bloody, mucous liquid through the vagina. This is called *menstruation*. Some days before the flow the mucous membrane of the body of the uterus begins to thicken by the growth of its connective tissue and by the engorgement of its bloodvessels until it is from two to three times its normal thickness. The swollen capillaries become ruptured and the epithelial cells undergo a fatty degeneration. Usually only the superficial portions of the mucous membrane are involved, and those cases where it is removed to its deepest layers are very likely pathological. The flow continues for four days or more, during which 100 to 200 c.c. of blood are lost. The latter is slimy with mucus, does not coagulate, contains disintegrated tissue, epithelial cells, and has a characteristic odor. Menstruation is accompanied by many other symptoms. The ovaries and breasts are congested, dark rings form about the eyes, mental depression often exists, skin and breath have a characteristic odor. The intermenstrual period exhibits a gradual increase in nervous tension and metabolic activity, manifested in an increased production and excretion of urea, in a higher temperature, and an increase in the strength and rate of the heart-beat. These reach their maximum a few days before the menstrual flow, and then undergo a rapid fall, reaching a minimum with the cessation of the flow. The first menstruation is an index of puberty, and occurs in temperate climates at the age of from fourteen to seventeen. The time varies with the climate, food, growth, environment, etc. Occasionally menstruation may be entirely absent in otherwise normal women. The removal of the ovaries puts an end to further menstruation. Its cessation at the age of forty-five to forty-eight marks the *menopause* or *climacteric*.

The meaning of menstruation has been much discussed. In the lower mammalia reproduction is limited to seasonal periods, which are characterized by sexual excitement, congestion and swelling of the external genital organs, and a uterine discharge. During the remainder of the year sexual excitement is absent. These periods of excitement are known as *rut* or *heat*. Domestication with its regular food-supply and care has increased productiveness by rendering the reproductive periods more frequent. This has taken place in like manner in the human, but has progressed further in that woman during the menstrual flow has largely lost sexual desire. According to Pflüger, menstruation is a preparation of the uterine surface for the reception of the impregnated egg. The *mechanism* by which the uterus is prepared is as follows—

The growth of the cells of the ovary reflexly, by constant stimulation of the spinal cord, causes a dilatation of the vessels of the genital organs, which results in a breaking down of the mucous membrane of the uterus. At the same time the increased blood-supply causes a ripening of the Graafian follicle. It is the general view that ovulation and menstruation are the result of a common cause, but either, in the human, may occur without the other. It is probable that ovulation takes place a few days before the onset of the menstrual period.

Copulation is the act of sexual union that has for its object the introduction of semen into the genital passages of the female. It is preceded by a preliminary period of sexual excitement, during which the penis becomes swollen, turgid, and erect, while the vulva also becomes firm and turgid. There are *vascular* phenomena. In the penis the arteries relax, filling the cavernous spaces with blood, while simultaneously the exit of the blood is prevented by the contractions of the *erector* penis and *bulbocavernosus* muscles. The penis is then introduced into the vagina, and as a result of muscular movements producing friction upon delicate sensory nerve-endings of the glans penis and clitoris there are produced intense nervous sensations which lead to a *climax* or *orgasm*, consisting of the *ejaculation* of the *seminal* fluid into the upper end of the vagina. There is at the same time a secretion in the female from the *glands* of *Bartholin*, and perhaps also *rhythmical opening* and *closing* of the *cervical* canal. *Erection* is a *reflex* act, the *centre* lying in the *lumbar cord*. It may be aroused by impulses arising from the walls of the testes due to the pressure of contained semen, or from the nerve-endings in the skin of the penis or from the brain. The *efferent* nerves are the *nervi erigentes*. The *clitoris* is the homologue of the penis.

The sexual excitement accompanying an orgasm is more intense usually in the male. The *discharge of semen* begins with powerful *peristaltic* waves, probably in the *vasa efferentia*, and ends with *rhythmic contractions* of the *ischiocavernosus* and *bulbocavernosus* muscles. This is also a reflex act with the centre in the lumbar portion of the cord. The spermatozoa probably reach the Fallopian tube mainly by their own movements, but it is possible that after coitus the uterus may exert a suction and draw them from the vagina. It is claimed by some that the uterus dips down into the pool formed by the discharged semen. The time involved in the passage of the spermatozoa to the ovary is unknown, except that it is quite short; in the rabbit the time is only two and three-quarters hours. When spermatozoa meet an ovum, they surround it in great numbers until one of them succeeds in uniting with the egg, after which the remainder perish. When fertilized, the ovum undergoes repeated *segmentation*, increases in bulk, histological differentiation and the physiological division of labor set in, until finally there results a new individual that is expelled at the proper time. *In such cases where more than one spermatozoön succeeds in entering the ovum (polyspermy) the embryo dies early.*

While in the uterus the growing fœtus derives by far the greater part of its nourishment from the mother by means of the *placenta. Here the circulation of the child is brought into intimate relation to that of the mother, but they are nevertheless separated by four layers of cells:*

1. The wall of the chorionic capillary.
2. The cells of the chorion.
3. The cells of the uterine follicle.
4. The wall of the uterine sinus.

Although there is no direct communication, there is an exchange of material between the mother's blood and the fœtal blood. The *mother's blood* furnishes to the fœtal blood food and *oxygen*, and in turn removes the *carbon dioxid* and *excrementitious material* which the fœtus must lose. The placental circulation supplies the place taken in after-life by the alimentary and respiratory tracts. When the placenta is expelled, a part of the maternal tissue is left behind, and there is, of course, a loss of blood contained in the uterine sinuses, but the general balance of the circulation is not disturbed at childbirth. The reason for this is the oblique entrance of the placental vessels. They enter the sinuses at an angle, and are therefore compressed by the muscular tissue of the uterus in its contracted state. There are two distinct types of circulation in fœtal life—the *vitelline* and the *placental* circulation. In both types the blood is driven on by the heart, the essential difference being the site where the fœtal blood is enriched. The *vitelline circulation* precedes that of the placenta, and as soon as the latter is formed the former disappears. The vitelline circulation in the human is very short-lived.

The *placental circulation* presents two prominent features in which it differs from adult circulation—

1. Modifications are necessary in the heart and great bloodvessels in order that the blood may enter the lungs.

2. In the circulation through the liver the veins are modified so as to allow for the return of placental circulation.

The *course* of the *fœtal circulation* is as follows: The fœtal blood, purified and enriched in the placenta, passes by the umbilical vein in the umbilical cord to the under surface of the liver; here the vein divides into two parts. One portion of the blood enters the liver substance, and after traversing its capillaries is poured out by the hepatic veins into the inferior vena cava. The other portion of the blood passes directly from the umbilical vein to the inferior vena cava by means of a blood-channel, the ductus venosus. The blood of the vena cava inferior is carried to the right auricle of the heart, and instead of passing from there into the right ventricle, as in the case of the adult heart, it goes directly into the left auricle by means of an opening in the auricular septum, known as the *foramen ovale.* The flow of blood from the inferior vena cava through the foramen ovale and into the left auricle is facilitated by the fact that the inferior vena cava points almost directly into the foramen ovale. The Eustachian valve, consisting of a crescentic fold of fibrous tissue covered with endocardium and extending from a point between the opening of the superior and inferior venæ cavæ over to the lower and anterior margin of the foramen ovale, also favors this peculiar course of the blood. The base of the fold lies on the right auriculoventricular ring, and the concavity of the fold is directed upward. From its position the Eustachian valve acts as a guiding groove or gutter for passing the blood from the inferior vena cava to the foramen ovale. On entering the left auricle the blood is passed into the left ventricle and thence into the aorta, to be distributed all over the body; but principally to the head and upper extremities. From the latter regions the blood returns to the heart by the superior vena cava. On entering the right auricle the blood from the superior vena cava passes in front of the stream that flows from the inferior vena cava to the foramen ovale, and enters the right ventricle. The direction in which the superior vena cava points (toward the auriculo-ventricular ring), and also the Eustachian valve, are the factors that determine the separation of the two streams. On entering the right ventricle the blood from the superior vena cava is forced into the pulmonary artery toward the lungs. Before reaching the lungs this blood meets with a channel of communication between the pulmonary artery and the aorta-(ductus arteriosus), into which the larger portion of the blood from the pulmonary artery enters and mingles with the blood of the aorta; the remainder passes along the pulmonary artery to the structure of the lungs, which it nourishes, and thence back to the left auricle by means of the pulmonary veins.

The blood in the aorta that comes from the left ventricle passes largely to the head, but that which enters from the ductus arteriosus largely passes into the descending aorta. On passing down the descending aorta, some of the blood enters the mesenteric arteries, and thence back to the venous circulation by means of the portal vein and the liver. Some of the blood enters the iliac arteries and nourishes the lower extremities; but the major part of the blood leaves the fœtal body by the hypogastric arteries. The hypogastric arteries are branches of the internal iliacs, and course along the abdomen to leave the fœtal body at the umbilicus, where on emerging they change their names to umbilical arteries and proceed to the placenta.

The liver, receiving the freshest blood (from the umbilical vein), is the best nourished of all the organs of the fœtus. The result is that the fœtal liver is vastly larger in proportion than the adult liver. The branches of the aorta given off to the head and upper extremities distribute blood from the inferior vena cava, while the ductus arteriosus, carrying the blood from the superior cava and right ventricle, enters the aorta in such a way that most of its blood is sent to the lower extremities, abdominal organs, and umbilical arteries. In this way the deoxidized blood is sent back to the placenta for the renewal of its oxygen. The lower extremities are less developed than the upper. There are two reasons for this:

1. The blood contains less oxygen and nourishment.
2. The internal iliac arteries, giving off the umbilical arteries, divert a considerable portion of the blood-supply from the external iliacs which go to the lower extremities.

Owing to the ductus arteriosus, but little blood goes to the lungs. The amount is sufficient, however, to keep up the nutrition of the lungs, and they have no function before birth.

The *respiratory centre* in the medulla, which has been quiescent because it has been well supplied with oxygen, is awakened as soon as the connection with the uterine sinuses is interrupted. As soon as the supply of oxygen sinks to a certain point, an *impulse* of *inspiration* is generated, and as the infant breathes the lungs assume a condition of partial expansion. With the diminished resistance in the expanded lungs the amount of blood in the pulmonary circulation increases, and as the amount passing through the *ductus arteriosus* consequently decreases, this soon is obliterated. At the same time the amount of blood returning to the left auricle increases in quantity, and the intra-auricular pressure becomes greater; then, too, the inferior vena cava sends less blood, for the ductus venosus no longer carries the blood from the placental circulation, and therefore the foramen ovale is not used, and is soon closed by the adhesion of its valve-like curtain. Thus, the adult circulation is established in place of the fœtal circulation in consequence of respiratory movements. Owing to the division and occlusion of the umbilical cord, blood no longer passes through the umbilical vessels, with the result that the umbilical vein degenerates into a fibrous cord (round ligament of the liver). The hypogastric arteries remain pervious for the first part of their course, as the superior vesicle arteries; but the remainder of their course is obliterated and degenerates into fibrous cords.

The *period of gestation* during which the embryo is developing in the uterus may be put at 280 days, and probably dates from the first day of the last menstruation. Owing to the difficulty of knowing the time of fertilization, the exact period is not known. One of the earliest, and most obvious and most usual, signs of pregnancy is the cessation of menstruation. The *cause* of the *expulsion* of the fœtus from the uterus is not well known, and it is probable that on account of the exceedingly irritable condition of the uterus a number of causes may exist. Among these have been suggested the pressure on the tissue of the uterus or on the ganglia of the cervix, and the gradually increasing venosity of the fœtal blood.

The frequency of *multiple conceptions* is for twins at a ratio of

1 : 120 ; for triplets, 1 : 7910 ; and for quadruplets, 1 : 371,126 births. *Twins* may arise from separate eggs or from a single egg. The presence of a double chorion is diagnostic of the former, and a single chorion of the latter. The separate ova may come from a single Graafian follicle or not. When the offspring come from separate ova, they may be of separate sexes, and do not necessarily resemble one another ; but whenever they come from the same ovum, by a separation of the blastomeres, they are of the same sex, and their personal resemblance is very great.

The *factors* that *determine sex* are very little understood. As a general rule, more boys are born than girls. The sexual organs are differentiated at the eighth week of uterine life, but it is impossible to say whether the sex is determined in the germ-cells, in fertilization, or during the early life of the embryo. Many hypotheses have been offered. According to the *Hofacker-Sadler* law, if the father is older than the mother, more boys are likely to be born ; but if the mother is the older, the probability of girls is still greater. Breeders have, with great success, made use of the rule that the earlier the ovum is fertilized after liberation the greater is the tendency to females ; the later the fertilization takes place, the greater is the probability of males resulting. *Schenk* takes a similar view in that the ovum in its earlier stages is considered unripe. The presence of sugar in the urine of a pregnant woman he regards as an indication of incomplete metabolism of the body which results in a tendency to females. By means of a highly nitrogenous diet he claims to make the metabolism more perfect and insure the production of male offspring. *The sex in some of the lower organisms has been altered at will by feeding and by temperature.* Taking all the ascertained facts into consideration, it seems probable that whenever the parents, especially the mother, are surrounded by unfavorable nutritive conditions, the production of males will result ; while favorable nutritive conditions result in females. It may, moreover, be said that the production of sex is *self-regulating*, inasmuch that a scarcity of the sex of one kind tends to a production of individuals of that sex. Another theory states that whichever parent possesses the *higher sexual energy* (not to be confounded with *sexual desire*) will determine the sex of the offspring, but always of the opposite line—*e. g.*, females of higher energy produce males.

QUESTIONS ON CHAPTER XIV.

What is reproduction?
How many methods are there?
Describe the asexual method.
Why does a growing mass of protoplasm divide?
What is the essential fact of sexual reproduction?
Describe various stages in the development of sexual reproduction.
What are the primary and secondary sexual characters?
Describe the development of a spermatozoön.
What difference is there between the sexual elements?
In what respects are they alike?
What is the rate of movement of a spermatozoön?
What is semen?
What is meant by the maturation of the ovum?
What is a Graafian follicle?
Describe ovulation.
How does the ovum reach the uterus?
What is fertilization? Where does it take place?
Describe the process and development of menstruation.
How long does menstruation last? What are the symptoms accompanying it?
Give the physiological causes of menstruation.
Discuss puberty.
What is the menopause?
What is the object of menstruation?
What is the relation of ovulation to menstruation?
Describe copulation.
Discuss the erection of the penis.
Discuss the nervous mechanism of an orgasm.
How do spermatozoa reach the Fallopian tubes?
What is polyspermy?
How many types of fœtal circulation are there?
Describe the placental circulation.
What changes take place in fœtal circulation at birth?
What is the length of the period of gestation in the human being? From what time does it probably date?
What is the earliest sign of pregnancy?
What is the cause of the expulsion of the fœtus from the uterus?
Discuss the occurrence of twins.
Discuss the determination of sex.
What is the Hofacker-Sadler law?
What is Schenk's hypothesis?
What are the most probable determining factors of sex?
Is the production of sex self-regulating?

APPENDIX.

CHEMICAL TESTS COMMONLY USED IN PHYSIOLOGICAL ANALYSIS.

FOR PROTEIDS:

Nitric Acid coagulates all except peptones.

Heat.—All are coagulated by boiling, except peptones.

Xanthroproteic Reaction.—A solution boiled with strong nitric acid becomes yellow: the color is deepened by the addition of ammonia.

Biuret Reaction.—With a trace of copper sulphate and an excess of potassium or sodium hydrate they give a purple reaction.

Millon's Reaction.—With a solution of metallic mercury in strong nitric acid (Millon's reagent) they give a white or pinkish reaction, and the color becomes more pink on boiling.

FOR STARCH:

Iodine Reaction.—Add to a solution of starch a small quantity of tincture of iodine, and a blue reaction results. The color disappears on heating and returns on cooling.

Glycogen.—Same test gives reddish reaction, port-wine color, which disappears on heating and returns on cooling.

FOR SUGAR (GLUCOSE):

Moore's Test.—Boil solution of sugar with an excess of potassium hydrate, brown color-reaction.

Trommer's Test.—Add to solution a sufficient amount of potassium hydrate to render it quite strongly alkaline. Then add a solution of copper sulphate, drop by drop, until a distinct blue tinge is visible. Heat, and the presence of sugar is shown by appearance of red, yellow, or orange color-reaction.

Fehling's Test Solution.—An alkaline copper solution by which a quantitative test may be made. The solution is somewhat unstable, and is for this reason to be tested by boiling before using. The strength of the solution is such that 1 cubic cm. (15 minims) will be exactly decolorized by $\frac{1}{200}$ of a gramme (0.075 grain) of glucose. This test is very delicate, and is quite commonly used for urinary examinations to detect glycosuria.

The Fermentation Test.—If a small quantity of yeast be added to a sugar solution, the fungus of the yeast (saccharomyces) will cause the sugar to be decomposed into carbonic acid and alcohol. If the process be continued until the sugar is entirely broken up, the amount of carbon dioxide evolved indicates the proportion of sugar present.

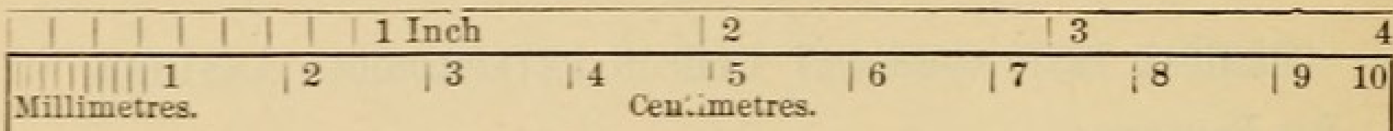
FOR BILE SALTS:

Pettenkofer's Test.—Upon the addition of sulphuric acid to a solution of bile-salts in water there is a precipitation of the salts, which are redissolved by a further addition of the acid. If a drop of a solution of cane-sugar be added, a deep cherry color is developed.

FOR BILE PIGMENTS:

Gmelin's Test.—Add a small quantity of nitroso-nitric acid to a solution of the bile pigments, and a play of colors results, beginning with green and changing to blue, violet, red, and yellow. This is seen best on a white background; therefore a plate is often used for this test.

METRIC SYSTEM.



The area of the figure within the heavy lines is that of a square decimetre. A cube one of whose sides is this area is a cubic decimetre or *litre.* A litre of water at the temperature of 4° C. weighs a *kilogramme.*

A litre is 1.76 *pint;* a pint is 0.568 of a litre.

The smaller figures in dotted lines represent the areas of a square centimetre and of a squre inch.

A cubic centimetre of water at 4° C. weighs a *gramme.*

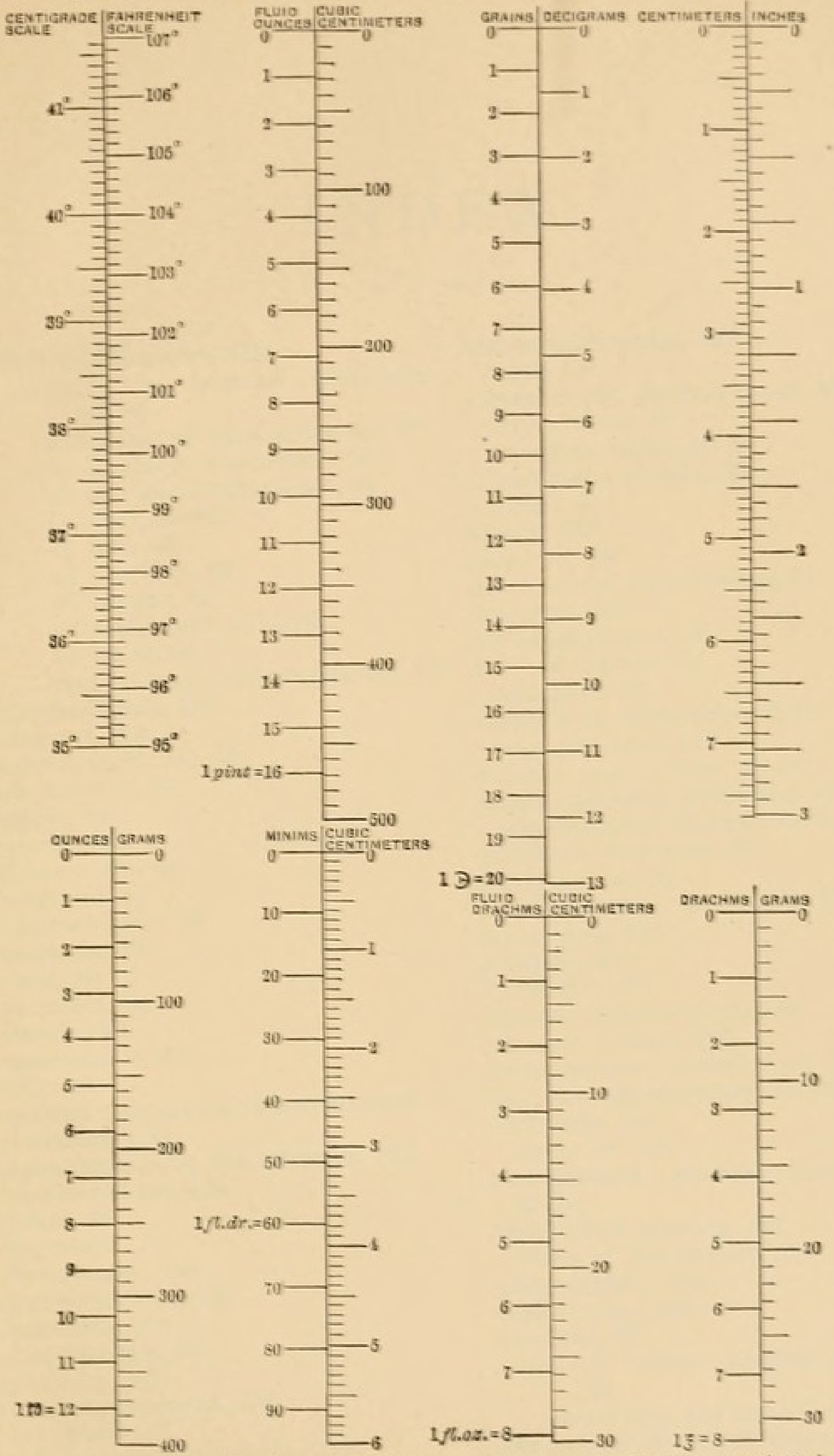
Square Inch.

Square Centimetre.

IMPORTANT EQUIVALENTS OF THE METRIC SYSTEM.

Gramme	$= 15\frac{1}{2}$ grains.	Metre	$= 39\frac{2}{5}$ inches.
Centigramme	$= \frac{3}{20}$ grain.	Centimetre	$= \frac{2}{5}$ inch.
Milligramme	$= \frac{3}{200}$ grain.	Millimetre	$= \frac{1}{25}$ inch.
Kilogramme	$= 2.2$ pounds.	Micromillimetre	$= \frac{1}{25000}$ inch

COMPARATIVE SCALES, showing at a glance the exact equivalent of ordinary weights and measures in those of the Metric System, and *vice versa.*



The equivalents of fractions, whether large or small, may be found with great nicety by these scales. For instance, ⅛ grain = ⅛ of the metric equivalent of 7 grains, and 1-200 grain =1-4000 of the metric equivalent of 20 grains. This method is, of course, reversible.

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