HUMAN PHYSIOLOGY

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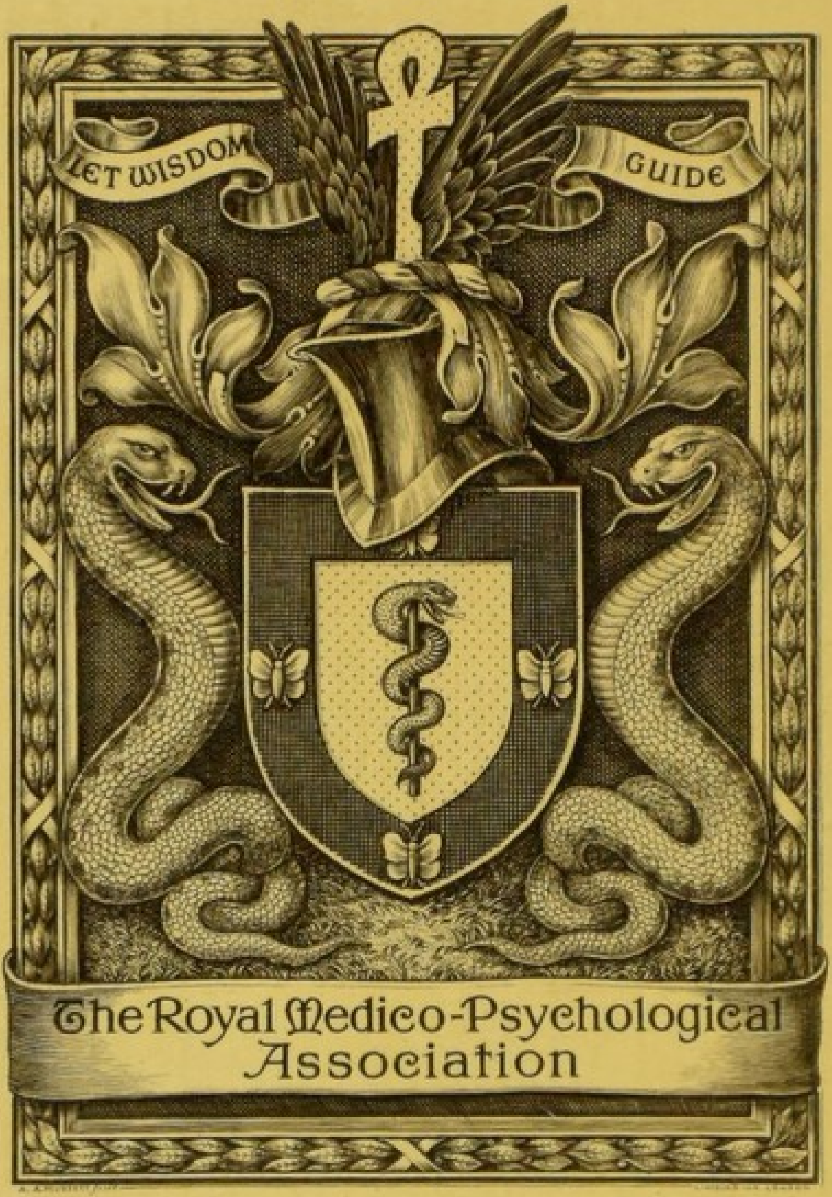
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ON

HUMAN PHYSIOLOGY

BY

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"Man know thyself."

"The proper study of mankind is man."

PREFACE.

THIS little book contains an outline of two short Courses of Lectures on Human Physiology delivered to many thousands of persons at large towns in the North of England and the Midlands, and also in the Metropolis. It embodies an attempt I have made to excite an interest in, and give some sound elementary knowledge of, a branch of science which surpasses all others in its practical bearing upon the maintenance and improvement of the health of the community. It is not intended as a text-book, but as an adjunct to the Lecture-room. Although written chiefly to help the numerous students who attend my own Lectures, it may also possibly prove of service to medical and other students who are engaged in attending Lectures on the same subject.

E. A. P.

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LECTURE I.

THE HUMAN BODY—ITS BUILD AND GENERAL STRUCTURE.

Physiology defined.—The branch of science which treats of the functions of living things is termed *Physiology*. It is divisible into *Animal* and *Vegetal Physiology*, according as animals or plants are dealt with. That portion of Animal Physiology dealing with the body of man is further distinguished as *Human Physiology*.

By the word *functions* is simply meant the changes and processes going on within the body making up its life. Physiology, in a phrase, is the *science of life*.

Physiology, therefore, treats of the human body as a living organism. It thus differs from *Anatomy*, or the study of the form and construction of the body independently of its life. Microscopic Anatomy is often called *Histology*.

Importance of Physiology.—The study of the human body as a living organism, or Physiology, is of great importance, for it is only by the aid of such knowledge as an acquaintance with it conveys that we can understand the proper relations of our bodies to the world in which we live. It teaches the true relation of our bodies to the air we breathe, to the water we drink, to the food we eat, to the house we live in, and to the work of our daily life. It thus has a most practical bearing upon the health of the individual, and upon the preservation and improvement of the health of the community of which he is a member.

The Problems of Physiology.—Life is the result of, or at least invariably accompanied by, perpetual change. The living human body is the seat of a series of perpetual changes. These changes involve a loss of substance and an expenditure of energy. Matter and force must, accordingly, be supplied to the body, to make good this loss. Matter is supplied in the form of food and oxygen; force as potential energy in the food, and as heat resulting from oxidation. Matter in chemical combination much simpler than that taken in is continually being passed away from the body by the excretory organs. The chain of connection between this gain of matter—in the form of complex food—and loss of matter—in the form of the much simpler compounds excreted,—and between the gain and loss of energy, and the relations of this gain and loss to the activity and growth of the various constituent parts of the body, and of the body as a whole, constitute the fundamental problems of Physiology.

Man a Vertebrate Animal.—Man is a member of the great family of backboned animals, or sub-kingdom Vertebrata. By this is meant that his body, in common with all members of the five great classes of animals—Mammals, Birds, Reptiles, Amphibia, and Fishes—has an internal bony framework or skeleton. This skeleton, in the main, determines the shape of the body, and is characterised by the presence of a central axis or backbone.

The word Vertebrata is derived from the fact that the so-called backbone is not one bone, but a series of similar small bones, piled up one above the other in the form of a column. Each of these bones is a *Vertebra*, and the column formed by them is called the vertebral column. *Vertebral Column* is the anatomical expression for what in ordinary language is called the backbone. The vertebral column with the bones directly attached to it determine the shape of the trunk of the body; the bones indirectly attached to it (excepting those of the skull) determine the shape of the limbs.

Head and Trunk considered as Two Tubes.—The head and trunk may be regarded as consisting of two tubes, placed one behind the other. There is a large anterior tube, made up of the cavity of the mouth, of the gullet in the neck, the cavities of the chest, abdomen, and pelvis. A smaller posterior tube is enclosed within the vertebral column and skull.

The Posterior Tube—

How formed. The posterior tube *in the Trunk* is formed by the peculiar structure of the vertebral column. A vertebra is an irregularly shaped bone, consisting of a solid mass of bone in front—the body—and of an arch behind, from which project processes. The arches of contiguous vertebræ correspond both above and below. In this way the arches form a tube—the *Vertebral Canal.* The posterior tube *in the Skull* is formed by the bones of the skull, and is here much larger than in the trunk.

Its Contents. The posterior contains the principal parts of the Central Nervous System, viz., the *Brain* in the skull, and the *Spinal Cord* in the vertebral canal.

The Anterior Tube—

How formed. The anterior tube is formed above by the bones of the skull surrounding the cavity of the *Mouth*. In the neck it is represented by the *Gullet*, lying immediately in front of the vertebral column. In the trunk it is composed above of the *Chest* or *Thorax*—a bony box, bounded behind by twelve vertebræ in the region of the back, on either side by twelve ribs, and in front by the *Breastbone* or *Sternum* and pieces of gristle joining it to the ribs. The chest is separated from the anterior tube below by a great fleshy muscle—the *Midriff* or *Diaphragm*—its upper surface being convex. Below the diaphragm are the *Abdomen* and *Pelvis*. The shape of this part is determined by two large bones—the *Hipbones*—joined posteriorly to five vertebræ near the bottom end of the vertebral column, and connected to one another in front. The five vertebræ thus forming a support for the hipbones behind are joined together in adult life to form one bone called the *Sacrum*. The basin-like cavity thus formed by the sacrum behind and the hipbones at the sides and in front is the *Pelvis*. The upper edges of the hipbones are joined to the ribs by strong fleshy muscles. The portion of the anterior tube thus enclosed between the pelvis below and the chest above is the *Abdomen*.

Its Contents—

In the Chest. The lungs, heart, large bloodvessels (aorta, pulmonary artery, venæ cavæ, and pulmonary veins), gullet.

In the Abdomen. Stomach, small and large intestine, liver pancreas, spleen, kidneys, bloodvessels, and nerves supplying these organs.

In the Pelvis. The urinary and generative organs, termination of alimentary canal.

Extending from the neck to the pelvis in the anterior tube is also the *Sympathetic Nervous System*.

Contents of Two Tubes connected.—The contents of the anterior tube are connected with those of the posterior, *i.e.*, with the brain and spinal cord, by fine, smooth, whitish cords of varied thickness. These are *Nerves*.

The Limbs.—There are no tubes in the limbs comparable to those in the trunk just considered. The shape and length of the limbs are determined by the bones forming their innermost part. These bones are indirectly connected to the vertebral column. Those of the lower limbs through the hipbones ; those of the upper through the shoulder-blade, collar-bone, breastbone, and ribs. Attached to and surrounding the bones of the limbs are muscles. The muscles are more or less enveloped in fat, and the whole is enclosed by the skin. Amongst and supplying the different parts are nerves and bloodvessels (arteries and veins).

Analysis of the Human Body—

a. Chemical. About 70 per cent. of the body consists of *Water.* Of the 30 per cent. solid matter the most important and characteristic constituents are highly complex, but imperfectly understood, chemical compounds containing nitrogen, known by the generic term of *Proteids.* There are then non-nitrogenous organic bodies, of which *Fat* is the most widely distributed. In much smaller but most constant quantities there are *Salts* of such metals as potassium, sodium, calcium, and magnesium, some of which contain *Phosphorus.*

b. Anatomical—

1. Head, trunk, and limbs.

Regarded from the exterior, the human body exhibits a striking *Bilateral Symmetry;* that is to say, the parts of the body on either side of a vertical median line are similar. Indications of a *Serial Symmetry* are visible in the two pairs of limbs and the twelve pairs of ribs.

2. Organs (as heart, liver, lungs, brain, &c.) and tissues (as muscle, bone, nerve, blood, &c.).

3. Microscopic anatomical elements, or **Cells.** The application of the microscope to the constituent tissues and organs of the body shows that, however different in their appearance they may be, they all agree in being composed of minute anatomical elements called cells. So universal is this that the generalisation has been made that the whole body is composed, or is an aggregation, of cells (*Cell Theory*). Certain exceptions are observable in the form of fibres, but the study of development points to these fibres having arisen from cells, or being modified cells. There may thus be said to be an underlying *Unity of Structure* throughout all parts of the body. This unity of structure applies only to the cellular nature of the constituent elements. The cells differ widely from one another in their shape, appearance, structure, and constitution in the different tissues and organs, *e.g.*, the cells of muscle, nerve, and blood; or the liver-cells and those of the lung and kidney.

c. Physiological. Correlated with these differences in the structure of the component cells of the tissues and organs are differences of function or use. The muscle-cells, especially endowed with the power of contraction, have a very different use from the nerve-cells, the special function of which is to evolve, receive, or transmit nervous energy. Whilst the bone-cells are embedded in a hard passive substance, especially adapted to protect and support, the blood-cells are in a state of perpetual motion, enabling them to play an active part in the dynamical changes of the body. Whilst the cells of the salivary glands have the power of secreting saliva, the liver-cells are endowed with the function of producing bile, and so on through the whole body. In fact, when we make a physiological analysis we see that there is a most evident division of labour in the human body. Each and every organ and tissue is endowed with one particular function or use more than any other. It performs a definite, more or less restricted, duty. In so doing it benefits itself, and conduces to the welfare of the whole organism. There is, indeed, a *physiological division of labour* in the human body comparable to that which obtains in a social community. The organs and tissues may be compared to the individuals, or groups of individuals, who pursue some special calling, which by their education and situation they can perform better than any other. Any particular work is thus done better and more thoroughly, to the advantage both of the individual who accomplishes it and of the whole community to which he belongs. This physiological division of labour is possible, and is carried on in a harmonious manner, because the organs and tissues are brought into relation with one another, and their activity regulated, modified, and harmonised by a complex mechanism called the *Nervous System*.

In the cellular nature of its constituent parts the human body resembles the bodies of all other animals, from the highest to the lowest. This remarkable similarity in fundamental microscopic structure throughout the animal world is not the least striking of the many facts pointing to a common law of development.

LECTURE II.

LOWEST FORMS OF LIFE—CELLS.

In the last lecture the cellular nature of the body was illustrated, and the similarity in this respect of the human body to all other animals referred to. As we descend the scale of life we find that the variety in the nature and structure of the constituent cells becomes less and less as the organism becomes less complex. The division of labour correspondingly diminishes. At last, when the lowest forms are reached, they are found to consist of only one cell, which, living an independent existence, carries on all the processes necessary to its life, and, in fact, all division of labour has disappeared. Such cells are not only anatomical, but also physiological, units. In their cellular structure there is thus a connection between the highest and the lowest, the most complex and the simplest, forms of animal life. These remarks apply equally to plants. In the lowest forms of animal and plant life we therefore have organisms consisting of a single cell, of a very minute mass of living matter or protoplasm, the life-changes and life-history of which can be brought under observation by the microscope. Any knowledge such observation and experiment can reveal to us concerning the functions or vital actions of these simple organisms is so much information regarding the nature of living matter in its simplest form. From the study of these simple organisms something may, therefore, be learnt regarding the fundamental properties of living matter which cannot fail to throw light upon the great problem of life, even of life as manifested in man himself. Two unicellular organisms will be considered: one a plant (Yeast), the other an animal (Amœba).

Yeast (*Saccharomyces Cerevisiæ*).

A drop of the brown-coloured liquid called yeast, when examined under the microscope, is found to consist of two distinct parts, viz., a colourless liquid in which float enormous numbers of minute globular bodies termed yeast-cells. The cells are rounded or oval in shape, $\frac{1}{2000}$ to $\frac{1}{7000}$th inch in diameter. They exist singly or joined together as strings or masses.

Structure of the Cell.—Each cell is an independent organism, a minute plant, sometimes called *Torula*. The cell is comparable to a sac, and consists of two parts :

(i.) The *Cell-wall*, an external, enclosing, colourless, transparent membrane, consisting chiefly of *Cellulose*, a compound of carbon, hydrogen, and oxygen.

(ii.) The *Cell-contents*, or semi-fluid substance within, called *Protoplasm*. The protoplasm encloses one or more spaces, or *Vacuoles*, filled with liquid. Usually plain and clear but sometimes granular in appearance, the protoplasm is of the utmost importance, for it is the essential part of the cell. It is the part alone endowed with life. On it depend all the vital functions exhibited by the little yeast plant. If then, by observation or by experiment, any insight into the life of the plant can be gained, it will be perfectly justifiable to attribute the functions and vital activities observed to the simple living matter, or protoplasm.

Nature of the Protoplasmic Contents.—The protoplasm is not a definite chemical compound such as cellulose, but has an exceedingly complex constitution. It appears to be rather a mixture of substances (or in only a very loose chemical combination), some of which are of a very complicated nature. It is largely composed of the three elements Carbon, Hydrogen, and Oxygen. In addition there is *Nitrogen*, and probably always Sulphur. These five elements are united to form a highly complex chemical body which goes by the name of *Proteid*—a generic term for a number of substances all containing the foregoing elements in the same percentage composition (within narrow limits), one or more of which are invariably present in all forms of living matter. Besides proteid the protoplasm contains *Water*, and *Salts* of Calcium, Potassium, and Magnesium. In addition, in some cases—*e.g.*, in yeast—*Fat* may be present, composed of Carbon, Hydrogen, and Oxygen.

Reproduction.—Under favourable conditions of temperature and medium, the yeast-cell not merely lives an independent life, but lives an extremely active one, for it reproduces itself at a rapid rate. This multiplication or *Reproduction* is effected by a process of *Gemmation* or budding, thus producing the strings of cells previously alluded to. In such circumstances Torula must manufacture a considerable amount of protoplasm, and it has the remarkable power of manufacturing this exceedingly complex substance out of comparatively simple bodies. This is proved by growing yeast in a liquid (Pasteur's fluid) in which are dissolved substances the chemical composition of which is exactly known. All these dissolved substances are of simpler composition than proteid, the essential constituent of the protaplasm. The yeast-cell can obtain the nitrogen necessary to form the proteid of the protoplasm from chemical compounds much simpler than the proteid itself. In this respect it profoundly differs from all animals, for they are able to obtain the necessary nitrogen only from some form of proteid.

Assimilation.—The process of the manufacture of protoplasm out of simpler substances forming the food may take place quite independently of reproduction. It obviously must occur whenever growth of a yeast-cell takes place. To this important and fundamental process, viz., the conversion of the dead matter of the food into the living matter of the organism, the term *Assimilation* is applied.

Respiration.—The yeast-cell absorbs oxygen, and gives out carbonic acid in about equal volumes. This exchange of gases is called Breathing, or *Respiration*. Under favourable circumstances this function is performed with considerable activity. Nevertheless the yeast-cell can live and grow without a supply of *free* oxygen, in which case it is assumed that it obtains oxygen from some compound containing it (*e.g.*, sugar).

Inasmuch as the carbonic acid given out contains as much oxygen as has been taken in, it is obvious that respiration must entail a waste of the organism. If yeast be placed in distilled water instead of in Pasteur's fluid, the result of this becomes obvious in the gradual diminution in substance of the cells.

We may infer, then, that under ordinary conditions there are *two opposite kinds of processes* going on in a yeast-cell—one tending to its growth and reproduction (Assimilation), and, since it involves the building up of the materials of the cell, may be described as of a *constructive* character ; the other tending to its diminution or decrease (Respiration), and may, conversely, be said to be of a *destructive* nature. The cell is, therefore, the seat of a perpetual conflict between these two opposing influences. If the former is in the ascendency, the cell grows and ultimately reproduces ; if the latter gets the upper hand, the cell decreases, and, if continued long enough, decays, and ultimately dies. If the two forces are equal, there is neither increase nor decrease : there is a condition of physiological equilibrium. Every living organism is the seat of two great opposing forces—constructive on the one hand, and destructive on the other—of this kind.

The Yeast-cell is a Plant for two reasons—

1. Its protoplasm is enclosed within a cell-wall of cellulose.

2. It can manufacture living matter out of chemical substances, all of which are of simpler composition than proteid.

Fermentation.—When yeast is put into a saccharine solution it produces certain changes, viz., an evolution of carbonic acid gas, the formation of alcohol and small quantities of glycerin and succinic acid. These changes constitute the phenomenon of fermentation. The above-mentioned substances apparently result from the decomposition of the sugar, for 99 per cent. of the sugar which disappears is thus accounted for. How the yeast-cell causes this decomposition of the sugar has been a question of much dispute. According to Pasteur, the yeast-cell, by its vital activity, takes oxygen from the sugar, this being the 1 per cent. unaccounted for. In fact the yeast is able to obtain its supply of oxygen from this chemical compound in place of the gas in the free condition. It is thus able to live independently of a supply of air, and has in consequence been termed by Pasteur *anaërobic*. According to this view, fermentation is essentially a vital phenomenon.

AMŒBA.

The Amœba is an irregularly-shaped mass of protoplasm found in liquids containing decomposing organic matter.

Differences between the Yeast-cell and Amœba—

1. It is usually irregular in shape and *has no cell-wall*. Although there is no cell-wall, yet a slight difference (*differentiation*) is to be observed between the outer and inner parts of the cell. The outer portion, or *Ectosarc*, is clearer and denser than the granular, more fluid central part, or *Endosarc*.

2. It exhibits movements of a curious and distinctive character, consisting in the protrusion of a process, or *pseudopodium*, which may be soon retracted, or draw the rest of the cell after it, thus causing a distinct locomotion of the amœba. Hence its old name of *Proteus animalcule*.

3. Within its protoplasm is a round body, the *nucleus*, in the centre of which is a round granule, the *nucleolus*. The absence of a nucleus from yeast may be apparent rather than real, due to our imperfect means of observation.

4. In the Ectosarc is sometimes seen a clear space which rhythmically appears and disappears. This structure, known as the *Contractile Vesicle*, has been regarded by some as a primitive heart.

5. It is *Irritable* and *Contractile*. The properties of irritability and contractility are intimately connected with one another, the presence of the former becoming known through an exhibition of the latter. Contractility probably causes movement solely by a rearrangement of the ultimate particles of the protoplasm, and not by their approachment nearer to each other. It is therefore not synonymous with contraction as applied to inorganic bodies under the influence of variation of temperature. The contractility of the protoplasm occurs in consequence of its response to external stimuli, or of its irritability. Such stimuli are: (*a*) Heat; (*b*) Oxygen; (*c*) Electricity. Of all such stimuli it may be said that they are quite inadequate to produce by direct application that change of form of the protoplasm which constitutes its movement. And it may be said generally that living matter which exhibits movement, when acted upon by some stimulus which is of itself quite incommensurate with that movement, is irritable.

Here again it must be noted that this difference between the yeast-cell and amœba is probably apparent rather than real. The protoplasm of the yeast-cell being completely surrounded and bounded by the non-living cell-wall has no opportunity of exhibiting these properties, should it possess them. If, as from analogy, we may perhaps assume contractility and irritability are fundamental properties of all protoplasm, that of yeast will be endowed with them.

Resemblances between the Yeast-cell and Amœba.—They agree in exhibiting the three fundamental functions of—

1. *Respiration.* Like the yeast-cell, the amœba absorbs oxygen and evolves carbonic acid in about equal volumes, or respires.

2. *Reproduction.* The amœba reproduces by division, or *fission.* The protoplasm becomes cleft into two portions, its division being preceded by a division of the nucleus.

3. *Assimilation.* Whilst this is fundamentally the same in both cases, viz., the conversion of the dead matter of the food into the living protoplasm, yet there is a striking difference in the conditions necessary for the transformation. The amœba requires in its food the complex proteid. It can obtain nitrogen only from

this. In this respect all animals resemble it. The yeast-cell can obtain nitrogen from ammonia or some salt of ammonia or from nitrates, and in thus being able to obtain this essential element from such simple combinations resembles all other plants. Another difference is that the amœba can make use of solid food, whereas yeast, like all other plants, requires its food in a fluid condition.

Automatism.—Movements of the amœba appear sometimes to take place independently of any external stimulus. Its movements are of that kind called Spontaneous. The amœba on this account is said to be endowed with automatism, or to exhibit automatic movement. This is a somewhat unfortunate term, for it is often used in a sense the opposite to spontaneous. The doctrine that animal bodies are automata asserts that all actions (*i.e.*, all movements) are the result of external influences direct or indirect. In the case of amœba it is impossible to be sure that no external stimulus is acting upon it, or that some change due to a previous external stimulus is not taking place internally—in other words, the effect of an external stimulus having been stored internally for a time.

Hydra Viridis.

Organisms next above the preceding in the scale of life consist of aggregations of simple cells. An example of such is the freshwater polype *Hydra Viridis.*

Structure of Hydra.—Tubular in shape, Hydra is usually attached at one end. At the free extremity is a circular row of *tentacles* surrounding an orifice, or *mouth*, opening into a central space, the body cavity. The body-wall is composed of cells arranged in two layers—

1. An outer layer, or *Ectoderm.*
2. An inner layer, or *Endoderm.* The cells of this layer contain chlorophyll.

Reproduction of Hydra.—This occurs either (1) *Asexually*, by budding, or (2) *Sexually*, by the action of uniciliated motile cells, or *spermatozooids* (formed in projections from the body near the fixed end), on a large cell, the *Ovum* or *Egg-cell*, enclosed within a projection, the *ovary*, near the free end. As the result of the action of the spermatozooids on the egg-cell a series of remarkable changes take place in the latter. It divides and subdivides until a mass of similar cells is produced. This becoming surrounded with a chitinous coat passes into a resting condition, and by the rearrangement and alteration of the cells a new Hydra is developed. The reproduction of this organism is interesting, for both in its origin from a single cell, and in the series of changes the egg-cell undergoes in the first stages of development, the reproduction of Hydra resembles in a striking manner the earliest stages in the reproduction of the higher animals.

LECTURE III.

TISSUES—THE SKIN.

The Blastoderm.—The higher animals originate from a single egg-cell, or ovum. As the result of fertilisation of the ovum, it divides into two cells. These again divide. Further division and subdivision produce a mass of cells from which a germ-membrane, or *Blastoderm*, is formed. The blastoderm, consisting at first of two layers, soon has a third. These three layers are known as the *Epiblast* (upper), *Hypoblast* (lower), and *Mesoblast* (middle). From these three layers the several tissues and organs of the body are developed, viz.: *from the Epiblast* the nervous system, including the organs of sense, the epidermis, and the epithelium of the mouth; *from the Hypoblast* the epithelial lining of the air-tubes and of the alimentary canal, and also the proper substance of the glands communicating with these passages; *from the Mesoblast* all the remaining parts of the body.

The development of the different structures of the body consists essentially in the alteration, modification, and development of the comparatively simple cells of the blastoderm, so as to form the many varied forms of cells which go to build up the tissues and organs of the body, briefly referred to in the first lecture, and which will be further explained hereafter. Cells of similar structure are aggregated together in masses. Such cells not only resemble each other in structure, but also in the use they subserve in the economy. Such masses of cells form what are known as the tissues of the body.

Definition of Tissue.—A tissue may be defined as an aggregation of similar cells, having a common embryonic origin, endowed with one particular function or use more than any other.

Simple Tissues.—That the human body is largely composed of tissues is seen from the following list:

1. *Epidermal*, or epithelial (epidermis, cellular lining of mucous membrane.)
2. *Connective* (fat, tendon).

3. *Cartilaginous* (gristle).
4. *Osseous* (bone).
5. *Muscular* (muscles).
6. *Nervous*.
7. *Blood*.

Compound Tissues.—Several of the above may be combined together to form what are called compound tissues; *e.g.*:

1. *The Bloodvessels* (connective, muscular, nervous).
2. *Lymphatics* (connective, muscular).
3. *The Skin* (connective, muscular, nervous, epidermal).
4. *Serous*, *Synovial*, and *Mucous Membranes* (connective, epithelial, nervous, muscular).

Organs.—Several tissues may be combined together so as to form in one particular definite position in the body a special structure which performs some particular and peculiar function. Such a structure is termed an *organ*. The *Heart* is a very good example of such an organ. In other cases the special function of the organ is due to its being chiefly composed of cells peculiar to it; *i.e.*, not found in any tissue or other organ. The *Liver* is a striking instance.

Division of Labour.—All the actions, processes, changes, and functions which in the aggregate constitute the life of a human being are therefore carried out and performed by a number of different and separate agents—the afore-mentioned tissues and organs. There is thus a most elaborate and beautifully-adjusted *physiological division of labour*, each organ and tissue doing the work best suited to it, for which it is specially adapted, both to its own advantage and to that of the body as a whole.

I. The Epidermal Tissue.—This tissue comprises the outer skin or *Epidermis*, with the parts developed from it, and the cellular lining of the alimentary canal and air-tubes, or *Epithelium*.

The Epidermis.—This is composed of a number of layers of cells separable into two strata.

i. The *Horny layer*, or outer stratum, consisting largely of cells modified to scales.

ii. The *Rete mucosum*, or Malpighian layer. This inner stratum is much softer, the cells being highly vital, and capable of multiplication. The innermost part, viz., that next to the dermis, consists of a single layer of columnar-shaped cells. The rest is made up of many layers of cells having a ridged outline, hence called "ridged" or "prickle" cells. The ridges meeting, channels are left between the cells by which nutriment is probably conveyed by the plasma exuded from the bloodvessels of the dermis, for no *bloodvessels* pass into the epidermis. Fine *nerve-fibrils* are said to penetrate into the epidermis.

The *thickness of the Epidermis* varies in different parts of the body. It is thinnest on the back and neck, thickest on the palms of the hands and soles of the feet.

The *black colour of the negro's skin* is due to the deposition of pigment granules in the rete mucosum, especially in the layer of columnar cells.

The Dermis, True Skin, or Corium is situated immediately beneath the epidermis. *It does not belong to the epidermal tissue*, but is composed of connective tissue (*vide* Lecture IV.). It is dealt with here for convenience' sake. It is composed of a mass of fibres in which two layers can be distinguished:

i. The *Outer* or *Papillary layer*, so dense that the fibres are scarcely distinguishable in it. It is raised up into a great number of conical or finger-like projections, termed **Papillæ.** The epidermis is moulded over the papillæ of the dermis, from which it can be separated by maceration. The papillæ are in some parts arranged in a very definite manner, in rows producing a ridged appearance of the epidermis. This is well seen in the *Curvilinear markings* on the palm of the hand. The papillæ are sometimes cleft, forming *Compound Papillæ*. The papillæ are largest and most numerous in parts most sensitive to touch. Length $\frac{1}{100}$th inch; in some cases much less. Nerves pass into many of them, there terminating in end-organs. The papillæ are very vascular.

ii. The *Inner* or *Reticular layer*, in which the fibrous tissue is much looser. It passes gradually into the fatty tissue beneath.

Modifications of the Epidermis are Nails, Hairs, and Glands.

A **Nail** consists of three parts:

1. The *Root*, or part under the skin.
2. The uncovered part, or *Body*, terminating in
3. The *Free-edge*.

In structure the nail agrees essentially with that of the epidermis. The horny layer has become much thickened and hardened. The dermis beneath the nail is called the matrix, or *bed of the nail*. It is raised up into a great number of very vascular papillæ, arranged in rows slightly diverging from the posterior part. The series of ridges, or *laminæ*, thus formed fit into corresponding depressions on the under surface of the nail. The nail grows by new cells being continually formed at the root and on the bed.

A **Hair** may be said to be composed of three parts:

1. The *Root;* 2. the *Shaft* or *Stem;* 3. the *Point.*

The depression of the skin containing the hair is called the *Hair-follicle.* It consists of an inner part continuous with the dermis, and an outer continuous with the epidermis. The follicle becomes closely connected with the root, forming the *Root-sheath.* The portion continuous with the dermis is called the Outer Root-sheath, that with the epidermis the Inner Root-sheath. At the bottom of the root is a conical projection of cells known as the *Papilla of the Root.* Growth and regeneration of the hair is effected by this papilla, which is a modified papilla of the dermis.

The *stem* or *shaft* consists of three parts—

i. The *Cuticle,* composed of finely imbricating scales causing the appearance of fine waved transverse lines. It completely surrounds the shaft, and is found in all hairs.

ii. The *Fibrous substance* inside the cuticle is resolvable into straight rigid longitudinal fibres. In some hairs the whole internal part consists of this. Within it are cavities containing pigment granules, giving a dark colour to the hair, or air when it is light coloured or white.

iii. The *Medulla,* or Pith, innermost of all, does not exist in all hair; *e.g.,* woolly hair. It appears to be composed of little clusters of cells of different shapes containing granules or air.

Muscles of the Hairs (arrector pili) are small bundles of involuntary muscular tissue passing from the upper part of the dermis to the hair follicle near the root. In their course they, to some extent, surround the sebaceous glands. By their contraction, the upper end being fixed, they necessarily cause the hairs to become erect. They also facilitate the passage out of the secretion of the sebaceous glands by compressing them.

Glands.—These are of two kinds—

1. *Sebaceous Glands* are small racemose glands, the ducts of which open into the hair follicles near their mouths. They pour out a thick fatty secretion which moistens the hair. There are usually two glands to each hair.

2. *Sudoriparous,* or *Sweat Glands,* are fine tubes terminating below at various depths in the subcutaneous tissue in a coiled, blindly ending knob. In its passage through the epidermis the tube is coiled like a corkscrew. The tube, except in the epidermis, is lined by layers of cubical cells resting upon a basement membrane. The coiled knob has only a single layer of cells. In the larger glands the duct may divide. They are most numerous where there are

no hairs. As many as 3000 in a square inch have been counted on the palm of the hand, where the orifices are on the ridges formed by the lines of papillæ. It is estimated that there are between two and three millions on the surface of the whole body, or a surface of more than 1000 square yards. Surrounding the knob is a network of capillaries, and nerves are distributed to the glands.

The Epithelium.—The mouth and œsophagus are lined by layers of delicate flattened cells (*Stratified Epithelium*); the rest of the alimentary canal by a single layer of columnar cells (*Columnar Epithelium*). The air tubes, including the nostrils (except the olfactory part) and nasal part of pharynx, are also lined with a columnar epithelium, the cells of which are provided with minute vibratile filaments ($\frac{1}{4000}$ to $\frac{1}{2500}$th inch long) or cilia (*Ciliated Epithelium*). These cilia are, during life, in a state of incessant movement of a peculiar and definite nature. Their motion consists in a quick bending towards the mouth, followed by a slower return to the vertical. Although unknown to be co-ordinated by the nervous system, all the cilia act in unison, thereby gradually passing up the air tubes to the mouth any substances—*e.g.*, mucus—accumulated on the surface. Ciliated epithelium is also found in the central canal of the spinal cord and the ventricles of the brain, and in various tubes and ducts. In the embryo they are found also in the œsophagus and stomach. The motion of the cilia is affected by temperature, water, alkalis, chloroform, carbonic acid.

Functions of the Skin.—Apart from its being the end-organ for the sense of touch (*vide* Lecture XX.), and *Protective*, the great function of the Skin is **Excretory.** By it the body loses—

1. **Water.** The amount of water given off from the body by the skin is very considerable (2 lbs. in 24 hours), being nearly double that passing out from the lungs. The quantity has been determined by enclosing the body, or a limb, in an air-tight chamber. In the former case respiration changes are carried out independently of the chamber.

The greater portion of the water passes off as invisible aqueous vapour. This is known as *Insensible Perspiration* in contradistinction to that which appears as drops upon the skin when the loss of water is copious, or *Sensible Perspiration.* The perspiration is secreted by the sweat glands, and probably little or none passes through the epidermis directly. Perspiration contains about 1 per cent. of solids, amongst which are common salt, acids of the fatty series, neutral fat, and cholesterin. These latter are probably wholly, or in part, derived from the secretion of the sebaceous glands. To this small extent the skin is therefore an organ for the excretion of these substances. The amount of water given off is affected by the nature and quantity of *Food*, amount of *Liquid* drunk, by *Exercise*, and by *Poisons* (increased by strychnin, nicotin, calabar bean, pilocarpin, and camphor ; decreased by atropin and morphia).

2. **Carbonic Acid.** This gas is given off by the skin to the extent of about $\frac{1}{200}$th that evolved by the lungs. Oxygen is absorbed in slightly less volume. There is thus, to a very slight degree, a breathing function carried on by the skin, or

Cutaneous Respiration. Compared with the Pulmonary Respiration it is insignificant. It is more marked in some of the lower animals ; *e.g.*, the frog. Respiration by the skin is estimated by a method similar to that used for determining the loss of water. The amount of carbonic acid evolved by the skin is increased by strong exercise, and by rise of temperature of the surrounding air.

3. **Heat.** Heat is lost from the surface of the body by conduction, evaporation, and radiation. This loss necessarily follows from the physical conditions present, viz., a thin membrane (the epidermis) having on one side a hot liquid (the blood) and on the other side a cooler fluid (the air). Heat in consequence passes through the membrane from the hot blood to the cooler air. The skin in thus permitting a loss of heat from the blood, becomes a

Regulator of the Temperature of the body. When, for example, in consequence of violent exercise, much extra heat is produced in the body, it enters the blood, which, on passing through the skin, parts with the surplus to the air, and thus prevents an accumulation of heat and consequent rise of temperature. This regulation is further assisted by a coincident dilation of the arteries of the skin (flushing of the skin) causing a much larger quantity of the blood than usual to be brought into close proximity to the colder atmosphere and thereby a correspondingly greater loss of heat.

Clothing, by diminishing the loss of heat, warms the body. The worse conductor of heat the material composing it the warmer the clothing is. The looseness and denseness of its texture must, however, be taken into account.

Washing the Skin is of importance for the removal of the outer scales of the epidermis continually being shed ; also to remove the solid constituents of the sweat and sebaceous secretion. These, if not removed, soon decompose, become offensive, and injurious.

Influence of the Nervous System on the Secretion of Sweat.—Although usually associated with increased blood supply, yet that the secretion of sweat may be dependent on direct nervous action is seen from the fact that profuse perspiration may occur when the skin is pale through want of blood. From experiments on animals the nerves to the sweat glands affecting their secretion appear to arise from definite *Sweat Centres*, one for the lower limbs being situated in the lower part of the dorsal spinal cord, another for the upper limbs in the cervical spinal cord. A general centre for the whole body is said to be present in the medulla oblongata.

LECTURE IV.

THE CONNECTIVE TISSUES—CARTILAGE AND BONE.

II. Connective Tissue.—This is the most widely diffused of all the tissues, being found in almost all parts of the body. Microscopic examination shows it to be composed largely of *fibres* of which there are two kinds—*white* and *elastic*. In addition, there are large much-branched cells, or *connective tissue corpuscles*. Finally, there is a homogeneous cementing material, or *ground substance*. According to the proportion and arrangement of these constituents, connective tissue has different names. The most common variety is—

Areolar Tissue situated beneath the skin, the mucous and serous membranes. It is also found in nearly all the tissues and organs—in fact is continuous throughout all parts of the body. It has the appearance of consisting of little interlacing bundles forming a network. The meshes or spaces—the *areolæ*—thus resulting communicate. The bundles are made up of numbers of excessively fine-waved *White Fibrils*, $\frac{1}{25000}$ to $\frac{1}{50000}$th inch thick. The bundles join and interlace in all directions, but the individual fibrils neither branch nor join. The *Elastic Fibres* are much larger than the white, measuring on an average about $\frac{1}{10000}$th inch across. They branch and join with one another, forming a network. Their elasticity is shown by their free ends curling up. They resist boiling water, and for a time even the action of potash. *Connective Tissue Corpuscles* are also present. They are irregular cells with branches by which neighbouring cells seem to be connected. Fat, in the form of drops of oil, may be deposited within the cells. When this occurs to any extent what is usually called fat is produced, and the tissue is then distinguished as adipose.

Adipose Tissue, or Fat.—The cells measuring $\frac{1}{300}$th to $\frac{1}{600}$th inch across are more numerous in this form of connective tissue, and are much distended with the contained oil. The nucleus is pressed up against the side of the cell, and usually has a little granular protoplasm around it. The cells are aggregated in lumps, or *lobules*, which are well supplied with bloodvessels. The cells are now called *fat-cells*.

Uses of Fat.—Fat is useful in several ways—

1. It acts as *Padding* around the different parts of the body. Deposited around and between the organs, it supports them, permits easy movement, and protects them from pressure. Beneath the skin it forms a considerable layer. In this situation it constitutes the *Panniculosus adiposus*, and gives the exterior of the body its smooth rounded contour.

2. Being a bad conductor of heat, the layer of fat beneath the skin *retains heat*, and serves to maintain the temperature of the body. Accordingly, warm-blooded animals living in water have this layer of fat especially thick.

3. It is a *Store of Nutriment*. Consisting chiefly of carbon and hydrogen, its oxidation within the body to form carbonic acid and water contributes to the maintenance of its heat. It is supposed that excess of carbon and hydrogen, when introduced into the body, may be stored up as fat for use at some subsequent period when the expenditure is greater than the supply. From this would be expected what actually happens, viz., that muscular exertion, by increasing oxidation, prevents the accumulation of fat, and may even cause a diminution of the amount stored up. Also when the supply of oxidative material is diminished by want of food, or failure of digestion, recourse is had to the fat already accumulated, for, in wasting through starvation or disease, the fat of the body is the part first used up.

Fibrous Tissue.—The *Ligaments*, *Tendons*, and fibrous expansions found on the surfaces of flat muscles known as *Aponeuroses* or *Fasciæ*, are composed of this form of connective tissue. It is made up of the pure white fibrils collected in bundles which join, intersect, and decussate with one another. In *tendons*, in addition to the fibrils, there are oblong-shaped *cells* arranged in rows.

Elastic Tissue.—This variety of connective tissue is found in certain ligaments of the vertebral column called *ligamenta subflava*, in the *ligaments of the larynx*, and composing the *vocal chords*. It is composed solely of elastic fibres of a yellowish tinge: hence the light yellow colour of the tissue. The largest fibres measure $\frac{1}{4000}$th inch across, but others are much smaller. The fibres branch and join to form a network which may be so close as to become quite a membrane; *e.g.*, the *fenestrated membrane* in the coats of the arteries.

Retiform and Lymphoid Tissue. Sometimes fibres and ground substance are absent. The cells are then much branched, and, joining one another by their branches, form a fine network. This is termed *Retiform or Adenoid Tissue.* The meshes of this cellular network may be filled with lymph corpuscles, and the tissue is then known as *Lymphoid.* It is found largely in the mucous membrane of the alimentary canal, and in lymphatic glands.

Jelly-like, or Mucous Tissue. In this form only the ground substance remains. All the other elements, excepting perhaps a few cells, have disappeared, as in the *vitreous humour* of the eye.

III. Bone or Osseous Tissue is distinguished from other tissues by its hardness, due to the large amount of mineral matter in it.

Composition of Bone.—Two-thirds of bone consists of mineral matter, as the following analysis by Berzelius shows :

Animal matter, - - - - - - -		33·3
Mineral matter—		
Phosphate of Lime, - - -	51·04	
Carbonate of Lime, - - -	11·30	
Fluoride of Lime, - - -	2·00	
Magnesic Phosphate, - - -	1·16	
Soda and Sodic Chloride, - -	1·20	
	——	66·7

By the action of dilute hydrochloric acid all the mineral matter can be dissolved out, when the animal matter remaining still retains the original form of the bone. By the action of heat all the animal matter can be burnt away, leaving the mineral alone. The animal matter when boiled yields *gelatin.*

Bone is tough and elastic. Its specific gravity is 1·9. The bones are covered externally by a fibrous membrane called the *Periosteum*, and they contain a fatty substance, or *Marrow.*

Different Kinds of Bones.—There are four—

1. *Long Bones*, as the Humerus and Femur. A long bone consists of a central *shaft* at each end of which is an enlargement.

2. *Flat Bones*, as the Parietal and Frontal bones of the skull.

3. *Short Bones*, as the Metacarpal and Metatarsal bones.

4. *Irregular Bones*, as the Vertebræ, and the Ethmoid and Sphenoid bones of the skull.

Minute Structure of Bone.—The hard substance of bone is of two kinds :

(1) *Dense* or *Compact*, and (2) *Spongy* or *Cancellated*. These are differently distributed in the different sorts of bones.

A Long Bone, *e.g.*, the Humerus, when cut down the middle lengthwise is seen to contain an elongated cavity extending throughout the length of the shaft—the *medullary canal*—in which is the *marrow*. The bone surrounding this canal is of the dense or compact variety, no spaces being visible to the naked eye. Very little magnification is sufficient, however, to show that it is traversed longitudinally by very fine canals—the *Haversian Canals*—which communicate with one another by side branches, with the exterior, and with the medullary canal. The enlarged extremities of the bone consist chiefly of spongy or cancellated bone, *i.e.*, with an open texture, in which are spaces discernible to the naked eye. The mass of spongy bone is invested by a thin layer of compact substance.

A transverse section of the shaft shows the medullary canal as a central orifice circular in shape. A hand-glass is sufficient to show in the bone surrounding it a number of small holes, which are the Haversian canals cut across. A thin transverse section of this compact bone more highly magnified shows each Haversian canal to be surrounded by a concentric series of alternate dark and light rings, due to the bone being deposited around each Haversian canal in layers or *lamellæ*. At intervals on the dark rings are irregular markings. These are little flattened fusiform-shaped cavities called *lacunæ*. From the lacunæ pass excessively fine channels—*canaliculi*—which communicate with one another, and with the Haversian canals. There is thus a network of fine channels ramifying throughout the bone substance. In the living state each lacuna contains a cell—a *bone-cell*—and it gives off fine branches into the canaliculi. A Haversian canal with the lamellæ surrounding it constitutes a *Haversian System*. Lamellæ are also found disposed between the Haversian system, and also parallel to the surface of the bone.

Structure of the Lamellæ. A lamella is composed of a great number of very fine fibres which cross one another—*decussating fibres*—so as to give the appearance of a fine network. In the lamellæ minute round holes are seen which are the points of passage of the canaliculi. There are often seen other larger holes where have been situated elongated pointed fibres—the *perforating fibres of Sharpey*—which possibly are of use in binding together the superposed lamellæ.

A Flat Bone.—In a flat bone of the skull—*e.g.*, the Parietal bone—there are thin external and internal layers of compact substance—the *tabulæ*—and between these a spongy substance, here known as the *diploë*. Within the spaces of the diploë is marrow. The spongy bone has essentially the same structure as that just described. The thin plates of bone bounding the spaces are composed of lamellæ with lacunae.

Short Bones consist internally of spongy bone enclosed by a thin layer of the compact kind.

Comparison of Bone and Connective Tissue.—Both bone and cartilage have been classified with areolar tissue, &c., under the head of connective tissue. The grounds for this are that the bone-cells are regarded as similar and analogous to the connective tissue corpuscles, that the decussating fibres of the lamellæ resemble the white fibrils of areolar tissue, and that, on boiling, the animal basis of bone yields, like areolar tissue, gelatin. The fact that bone differs in being permeated with mineral substance, and, further, that the uses of the tissues are so widely different, suffice to make their separate treatment highly desirable.

The Periosteum.—The surfaces of bones except those parts entering into the formation of joints, where they are covered with cartilage, are closely invested with a fibrous membrane called the Periosteum. It is composed of white and elastic fibres, and serves as a support for bloodvessels and nerves going to the bone. It also assists in giving firm attachment to the tendons and ligaments connected to the bone. The inner surface immediately adjacent to the bone contains a layer of cells which are supposed to be intimately connected with the development and growth of bone. The *importance of the Periosteum* is seen from the facts: (1) that when removed the bone decays; (2) a portion removed and placed in skin or muscle may develop bone in those tissues.

The Marrow is composed chiefly of fat in the long bones, where it extends into the larger Haversian canals. In spongy bone it is of a reddish colour and contains few fat-cells. Other cells are present in marrow, some of which are believed to be of considerable importance in the development of the blood corpuscles—(1) The *proper marrow cells* somewhat similar to white blood corpuscles and endowed with amœboid movement; (2) smaller reddish nucleated cells, supposed to be transitional forms between (1) and red blood corpuscles; (3) cells containing red corpuscles; (4) cells containing reddish granules; (5) multi-nucleated cells, or *myeloplaques*, probably connected with the absorption of bone.

IV. Cartilage, or Gristle, is a soft elastic substance covering the surfaces of bones where they enter into the formation of joints (*Articular Cartilage*); or connecting bones together, as the ribs and sternum (*Costal Cartilage*), or the hipbones to the sacrum, or the vertebræ to one another.

Hyaline Cartilage is applied to articular and costal cartilage. In thin layers it is translucent. The microscope applied to such thin layers reveals a homogeneous groundwork or matrix, scattered throughout which are cells collected in 2's or 4's or groups of larger numbers.

Fibro-cartilage. When the matrix is permeated with fibres the cartilage is called Fibro-cartilage, which is of two kinds:

1. *White Fibro-cartilage*, when the fibres are white. The Intervertebral, Interarticular, Circumferential, and Sesamoid Cartilages are formed of this variety.

2. *Elastic Fibro-cartilage*, when the fibres are of the elastic or yellow kind. It forms the Epiglottis, the Cartilages of the Ear, and of the Eustachian tube.

Cartilage differs from bone in yielding *Chondrin*, instead of Gelatin, on boiling.

Cartilages, with the exception of the Articular, are covered with a fibrous membrane called the *Perichondrium*.

Ossification and Growth of Bone.—The *intimate connection between bone and cartilage* is seen when the development of the former is studied. In the embryo the long bones are preceded by similarly shaped masses of cartilage. These cartilaginous models are gradually replaced by bone through a process of *ossification* which begins in an individual bone at several different points, known as "centres of ossification".

The bone thus formed, however, is merely temporary, for *growth in thickness* takes place by layers being deposited on the outside of the shaft, and whilst this thickening proceeds a corresponding absorption takes place within, probably effected by large multinucleated cells, or *osteoclasts*. Consequently in the fully developed bone the whole shaft has been formed by the periosteum, or in membrane, and the cartilage must therefore be regarded as merely a temporary model on which the lines of the bone can be laid down.

Growth in length takes places by new layers being deposited at the ends of the shaft. For this purpose the shaft and extremities, when they are ossified, remain separated by a layer of cartilage, in which the new bone is formed. When the full size of the bone is attained these connecting pieces of cartilage become transformed into bone and the ossification is complete.

That growth of bone does actually take place in this way is shown by numerous experiments—*e.g.*, (*a*) *boring two holes* in the shaft of a growing bone at a certain distance apart, in the fully developed bone they are not more separated; (*b*) putting a *silver ring* round a young bone: it becomes enclosed by the new bone and may be found in the medullary canal, proving a simultaneous absorption; (*c*) feeding young animals on *madder*, which colours the bone formed pink; the exact mode in which the new bone is deposited is thus beautifully shown.

Ossification in Membrane.—The flat bones are not preceded by cartilage, but by membrane. The deposit of bone (*e.g.*, in the parietal bone) begins in the middle of the membrane as a centre of ossification, and gradually spreads in all directions until the whole bone is formed.

The active agent in the deposit of the bone is probably certain cells termed *Osteoblasts*. Some of these, becoming involved in the process of ossification, remain as bone-cells inclosed in lacunæ. The bone-cells and lacunæ in the long bones probably have a similar origin. There is much uncertainty regarding the destiny of the cartilage-cells. They probably either disappear altogether as the result of absorption, or by division form osteoblasts.

Alteration in shape of fully developed bones results from deposition and absorption in a manner precisely similar to that by which the bone is formed in the first instance. *Regeneration of bone* is brought about chiefly, if not wholly, through the instrumentality of the periosteum.

LECTURE V.

THE SKELETON.

Vertebrate Type.—All the bones of the body, with the cartilages and ligaments connecting them, form together an internal framework, or skeleton. The form of the skeleton determines the shape of the body. All vertebrate animals are characterised by the presence of such a skeleton, built up on the same fundamental plan, viz., of a central or axial portion and an appendicular portion. It is the varied modification of this fundamental plan which is the underlying cause of the different shapes of the bodies of vertebrate animals. To this fundamental plan, in which the body of man agrees with that of all the five classes of vertebrate animals — Mammals, Birds, Reptiles, Amphibia, and Fishes—the term *Vertebrate type* is often applied.

Classification of the Bones of the Skeleton. — The expression "Vertebrate type" is derived from the fact that all the animals forming the sub-kingdom Vertebrata have a long, central, bony axis, or "backbone," at one extremity of which is the skull, at the other the coccyx, or tail. This central axis is the *Vertebral column*, and is composed of a number of small bones, or *vertebræ*, of similar construction, placed one above, or in front of the other. All the other bones may be regarded as appendages to this central axis. Of these bones those directly attached to the vertebral column determine the shape of the trunk, whilst those indirectly attached determine the shape of the limbs. The former, together with the vertebral column, constitute the *axial* portion, and the latter the *appendicular* portion of the vertebrate skeleton previously alluded to.

Homology and Analogy.—Those bones which in different animals have a similar position and relation in the skeleton are termed *homologous*. To those which, whether homologous or not, subserve a similar use or function is applied the term *analogous*.

Exoskeleton and Endoskeleton.—The skeleton of Invertebrate animals differs from that of Vertebrata in being external, in the form of a calcareous or chitinous covering. This hard investment is termed an *Exoskeleton*, in contradistinction to the internal bony framework, or *Endoskeleton*, of Vertebrata. In some Vertebrata there is an additional exoskeleton—*e.g.*, scales of Fishes, and scales and plates of Reptiles.

Number of Bones.—In the adult there are 200 distinct bones, omitting the *auditory ossicles* (6) (*vide* Lecture XXIII.), and several masses of bone, termed *sesamoid*, situated in the tendons.

	Single Bones.	Pairs.	Total.
Vertebral column, - - -	26	0	26
Skull, - - - - -	6	8	22
Ribs and Sternum, - - -	1	12	25
Shoulder-blade, Collar-bone, Hipbone, -	0	3	6
Hyoid-bone, - - - -	1	0	1
Upper Limb, - - - -	0	30	60
Lower Limb, - - - -	0	30	60
			200

Weight of Skeleton.—The skeleton constitutes rather less than one-fifth of the body by weight.

Uses of the Skeleton.—1. It supports the softer parts of the body. 2. Protects internal delicate organs. 3. Gives attachment to muscles, forming an essential part of the mechanism of movement.

The Vertebral Column, averaging in length 28 inches, supports at its upper extremity the skull, and in the region of the back the ribs. It rests below upon the hipbones, which are supported by the legs.

Its Structure. It is composed of a number of similarly-shaped bones or vertebræ, piled up one above the other so as to form a column.

A Vertebra is a very irregularly-shaped bone composed of a solid mass of bone in front, the *Body* or *Centrum*, and of an *Arch* of bone behind. Coming off from each side of the arch is a projection of bone, or *Transverse Process.* From the middle of the back of the arch projects backwards, and more or less downwards, another, often pointed, projection, or *Spinous Process.* The arch is thus divided into two parts on each side—(1) a front portion between the body and transverse process called the *Pedicel*, and (2) a posterior much broader portion between the transverse and spinous processes, called the *Lamina.* On the upper and lower sides of the arch are two smooth, more or less inclined surfaces, by means of which contiguous vertebræ are jointed together. These projections are the joint, or *Articular Processes*, of the vertebra. The surfaces of the upper pair face backwards; those of the lower pair forwards. The upper surfaces fit on to the lower of the vertebra next above, and they are firmly connected so as to form a joint.

Between the pedicels of each two contiguous vertebræ is a space or orifice, termed an *intervertebral foramen*, through which passes a spinal nerve.

Peculiar Vertebræ.—Some of the vertebræ show deviations from this type. The first vertebra, or **Atlas,** on which the skull rests, has no body, and only a very small spinous process. On the upper surface of its arch are two elongated, slightly concave, joint surfaces, on which rest two corresponding convex joint surfaces, one on either side of the foramen magnum of the skull. The second vertebra, or **Axis,** not only has a body of its own, but a long projection—*odontoid process*—from the upper surface of it, which takes the place of the absent body of the atlas, being kept in position by a strong cord-like ligament (*transverse ligament*). The transverse processes of these two vertebræ, like all the other cervical vertebræ, are pierced by a hole through which passes the vertebral artery. The four last vertebræ, consisting of little more than small solid masses of bone, are joined together in adult life to form one bone, called the **Coccyx.** The five vertebræ next above the coccyx are also joined to form one in the adult. This bone, the **Sacrum,** has a peculiar shape. Shaped like a V, with the point downwards, it is concave forwards and convex backwards. The transverse processes, which are enormously developed, are joined to form a large lateral mass of bone on either side, to which are connected the *hipbones*.

The bodies of contiguous vertebræ are firmly joined by flattened discs of fibro-cartilage (*intervertebral discs*). The bodies and arches are also connected by ligaments. They are also jointed together by means of the articular processes.

Regions of the Vertebral Column.—The vertebræ are named according to their position: *Cervical*, or the 7 uppermost, *Dorsal* (12), *Lumbar* (5), *Sacral* (5), *Coccygeal* (4).

Curves of the Vertebral Column. There are four curves, being from in front as follows: (1) *Cervical*, convex; (2) *Dorsal*, concave; (3) *Lumbar*, convex; (4) *Sacral*, concave. The cervical and lumbar curves are due to the intervertebral cartilages being thicker in front than behind, and in the case of the latter also to the body of the 5th lumbar vertebra being deeper in front. The dorsal and sacral curves arise from the bodies of the vertebræ in those regions being deeper behind than in front. These curvatures increase the mobility of the column and make it less liable to injury. Sometimes a slight *lateral curvature*, convex towards the right side, is observed in the dorsal region.

I. **Bones directly attached to the Vertebral Column.**—These are:

1. The *Occipital Bone* of the skull resting upon the atlas. It is pierced by a large hole, the *foramen magnum*, forming the communication between the vertebral canal and the interior of the skull.

2. The *Ribs*, twelve on either side, are flattened, elongated, curved, slightly twisted bones, possessing a considerable amount of elasticity. The upper seven are attached directly by cartilage—*costal cartilages*—to the sternum, hence termed *Sternal Ribs*. Of the remaining five *Asternal Ribs*, three are attached by cartilage to the costal cartilage next above, and thus indirectly to the sternum. The last two, not being so attached, are called *Free or Floating Ribs*. A rib ends in the *Head* jointed to the bodies of two contiguous vertebræ, except the first, which is jointed exclusively to the first dorsal vertebra: a narrower portion, the *neck*, lies between the head and the *Tubercle* by which the rib is articulated to the transverse process of the lower of the two vertebræ connected with the head. The *Costal Cartilages* are directly joined to the ribs. Those of the sternal ribs are (except the first) connected to the sternum by joints.

3. The *Hipbones*, or *Ossa innominata*, are firmly joined to the sacrum behind, and connected together in front by cartilage (*Symphysis pubis*). The three bones together form the *Pelvis*. On the outer lower aspect of the hipbone is a deep cup-shaped depression, the *acetabulum*. Into this fits the head of the femur forming the hip-joint. Until puberty the hipbone consists of three separate bones joined by cartilage. The connecting cartilage is visible as a Y-shaped mass in the acetabulum until the seventeenth or eighteenth year. The upper of these three constituent bones is called the *Ilium*, the lower posterior one the *Ischium*, and the front one the *Pubis*. In the lower part of the bone is a large oval hole, the *Obturator foramen*, closed by a fibrous membrane. The **Pelvis** is wider transversely, obliquely, and from front to back in the female than in the male. The pelvis is inclined to the horizontal 60-65°. The pressure of the body on the sacrum is thus transmitted to the thigh-bones more directly than if it were horizontal.

II. **Bones indirectly attached to the Vertebral Column.**

i. **Bones of the Skull.**—Of the twenty-two skull bones eight are said to form the Cranium and fourteen the Face.

a. The *Cranium.* Most posteriorly is the *Occipital;* joined to it in front are the two *Parietal*, connected together along the middle line of the cranium, and in front to the *Frontal*, and below to the two *Temporal.* Each temporal bone is composed of three parts, viz., (*a*) *Squamous* in front and above, joined in front to the sphenoid bone, and by its zygomatic process to the malar bone, above to the parietal bone; (*b*) *Mastoid*, behind joined to the parietal and occipital; (*c*) *Petrous*, a pyramidal-shaped mass in the middle and projecting internally. It is of importance, for it contains the internal ear. Extending downwards and forwards from this part is a long, tapering projection, the *Styloid* process. Two *Sphenoid* are most complex bones, each consisting of a central *body* and two pairs of lateral expansions, the *great* and *small wings*. The body is directly continuous behind with the body of the occipital bone. In front it is connected with the ethmoid and vomer. The great wings are joined to the frontal, parietal, and temporal. The *Ethmoid*, situated in front of the sphenoid and below the frontal, enters into the formation of the cranium, orbits, and nose. It is composed of a *central vertical plate* and *two lateral masses*, joined above by a horizontal sieve-like mass, the *cribriform lamella*, on which rest the olfactory lobes.

b. The *Face.* The fourteen bones forming the face are two single, viz., the *Inferior Maxillary* and the *Vomer*, a small thin-plate bone placed vertically between the nostrils, and six pairs, viz., *Superior Maxillary*, *Malar*, *Lachrymal*, *Nasal*, *and Inferior Turbinate.* The first three enter into the formation of the *Orbit,* together with the frontal and sphenoid. The anterior orifice of the nostrils is formed by the superior maxillary, nasal, and vertical plate of ethmoid. The inferior maxillary is jointed to the squamous portion of the temporal, its *condyle* being articulated to the *glenoid fossa.*

Shape of the Skull. At birth the proportion which the face bears to the cranium is only about half that of the adult. Slight differences are usually observable between the male and female skull: the muscular prominences and the frontal sinuses are not so much developed in the latter, and the face is less in proportion to the cranium. The classification of the skulls of different races has been attempted by a comparison of the amount of projection of the jaws (*prognathous* and *orthognathous*), and of the length of the skull (*brachycephalic* and *doliocephalic*).

The *Hyoid Bone* is a U-shaped bone situated at the back of the tongue. It is composed of a *body* and two pairs of horns or *cornua*, great and small. It is kept in position by the small horns being attached by ligaments to the styloid processes of the temporal bones. The body flattened from before back is concave posteriorly and situated in front of the epiglottis. A great number of muscles are attached to the hyoid bone, connecting it with the temporal and lower jawbones, to the scapula and sternum, to the tongue and larynx.

ii. **Bones of the Lower Limb**—

a. The *Thigh* is formed by the *Femur* jointed at its upper extremity to the hipbone, and by its lower to the tibia.

b. The *Leg* is formed by the *Tibia* and *Fibula*, the former (internal) is much thicker and stronger than the latter. The fibula does not enter into the knee-joint, being jointed at its upper extremity to the tibia. The *Patella*, or kneepan, is situated in front of the knee-joint, between the femur and tibia : it may be regarded as a sesamoid bone developed in the tendon of the extensor quadriceps cruris muscle. The tibia and fibula are both articulated below to the astragalus.

c. The *Tarsus*, or ankle, is composed of seven bones, viz., the *Astragalus*, behind and above to which are articulated the tibia and fibula ; it rests upon the heelbone, or *Calcaneum*, between which and the metatarsus is the *Cuboid* bone. The astragalus is jointed in front to the *Scaphoid*, and it in turn to the *three Cuneiform* bones—outer, middle, and inner.

d. The *Metatarsus* is composed of five similar shafted bones, jointed behind to the tarsus, in front to

e. The *Phalanges*. These are fourteen in number, arranged in three rows, there being three phalanges for each toe except the great, for which there are only two.

iii. **Bones of the Upper Limb** make up the shoulder girdle, the arm, the forearm, and hand.

a. The *Shoulder Girdle* is composed of sternum, clavicle, and scapula.

Sternum, or *Breastbone*, forming the front of the chest, is dagger-shaped, the lower extremity ending in a pointed piece of cartilage —the *xiphoid cartilage*. The upper end is enlarged to form the *manubrium*, on each upper angle of which is a joint surface for articulation with the inner end of the clavicle. *Clavicle*, or *Collar-*

bone, is curved in shape somewhat like an italic *f*. Situated above the ribs, it passes outwards at the base of the neck, and is jointed at its outer extremity to the acromion process of the scapula. *Scapula*, or *Shoulder-blade*, is a flattened V-shaped bone lying at the back of the chest. On its posterior surface is a prominent ridge, or *Spine*, terminating in front in the acromion, to which the clavicle is jointed. At its upper outer angle is a shallow depression, or *glenoid fossa*, into which fits the head of the humerus.

b. The *Arm* is formed by the *Humerus* jointed above to the scapula, below to the radius (externally) and ulna (internally).

c. The *Forearm* is formed by the Radius and Ulna. The *Ulna*—large above, small below—has a deep *sigmoid* cavity at its upper extremity, by which it articulates with the humerus, thus forming with that bone the elbow-joint. The *Radius* —small above, large below—is articulated by its *head* to a separate surface—*capitellum*—of the humerus, and also to the ulna, by its *lesser sigmoid notch*. The radius alone enters into the wrist-joint by its large lower extremity. The small end of the ulna is separated from the carpal surface by a piece of cartilage. Externally it is jointed to the radius.

d. The *Carpus*. Eight bones arranged in two rows of four each, upper and lower, form the carpus. The bones are: Upper row—*Scaphoid* (external), *Semilunar*, *Cuneiform*, *Pisiform*. Lower row—*Trapezium* (external), *Trapezoid*, *Os Magnum*, *Unciform*.

e. *Metacarpus*. Five shafted bones similar to those of the lower limb form this portion of the hand.

f. *Phalanges*, fourteen in number, arranged in three rows, resemble those of the lower limb, but are longer. There are only two phalanges forming the thumb, as in the case of the big toe.

LECTURE VI.

THE MUSCLES.

V. Muscular Tissue.—The physiological importance of this tissue is evident from the facts—

1. That the muscles form $\frac{2}{5}$ths of the body by weight.

2. By their contractions they produce the movements of the body, and of its parts.

3. A study of the chemical changes occurring in muscle as the result of its activity gives some knowledge of the nature of its nutrition, and so far throws light upon the chemico-vital changes of the body generally.

General Arrangement of the Muscles.—The muscles may be classified into two systems—

1. *Dermal*, which is much better seen in some other vertebrate animals, and is represented in man by a few muscles only, viz., the *Platysma myoides*, a thin, broad muscle, passing up from the collar-bone and shoulder-blade to the lower jawbone, just below the skin, and the muscles attached to the hairs by which they are made erect in gooseskin.

2. *Skeletal.* There is an intimate connection between the development of the skeleton and the muscles attached to it, since both subserve the same use, viz., movement. When there is an increase or decrease of one there is a reciprocal increase or decrease of the other.

The muscles are symmetrical, and, with few exceptions, are in pairs.

Number of the Muscles. The muscles number about 240, and may be thus apportioned—

(1) Head and neck, 75; (2) vertebral column and trunk, 51; (3) upper limb, 58; (4) lower limb, 59.

Coverings of Muscles. The muscles are covered and more or less enclosed by expansions of connective tissue, often called *Fasciæ.* When this covering is composed of the white fibres densely arranged so as to give it a shining appearance, it is spoken of as an *Aponeurosis*.

Attachment of the Muscles to the Bones.—There are two modes of attachment—

1. In some cases the muscular substance is directly attached to the bone.

2. In most cases the muscle is attached to the bone through a tendon.

A *typical muscle* may be said to have a tendinous extremity at either end, with a central fleshy mass called the *belly*. Rarely there is a central tendon dividing the fleshy mass into two parts or bellies, hence termed *Digastric*. The tendinous extremity which when a movement is produced by the contraction of the muscle is fixed is termed the *origin;* the extremity which under similar circumstances is movable is called the *insertion*.

Composition of Muscle.—About 75 per cent. of muscle consists of water. The following gives the amount of the chief constituents in 1000 parts:

a. *Organic Matters*, - - - -	208		245	
Proteids, - - - - -		173·5	—	197·1
Extractives, Nitrogenous, -		2·9		
Extractives, Non-nitrogenous, -		15·1		
b. *Inorganic Matters*, - - -	9	—	10	
Phosphoric Acid, - - -		3·4	—	4·8
Potash, - - - - -		3	—	3·9
Soda, Lime, Magnesia, Sodium Chloride, Iron		minute quantities.		

Structure of Muscle.—From the point of view of their microscopic structure the muscles are separable into three classes—

1. **Skeletal Muscles,** also termed *Striped*, **Striated,** and *Voluntary*. These muscles are easily seen to be composed of coarse threads, or *Fasciculi*, which are separated by inward prolongations of the investing fascia. The thin sheath of connective tissue thus surrounding a fasciculus is termed the *perimysium*. Each fasciculus is composed of a great number of elongated cylindrical cells (1 to $1\frac{1}{2}$ inches in length), with rounded extremities, and an average diameter of $\frac{1}{400}$th of an inch, known

as **muscular fibres.** Each fibre consists of a semi-fluid mass of living matter enclosed within a very fine, colourless, transparent, elastic sheath—the *sarcolemma*—and is curiously striated both longitudinally and transversely, especially the latter. Beneath the sarcolemma are *nuclei*. The transverse striæ appear alternately light and dark under the microscope. It is a much-disputed question what is the cause of this curious and characteristic appearance, which has given to all muscles exhibiting it the name of *Striated*. Possibly it is merely an optical effect. These muscles are also often called "Voluntary," from their being for the most part under the control of the will.

2. **Unstriated Muscles,** also called *Plain* and *Involuntary*. These muscles, which surround the bloodvessels, the alimentary, canal, &c., consist of much elongated fusiform cells—**contractile fibre-cells**—of various sizes. Within each cell is a much-elongated nucleus. The cells measure $\frac{1}{600}$ to $\frac{1}{120}$ inch in length, and $\frac{1}{6000}$ to $\frac{1}{2500}$ inch in breadth.

3. *Muscle of the Heart.* This is composed of oblong or square shaped cells exhibiting a faint transverse and longitudinal striation. Each cell has an oval nucleus. This kind of muscle, as well as the preceding, not being under the influence of the will, is sometimes called "Involuntary".

Function of Muscle.—Muscular tissue possesses in a very high degree that property observed in the Amœba—*Contractility*. Muscle is eminently contractile. When stimulated a muscle contracts, becoming shorter and broader; on removal of the stimulus, it relaxes to its original dimensions. The contraction in the living body takes place as the result of a nervous impulse arriving at the muscle after passing along a nerve connected with it. There is good evidence to show, however, that

Muscle is independently contractile—

1. The end of the *sartorius muscle* containing no nerve terminations contracts when stimulated.

2. After *urari poisoning*, which destroys the end structure by which the nerve is connected to the muscle, direct stimulation of the muscles causes them to contract.

3. Certain chemical substances do not cause contraction when applied to the nerves, but do so when directly applied to the muscles—*e.g.*, ammonia, carbolic acid.

4. Contraction may occur in the absence of nervous tissue—

a. The rhythmical contraction of the fœtal heart.

b. In vegetal protoplasm, by which movements of plants are produced (*e.g.*, mimosa pudica).

Graphical representation of a muscular contraction. The contraction and relaxation of muscle can be graphically represented by a curve, when it is seen that a certain period elapses after the application of the stimulus, before the contraction begins (*latent period*). The curve then rises to a maximum (*contraction*), and immediately after falls to the original level (*relaxation*). The whole contraction occupies $\frac{1}{10}$th of a second, thus divided—Latent period $\frac{1}{100}$th, Rise (contraction) $\frac{4}{100}$ths, Fall (relaxation) $\frac{5}{100}$ths. The instrument by which this is shown is termed a *Myograph*. It essentially consists of a drum or a plate covered with a coating of lampblack movable at a definite rate, against which the point of a fine lever can be brought. This lever has attached to it between the fulcrum and free point the lower extremity of a muscle. When the muscle contracts the lever is raised, when it relaxes the lever falls. The time is determined by making a tuning-fork in a similar manner record its vibrations.

Tetanus. When a series of electric shocks, following one another very quickly, is passed into a muscle, it remains contracted so long as the stimuli continue to enter it. The myographic curve under these circumstances shows the first two phases, but not the last, the lever writing a straight line on a level with the summit of the curve. A muscle so contracted is said to be in a state of *Tetanus*. Tetanus occurs as the result of disease (lockjaw), and of poison (strychnin). The number of successive stimuli required varies from 15 (frog) to 330 (insects) per second.

Different kinds of Stimuli. In addition to the ordinary normal nervous stimulus, muscles may be excited to contract by (1) chemical, (2) thermal, (3) mechanical, (4) electrical stimuli.

Changes occurring during contraction. Important changes take place in a muscle when it contracts—

a. Structural:

(i.) It shortens, thickens, and hardens.

(ii.) The light and dark striations change places.

b. Physical:

(iii.) There is an elevation of temperature.

(iv.) The electrical conditions are changed, there being a negative variation of the natural muscle current.

(v.) The extensibility of the muscle is increased.

c. Chemical:

(vi.) Carbonic acid (CO_2) gas is evolved.

(vii.) The muscle has an acid reaction due to the production of sarkolactic acid ($C_3H_6O_3$). The appearance of these bodies points to a chemical decomposition of the muscular substance, or at least of a part of it—that part free from nitrogen.

The components of the muscle soluble in water decrease, whilst those soluble in alcohol increase, in quantity.

Rigor Mortis.—Soon after death the muscles become stiff and rigid, a change termed Rigor Mortis. Many of the *changes occurring during rigor mortis* are strikingly similar to those connected with contraction—*e.g.*, (1) the muscle does actually contract; (2) there is a rise of temperature; (3) carbonic acid is evolved; and (4) sarkolactic acid formed.

The following differences are, however, apparent:

(1) The extensibility is not increased; (2) the electric currents altogether disappear; (3) The *muscle becomes rigid and opaque.* This rigidity is the *cause of rigor mortis*, and is due to the proteid constituent of the muscle, or *Myosin*, coagulating.

Fatigue and Exhaustion of Muscle.—When from exertion the muscles are contracted beyond a certain limit, the products resulting from the contraction are too great to be immediately removed by the bloodstream, and by their accumulation make further contraction more difficult. If contraction be carried on further still (beyond what may be called the maximum) the accumulation is so great that the muscles cannot be thrown into contraction any longer, and are said to be exhausted. Recovery occurs after a period of rest, during which the bloodstream both removes the accumulated products, and brings a supply of nutriment to make good what has been lost. During ordinary muscular contraction the blood supply is increased, and in consequence the amount of nutriment brought overbalances the muscular substance that has been lost, and hence the muscle increases in size. In thus increasing by use a muscle regarded as a machine differs from any machine of human contrivance.

LECTURE VII.

MOVEMENT—NERVOUS TISSUE.

Amœboid Movement is seen in low forms of life, like Amœba (animal) and Myxomycetes (plant). The white blood corpuscles also exhibit it.

Ciliary Movement may produce locomotion of a complete organism, as in Infusoria (animal) and Protococcus (plant), or may exist in the stationary organs of the higher animals—*e.g.*, the epithelium lining the air tubes.

Muscular Movement is produced either by involuntary or voluntary muscles.

A. By *Involuntary Muscles*. These may be divided into three classes—

i. Those *surrounding tubes*, as the bloodvessels, alimentary canal, ureters, &c., which, by their contraction, diminish the calibre of the tube.

ii. Those *surrounding cavities*, as the heart. By their contraction they diminish the capacity of the cavity.

iii. Those in other parts—*e.g.*, the muscles in the skin or *arrector pili*.

B. By *Voluntary Muscles*. These, by their contraction, cause the bones to move over one another, thus producing the movements of limbs and other parts, and also movement of the whole body, or locomotion. The manner and extent of the movements of the bones are dependent upon the way in which they are connected together.

Modes of Connection of the Bones. There may be said to be three—

a. Immovable connections, as in the bones of the skull by *Sutures*.

b. Slightly movable connections, as by cartilage in the vertebral column and pelvis.

c. Truly movable connections, as in all true *joints*.

Structure of a Joint.—A joint consists of the free ends of two bones in contact, which can move over one another within an area circumscribed by the extent of the surrounding ligaments and muscles, and also by the shape of the bones. The surfaces of the bones entering into the joint are covered with gristle (*articular cartilage*). Lining the inner surface of the ligaments, and extending a short distance on the surface of the bones, is a delicate smooth membrane (*synovial membrane*), which secretes a lubricating liquid (*synovia*). The extremities of the bones entering into the joint are kept in close apposition by the connecting ligaments and muscles, by the oily covering, and by atmospheric pressure (hip-joint).

Classification of Joints—

1. Those having *one axis of rotation.*

a. True Hinge Joints, *e.g.*, the fingers and toes, in which there is movement in one plane only, there being either bending (flexion) or straightening (extension).

b. Screw-hinge Joints, as the elbow and ankle-joint, in which the flexion and extension are complicated by a screw-like movement of one bone over the other (*e.g.*, the ulna over the humerus).

c. Pivot-joints, in which one bone *rotates* around another as the atlas round the axis, and the radius round the ulna in pronation and supination.

2. Those having *two axes of rotation.*

d. Saddleshaped-joints, in which there is movement in two planes more or less at right angles to one another; *e.g.*, the thumb-metacarpal bone, and the carpus (trapezium).

3. Those having *several axes of rotation.*

e. Ball and Socket-joints, *e.g.*, shoulder and hip-joints, in which there is movement in all planes. The varied movements of these joints are Flexion and Extension, Abduction and Adduction, Rotation around the long axis of the moving bone, Circumduction. Circumduction is possible to a limited extent in the metacarpo-phalangeal joints.

4. *Rigid joints*, in which slight movement is possible in all directions; *e.g.*, the carpal and tarsal joints.

The Bones as Levers. The bones, moving in the joints under the action of the contracting muscles, act precisely as ordinary levers, and the different movements can be referred to the three systems of levers. The third kind of lever in which there is a gain in the rapidity at the expense of the force of its movement is the most common.

Relation of Muscles to Joints. The arrangement of the muscles around a joint depends upon the movements of which it is capable. Where there is movement in one plane only, the muscles are arranged on opposite sides in the plane of motion. Those causing bending are termed *flexors;* those straightening *extensors.* If movement is possible in several planes, the muscles are on all sides of the joint.

The Erect Posture, which so eminently distinguishes man from the lower animals, is maintained by the harmonious contraction of a great number of muscles. The centre of gravity of the whole body is at the *promontory* (the anterior projection at the top of the sacrum). A vertical line down from this point falls in front of the line joining the two ankle-joints. The consequent tendency of the body to fall forward is counteracted by the contraction of the muscles of the calf and other muscles of the leg. The centre of gravity of the head, trunk, and upper limbs is in front of the tenth dorsal vertebra. The vertical line down passes behind the line joining the hip-joints. The consequent tendency of the trunk to fall backwards is overcome by the attachment of ligaments and contraction of muscles (*e.g.*, psoas and rectus femoris). The centre of gravity of the head is in front of the atlas, and hence the head tends to fall forwards, as is seen in sleep and death. Antagonistic to this tendency is the contraction of muscles passing from the neck to the back of the skull. The vertebral column being movable in the neck and loins, the contraction of strong muscles in these positions is necessary in order to fix it; *e.g.*, extensor dorsi communis and quadratus lumborum.

Sitting.—In sitting, the body rests upon the tubera ischii of the hipbones. In the forward and backward movements of the body, possible in this posture, the trunk may be regarded as a lever moving on its fulcrum at the tubera ischii.

Walking.—In walking, each leg is alternately swung from back to front past the other, which then alone supports the body. In this, as in other pendulum motions, the extent of the swing depends on the length of the pendulum; hence the length of the legs determine the natural rate of walking. The rate, also, depends on the length of time the two feet are on the ground together. As the rate quickens this time diminishes, until, in very quick walking, it becomes zero; *i.e.*, at the very moment one foot reaches the ground the other rises from it.

Running.—In running there is during each step a time when both feet are off the ground.

By means of indiarubber bags (tambours), with which are connected flexible tubes, fitted to the feet, Marey has been enabled to obtain graphic representations of the movements of the legs of men and animals in walking, running, galloping, &c. Also by taking a series of consecutive instantaneous photographs (Muybridge).

VI. Nervous Tissue.—This tissue is characterised by two distinct structures—

Structure—

1. *Nerve cells.* These are usually irregular in shape, and passing off from them are processes, or poles, some of which are directly continuous with nerve fibres; others join with similar processes from neighbouring cells, and by their union a network is often produced.

2. *Nerve fibres,* which are of two kinds—medullated and non-medullated.

i. A *medullated nerve fibre* consists of a *central axis* or *axis-cylinder*—the essential part—which is always in connection with a nerve-cell. This axis, which is fibrillated, is surrounded with a fatty layer, or *medullary sheath*, and the whole is enclosed within a very fine membrane—the *primitive sheath*, or sheath of Schwann. The medullary sheath is divided at equal intervals into segments. The intervals thus regularly occurring are termed the *nodes of Ranvier.* Between each two consecutive nodes is a *nucleus* lying between the medullary and primitive sheaths. The axis cylinder and the primitive sheath are continuous throughout.

These fibres differ much in size, the diameter varying from $\frac{1}{1500}$th to $\frac{1}{12000}$th of an inch.

ii. *A non-medullated nerve fibre* differs from the preceding in not possessing the medullary sheath. The non-medullated fibres are found chiefly in the nerves of the sympathetic nervous system, but also to some extent in the cerebro-spinal nerves, and the olfactory nerve is solely composed of them.

Function.—Nervous tissue possesses in a highly specialised manner the property of **irritability.** The irritability of nerve is sometimes termed *excitability.* Nerve-cells may be said to be endowed with the power of giving out, receiving, and storing up nervous impulses; whilst nerve fibres conduct these impulses either to or from the nerve-cells with which at their central ends they are connected.

The *excitability is diminished* by cold, by lessened supply of blood, by being cut off from the centre with which it is connected.

A nervous impulse travels along a nerve at the rate of about 30 yards per second.

White and Grey Matter. Nervous tissue containing nerve fibres only is white in colour, and is therefore called white nervous matter; when nerve-cells are present the tissue has a grey colour, and it is hence known as grey nervous matter.

Chemical Composition.—30 per cent. *Water.* It is neutral to test-paper. In the medulla of nerve fibres is *Lecithin* (containing Phosphorus). The axis cylinder contains proteids.

LECTURE VIII.

THE BLOOD AND LYMPH.

VII. The Blood has been well described as the great *internal medium* by which the different parts of the body are brought continually into connection with each other, and with the external world.

From the nature of the uses the blood subserves in the animal economy, its composition must necessarily be continually altering as it circulates through the different parts of the body. Notwithstanding this continual variation, there are certain structural and chemical characteristics which are constant wherever the blood is found.

General Characteristics.—The average *specific gravity* of blood is 1055. The *colour* varies from bright scarlet (arterial) to a very dark red (venous). Venous blood is *dichroic*, for it is dark red by reflected, and green by transmitted, light. It is *alkaline* in reaction. The alkalinity diminishes after the blood is shed. The alkalinity is said to be diminished by great muscular exertion, probably due to the greater formation of acid in the muscles. It has a characteristic *odour* and salt *taste.*

Structure of Blood.—Under the microscope the blood is seen to consist of two distinct parts: (1) a transparent colourless liquid, the *plasma*, in which float enormous numbers of minute solid particles, (2) or *corpuscles*. These corpuscles are of two kinds, red and colourless or white.

The Red Corpuscles, first observed in human blood by Leeuwenhœck in 1673, are circular, biconcave discs, $\frac{1}{3200}$th inch in diameter, and one-quarter this in thickness. This shape and size is characteristic of the red blood corpuscles of Mammalia generally, with the exception of the camel tribe, in which they are elliptical in shape, and in the musk deer and elephant, in which they are $\frac{1}{12000}$th inch and $\frac{1}{2700}$th inch in diameter respectively.

In the rest of the vertebrata the corpuscles are oval in shape, with a central elevation on either side. They also possess a nucleus. They increase in size as you descend the vertebrate scale, being about $\frac{1}{2000}$th inch in birds, $\frac{1}{1000}$th in the frog, and only $\frac{1}{300}$th in Amphiuma tridactylum. *Amphioxus* has colourless blood, as also have most *Invertebrata.*

Their *number* is estimated to be 5,000,000 in a cubic millimetre. They are flexible and elastic. Soon after the blood is shed the red corpuscles show a remarkable tendency to run together, and, remaining adherent by their sides, form *rouleaux.*

A Red Corpuscle seen singly has a pale yellow colour. It consists of two parts—

1. A soft, colourless mass of protoplasm—the *stroma.*
2. A semi-fluid colouring matter uniformly distributed throughout the stroma. This colouring matter is *Hæmoglobin.* Each corpuscle contains about 43 per cent. of solids, of which about 91 per cent. is hæmoglobin. *These two parts can be separated* by the action of water, and better still by addition of ether or chloroform, the colouring matter being set free. Dilute acids, electric shocks, and alternate freezing and thawing have the same effect. Tannic acid causes the dissociation without producing an actual separation, and boracic acid causes the hæmoglobin to collect around the nucleus of the corpuscle of the lower vertebrata. The first effect of water is to cause the corpuscle to swell out and become spherical in shape, and this change is followed by an alteration of the colour of the blood from light to very dark red. The hæmoglobin when separated from the stroma becomes dissolved in the serum, and the transparent solution then obtained is termed *lake-coloured* blood.

Source of the Red Blood Corpuscles. The renewal of large quantities of blood after hæmorrhage show that large numbers of red corpuscles can be quickly manufactured in the body. The red corpuscles have been supposed to originate from the white, concerning which there are two views :

(i.) That they originate from the nucleus only of the white corpuscle.

(ii.) That the white corpuscle loses its nucleus, and, becoming coloured, forms the red.

There is, however, better evidence in favour of their being developed from peculiar cells found in the red marrow of bone.

Destiny of Red Corpuscles. They are probably broken up in the spleen or liver, or in both. The hæmoglobin thus set free is, in accordance with this view, used up in the manufacture of Bilirubin, the colouring matter of the bile.

The Colourless Corpuscles are nucleated spherical cells $\frac{1}{2500}$th of an inch in diameter. The nucleus is made evident by addition of acetic acid, or of carmine when it is stained more strongly than the surrounding protoplasm. The protoplasm is granular in appearance, and sticky. They reproduce by division. They are fewer in number than the red in the proportion of 2 or 3 to 1000. Venous blood contains greater numbers than arterial blood. They differ from the red in possessing the power of independent movement, which may consist of (*a*) mere change of shape (*amœboid*), or (*b*) of movement of the whole corpuscle (*migratory*). A temperature of 35°-40° C. is most favourable to the movement; at 50° C. they are killed. Electric shocks cause them to assume a spherical shape. The presence of oxygen is essential for the movement.

Chemical Composition of the Red Corpuscles. In 100 parts, 56·5 are water and 43·5 solids, which are almost wholly organic, less than 1 per cent. being inorganic. Of the organic, the chief constituent is hæmoglobin, forming 90·54 per cent.; proteids, 8·67; lecithin and cholesterin, ·79. Of the inorganic salts, potassium and phosphates are present in largest quantities.

Hæmoglobin has a percentage composition in the blood of the dog of *carbon*, 53·89; *hydrogen*, 7·32; *nitrogen*, 16·17; *oxygen*, 21·84; *iron*, ·42; *sulphur*, ·39.

1. It is thus seen to *contain iron* in minute quantity.

2. It is *crystalline:* the crystals, of a bright scarlet colour, belong to the rhombic system. The crystals may be obtained by freezing defibriated blood and then allowing it to gradually thaw, or by the consecutive action on defibriated blood of 20 per cent. salt solution, ether, and alcohol. Hæmoglobin readily *dissolves in water*. The solution is *dichroic*, being red in reflected light, green by transmitted light.

3. **It unites with a definite quantity of oxygen gas.** One gramme unites with 1·7 cubic centimetre of oxygen. When deprived of this oxygen, the solution or crystals become darker in colour.

4. It has a *distinct spectrum*.

A very dilute solution of hæmoglobin united with oxygen, or *oxyhæmoglobin* shows two absorption bands, one, narrow, in the yellow just to the right of the D sodium line, another, broader, in the green to the left of the E line. If the oxyhæmoglobin be deprived of its oxygen, as by the air-pump, or by addition of a reducing liquid such as ammonium sulphide, a different spectrum is seen, consisting of one broad band, the darkest part of which is situated in the space between the two bands of oxyhæmoglobin. The *reduced hæmoglobin* thus obtained very readily takes up oxygen again, being thus reconverted into oxyhæmoglobin. Mere shaking up with air is sufficient to effect this conversion.

Carbonic Oxide Hæmoglobin. Hæmoglobin unites with carbonic oxide (CO), in a manner analogous to its union with oxygen, but far more readily, and to form a more stable combination. Carbonic oxide displaces oxygen in combination with hæmoglobin, and when present in the atmosphere in large quantities thereby causes poisoning. *Carbonic oxide hæmoglobin* has a distinctive cherry-red colour, and gives a spectrum very similar to that of oxyhæmoglobin; the two bands are, however, a little closer together and slightly nearer the violet end.

Nitric Oxide Hæmoglobin. Hæmoglobin unites with nitric oxide (NO) to form a more stable combination than even carbonic oxide hæmoglobin. It gives a similar spectrum of two bands, which do not disappear on addition of reducing agents. Like oxyhæmoglobin, carbonic oxide- and nitric oxide- hæmoglobin are crystalline. In all three cases the crystals are isomorphous.

Composition of Hæmoglobin. By the action of acids, alkalis, or heat, hæmoglobin is decomposed into a proteid body of the *globulin* group, and a coloured substance termed *Hæmatin.* Hæmatin, which constitutes about 4 per cent. of hæmoglobin, contains iron, and has had the following chemical formula assigned to it, $C_{68}H_{70}N_8F_2O_{10}$. The alkaline solution of hæmatin takes up and parts with oxygen. When acted upon by strong sulphuric acid it is deprived of its iron; although still retaining its colour, it now loses its power of taking up oxygen. This points to the small quantity of *iron* present in hæmoglobin as having an important relation to its power of combining with oxygen. Hæmatin is non-crystalline, but united with hydrochloric acid it forms characteristic acicular crystals of *Hæmin.* These crystals can be readily prepared, even from dry blood, by the action of glacial acetic and sodium chloride, and their formation in this way serves as an easy and conclusive test of the presence of blood.

Arterial and Venous Blood.—The striking difference in colour between arterial blood (scarlet) and venous blood (purplish red) is chiefly due to the much larger quantity of oxygen united with the hæmoglobin of the former, or, in other words, to the larger proportion of oxyhæmoglobin present in the former, and of reduced hæmoglobin in the latter. The following differences have been observed : Venous blood contains more carbonic acid, less water and fibrin, and a greater number of blood corpuscles than arterial. It also differs from arterial blood in being dichroic, or appearing of a different colour by transmitted (green) than by reflected (dark purple) light, and of a lower temperature (1° C.).

Quantity of Blood. The quantity is, by weight, about $\frac{1}{13}$th that of the body. It may roughly be said to be distributed as follows : One quarter to (1) the skeletal muscles, (2) to the liver, (3) to the heart, lungs, and great bloodvessels, (4) to the rest of the body.

Coagulation of the Blood.—Soon after being shed (4 minutes) the blood begins to pass into a jelly-like mass, or to clot, a change (complete in about 10 minutes) known as *coagulation*. As the clot becomes firmer drops of a pale yellow liquid are exuded from it, until, after the lapse of several hours, a red jelly-like mass of the same shape as the containing vessel is surrounded by this liquid. The blood thus becomes separated into two parts : (1) a solid red clot, and (2) a pale yellow liquid, or *serum*. The clot results from part of the liquid plasma solidifying. This solidification (which is indefinitely deferred at 0° C., and occurs most readily at 45° C.) takes the form of excessively fine threads, which, interlacing, form a most delicate network, in the meshes of which are entangled the blood corpuscles. These solid threads are composed of a substance called *fibrin*, and the network formed by them, gradually contracting, squeezes out the remaining liquid portion of the blood, which appears as the pale yellow drops previously mentioned, or the *serum* of the blood. A blood-clot, therefore, consists of fibrin and corpuscles. The changes may be thus represented :

Liquid blood { Plasma { Serum............... } Coagulated Blood.
Liquid blood { Plasma { Fibrin... } Clot ... } Coagulated Blood.
Liquid blood { Corpuscles............ } Clot ... } Coagulated Blood.

Fibrin.—It is obvious from the above that the determining cause of coagulation is the formation of fibrin. According to the researches of A. Schmidt, fibrin results from the union of two proteid substances—*fibrinogen* and *fibrinoplastin*—which, in the living blood, remain separately dissolved in the plasma ; and that the union of these two bodies take place only under the influence of a third, called the *blood ferment*, or *fibrin ferment*. Subsequent investigations render this explanation doubtful.

The *formation of fibrin is prevented* by the addition to blood of a dilute solution of a neutral salt—*e.g.*, sodium chloride or magnesium sulphate. Coagulation is also prevented by the contact of living bloodvessels, as is seen in (1) the case of the heart of a cold-blooded animal, or (2) of a portion of a vein removed from the body.

Although playing an important part, the *quantity of fibrin* in the blood is very small, only about ·2 per cent. It is a proteid substance insoluble in water, alcohol, or ether. Dilute hydrochloric acid converts into acid-albumin or Syntonin.

The Colourless Corpuscles and Coagulation. The following facts point to the colourless corpuscles playing an important part in coagulation. (1) They are always present in spontaneously coagulable fluids; (2) threads of fibrin may be observed to start from them; (3) a portion of blood freed from them either (*a*) by subsidence or (*b*) by filtration clots with difficulty.

The presence of *oxygen* and of a certain quantity of *salts* appears to be necessary for coagulation to take place.

The *formation of fibrin is aided* by (1) presence of foreign bodies; (2) rapid movement. Blood whipped with a bundle of twigs has its fibrin quickly removed in the form of sticky threads adhering to the twigs; (3) warmth within certain limits of temperature (39° to 45° C.).

Composition of the Plasma.—As there is only ·2 per cent. of Fibrin, the plasma chiefly consists of *Serum*, which consists of 90 per cent. water and 10 per cent. solids. Of the latter proteids constitutes 8 per cent., and Fats, Extractives, and Salts 2 per cent. Of the salts, sodium chloride predominates. The chief proteids are *Fibrinoplastin* or *Paraglobulin* (3·1), and *Serum albumin* (4·5).

Gases of the Blood.—The gases Oxygen, Carbonic Acid, and Nitrogen can be removed from the blood by Pflüger's mercurial gas-pump.

Oxygen. Since the plasma dissolves oxygen only to about the same slight extent as water, almost all of that gas present must be united with Hæmoglobin. In arterial blood it is present to the extent of 17 per cent. per volume, in venous blood to a variable extent (6 per cent. in quiescent muscle). The absorption of oxygen is independent of pressure. Oxygen may be removed from the blood by the following methods: (1) A vacuum; (2) boiling; (3) displacement by other gases, as N and H; (4) chemical reagents, as ammonium sulphide.

Carbonic Acid is present in arterial blood to the extent of 30 per cent. per volume; and in venous blood to 35 per cent., and in asphyxia may rise above 50 per cent. It is chiefly contained in the plasma, probably in a state of chemical combination, for it is absorbed independently of pressure. A portion can be removed by vacuum, and is supposed to be present in the form of bicarbonate; the remainder is set free by the action of acids, and is supposed to be in the form of carbonate. The observation that blood absorbs as much carbonic acid as an equal volume of serum has been urged in favour of the view that the red corpuscles hold carbonic acid in loose combination.

Nitrogen. Blood contains 1·4 per cent. per volume of this gas, which is apparently merely dissolved in the plasma.

Lymph and Chyle.

Lymph is the liquid found in the system of vessels called the *Lymphatics*, vessels very similar to veins in structure, and, like them, provided with valves. Like blood, it consists of two parts—

1. A colourless liquid or *plasma*.
2. *Colourless corpuscles* precisely similar to those of blood.

It resembles blood in coagulating. It differs from that liquid, however, in the slowness with which coagulation takes place, also in not possessing the red corpuscles. Its corpuscles are derived partly from tissues, but chiefly from the **Lymphatic Glands**—glandular enlargements on the course of the lymphatic vessels.

The lymphatics, originating in the walls of the alimentary canal, are distinguished as *lacteals*. During digestion, the liquid within them is loaded with minute fatty particles, and is then known as **Chyle.** All the lymphatics, except those coming from the right arm and the right side of the thorax and head and neck, end in one great vessel, the *thoracic duct*, which, beginning as an enlargement—the *receptaculum chyli*—in the region of the loins, passes up on the vertebral column, and opens into the left subclavian vein at the point of its union with the internal jugular vein. The rest enter the venous system on the right side by *the right lymphatic duct*. In this way all the lymph and *chyle finds its way into the blood*.

Composition of Lymph. 98·6 per cent. water, 1·4 per cent. solids, consisting of urea, proteids, and salts (chiefly soda and sodium chloride). Carbonic acid is present to the extent of 70 vols. per cent.

Composition of Chyle. 90·5 per cent. water, 9·5 per cent. solids, consisting of albumin (7), fats (·9), and salts (·4) (chiefly sodium chloride and soda).

Movement of Lymph. The following influences probably assist the movement of the lymph: (1) The *vis a tergo* caused by the absorption of chyle into the lacteal; (2) the presence of valves which must cause all muscular contraction acting upon the lymphatics to force on the lymph; (3) the movements of respiration acting as an aspirator on the thoracic duct; (4) in some animals (*e.g.*, the frog) there are special pumping organs known as *Lymph Hearts.*

LECTURE IX.

THE CIRCULATION OF THE BLOOD.

To understand the circulation of the blood it is necessary to study—

a. The system of connected tubes through which the blood moves, or the *Vascular System.*

b. The nature and character and the conditions necessary for the production of the movement of the blood in this vascular system, or the *Circulation.*

A. The Vascular System is composed of four parts: (1) the *Heart*, (2) the *Arteries* originating from the heart and ending in (3) *Capillaries* which give rise to (4) *Veins* terminating in the heart. It is divisible into two parts: (1) The *Lesser* or *Pulmonary*, through the lungs, (2) The *Greater* or *Systemic*, through the rest of the body.

I. The **Heart** is a hollow muscular organ, bluntly conical in shape, situated in the chest.

Pericardium. It is enclosed within a loose fibrous bag called the pericardium. The pericardium is conical in shape, the base being below is attached to the diaphragm, and the apex surrounds the great vessels as they leave the heart. It consists of two parts: an outer fibrous and an inner serous. The latter, like other serous membranes, is double, having a visceral layer covering the outer surface of the heart and a parietal layer lining the fibrous part. In passing round the aorta and pulmonary artery it encloses them in a common short tubular sheath. The serous membrane secretes a liquid known as the pericardial fluid.

Position. The heart occupies an oblique position in the chest and projects a little more to the left than to the right side. Situated behind the sternum and costal cartilages, the base of the cone is directed upwards, backwards, and to the right, extending from the fifth to eighth dorsal vertebræ; the apex downwards, forwards, and to the left. The apex is felt when the heart beats between the fifth and sixth costal cartilages, $1\frac{1}{2}$ inch below the nipple and a little internal to it.

Size. Is said to be that of the closed fist. Average dimensions are 5 inches long, $3\frac{1}{2}$ broad, and $2\frac{1}{2}$ deep.

Weight. 9 to 10 ozs.

Furrows. On the surface of the heart are longitudinal and transverse furrows indicative of the internal divisions into four chambers.

Endocardium is the smooth membrane lining the internal surfaces of the heart. It is continuous with the inner coat of the bloodvessels, and is lined with a layer of epithelioid cells.

Chambers. The heart is divided by a fleshy longitudinal septum into two completely separate halves, a right and a left. Each half is again divided by a movable partition or valve into an upper and a lower cavity. There are thus four cavities or chambers within the heart, viz., two above named *Auricles*, two below named *Ventricles.*

Right Auricle.—Is situated rather more anteriorly than the left. It may be said to consist of two parts, the *Auricular Appendix*, projecting from the upper anterior angle, and the main part, or *Atrium.* The posterior wall corresponds to the septum separating it from the left auricle. In the lower part of this wall is a depression called the *fossa ovalis*, the remaining indication of an oval orifice, *foramen ovale*, by which the two auricles communicated with one another in the embryo.

Orifices. At the upper and lower posterior angles are the openings of the *Venæ Cavæ.* At the opening of the inferior vena cava is an incomplete valve—the *Eustachian Valve.* It is riddled with holes, giving it a cribriform appearance. It plays an important part in the embryo by directing the blood towards the foramen ovale. In front of the inferior vena cava is the oval *auriculo-ventricular orifice* opening into the right ventricle. Between this opening and the inferior vena cava is the *opening of the coronary sinus*, guarded by a semilunar valve—the *Thebesian valve.* In addition there are the orifices of two or three *smaller cardiac veins*, and the *foramina of Thebesius*, or the orifices of the *venæ minimæ cordis.*

Right Ventricle.—This forms the main part of the anterior surface of the heart, its right edge, and a portion of the posterior surface. It does not reach quite to the apex. In transverse section it is crescentic. Its walls are thicker than those of the auricle, and are thicker above than below.

Orifices. The *Pulmonary Artery* at the upper left angle. The part of the ventricle leading to it is called the conus arteriosus.

At the opening is a **Semilunar Valve** similar to that at the orifice of the aorta (*q.v.*) The *auriculo-ventricular*, which is closed at every beat of the heart by the shutting of the **Tricuspid Valve.** This consists of three pointed flaps, the broad ends of which are attached to the border of the orifice, which is strengthened by a ring of fibro-cartilage. The flaps are folds of the endocardium enclosing fibrous tissue. Their under surfaces and edges are connected to muscular projections from the ventricular surface by fine strong tendinous chords—*chordæ tendineæ.* The numerous muscular projections on the inner surface of the ventricle are called *columnæ carneæ*, and those to which the chordæ tendineæ are attached are distinguished as *musculi papillares*, and are collected into two masses, anterior and posterior. The tricuspid valve closes when the ventricle contracts, thereby preventing the blood from flowing back into the auricle. The chordæ tendineæ are for the purpose of keeping the flaps quite horizontal, so that they may not be pushed up into the auricle by the blood. By the simultaneous contraction of the musculi papillares to which they are attached any slackening of their tension arising from the shortening of the ventricle during its contraction is compensated for. The chordæ are thus kept tense, the flaps horizontal, and the valve completely closed.

Left Auricle.—Consists, like the right, of an *Auricular Appendix*, the only part visible in front, and the *Atrium*, or auricle proper. On the auricular septum is a depression indicating the former position of the foramen ovale.

Orifices. Pulmonary Veins, two on each side behind. *Auriculo-ventricular*, below and in front.

Left Ventricle.—About one-third of the anterior surface of the heart is formed by the left ventricle. It alone forms the apex of the heart. It is circular in cross-section. Its walls are much thicker than those of the right ventricle. The *columnæ carneæ* are smaller, but more numerous than those in the right ventricle. The *musculi papillares* are in two groups, which are larger than those of the right ventricle.

Orifices. Auriculo-ventricular, closed by the **Bicuspid** or **Mitral Valve.** This has a structure similar to the tricuspid, but consists of only two flaps. The larger flap is to the right and in front, between the auricular and aortic openings. The *Opening of the Aorta*, situated to the front of and very close to the auriculo-ventricular orifice, is closed by the **Semilunar Valve,** composed of three semicircular flaps. These flaps are composed of fibrous tissue, lined on the ventricular side by an extension of the endocardium, and on the aortic side by an extension of the inner coat of the artery. The free edge of each is strengthened by a tendinous band, in the middle of which is a fibro-cartilaginous thickening, or *corpus Arantii.* Tendinous fibres pass to the corpus Arantii from the attached border, spreading over the whole flap, with the exception of two narrowly crescentic portions—the *lunulæ.* The attached border is strengthened by the presence of a fibrous cord. The action of this valve is to prevent the blood passing back into the ventricle when it relaxes. The walls of the aorta (as also of the pulmonary artery) are expanded slightly at the beginning of the artery so as to form three bulgings known as the *Sinuses of Valsalva.* These are situated one anteriorly and two posteriorly. From the anterior arises the *Right Coronary Artery;* from the left posterior the *Left Coronary Artery.* The coronary arteries run in the auriculo-ventricular grooves, and send main branches between the ventricles along the ventricular grooves. It is a debated point whether, when the semilunar valve is open, its flaps cover over the orifices of the coronary arteries so as to prevent the entrance into them of blood at that moment.

Arrangement of Muscles of the Heart is very complicated, and very incompletely understood. The fibres have an oblique direction, and are disposed apparently in a number of more or less distinct layers. Within the muscular substance are found bloodvessels, lymphatics, and nerves. The latter are derived from the vagus nerve and from the cervical and superior thoracic ganglia of the sympathetic. They form gangliated plexuses.

II. The **Arteries** are tubes with strong, extensible, elastic walls. *A typical artery has three coats.* (1) *Internal,* lined by a layer of epithelioid cells, beneath which is a homogeneous sub-epithelioid layer containing scattered branched cells. Outside this is a layer of elastic tissue, which in the larger arteries is a very evident and considerable membrane, termed the fenestrated membrane of Henle. (2) *Middle,* consisting chiefly of involuntary muscular tissue, the fibre-cells being arranged with their long axes transverse to the course of the artery. Comparatively to the size of the artery the muscular coat is thicker and purer (*i.e.*, less admixture of connective tissue) in the smaller arteries. (3) *External,* composed of connective tissue, in which there is the elastic element.

The **Pulmonary Artery** soon after leaving the heart divides into two—one branch goes to the right lung, the other to the left. Subdividing within these organs, they ultimately end in the pulmonary capillaries.

The **Aorta,** after giving off the two small *Coronary Arteries* close to the heart, soon turns upon itself, and at the *arch* thus formed gives off three branches to supply the head and upper limbs. These branches are the *Innominate*, which divides into the *Right Carotid* (for head and neck) and *Right Subclavian* (for right arm) arteries, the *Left Carotid* (for head and neck), and the *Left Subclavian* (for left arm). The aorta, then passing down in front of the vertebral column—after giving off branches to the alimentary canal, kidneys, and other viscera—divides opposite the fourth lumbar vertebra into the two *Iliac Arteries*, which supply the pelvic organs and the lower extremities. All these branches divide and subdivide, until finally the smallest divisions terminate in the systemic capillaries.

III. The **Capillaries** are the minute bloodvessels connecting the smallest arteries with the smallest veins. They vary in diameter from $\frac{1}{1500}$ to $\frac{1}{4000}$th inch. Their walls are extremely delicate, consisting of a single layer of flattened, elongated epithelioid cells, containing large nuclei, continuous with the epithelioid lining of arteries and veins. The constituent cells are connected together at their edges by a cement-like substance, which is stained black by nitrate of silver. The addition of this reagent thus brings out the cellular nature of the capillary wall, and reveals thickenings of it at certain points termed *stigmata*, which have been supposed to be spaces in the walls through which, during life, the white corpuscles can pass out to the tissues.

The cells of the connective tissue, which in most parts more or less surround the capillaries, are connected by branches with the epithelioid cells of their walls. This is especially the case where the surrounding tissue is of the retiform variety (mucous membranes, lymphatic glands). Here a complete investing membrane may be thus formed, known as the *adventitia capillaris* of His.

IV. The **Veins** have walls thinner, less resistant, and less elastic than those of the arteries. Like an artery, a *typical vein has three coats:* (1) *Inner*, composed of three layers. The cells of the innermost epithelioid lining differ from those of the arteries in being less elongated in shape. The elastic layer seldom forms a distinct membrane. (2) *Middle* differs from that of arteries in having the muscular fibre-cells disposed longitudinally as well as circularly. Moreover, it never consists wholly of muscle.

(3) *Outer.* The proportion of elastic tissue is less than in arteries, and the coat as a whole is thicker.

The following veins are destitute of muscular tissue: Intercranial, interosseous, retinal, superior vena cava, upper part of inferior vena cava.

The veins are characterised by the presence of *valves*, which are semilunar flaps, with their convex edges attached to the wall of the vessel. They are usually in pairs. The valve is formed of the internal coat, with a little included connective tissue. *Valves are not found* in veins less than a line in diameter, in the pulmonary veins, and generally those coming from the viscera, intercranial, intervertebral, and interosseous. The valves are most numerous in the veins of muscular parts.

Pulmonary Veins.—There are two from each lung, which enter the left auricle in pairs, to the left and right sides of it. The orifices of each pair are close together, sometimes forming only one.

The **Vena Cava Superior** is formed by the union of the right and left *Innominate Veins*, each of which is again formed by the union of the *Subclavian* and *Int. Jugular Veins* of its side. The former carries the blood from the upper limbs, the latter from the brain and cranial cavity.

The **Vena Cava Inferior** is formed by the union of the *two Common Iliac Veins* at the fifth lumbar vertebra. In its upward course it lies along the right side of the aorta as far as the liver. It then passes through a groove in the posterior edge of the liver, and, after passing through the diaphragm, ends in the right auricle. In its course it receives the *Lumbar*, *Renal*, and *Hepatic Veins*. The common iliac vein on either side is formed by the union of the *Internal Iliac* (which receives the blood from the pelvic organs) and the *External Iliac*, which lower down is known as the *Femoral Vein*, and which receives the blood from the lower limb.

B. The Circulation.—The auricles, contracting, force the blood down into the ventricles. The ventricles immediately after contract, and, pressing strongly on the contained blood, force it in all directions. It is prevented from passing back into the auricles by the closure of the tricuspid and mitral valves. The only outlets for it, therefore, are the aorta and pulmonary artery. The arteries, however, being already full, the blood from the heart is able to enter them only by their elastic walls being distended. As soon, therefore, as the heart ceases to contract, and begins to relax, the elasticity of the arterial walls comes into play, and, pressing strongly upon the contained blood, forces it onwards, because its return into the heart is prevented by the closure of the semilunar valves. In this way the blood is kept moving in the bloodvessels when the heart is relaxing, or in the period of rest. Put in another way, it may be said that a part of the energy of the contraction of the muscular tissue of the heart in forcing the blood out of the ventricle into the artery is expended in distending its elastic walls, and that when the contraction ceases the energy thus stored up in the walls of the artery comes into play, with the result of forcing the blood on through the bloodvessel.

Passing on into the smaller arterial branches, the blood at last reaches the capillaries. From them it passes to the veins, by which it is brought back to the auricles, and the circulation is completed.

Double Circulation.—From what has been previously said regarding the vascular systêm, there must obviously be a *Double Circulation*.

1. **The Lesser or Pulmonary Circulation,** by which the blood passes from the right to the left side of the heart through the lungs. From the right ventricle it passes to the lungs by the pulmonary artery, through the capillaries of the lungs to the pulmonary veins, by which it is brought back to the left auricle. The blood in the pulmonary artery is dark or venous, that in the pulmonary veins scarlet or arterial.

2. **The Greater or Systemic Circulation,** or the circulation of the blood from the left to the right side of the heart through all parts of the body other than the lungs. It passes from the left ventricle into the aorta and arteries to capillaries, thence to veins which end finally in the venæ cavæ, by which the blood is brought back to the right auricle.

Any portion of the blood on leaving one chamber of the heart must complete both these circulations before it can come back to the place from which it started.

The Portal Circulation.—The blood coming from the alimentary canal, spleen, and pancreas is not returned directly to the heart. It is conveyed to the liver by a large vein—the portal vein, or **Vena Portæ.** In that organ, this vein, unlike any other in the body, branches and divides, and ultimately breaks up into capillaries which end in the hepatic vein. The hepatic vein terminates in the vena cava inferior, near its entrance into the right auricle. The course thus pursued by this portion of the blood is sometimes spoken of as a third and different circulation of the blood. It is, however, merely a portion of the greater circulation.

Coronary Circulation.—The shortest route by which the blood can pass from the left ventricle to the right auricle is by the coronary arteries and veins through the substance of the heart itself. The coronary arteries being branches of the aorta, this is strictly a portion of the systemic circulation. Inasmuch, however, as the venous system is independent of the venæ cavæ, it is sometimes spoken of as a distinct circulation—the coronary circulation.

LECTURE X.

THE CIRCULATION OF THE BLOOD
(*Continued*).

Blood-pressure.—The blood in the arteries is always pressing with considerable force against the arterial walls. Conversely, the elastic walls of the arteries are continually pressing upon the contained blood. This pressure is termed *Blood* or *Arterial Pressure.* That it is considerable, is proved by the fact that when an artery is cut, the blood spurts out with some force. Blood-pressure (first studied by Hales in 1722), is investigated by means of a Kymograph (wave-writer).

The *Kymograph* consists essentially of a U-shaped tube or *manometer*, one leg of which is shorter than the other. In the bend of the tube is put quicksilver. The shorter leg is connected with an artery by means of a piece of flexible tubing, and a T-shaped tube inserted into the blood-vessel. The flexible tubing is filled with a neutral saline solution, and thus the pressure of the blood is communicated to the quicksilver which falls in the short leg, and rises in the long leg to an extent proportional to the blood-pressure. Resting on the quicksilver in the long leg is a float carrying an upright lever, to which at right angles is fitted a pen. This pen is brought in contact with the paper covering a revolving drum. The pen will rise to an extent proportional to the blood-pressure, and any alteration of the blood-pressure will be graphically shown by the marks written by the pen on the surface of the revolving drum.

By its writing the pen of the kymograph shows that *the blood-pressure is influenced by the act of respiration, and by the contraction of the heart*, for it produces a double curve—a larger one found to correspond with the movements of respiration, and smaller curves, superposed on the larger, corresponding to the heart-beats. The rise of the larger curve corresponds in the main with expiration, the fall with inspiration, showing that whereas the former act increases the blood-pressure, the latter diminishes it.

It is impossible to say what the pressure exactly is in the human body; but it is probably not very different from that in the carotid artery of the horse, where the kymograph shows it to be equal to a column of mercury 150-200 mm. (6-8 inches) high.

The blood-pressure is greatest in the largest arteries, and becomes less as the arteries become smaller. This is especially the case when the arteries begin to divide much.

Blood-pressure is affected by exercise, and by the position of the body, being greater in the horizontal than in the sitting, and in the sitting greater than in the standing position. The blood-pressure is increased by an increase in the amount of blood in the arteries, and by increased action of the heart; it is diminished by the opposite conditions. The gain and loss of blood has, however, to be considerable to make any appreciable alteration of the blood-pressure. The blood-pressure is affected by the condition of dilation or constriction of arteries of certain parts, *e.g.*, of the abdomen. In the rabbit stimulation of a nerve called the *Depressor* causes such a dilation of the abdominal arteries that there is a fall of the general blood-pressure.

The conditions chiefly affecting blood-pressure are the calibre of the peripheral bloodvessels (vasomotor action), and the beat of the heart. The importance of the latter is seen when the action of the heart is stopped or interrupted by stimulation of the vagus nerve. There is a great fall of the blood-pressure.

The blood-pressure of the pulmonary artery is less than that of the aorta in the proportion of at least one to two.

The Pulse.—Every time the heart beats, blood is pumped into the already full aorta. The distension of the aorta thus caused at every heart beat passes as a wave over the arterial system. This distension wave, which can be felt by the finger in arteries sufficiently near the surface, is the *Pulse*. The features of the pulse can be graphically shown by an apparatus known as the *Sphygmograph*. This instrument consists essentially of a spring, fixed at one end and movable at the other which rests upon an artery. The spring, following the movements of the artery, communicates them to a lever which writes them in a magnified form on a blackened surface moved by clockwork. The writing or tracing thus obtained shows a double curve. The second curve (*dicrotic wave*) probably represents a wave of oscillation intensified by the closure of the semilunar valves. When the secondary wave is very pronounced, the pulse is said to be dicrotic. A *Dicrotic Pulse* is favoured by (1) a short strong heart-beat, (2) diminished blood-pressure.

The *Frequency of the Pulse* is dependent upon: (1) *Age*—whilst 130 beats per minute in the newly born, the number gradually diminishes to 70 at the age of puberty, at which it remains until about 50. In old age it quickens a little, rising to 80 or more above 80 years of age; (2) *Length of the Body*—the longer the body the less frequent the pulse; (3) *Exercise*, (4) *Food*, (5) *Rise of Temperature* all increase the frequency. There is a slight daily variation—the minimum being in the night, the maximum in the morning towards mid-day.

In addition to frequency, the pulse may vary in *quickness* (pulsus celer et tardus), dependent on the quickness of the heart-beat; in *strength* (pulsus fortis et debilis), shown by the weight the artery can raise; in *tension*, whether it feels hard or soft (pulsus durus et mollis); in *volume*, being either large (pulsus magnus), or small (pulsus parvus). The pulse-wave is not to be confounded either with the shock, which is practically instantaneous, or with the velocity of the bloodstream, which is much slower. The rate of the pulse-wave is said to be about ten yards per second.

The pulse becomes less and less marked as it recedes from the heart, and is not present in the capillaries and veins.

Movement of the Blood in the Capillaries.—As the blood flows through the capillaries, considerable resistance is offered to its passage. The *capillary resistance* thus offered is an important factor in considering the mechanics of the circulation. In the larger capillaries and smallest arteries the red corpuscles pass along the middle of the minute tube in an axial stream; surrounding them is an inert layer in which white corpuscles are often visible. This separation of the two kinds of corpuscles is probably due to the white having a less specific gravity, and to their being more sticky The peculiar position of the white corpuscles in the capillaries is no doubt associated with their passage out through the capillary walls into the surrounding tissues. This migration of the corpuscles is termed *diapedesis*.

Movement of the Blood in the Veins.—This differs from the movement in the arteries in three respects—

1. The *blood-pressure*, even in the small veins, where largest is very small.

2. A *pulse*, with certain exceptions, is absent. A pulse is normally present in the veins of the bat's wing, and sometimes in the common jugular vein of man.

3. The *velocity* is much less.

The *valves* of the veins are of importance in several ways. In muscular parts they assist the onward flow of the blood towards the heart. When the body is in the upright position they save the lower veins from the pressure of the column of blood above them, which, in the case of the veins of the feet, would be considerable.

The Velocity of the Bloodstream diminishes from the heart to the capillaries. Whilst in the aorta it is probably one foot, in the capillaries it is only $\frac{1}{50}$th inch per second. This diminution is due to the enormously increased area of the vessels—the combined area of the capillaries being 500 times as great as the area of the aorta. The velocity is to some extent regained in the veins for just the contrary reason. The rate in the venæ cavæ, where greatest, is only about half that in the aorta. The differences in the area of sections of arteries, capillaries, and veins may be represented by comparing the arterial and venous systems to two pyramidal cones with a common base at the capillaries and the two apices at the heart. The velocity of the bloodstream is estimated by Ludwig's Strom-uhr, or current gauge.

Duration of Circulation has been determined by injecting a particular salt into one jugular vein and noting how soon it appears in that of the opposite side. The time differs in different animals, but generally may be said to occupy the time corresponding to 27 heart-beats. Taking the number of beats in the human body to be 70 per minute, the time taken will be about 23 seconds. The duration of course must vary according to the length of circuit, and is affected by exercise.

The Mechanics of the Circulation.—The actual circulation is essentially due to the difference of pressure in the arteries and veins. In a system of closed tubes (vascular system) the contained liquid (blood) necessarily passes from that part where the pressure is high (arteries) to that where the pressure is low (veins). The equalisation of the pressure by the immediate passage of the blood from the arteries to the veins is prevented by the narrow diameter of the capillaries, which offer considerable resistance to the passage of the blood in this direction. This *capillary resistance*, reacting through the *elastic walls of the arteries* upon the *intermittent beat of the heart*, keeps up the excess of pressure in the arteries, which is such as to cause just as much blood to pass through the capillaries during the period between two heart-beats as enters the arterial system at each systole, and thus produces that continuous steady flow of blood through the capillaries which is such a characteristic and important feature of the circulation.

The essential character of the bloodstream can be copied in a simple mechanical apparatus in which the heart is represented by an elastic valvular bag, the arterial and venous systems by a series of elastic tubes, and the capillary resistance by a piece of drawn-out tubing or sponge. Such a mechanical contrivance is termed an *artificial schema*.

Physiology of the Heart—

The *Heart-beat*. The contraction of the heart, or its *systole*, consists of the contraction of the auricle, followed immediately by the contraction of the ventricle. The systole, which occupies about 4½ tenths of a second, is followed by a period of rest, or *diastole*, during which the heart relaxes and refills. When the heart contracts it shortens, becomes more rounded at the base of the ventricles, and hardens. The movement forward of the apex causes the "beat" of the heart, which is felt between the fifth and sixth costal cartilages a little to the inner side of a verticle line passing through the nipple. The *frequency* of the heart-beat is affected by age, sex, light, exertion, food, and emotion.

The beat of the heart on the chest-wall may be graphically represented by means of the *Cardiograph*, an instrument consisting of a tambour or drum, which is placed on the chest over the place where the impulse is felt. The movements of this drum are communicated by means of an elastic tube to another drum which moves a writing lever.

So unds of the Heart. These are two—(1) The *first*, a dull sound synchronous with the systole of the ventricle, and hence generally held to be due to the vibration of the auriculo-ventricular valves when rendered tense by their closure. It may be a muscular sound, for it is said to be heard in a heart quite empty of blood. (2) The *second* occurs at the beginning of the relaxation of the ventricle, and, being a sharper, shorter sound, is doubtless due to the closure of the semilunar valves. It is said to be absent when these valves are incompetent.

Work done by the Heart is the product of the quantity of blood ejected at each systole and the arterial pressure. Putting the amount pumped out of the left ventricle at 180 grammes, or 6 oz., and the blood-pressure at 250 mm. of mercury, or 3 metres of blood, 180 grammes × 3 metres = ·540 kilogrammetre will be the work done at each systole. At 70 beats per minute, this gives 37·8 kilogrammetres per minute, or (37·8 × 60 × 24) 54,532 kilogrammetres per day. Putting the work of the left ventricle at one-third that of the right, this gives 72,709 kilogrammetres as the work done by the heart in 24 hours. [A kilogrammetre means the force necessary to raise 1 kilogramme (about 35 oz.) 1 metre high.] Put in English measure, it amounts to a force sufficient to raise 70 tons a yard high.

Influence of the Nervous System on the Circulation.—

The Heart.—*Cause of the Heart's Contraction.* The beat of the heart is an automatic action, for the hearts of some animals continue to beat after removal from the body. This automatism is connected with the presence of nerve-cells in the muscular substance of the organ, for, if divided and subdivided, those parts containing these nervous elements still contract, while those destitute of them (apex of ventricle) at once come to a standstill.

Modification of the Heart-beat. Stimulation of the Vagus nerve, if slight, diminishes the action of the heart; when strong stops it, bringing it to a standstill in diastole. This *inhibition of the beat* does not take place immediately; there is a latent period of about one-sixth of a second. When the vagi are divided the heart beats more quickly. It is hence assumed that an inhibitory influence through the vagi is continually being exerted upon the heart, originating from a spot in the medulla oblongata called the *cardio-inhibitory centre.* This centre may be stimulated directly by anæmia of the medulla, or rise of blood-pressure in the arteries of the brain; and indirectly by afferent impulses coming to it along the vagus nerve, or other sensory nerves, especially those of the intestines.

Accelerator Nerves, originating in an *accelerator centre* in the medulla oblongata, stimulation of which causes a quickening of the heart-beat, are believed to exist. There is some uncertainty, however, as to the course of the fibres from the medulla to the heart. They appear to pass along the cervical spinal cord, then to the first thoracic ganglion, and by the sympathetic to the heart. The vagus is said, in some animals at least, to contain acceleratory as well as inhibitory fibres. There is a long latent period.

Action of Poisons on the Heart. After *Atropin* the vagus ceases to exert any inhibitory action; and even direct stimulation of the heart does not produce inhibition. *Urari* also does away with the inhibitory action of the vagus; but inhibition follows direct stimulation of the heart. *Nicotin* slows the heart-beat and may even stop it, but it afterwards recovers. Stimulation of the vagus then fails to produce any inhibitory effect. These facts are best explained on the assumption that there is within the heart an *inhibitory mechanism* which may be excited either through the vagus or by direct stimulation.

The Arteries.—*Vasomotor Action.* The arteries are normally in a partially constricted state known as *tone.* This tonic condition is due to the action of the nervous system, for it disappears when the nerves distributed to the vessel are divided. The artery is then said to have "lost tone". Stimulation of these nerves, on the other hand, increases the constriction, or heightens the tone. The nerves exerting this controlling influence over the calibre of the arteries are termed *vasomotor nerves.* In this way the amount of blood sent to a part may be increased (*blushing*) or diminished (*pallor*).

All the vasomotor nerves are in connection with a small part of the medulla oblongata called the **vasomotor centre.** The tone of the arteries is supposed to be due to this centre, being in a continual state of tonic activity—in other words, is continually emitting impulses along the vasomotor nerves; for when *stimulated* there is a general contraction of the arteries, causing a rise of blood-pressure, and when *paralysed* a general dilatation causing a fall of blood-pressure.

The vasomotor centre can be excited *directly* by the condition of the blood, by anæmia, by poisons; and *reflexly* so as either to stimulate or diminish its activity. The former is produced by fibres known as *pressor;* they are found in the *superior and inferior laryngeal nerves.* The latter by *depressor* fibres contained in the *vagus.* [In some animals these fibres are so numerous in the *superior cardiac branch of the vagus* that it is known as the *depressor nerve.*] It is said that all sensory nerves, if sufficiently stimulated, are capable of reflexly affecting the vasomotor centre, either stimulating or depressing it

There is ground for believing that there are in the spinal cord vasomotor centres which can act independently of the medullary centre.

Recovery of tone after section of the vasomotor nerves shows that the matter is not fully explained by the foregoing. The recovery of tone has been attributed to a local nervous mechanism in the blood-vessels. In some cases stimulation of peripheral ends (*e.g.*, chorda tympani, nerves to muscles, nervi erigentes), of nerves distributed to the arteries, causes dilation instead of constriction. This has suggested there being two kinds of fibres—*constrictor* and *dilator*. Whether there are such and whether there is a local nervous mechanism are points at present quite uncertain. The whole so-called vasomotor action is probably very much more intricate and complicated than has often been supposed.

Evidence of the Circulation is chiefly *indirect*.

1. The structure of the heart, especially of the valves.
2. The direction in which blood flows from a cut artery and vein.
3. Effect of ligature of arteries and veins.
4. The presence of valves in the veins.
5. Watching the beat of the heart.

The Discovery of the Circulation was made on such evidence by William Harvey early in the seventeenth century, and first published in his work, *De motu Cordis et Sanguinis*, in the year 1628. The distribution of the bloodvessels was described with remarkable accuracy by Vesalius before Harvey was born, and some idea of the pulmonary circulation is to be found in the works of Servetus. A clear and consistent account of the circulation was, however, undoubtedly first given by Harvey, notwithstanding that he was unaware of the existence of the capillaries. These were first observed four years after Harvey's death by Malpighi in 1661. The circulation of the blood from an induction thus became a demonstration.

LECTURE XI.

RESPIRATION—THE LUNGS.

Uses of the Circulation.—The living organs and tissues require a continual fresh supply of oxygen gas and of nutrient matter to make good what is lost in the wear and tear of life. At the same time it is necessary that the substances resulting from this wear and tear, of no further use to the organism, should be got rid of. This exchange between the external world and the different parts of the body is effected by the blood which is continually circulating through them. The means by which the blood is supplied with oxygen and nutritive matter constitute the functions of respiration and digestion. There are organs specially adapted for each purpose. For the supply of oxygen a respiratory organ, the lungs; for the supply of nutrient matter a digestive organ, the alimentary canal and its appendages, the liver and pancreas.

Respiration defined.—All living matter breathes or respires. By this is meant that it takes in oxygen gas and gives out carbonic acid gas in nearly equal volumes.

Inasmuch as most of the living parts of the body are not in contact with the surrounding atmosphere, it is obvious that there must be some mechanical arrangement for conveying the oxygen of the air to the internal living parts if they are to breathe or respire. This arrangement consists of the lungs and chest, which take in oxygen from the air and hand it over to the red corpuscles passing through its capillary bloodvessels. By these corpuscles the oxygen is conveyed in the circulating bloodstream to internal parts. The carbonic acid, given out by these parts passing into the plasma, is conveyed back to the lungs, by which it is given out to the air. How the lungs are enabled to effect this exchange of gases, and also to pass out from the body other substances either useless or injurious, is what is usually called respiration. The subject may be conveniently divided into two parts:

1. The mechanical arrangements by which the lungs are enabled continuously and regularly to take in fresh supplies of air.
2. The changes this air undergoes in passing through the lungs.

I. The Mechanics of Respiration.—The organs of respiration are the **Lungs,** located in the thorax, or chest, the greater part of which they fill. Each lung is cleft into *lobes*. When distended, the surface is seen to be marked out into little polygonal areas, the *lobules*. At the root of the tongue an orifice in the anterior wall of the œsophagus opens into the *larynx*, which ends below in the windpipe, or *trachea*. The trachea has in in its walls sixteen to twenty incomplete rings of cartilage. The tube is thus always distended. These cartilage rings, incomplete behind, are connected together by strong fibrous and elastic tissue. At the back where there is no cartilage, are bands of involuntary muscle fibres. It is lined with a mucous membrane provided with a ciliated epithelium.

Four to five inches in length, the trachea passes down in front of the œsophagus. Entering the chest, it lies between the two pleuræ, and soon divides into two branches, the *bronchi*, one to either lung. The bronchi have a structure similar to the trachea. Each bronchus enters the lung at the same part as the bloodvessels—a part known as the *root* of the lung. Within the lung the bronchus divides and subdivides dichotomously to form the *bronchial tubes*. In the bronchial tubes the cartilages consist of irregular plates embedded in connective tissue, and on the exterior is a circularly-disposed layer of involuntary muscle. The smallest branches, or *bronchioles*, have no cartilages, but the epithelium is still ciliated, and they terminate in sac-like, pear-shaped expansions called *infundibula*. Each bronchiole, with its infundibula, constitutes a lobule.

The different lobules are connected together, or separated from one another by septa of connective tissue, the *interlobular* septa. The infundibula have sacculated walls, and each saccule is called an *air-cell*, or *alveolus*. The walls of the air-cells are composed of a thin layer of connective tissue with scattered corpuscles, with a few coiled elastic fibres, which are more numerous near their orifices. A few muscular fibre cells are also said to be present. They are lined by a delicate layer of flattened, non-ciliated cells, forming a *tesselated epithelium*. In the wall of the alveolus is a fine and close network of blood capillaries separated from the interior of the air-cell only by the tesselated epithelium.

The air which has reached the air-cells by way of the bronchial tubes is thus separated from the blood only by a double layer of flattened cells, viz., the wall of the capillary, and the tesselated epithelium of the air-cell.

The Pleuræ.—The outer surface of the lung is pressed up closely against the inner surface of the wall of the chest, and closely follows its movements. The two surfaces are not, however, adherent. The surface of the lung and that of the chest and diaphragm are each lined by a smooth membrane, which really forms a closed sac called the *Pleura*, the space within which is practically obliterated during life. The pleura is a serous membrane, and secretes a liquid which lubricates the two opposed surfaces.

In addition to the blood conveyed to the lung by the pulmonary vessels for its purification, blood is carried to it for the nutrition of the organ by the *bronchial vessels* which accompany the bronchial tubes. The arteries do not communicate with the branches of the pulmonary arteries. This blood leaves the lungs by the *bronchial veins* (some is said to pass into the pulmonary veins), which terminate in the vena azygos, intercostal vein, or superior vena cava.

The *Nerves* to the lungs come from the *Vagus* and *Sympathetic*. The nerves accompany the arteries, and both medullated and non-medullated nerve-fibres are found in them. Connected with them are many small *ganglia*. It is not certainly known how the nerves end.

The Diaphragm.—The floor of the chest is formed by the midriff, or diaphragm. It is a strong muscle, tendinous in the middle, with muscular fibres radiating all round, and inserted into the lumbar vertebræ, into the cartilages of the lower six ribs, and into the lower end of the breastbone. In the uncontracted state it is convex towards the chest; when contracted it becomes flatter. The diaphragm is ennervated by the *Phrenic nerve*, which originates from the fourth and fifth cervical nerves. There is also a *diaphragmatic plexus* derived from the sympathetic (semilunar ganglion).

The Respiratory Act.—This consists of a breathing-in, or *inspiration*, followed by a breathing-out, or *expiration*. Between expiration and inspiration there is a pause, or period of rest. In an adult the respiratory act occurs from sixteen to twenty times per minute. It is more frequent in very early life, occuring as many as forty times per minute in very young infants. It varies according to the position of the body, being more frequent in the sitting than the lying posture, and standing than sitting. Its frequency is quickened by *rise of temperature* of the blood (*fever*), by *exercise*, and after taking *food*, also by *emotional states*. The "respiratory cycle" is thus divided as regards time: Inspiration, $\frac{3}{10}$; expiration, $\frac{4}{10}$; pause, $\frac{3}{10}$. The time occupied by the pause may, however, vary a good deal, and may in some cases hardly exist at all.

Inspiration.—Inspiration is brought about by the capacity of the thorax being increased by the contraction of certain muscles. In a vertical direction by the contraction (flattening) of the *Diaphragm*, antero-posteriorly and laterally by the *Levatores costarum*, and possibly by the *Intercostals*. When inspiration is *laboured*, other muscles are brought into play, viz., the *Scaleni*, *Serrati postici*, *Pectorales*, and possibly others. The *muscles of face and larynx* are also thrown into contraction, enlarging the orifices of the nares and glottis.

The outer surface of the lung being always pressed up against the inner surface of the chest, it follows all its movements, and in consequence the lung undergoes a corresponding enlargement in inspiration. This increase in the capacity of the lung causes a rarefaction of the contained air, resulting in the pressure within being less than that of the atmosphere. In consequence air is forced into the lung. The volume of air thus forced in by atmospheric pressure, or inspired, is normally 20-30 cubic inches, and is called *tidal air*. Putting the number of inspirations at seventeen to twenty, it follows that 340-600 cubic inches of air will be inhaled per minute.

Expiration.—At the end of inspiration, the muscles ceasing to contract, the chest returns to its original dimensions. In this it is followed by the lungs, which thereby force out a volume of air equal to that breathed in during the act of inspiration. The expiratory movement of the chest is due chiefly to the elasticity of its walls and of the lungs. The intercostal muscles may to some extent help.

When *expiration is laboured*, the *abdominal muscles*, the *triangularis sterni*, and *quadratus lumborum* are called into action.

Vital, or **Respiratory Capacity.**—By making a forced inspiration 100-130 cubic inches more than the tidal air can be inspired, to which the name of *Complemental Air* has been applied. By making a forced expiration 100 cubic inches more than the normal can be expired. This is distinguished as *Supplemental Air*. The greatest volume of air a person can thus exchange in a breath is termed the *Vital*, or *Respiratory Capacity*. Since it consists of the tidal, complemental, and supplemental airs combined, it will amount to 220-260 cubic inches. For every inch increase in chest-girth, or in height between 5 and 6 feet, there is an increase in vital capacity of 9 cubic inches. The vital capacity is at a maximum at 35. It is less in women than in men in the proportion of 7 to 10. The vital capacity is measured by the *Spirometer*. After the most forced expiration there still remains in the lungs a volume of air equal too 100-130 cubic inches. This is called *Residual Air*.

The *Movements of the Chest-wall* are indicated by instruments termed the *Stethometer* and *Pneumograph*. The *movements of the air in the trachea* can be graphically recorded by introducing a T-tube, with which a tambour is connected by a piece of tubing. The *movements of the diaphragm* can be shown by inserting a needle through the sternum so as to rest upon it. A lever attached to the free end will represent the movement of the diaphragm on a magnified scale.

Variations of Respiratory Movements.—In certain diseased conditions the respiratory rhythm becomes much quickened —a condition known as *Dyspnœa*. This state is brought about by an increased venosity of the blood, and it is a preliminary condition to the occurrence of that total suspension of respiration termed *Asphyxia*. When there is an excess of oxygen in the blood respiration is slowed even to stoppage, a state called *Apnœa*.

LECTURE XII.

RESPIRATION.

II. The Changes the Air undergoes in passing through the Lungs—

1. Its *Oxygen* is diminished from 21 to 16 per cent.

2. Its *Carbonic Acid* is increased from ·04 to 4 per cent. In a single breath the air is richer in carbonic acid and poorer in oxygen at the end than at the beginning. The greater the number of respirations in a given time, the less the quantity of carbonic acid evolved at each expiration, though the whole amount exhaled in a given time is increased. Also when the number of respirations remains the same, but the amplitude of each is increased, the quantity of carbonic acid in the given time is increased. Putting the tidal air at 500 cc. (22 cc. of CO_2) and the number of respirations at 17 per minute, the *day's production of Carbonic Acid* amounts to 500 litres, which contain about 8 oz. of carbon. The *amount of* CO_2 *evolved* is affected by exercise, food, sex, age, and temperature.

3. It is almost saturated with *aqueous vapour*. The amount evolved in 24 hours is about half-a-pint.

4. The *Temperature* is raised to nearly that of the blood.

5. Its *Volume* is diminished by $\frac{1}{40}$th or $\frac{1}{50}$. Since carbonic acid occupies the same volume as the oxygen entering into its combination, this diminution must be due to a small portion of the inhaled oxygen entering into some other combination than with carbon to form carbonic acid.

6. It contains much more *organic impurity*. This is of a highly decomposable character, and most injurious to the human economy. Its amount varies in a remarkably uniform manner with that of the carbonic acid. So much so, that an estimation of the amount of carbonic acid is taken as a measure of the amount of organic impurity. Its injurious nature is shown by the fact that whereas an atmosphere containing 1 per cent. of carbonic acid by breathing is extremely harmful, one simply containing 1 per cent. of carbonic acid is very little so.

Ventilation.—The object of ventilation is to prevent the air becoming deficient in oxygen, or loaded with too much carbonic acid and organic matter. To neutralise the accumulation of the latter in rooms which have been crowded with human beings, an abundance of oxygen and sunlight is necessary.

The obvious evil effects of Foul Air in extreme cases are strikingly illustrated in destruction of life and production of disease in the case of the Black Hole of Calcutta, in gaols, and epidemics of disease in crowded districts. Diseases of the chest, especially *consumption*, have been proved to be due to deficient ventilation. In the army, before the *Report of the Army Sanitary Commission*, in 1858, it was shown that in the *Foot Guards*, with an allowance of 331 cubic feet of space per man, the mortality from consumption was 13·8 per 1000; in the *Horse Guards*, with 572 cubic feet, it was only 7·2 per 1000. In the whole army, as the result of the improved ventilation following on the recommendations of the above Commission, the mortality from consumption has fallen from 8 to 3 per 1000. Similar results have been obtained in the navy by the better ventilation of the holds of ships. And the connection shown between the occurrence of galloping consumption in animals (horses, dogs, and monkeys) and the deficient ventilation of stalls, kennels, &c., points to the same conclusion.

When the hereditary character of this disease is remembered, the importance of adequate ventilation as a means of combating this terrible malady cannot but be appreciated. "It may be laid down as a general rule that foul air is the most constant, the most widespread, and the most serious cause of disease that exists" (De Chaumont).

Amount of Air Required.—To prevent evil effects the *carbonic acid* (taken as a measure of the *organic matter* present) should not exceed ·06 *per cent.*—*i.e.*, 50 per cent. above the amount normally present in the atmosphere. If it exceeds ·08 per cent. the air is offensive to the *Smell*, and its evil effects are such as to demand immediate attention. Above ·1 per cent. the air is foul and offensive.

The Problem of Ventilation is, therefore, how to keep the percentage of carbonic acid of breathed air below ·06 per cent. To attain this calculation shows that 3000 *cubic feet per hour per person* are required, and that each person should have clear space of 800 to 1000 cubic feet.

The Essential Conditions of Ventilation are, then—

1. A complete and continuous change of air, so that this amount of 3000 cubic feet may be obtained and the impurity never exceed the standard of ·06 per cent. of CO_2;

2. To obtain this fresh air without *draughts* ;

3. Of a proper *temperature* ; and

4. Sufficiently *moist*.

To Meet these Conditions are required—

1. *Rooms of sufficient size.*

2. *Inlets for fresh air* by windows (easily and properly opened), tubes, and other suitable and convenient openings. The pores in walls also afford a passage for air : they are stopped up by damp.

3. *Outlets for foul air*, as by chimneys, openings in the walls and ceilings.

4. *A pure surrounding atmosphere*, which is apt to be contaminated by two influences, which it is the duty of public authorities to cope with and remove, viz., (*a*) Effluvia from drainage, (*b*) Smoke, fog, and chemical fumes.

Ideal Ventilation will not be satisfied until the above conditions are universal. To aim at the attainment of that ideal is one of the gospels which Physiology brings to the individual and to the State. "We shall never have a thoroughly healthy people until we have learnt the great importance of breathing pure air" (E. A. Parkes).

Passage of Gases to and from the Blood and the Lungs.—Gases pass to and from the larger bronchial tubes and the smaller air-cells by diffusion. The proportion of *oxygen* in the air-cells being greater than that in the venous blood, it passes into the blood by diffusion. The affinity of the hæmoglobin of the red corpuscle for oxygen (the amount in combination at this place being a comparatively small quantity) will, no doubt, assist this passage. There is much uncertainty as to what are the causes determining the passage out of the blood into the air-cell of the carbonic acid. It has been thought that the tension of carbonic acid is greater in the air-cell than in the blood, so that none could pass out by diffusion. An explanation of the difficulty has been sought by supposing that carbonic acid in combination as carbonate is set free at the moment the blood passes the air-cell, thereby greatly increasing the carbonic acid tension and raising it above that in the air-cell. It has been suggested that this decomposition is brought about by the combination of oxygen with hæmoglobin acting as an acid.

Apparatus for determining changes air undergoes in passing *through lungs*. These consist either of an apparatus by breathing into which the expired air can be carefully analysed; or of a box, into which the whole body can enter, and through which air can be drawn, so that when it comes out its volume and chemical constituents can be carefully estimated, especially the water and carbonic acid. That of Pettenkofer is the most complete.

Influence of the Nervous System on Respiration—

Respiratory Centre. The nerves supplying the respiratory mechanism all originate from a small portion of the medulla oblongata, hence termed the respiratory centre. Injury to this part of the brain at once puts a stop to respiration. This centre is supposed to be *automatic*—that is to say, the nervous impulses which pass from it along the respiratory nerves are supposed to originate, *de novo*, from the nerve-cells constituting the centre. This is assumed from the fact that respiration still continues after all sensory nerves which can act in a reflex manner upon the centre are divided. Whether this be so or not, there is no doubt that its action is profoundly modified by nervous impulses brought to it by other nerves. Of these the most important is the *vagus*.

The Vagus Nerve. Afferent nervous impulses are continually ascending the vagus nerve to the respiratory centre, and affecting it in such a way as to determine the rapidity of its nervous discharge, for *section of the vagus* causes respiration to become slower, though the volumes of oxygen and carbonic acid gases respired are little altered. This is due to the diminution in rate being compensated by an increase in extent. *Stimulation of the central end of the vagus* quickens respiration, so that the normal rhythm can be artificially restored. Strong stimulation increases the rapidity, and may ultimately stop respiration. Just the opposite result, viz., slowing of respiration, is produced by stimulation of the *superior laryngeal* branch of the vagus. The impulses arriving by this nerve apparently inhibit the centre to some extent. It has been sought to explain the rhythmic character of the respiratory movements by assuming that the respiratory centre is of a double character—an inspiratory and an expiratory part—and that these are in constant conflict with one another in such a manner that alternately each gets the upper hand. The impulses which excite one inhibit the other, and *vice versa*.

The *condition of the blood* supplied to it profoundly affects the respiratory centre. The more venous the blood, the more active the respiratory centre becomes. The quickened respiration thus brought about is termed *Dyspnœa.* The cause of this change is *want of oxygen*, not excess of carbonic acid, for the same result occurs in an atmosphere destitute of oxygen but not containing an excess of carbonic acid, but not in an atmosphere containing plenty oxygen though, at the same time, an abundance of carbonic acid. If this venous condition of the blood remain for any time the dyspnœa continues, convulsions ensue, followed by a stage of exhaustion which culminates in death—a series of phenomena constituting *Asphyxia.* Death occurs in 3 to 5 minutes in warm-blooded animals. In young animals, however, it is often deferred much longer—*e.g.*, in new-born puppies, to 50 minutes. An excess of oxygen in the blood produces an effect exactly the opposite to that resulting from its deficiency, viz., a slowing of respiration, even to stoppage—a condition known as *Apnœa.* That these results are due to the direct effect of the blood on the respiratory centre is seen from the facts that dyspnœa results (*a*) from deficiency of oxygen in the blood after section of the vagi and of the spinal cord below the medulla, (*b*) after ligature of the blood-vessels of the neck, (*c*) after warming the blood in the carotid arteries.

Reflex Respiratory Movements. Sneezing, due to chemical or mechanical excitation of the nares (the nasal branch of the fifth nerve is the afferent nerve), and *Coughing*, resulting from excitation of the vocal cords, or of the mucous membrane of the bronchi, or bronchial tubes (the vagus and superior laryngeal are the afferent nerves), are examples of such reflex mevements.

Peculiar Respiratory Movements. Laughing is caused by short, quick expirations, the vocal cords being tense so that sounds are produced. The soft palate is thrown into vibration. The mouth is open, and the features assume a characteristic expression due to contraction of definite muscles. *Snoring* is due to respiration taking place through the open mouth, whereby the uvula and soft palate are caused to vibrate. In *Sighing* there is a long inspiration with a low sound. In *Yawning* the long inspiration is accompanied with widely open mouth.

LECTURE XIII.

THE ORGAN OF DIGESTION.

The Alimentary Canal consisting of the *Mouth*, *Pharynx*, *Œsophagus*, *Stomach*, and *Intestines*, with its **Appendages,** the *Liver* and *Pancreas*, constitute the organ of digestion. The lining membrane of this canal is modified in such a way as (1) to produce secretions, which, acting upon the food, render it soluble, and (2) to readily absorb the food when thus altered.

The Mouth.—The cavity of the mouth, bounded above by the hard and soft palate, below by the tongue, and at the sides by the cheeks, is lined by a squamous stratified epithelium. Opening on the surface of the lining membrane are numerous tubular *mucous glands*. Beneath the lining membrane there are also *lymph follicles*, which are especially numerous on the tongue, and in the *Tonsils* two rounded elevations at the back of the mouth, one on either side.

The *Tongue*, by its great mobility, assists in the mastication of the food and pushes it back into the pharynx. It is composed of striated muscles, some of which being solely in the tongue are called *intrinsic ;* others passing from the tongue to the hyoid bone, lower jawbone, palate, and styloid process, are termed *extrinsic*.

The Teeth.—The teeth which first appear remain only a few years, and are hence called *Temporary*, or *Milk Teeth*. They are 20 in number, 10 in each jaw, the five in either jaw being similar, viz., 2 incisors, 1 canine, 2 molars. The times at which these teeth appear is shown in *months* in the following table :

Molars.	Canines.	Incisors.	Canines.	Molars.
24 12	18	9 7 7 9	18	12 24

About the seventh year the milk teeth are followed by the *Permanent Teeth*, of which there are 32, 16 in each jaw. The increase in number is due to 3 more teeth being developed further back in the jaw. The germs of the permanent teeth are present before birth. At the sixth year all the milk and all the permanent teeth (except the wisdom) are present in the jaws. The wisdom tooth does not appear until the 18th to 25th year. The time of *eruption of the permanent teeth* is shown in *years* in the following table :—

Molar.			Bicuspid.		Canines.	Incisors.				Canines.	Bicuspid.		Molar.		
20	12	6	10	9	11	8	7	7	8	11	9	10	6	12	20

Structure of a Tooth.—A tooth consists of two parts—(1) the *Crown*, above the gum, (2) the *Root*, embedded in a socket in the jaw, consisting of one or more fangs. The interior of the tooth contains a soft mass of jelly-like connective tissue, the *pulp*, into which pass a nerve and bloodvessel through a minute aperture at the end of the fang. On the surface of the pulp is a layer of columnar cells, or *odontoblasts*, which send fine processes into the dentinal tubules. The greater portion of the hard substance of the tooth is formed of *Dentine*, characterised by being perforated by minute branching canals—the *dentinal tubules*. These tubules, $\frac{1}{4500}$th inch in diameter, pass in a radiate manner from the pulp to the periphery. The crown is covered with a layer of *Enamel* composed of elongated six-sided prisms, $\frac{1}{5000}$th inch diameter, placed vertically to the surface of the dentine beneath. Enamel is the hardest substance in the body, containing only 2 to 3 per cent. of animal matter. The root is covered by a substance very similar to, if not identical with, bone, called the *crusta petrosa*. It is thickest at the end of the fang.

Development of the Teeth. A depression of the epithelium forms the *enamel-germ*. This becomes separated off into 10 sac-like depressions, in each of which is developed the enamel of a milk tooth. *A papilla* grows up below each enamel-germ and assumes the shape of the tooth. It forms the basis of the pulp, and on it is deposited the dentine. During the development of the milk teeth a lunated depression enclosing epithelium is formed behind each. These are the germs of the 10 anterior permanent teeth. The permanent molars are developed in a manner essentially similar to the milk teeth.

The Salivary Glands.—Opening into the mouth are the ducts leading from the salivary glands. There are three on either side, viz., the *Parotid* situated below the ear, the *Submaxillary* under the lower jaw, *Sublingual* under the tongue. All these glands are of the racemose type. The main duct divides and subdivides until the ultimate tubules terminate in rounded spaces lined internally with cells which secrete the liquid poured into the mouth from the gland. The duct of the parotid gland opens upon the inner side of the cheek opposite the crown of the second molar of the upper jaw, that of the submaxillary by the side of the tongue, those of the lingual at side of tongue.

The Palate.—The *Hard Palate* is formed by the bones entering into the roof of the mouth with the lining mucous membrane. The *Soft Palate* (velum pendulum palati) is an incomplete and movable partition extending backwards and downwards between the mouth and the pharynx. It consists of a double layer of mucous membrane with muscular tissue and glands between. The anterior surface has an epithelium resembling that of the hard palate. The posterior surface has on its lower part a stratified, on its upper part a columnar, epithelium.

The Tonsils are two oval masses situated one on either side between the anterior and posterior pillars of the fauces. They measure $1\frac{1}{2}$ inch long by $\frac{1}{3}$ inch broad and thick. On the surface are more than a dozen orifices leading from spaces surrounded with lymphoid follicles. The rest of the tonsil consists of less dense lymphoid tissue largely supplied with blood.

The Pharynx.—The mouth opens behind into the pharynx, into which open also the posterior nares, the eustachian tube, and the larynx. The pharynx is attached above to the skull and is enveloped by muscles, viz., the Constrictors, Stylo-pharyngeus, and Palato-pharyngeus. Its walls are formed by a layer of fibrous tissue (dense at its upper part, lax and weak below), surrounded by muscles and lined by a mucous membrane. The epithelium is columnar and ciliated in the upper portion; in the lower it is stratified and non-ciliated. Below it ends in

The Œsophagus.—Tubular in shape, the *Gullet* is 9-10 inches long, opening below by an orifice (the *cardia*) into the stomach. Commencing behind the cricoid cartilage, where it is narrowest, it passes down through the neck, having the trachea in front and the bodies of the vertebræ behind. In the thorax it has in front of it successively the trachea, left bronchus, and pericardium; and in its lowest third has behind it the aorta. It is narrowed as it pierces the diaphragm, just beyond which it expands into the stomach. In common with all the rest of the alimentary canal, its wall is composed of *three distinct coats*, viz., muscular, areolar, and mucous. Outside the muscular is a layer of connective tissue.

i. The *Muscular Coat* (or External) is double, consisting of an external longitudinal and an internal circular layer. At the upper part the longitudinal is in three bands, anterior and two lateral, which coalesce to form a complete band below. In the upper part the fibres are voluntary; lower down they are involuntary.

ii. The *Areolar Coat* (or Middle), consisting of connective tissue, loosely connects the inner and outer coats together. In it are numerous small racemose glands, which open on the inner surface of the gullet.

iii. The *Mucous Membrane* (or Inner) resembles that of the pharynx, with which it is continuous. It has numerous minute papillae and is lined with a *stratified epithelium*. It is separated from the middle coat by a more or less perfect thin layer of involuntary muscular fibre-cells forming the *muscularis mucosæ*.

The Stomach lies largely on the left side of the body beneath the diaphragm and liver, and against the front wall of the abdomen. It is of irregular shape, with curved surfaces. With its long axis transverse, the larger end is on the left side. It measures from 10-12 inches in length and 4-5 in breadth. The opening from the œsophagus on the left side, termed the *Cardia*, is separated from the orifice communicating with the small intestine on the right, or the *Pylorus*, by a concavity known as the *lesser curvature*, in contradistinction to the great convex surface below, or *greater curvature*. It is connected to the liver, spleen, and diaphragm by folds of the peritoneum. Its walls are thinner than those of the œsophagus, but thicker than those of the intestines.

In addition to the three coats previously mentioned, the stomach is provided with an additional fourth external coat in the shape of a layer of peritoneum. This *Serous coat* is closely attached to the outer surface of the muscular coat except along the two curvatures.

The *Muscular Coat* has, in addition to an external longitudinal and internal circular layer of fibres, which is much thickened in the neighbourhood of the pylorus, an innermost incomplete layer of obliquely disposed fibres.

The *Middle Coat* is composed of connective tissue.

The *Mucous Membrane* is modified in a remarkable manner, being folded in such a way as to form enormous numbers of tubular glands. These **Gastric Glands,** lined with cells, secrete the gastric juice. The epithelium of the mucous membrane consists of a single layer of columnar cells. The mucous membrane between the glands is composed of retiform or lymphoid connective tissue. The cells of the glands rest upon a *basement membrane* formed of flattened cells. The glands towards the pyloric end are shorter and simpler than those at the cardiac end. The glands in these two parts are, therefore, sometimes distinguished as *pyloric* and *cardiac* glands. Between the mucous membrane and middle coat is a muscularis mucosæ.

The mucous membrane is largely supplied with blood, the arterial branches from the cœliac axis ending in a very close and elaborate network which surrounds the glands. There are also numerous lymphatics. The nerves are derived both from the central nervous system (*vagi*) and the sympathetic (branches from the *solar plexus*).

The Small Intestine is a much convoluted tube about twenty feet long, divided into three parts, viz., (1) *Duodenum*, 10-12 inches; (2) *Jejunum*, 8 feet; (3) *Ileum*, 12 feet long. With the exception of a part of the duodenum it is invested throughout by the peritoneum, which passes back behind as the *mesentery* to attach the bowel to the posterior wall of the abdomen. The muscular coat consists of an outer longitudinal and an inner circular layer of fibres, the latter being much the thicker. The **mucous membrane** is highly vascular, and is lined with tubular glands or *Krypts of Lieberkühn*. These measure about $\frac{1}{200}$ inch in length and $\frac{1}{600}$ inch in breadth. They are lined with a columnar epithelium resting upon a basement membrane. At the beginning of the duodenum are small racemose glands which extend down into the submucous coat. They are called *Brunner's glands*. The surface of the mucous membrane is increased in two ways by elevation.

1. *Valvulæ Conniventes*. Crescentic folds consisting of a double layer of the mucous membrane with the mucous coat between. They are found from within one or two inches of the stomach to the end of the jejunum.

2. **Villi.**—The surface of the mucous membrane has a velvety

appearance, due to its being raised up into great numbers of conical projections (from $\frac{1}{50}$th to $\frac{1}{30}$th of an inch in length), or villi. Like the rest of the mucous membrane, they are covered with columnar epithelium resting on a basement membrane. Each villus contains in the middle of it a blindly ending lymphatic vessel, or *Lacteal*, surrounded by a close network of capillary blood-vessels. Muscular fibre-cells pass from the muscularis mucosæ into the villi, ending in the basement membrane, and by their contraction shorten them. The villi have been calculated to be over four millions in number; they are most numerous in the duodenum and jejunum.

Solitary Follicles are nodules of lymphoid tissue, scattered through the whole intestine, forming slight elevation of the mucous membrane and extending down into the connective tissue coat. In the ileum they are found in aggregated masses (*Agminated follicles*), forming patches from ½ inch to 2 or 3 inches in length and ½ inch wide (*Peyer's patches*). These are 20-30 in number, and are even more numerous in the young subject. These follicles are well supplied with blood, and are in most intimate connection with lymphatics.

Blood is brought to the small intestine by the *mesenteric artery*. Its nerves are derived from the *superior mesenteric plexus*, which is formed by branches from the sympathetic (cœliac plexus, semilunar ganglion) and vagus nerve. Two well defined nervous plexuses are found in the wall of the intestine: an external in the muscular coat called the *plexus of Auerbach;* an inner finer one in the submucous coat called the *plexus of Meissner*.

The duodenum embraces the head of the pancreas, and into it, 3 to 4 inches from the pylorus, enter by a common orifice the common bile and pancreatic ducts.

The Large Intestine, 5 to 6 feet in length and 1½ to 2½ inches wide, extends from the ileum to the anus. It is divided into three parts, viz., *Cæcum*, *Colon*, and *Rectum*. The colon again is divided into an ascending transverse and descending portion and the *Sigmoid flexure*. Where the ileum joins the cœcum is a valve, the *Ileo-cæcal valve*. The walls are formed of coats similar to those of the small intestine. The outer peritoneal covering does not in all parts completely surround the tube, and in the colon it is developed into little projections enclosing fat called *appendices epiploicæ*.

The *Muscular Coat* is peculiar in the longitudinal layer, being much thickened in three parts; and, being here shorter, the intestine is thereby thrown into *sacculations*, which distinguish it from the smaller bowel. This sacculation causes inward projections in the shape of ridges.

The *Mucous Membrane* has no villi, but numerous tubular glands, shorter than those of small intestine. Solitary follicles are present, but no Peyer's patches.

The *Vermiform Appendix* is a hollow, blindly-ending appendage to the cœcum. It is peculiar to man, the higher apes, and the wombat. In structure it resembles the rest of the intestine, but the solitary follicles are more numerous.

The Peritoneum is a serous membrane forming a closed sac in the male, but communicating with the Fallopian tubes in the female. The *parietal* layer lines the inner surface of the abdomen and pelvis and lower surface of the diaphragm; the *visceral* layer covers more or less completely the organs in those cavities.

LECTURE XIV.

FOODS.

The human body is often compared to a machine, *e.g.*, a steam engine, and the food taken into the body is compared to the fuel put into the furnace of the steam engine. This comparison is correct to this extent, that in each case the food or fuel supplies material by the ultimate oxidation of which a supply of energy is forthcoming, by which the work of the machine is carried out. The human body, however, differs from any machine ever devised by man, inasmuch as it is able to make use of food not only as a source of energy, but also as a supply of material for the repair of those parts of the machine which have wasted away in the wear and tear of its activity. This remarkable property it owes to its being alive. It is the most obscure secret of life.

It follows from this that the food must contain the same elements as enter into the chemical constitution of the various parts of the body, or at least of those elements which are continually being lost from the body as the result of its vital activity. The essential point, therefore, in the *definition of a food* is that it supplies material for the recuperation of the body; in addition, it supplies energy in a potential form, which will be, other things equal, proportional to its chemical complexity. If any one element can be said to transcend others in its importance as a constituent of living organisms, it is *Nitrogen*. It characterises all those highly complex substances classed together under the term *Proteid* which form the basis of all protoplasmic or living structures. This element must therefore be present in the food, and from its importance the constituents of all foods have been divided into two great classes—(1) Nitrogenous and (2) Non-nitrogenous. The animal body can make use of nitrogen as food only when combined with carbon, hydrogen, and oxygen, to form proteid. No simpler nitrogen compound can be made use of by animals as food.

Food-stuffs, or the compounds which singly or, more generally, mixed together form the different foods, can be classified as follows:

1. *Nitrogenous*, *Proteid*, or *Albuminous*, containing the elements carbon, hydrogen, oxygen, nitrogen, and sulphur. Examples of them are seen in *Myosin* of muscle, *Casein* of milk, *Gluten* of flour, *Albumin* of eggs.

2. *Non-nitrogenous Bodies* may be divided into—

a. *Carbohydrates*, consisting of carbon, hydrogen, and oxygen, in the proportion represented by the formula $C_xH_{2n}O_n$. *Starch*, the different kinds of *Sugars*, and *Cellulose* are examples.

b. *Fats* composed of carbon, hydrogen, and oxygen, the last element being in smaller proportion than in the carbohydrates. *Butyrin* of butter, *Stearin* of suet, and *Palmitin* are examples. Fats by the action of superheated steam or alkalies take up the elements of water and decompose into glycerine and a fatty acid of general formula $C_nH_{2n}O_2$;

e.g., $\underset{\text{(Palmitin)}}{C_{51}H_{98}O_6} + \underset{\text{(Water)}}{3H_2O} = \underset{\text{(Glycerine)}}{C_3H_8O_3} + \underset{\text{(Palmitic Acid)}}{3C_{16}H_{32}O_2}$.

c. *Salts* containing the elements Calcium, Sodium, Potassium, Magnesium, Sulphur, Chlorine, and Phosphorus, as in Phosphates, Sulphates, and Chlorides.

d. *Water*.

Uses of Food-stuffs.—Since *the nitrogenous food-stuffs* are the only source of nitrogen, they must be of use in making good the loss of that element wherever it may occur. From 30 to 40 grammes of urea are excreted during 24 hours, but regarding the exact source of this nitrogenous excretion there has been much dispute. The flesh (muscle) to which it was naturally referred has been said not to be its source on the ground of certain experiments (Fick and Wislicenus) going to show that no apparent increase in the excretion of nitrogen occurs during the most active and prolonged exercise. On the faith of these conclusions it has been referred to the body as a whole, or even in some degree to stored food not actually transformed into tissue. Inasmuch, however, as in starvation the muscles gradually waste, and on restoration to normal diet regain the amount lost, it is difficult to come to any other conclusion than that nitrogen is continually lost by them, and as continually made good by the proteid food taken into the body. A purely nitrogenous diet is said to cause an increase in those body changes resulting in loss of nitrogen.

Gelatin contains Nitrogen in addition to Carbon, Hydrogen, and Oxygen, but is nevertheless useless as a substitute for proteid. In conjunction with proteid it appears, however, to be of use.

Fat, containing a relatively small quantity of oxygen, the oxidation of its carbon and hydrogen into carbonic acid and water, gives rise to heat, which agrees with universal experience. That it is not converted into fat or stored up as such within the body, is shown by animals forming more fat than is present in their food (Lawes and Gilbert), by experiments with marked fats, and the phenomena of fatty degeneration.

During starvation the fat of the body almost wholly disappears.

Carbohydrates are less useful than fats for heat production, and are evidently largely useful as the source of fat, a fact attested by universal experience. Fats may also possibly be derived in part from proteids.

Salts. Although present in small proportion, they are of great importance, as is shown by the injurious effects following on their absence (*e.g.*, scurvy). *Phosphorus* and *Sulphur* appear to be the elements most closely connected and bound up with the vital processes, but what *rôle* they play in the life-cycle is, however, quite unknown.

Composition of Foods.—The foregoing food-stuffs are present in the following articles of food in the proportions named.

Flesh consists of from 25 to 35 per cent. of solids, of which 10 to 25 is proteid and 2 gelatin. There is invariably interstitial fat, and 1 to 2·5 per cent. of salts, in which potassium and phosphates predominate.

Milk may be styled an "ideal food," for it contains all classes of food-stuffs, viz., proteid in the form of casein (4), fat (2·5), milk-sugar (4·3), salts (1·2), and water (88) per cent. Milk is an emulsion, the fat being suspended in minute particles, each surrounded by an envelope of casein.

Eggs. 73 per cent. water, 14 per cent. proteids, 12 per cent. fat, and 1 per cent. salts.

Wheat Flour contains 13 per cent. proteid (gluten), and 73 per cent. starch, 1·5 per cent. salts.

Oatmeal. Proteids 13 per cent., starch and sugar 64 per cent., fats 6 per cent., salts 3 per cent.

Potatoes consist of water 75, proteids 1·5, starch 16, salts 1 per cent.

Pulses (peas, beans, &c.) are characterised by a small proportion of water, only 14 per cent, and a very high percentage (23) of proteid; also 38 per cent. of starch, and 2·5 of salts.

Succulent Vegetables contain a very high percentage of water (90). Their nutritive value is due to the presence of sugar, organic acids, and salts.

The salts of most foods consist chiefly of potassium and phosphates.

Beers. In addition to 2 to 10 per cent. of alcohol contain a small percentage of proteid, carbo-hydrates, and salts.

Alcohol, a compound of carbon, hydrogen, and oxygen, in the proportions represented by the formula C_2H_6O, does not appear to be assimilated by the tissues, and cannot therefore be regarded as a true food. Whilst its effect on the body in large quantities is only too evident and clear, there is the greatest uncertainty as to its action in strictly moderate amount. Experiment goes to show that whilst it produces an initial rise of temperature, there is a consequent fall, causing on the whole a diminution of temperature. Whilst it appears to be generally favourable to the production of fat, it is a question whether this end is obtained in a manner beneficial to the health of the body as a whole. In small quantities, by stimulating the mucous membrane of a sluggish stomach, it may assist digestion.

Tea. The dry leaf contains 1·8 per cent. of *Thein*, 2·6 of albumin, 9·7 of dextrin, 22 of cellulose, 15 of tannin, 20 of extractives, 5·4 of ash. The infusion owes its use and favour as a beverage to the presence of an ætherial oil, and the characteristic alkaloid *thein* ($C_8H_{10}N_4O_2$). Its astringent property becomes injurious when tea contains a large proportion of the tannin.

Coffee owes its stimulating effect to the presence of an alkaloid called *Caffein*, identical with thein.

Cocoa. Cocoa contains 1·2 to 1·5 per cent. of an alkaloid closely allied to thein, called *Theobromin* ($C_7H_8N_4O_2$). It is more nutritious than tea or coffee, for it contains 45 to 49 per cent. of fat, and 13 to 18 of proteid. Phosphate of potassium is largely represented in the constituent salts.

Diet.—Physiology and experience both show the advantage of a *mixed diet*, by which is meant a diet composed of nitrogenous, together with one or more non-nitrogenous, constituents. Although the non-nitrogenous foods do not add any new chemical element, yet their addition is necessary to health, for a mixed diet is more economical than a purely proteid one, both physiologically and economically. This arises from the fact that, if the diet contains nitrogenous food only, all the carbon required must be supplied by it. But if sufficient proteid is taken to supply the carbon, far more nitrogen than is required is necessarily taken in at the same time. This extra amount of nitrogen must be got rid of, which throws extra work upon the digestive and excretory organs. A mixed diet, which maintains health without gain or loss in weight, is termed an *adequate diet.* The following are examples of such a diet:

	Public Diet.	*Ranke's.*
Proteids,	30 grammes.	100 grammes.
Fats,	84 ,,	100 ,,
Carbo-hydrates,	404 ,,	240 ,,
Salts,	30 ,,	25 ,,
Water,	2800 ,,	2600 ,,

The Amount of Diet is affected by

Age. The vital processes being more active in early life a larger diet; being less active in old age a smaller diet, is necessary.

Season of the year, for the vital actions are greatest in the spring, and least at the end of the summer. By

Climate, more being required in a cold than in a warm climate; in uplands than in lowlands. And especially by

Exercise. This is shown both by the greater evolution of carbonic acid the greater the exercise, and by comparing the diets found adequate in labour of different degrees of intensity. The following table shows the amount of

Carbonic acid evolved by the lungs per minute.

In *profound sleep*, lying posture,	4·5 grains.
In *light sleep*,	4·99 ,,
Scarcely awake, 1·30 A.M.,	5·7 ,,
,, ,, *2.30 A.M.*,	5·94 ,,
,, ,, *6·15 A.M.*,	6·1 ,,
Walking 2 miles an hour,	18·1 ,,
,, *3* ,, ,,	25·83 ,,
Tread-wheel ascending 28·15 feet per min.,	43·36 ,,

Influence of exercise shown by diet.

Average daily diet in *quietude*, about	16 oz.
Standard daily diet in *ordinary work* (150 lbs. weight)— Moleschott,	22·8 oz.
Pettenkofer and Voit,	22·4 oz.
Average daily diet in *very laborious work*, or *soldier on service*,	26·7 to 31 oz.

The intimate connection between exercise and diet is also brought out by the *effects of insufficiency of food* where active work is being engaged in. This has been strikingly evident in cases of hard labour prisoners and of soldiers on active duty inadequately supplied with food.

Connection between Food and Temperature. That the body is much more readily affected injuriously by exposure to cold when insufficiently supplied with food is a common experience. The protection afforded by food against cold is, no doubt, in part due to the increased production of heat and consequent rise of temperature, which follows the taking of food. Observation shows that, whilst the temperature of the body falls to a minimum at 5 or 6 o'clock in the morning, it shows a striking rise after breakfast, and a still more evident one after dinner, reaching a maximum about 5 or 6 in the afternoon.

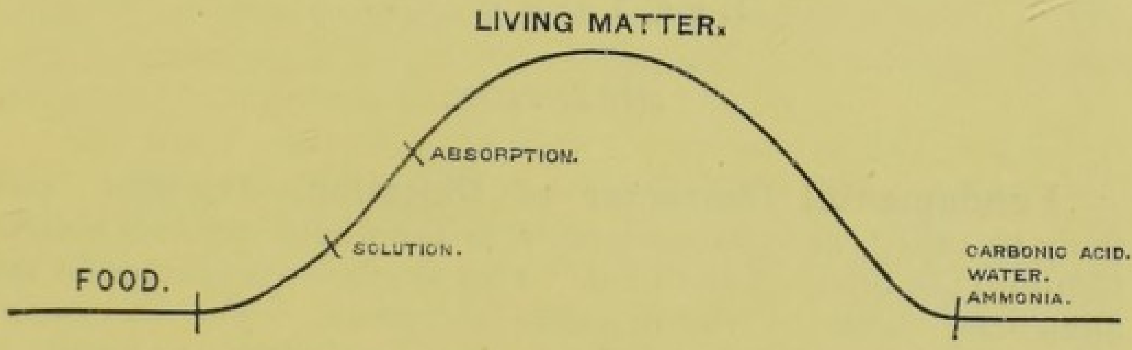
Digestibility of Food.—In choosing a diet, other circumstances, besides the chemical constitution of the food, have to be taken into account, especially its digestibility, which is often largely determined by the mode of *cooking; e.g., Eggs, raw,* are digested in the stomach in 1½ hours, *roasted* in 2¼ hours, *fried* 3½ hours: *Beef, boiled* 2¾ hours, *roasted* 3 hours. Whilst *Tripe* is digested in 1 hour, *Pork* takes 5¼ hours, *Potatoes roasted* take 2½ hours, *boiled* 3½ hours. Whilst *boiled Rice* takes only 1 hour, *Turnips* take 3½ hours.

Another circumstance of undoubted importance, although it is impossible exactly to explain its why and wherefore, is the *Palatability of Food.* This, no doubt, exercises a beneficial action both on its digestibility and its assimilation.

The *Income* of the body consists of oxygen, taken in by the lungs, and of food sufficient for an adequate diet. This latter is characterised by the complexity of its chemical composition. The *Outcome* is distinguished, on the other hand, by its simplicity of composition, for it may be said to consist of carbonic acid, water, and ammonia (as urea). The long series of changes taking place in the body between these two extremes of complex income and simple outcome, which changes involve the building up and breaking down or the construction and destruction of the living organs and tissues of the body, constitute what is called

Metabolism.—Those changes which have for their end the building up of living matter constitute *constructive metabolism;* those changes, on the other hand, which end in the breakdown of the tissues into simpler bodies, make up *destructive metabolism.*

Constructive metabolism may be said to consist of three main steps, viz. :—(i.) The solution of the food, (ii.) its absorption into the blood, (iii.), the transformation of this absorbed food into the living substance of the various structures composing the body—the first two steps constitute what is usually called digestion. The whole range of metabolism may be represented by a curve, thus :



CURVE OF METABOLISM.

LECTURE XV.

DIGESTION.

Fundamental Character of Digestion.—Digestion, properly so called, consists essentially in the alteration and absorption into the blood of the food. This alteration is effected in the alimentary canal by the digestive secretions. The ab orption takes place directly into the bloodvessels, ramifying in the walls of the stomach and intestine, and indirectly through the lymphatics.

Those portions of the food which readily dissolve in water or acid will pass into the blood without difficulty after reaching the stomach, for the dissolved substances are there practically separated from the blood by only two fine membranes, viz., the lining epithelium and the epithelioid walls of the capillaries. The physical process of diffusion, or osmosis, will suffice for this passage.

The insoluble proteids, carbohydrates, and fats must be acted upon by one or more of the digestive secretions, so as to be able to diffuse through the membranes into the blood. The digestive secretions are able to bring about this transformation of these food-stuffs from the insoluble to the soluble form, from an indiffusible to a diffusible condition, in virtue of their containing certain remarkable agents termed **Ferments.** The characteristic property of these ferments is that they have the power, under favourable conditions (of temperature and medium), of profoundly modifying certain other bodies with which they may come in contact, without themselves undergoing any change. The modification thus produced appears to result from the addition of water. The action of these ferments has, therefore, been called one of *Hydrolysis.*

Two ferment actions at least are well known—

1. The conversion of insoluble, indiffusible Proteids into soluble diffusible ones, or Peptones, by *Proteolytic Ferments.*

2. The conversion of insoluble starch into soluble sugar, by *Amylolytic Ferments*, as shown by the following formula:

$$\underset{\text{(starch)}}{C_6H_{10}O_5} + \underset{\text{(water)}}{H_2O} = \underset{\text{(sugar)}}{C_6H_{12}O_6}.$$

The Digestive Secretions.—The digestive secretions are—

Saliva, a thin, slightly alkaline liquid, of specific gravity 1002 to 1006, containing about ·5 per cent. of solids. Of these solids ·2 per cent. consists of *salts*, chiefly sodium chloride. The organic constituents are proteid bodies, and, in exceedingly minute quantity, an amylolytic ferment termed *Ptyalin*.

The *Use* of saliva is to moisten the food, thus assisting mastication and swallowing, and to convert starch into sugar. The action of Ptyalin is dependent on temperature. Whilst a temperature of 35° to 40° C. is most favourable, its action is stopped at 0° C., and above 70° C. Ptyalin cannot exert its characteristic action in the presence of much acid, nor of large quantities of the substance it produces, viz., sugar.

The secretion of saliva is a *reflex act* in which the *Lingual* is the afferent, the *Chorda tympani* branch of the seventh the efferent, nerve, and the centre in the medulla oblongata at the origin of the seventh nerve. When secretion is taking place the bloodvessels are dilated, but this does not stand in the relation to the secretion of cause and effect; for there may be dilation without secretion (by action of atropin), and secretion without dilation (as when the bloodvessels are ligatured). The nerve-fibres of the chorda tympani are said to end in the cells of the glands.

Gastric Juice is a thin, almost colourless, acid liquid of specific gravity 1002·5, containing ·5 per cent. of solids. Its acidity is probably due to the presence of free hydrochloric acid. It contains a proteolytic ferment named *Pepsin*. Pepsin converts the proteid food-stuffs into *Peptones*, the characteristics of which are—(1) They are not precipitated by potassium ferrocyanide and acetic acid. (2) Their aqueous solution is not coagulated by heat. (3) They are highly diffusible. (4) Perfectly soluble in water. Pepsin can exert this action only when the liquid is acid; neutralisation therefore stops it. Large quantities of peptone also interfere with its action. A temperature of 35° to 40° C. is most favourable. It alters gelatiniferous tissue. The presence of food in the stomach is the most efficient stimulus for the secretion of gastric juice. Dilute alkalis are also very stimulating. The mucous membrane becomes red, due to increased blood supply.

Pancreatic Juice is a clear, viscid, alkaline liquid. Of 8 to 10 per cent. of solids, a considerable proportion are proteids. Besides 1 per cent. of sodic carbonate (to which the alkalinity is due), and Leucin and Tyrosin (complex nitrogenous bodies), it contains an amylolytic and a proteolytic ferment (*Trypsin*).

Its *Action on Food-stuffs* is (1) to convert starch into sugar.

(2) To convert proteids into peptones. This is effected by the proteolytic ferment trypsin, which differs from pepsin in requiring the medium to be alkaline. Excess of sodic carbonate, however, hinders the action. The action also differs from gastric digestion in producing *Leucin* ($C_6H_{13}NO_2$) and *Tyrosin* ($C_9H_{11}NO_3$). Trypsin does not appear to exist as such in the pancreas, but in the form of zymogen, trypsinogen or mother ferment, which generates the trypsin under the influence of oxygen or some other agent. Whilst normally the secretion is possibly due to the action of a local nervous mechanism, it is also under the influence of the central nervous system, as is shown by the effect of emotion on its quantity.

(3) It acts upon fats in two ways: (*a*) emulsifying them; (*b*) splitting them up into fatty acids and glycerine; this action is supposed to be due to the presence of a peculiar ferment (steapsin).

$$\underset{\text{(stearin)}}{C_{57}H_{110}O_6} + 3H_2O = C_3H_8O_3 + \underset{\text{(stearic acid)}}{3C_{18}H_{36}O_2}.$$

If an alkali be present it unites with the fatty acid produced, thus forming a soap, the presence of which is highly favourable to the emulsionising of the fat. The secretion begins when food enters the stomach, and reaches a maximum two to three hours afterwards. It then diminishes, but rises again to a second maximum towards ninth to eleventh hour.

Bile is a thick, dark yellow alkaline liquid of specific gravity 1026, containing 14 per cent. of solids. It contains no proteids. Its chief constituents are the *Bile Acids* (9 per cent.), which are present united with soda. These acids are known as *Glycocholic* ($C_{26}H_{43}NO_6$) and *Taurocholic* ($C_{26}H_{45}NSO_7$). The latter is the more abundant in human bile. When boiled with potash or acids they both yield cholalic acid ($C_{24}H_{40}O_5$) thus:

$$C_{26}H_{43}NO_6 + H_2O = C_{24}H_{40}O_5 + C_2H_5NO_2 \text{ (Glycin).}$$
$$C_{26}H_{45}NSO_7 + H_2O = C_{24}H_{40}O_5 + C_2H_7NSO_3 \text{ (Taurin).}$$

The bile salts, sodium glycocholate and sodium taurocholate, are insoluble in ether, but soluble in alcohol and in water. The aqueous solution is alkaline. They crystallise in acicular needles and are very deliquescent. The colour of bile is due to a colouring matter, *Bilirubin*. By oxidation it yields *Biliverdin*, the green colouring matter characteristic of the bile of Herbivora. Bile also contains *Fats* (2 per cent.), *Mucus*, *Inorganic Salts* (2 per cent., amongst which are sodium chloride, phosphates of iron and magnesium), and *Cholesterin* (·04 per cent.), the only free alcohol present in the body. It has the composition $C_{36}H_{44}O$, and crystallises in transparent rhombic plates. It is insoluble in water, but soluble in hot alcohol and in ether.

Formation of Bile. Bile is manufactured by the liver-cells out of the raw material brought to them by the blood. It is continually being secreted, and is stored up in the gall-bladder until required for digestion, from which it passes to the duodenum by the bile-duct.

Action on Food-stuffs. It acts almost solely upon fats which it emulsionises, slightly dissolves, and especially assists their passage through membranes. The absorption of fat by the lacteals is probably further indirectly aided by the bile stimulating the muscles of the villi. In the absence of bile (biliary fistula) very much less fat than usual is absorbed and the chyle contains very little.

The bile salts are largely reabsorbed in the small intestine.

The passage of the chyme over the orifice of the biliary duct produces an immediate flow of bile, probably by reflex action.

Intestinal Juice is a thin yellow alkaline liquid of specific gravity 1011. It contains 2·5 per cent. of solids amongst which are proteids and sodic carbonate. It is chiefly the product of the glands of Lieberkühn, mixed with which is the secretion from Brunner's glands.

Its *action on Food-stuffs* appears to be very slight. Whilst having little or no amylolytic action it is said to convert cane into grape sugar. It converts fibrin into peptone.

Absorption of the Altered Food.—The presence of food in the *Mouth*, acting through the nervous system, causes a flow of saliva. The food is thus moistened, and a small quantity of starch converted into sugar. The stratified epithelium lining the mouth and œsophagus is not favourable to absorption into the bloodvessels present in their walls. Nevertheless, absorption of highly diffusible substances by the mouth is possible; *e.g.*, cyanide of potassium.

Passing into the *Stomach*, the food is the most efficient stimulus to the secretion of the gastric juice. Movements of the organ are gradually set up which cause the food to rotate within it. Gelatiniferous tissue is dissolved, and a certain amount of proteid converted into peptone. Peptone and diffusible carbohydrates are probably to some extent absorbed by the stomach, for when the pyloric orifice is ligatured a considerable absorption ensues. The partially altered food when it leaves the stomach is sometimes spoken of as *Chyme*.

In the *Small Intestine* starch is converted into sugar by the pancreatic ferment. Fats are emulsified, split up, and saponified under the joint influence of the bile and pancreatic juice. Proteids are converted into peptone by the trypsin of the pancreatic juice. The greater part of the altered food is absorbed by the small intestine, especially its upper part, where the villi are largest and most numerous. The villi are essentially the absorptive organs, the proteids and carbohydrates passing into the capillary bloodvessels, the fats into the lacteals. It is possible that some of the proteid may pass with the fat into the lacteals, but in view of the fact that the chyle contains very little peptone it is not likely to take place to any extent. The lacteals contain fat only during digestion.

The passage into the lacteal is assisted by the pressure of the intestinal wall upon the food resulting from peristaltic action, and also by the contraction of the villus, which, emptying the lacteal of chyle, and the reflow of which being prevented by valves, will cause the lacteal to act as a suction-pump. The passage may be compared to filtration.

The other force which assists the passage of food out of the intestine is *Endosmosis;* for, separated by its delicate lining membrane, there are on the one side highly diffusible peptones, sugar and soaps, and on the other the very indiffusible proteids of the blood and lymph. These physical processes are alone insufficient to explain all the facts of absorption. It must not be forgotten that the membrane in point is composed of living cells, which, in virtue of their vitality, may exert a definite and peculiar absorptive action upon the different constituents of the food, and even be endowed with definite selective properties.

In the *Large Intestine* water is chiefly absorbed. In the upper part (cæcum) food is probably absorbed to a slight extent, for the walls contain many lymphatics. Experiments with nutrient enemata also show that some absorption of food-stuffs is possible.

Movements of the Alimentary Canal—

Swallowing is a reflex act.

Peristalsis. The movement of the food through the alimentary canal after it is swallowed is brought about by a wave-like contraction of the muscular walls of the digestive tube. This contraction causes the food to be pushed simply forward along the œsophagus and intestines. This wave-like contraction is termed *peristallic action*, or peristalsis.

In consequence of the peculiar shape of the *Stomach* the movement of the food within it is not so simple ; for, instead of advancing, it circulates around the organ from end to end, forwards to the pylorus by the greater curvature, and backwards to the cardia by the lesser curvature. This movement is assisted by the closure of the pyloric orifice due to the contraction of the sphincter muscle.

The Liver.—The liver is the largest gland in the body, weighing fifty or sixty ounces. Seated beneath the diaphragm, chiefly on the right side, it is divided by an antero-posterior *fissure* into two lateral parts—the right and the left *lobes*. Of these the right lobe is the larger. Each lobe is composed of a great number of *lobules*, or *acini* ($\frac{1}{24}$th to $\frac{1}{12}$th inch in diameter). Each lobule is composed of minute polyhedral cells, termed *liver-cells* (about $\frac{1}{1000}$th inch in diameter), containing a nucleus, or in some cases two nuclei.

The lobules are each surrounded by the terminal branches of the portal vein, from which pass a fine network of capillaries into the substance of the lobule. It is characteristic that these capillaries always pass between the angles of contiguous cells. They terminate in the centre of the lobule in a small vein—the *Central Vein*—which ends in the hepatic vein. The hepatic vein ends in the vena cava inferior. The lobules are similarly sursounded by ramifications of the *Hepatic Artery*, from which minute capillaries pass into their substance, joining the capillaries from the portal vein. Each lobule thus receives a double supply of blood, arterial and venous, which mix in the substance of the lobule and leave it by the same channel, viz., the central vein.

Between the surfaces of the liver-cells are excessively minute channels, into which the secreted bile is passed. These are the *biliary capillaries*, and by their junction form larger tubes, and these ultimately end in the *bile-duct*, by which the bile is conveyed to the *gall-bladder*, a pear-shaped bag situated at the front edge of the liver, slightly to the right side. The bile-duct and the gall-bladder communicate with the duodenum by a common tube—the *common bile-duct*.

The liver-cells consist of proteids, salts of potassium, sodium, calcium, magnesium, iron, &c., sometimes of fats, and normally always contain a carbohydrate body closely allied to starch (discovered by Cl. Bernard in 1853) called **Glycogen.** It can be obtained as a white powder of the composition represented by the formula $6(C_6H_{10}O_5) + H_2O$. It is soluble in water, and is easily converted into sugar. It is coloured red by iodine. In starvation the amount of glycogen in the liver is greatly diminished, and may even disappear. Its production is most striking after carbohydrate food. It is, however, produced to some extent when the diet consists exclusively of purified proteid. It is uncertain whether the Glycogen is manufactured *de novo* by the liver-cell by the metabolism of its protoplasm, or is simply transformed carbohydrate arrested as it passes in the bloodstream through the liver.

Destruction of a small portion of the medulla oblongata, near the vasomotor centre, causes *artificial diabetes*, or an increase of sugar in the blood and its appearance in the urine. The nervous paths of connection between this spot (*diabetic centre*) and the liver appear to be through the spinal cord and sympathetic. Whether the result is brought about by direct nervous action upon the liver-cells or through a modification of the circulation is undetermined.

The Pancreas is a racemose gland of elongated shape, placed transversely in the abdomen. One end—the right—being considerably larger than the rest, termed the *head*, is embraced by the duodenum. The other extremity, or *tail*, is in contact with the spleen. It is behind the stomach, and at the level of the first lumbar vertebra. Its dimensions are 6 to 8 inches long, $1\frac{1}{2}$ broad, and $\frac{1}{2}$ to $1\frac{1}{2}$ thick. Its weight is 2 to 4 ounces. The *main duct of the gland*, or Canal of Wirsung, traverses the gland throughout, and enters the duodenum at the same orifice as the common bile-duct. The microscopic structure of the pancreas is essentially similar to that of the salivary glands (*q.v.* Lecture XIII.).

LECTURE XVI.

NUTRITION.

Definition of Nutrition.—Nutrition may be defined as the formation of new tissue, or of substances stored in the tissue, out of the blood. That this transformation of certain constituents of the blood into the living substance of the tissues is continually taking place is inferred from the facts that in starvation the tissues gradually diminish, and again increase when subsequently food is taken; that glandular and muscular tissues can be shown to lose substance during activity, and yet do not diminish, but rather tend to increase in quantity.

Over and above the fact that the living tissues are the seat of these two opposing influences which result in the maintenance of their normal substance and vitality, some exhibit an excess of construction, resulting in the storing up of certain bodies, whilst others are distinguished by the large quantity of products passed out from them, or excreted. In the one case the living matter of the tissue exhibits a power of selection from the blood of those constituents which can be appropriately stored up; on the other, a power of selecting from the blood those constituents which are either useless or harmful, and which are therefore desirably passed out or excreted.

From this point of view the tissues may be divided into three classes. (1) Those which are especially characterised by the constructive and destructive processes going on side by side, and on the maintenance of a suitable equilibrium between which contending forces the activity of the tissue depends. Such may be termed the *metabolic tissues*, and of them *muscle* is the most striking and characteristic. (2) Those in which the storing up of some product is the most characteristic feature, and may therefore be termed the *storage tissues*, e.g., *liver* and *fat*. (3) Those whose chief work appears to be the passing out of products, and may be appropriately termed the *excretory tissues*, of which the *kidneys* afford a most striking instance.

1. Metabolic Tissue.—As before explained, in Lecture VI., muscular activity is invariably accompanied by a loss of substance. This loss consists chiefly of carbonic acid and sarkolactic acid, and is remarkable in containing little or no nitrogen, although this element is so characteristic and so large a constituent of the muscular substance. An attempt has been made to explain this fact by assuming the existence of a peculiar muscular substance, *inogene* (Hermann), composed of a nitrogenous and a non-nitrogenous portion, and that in contraction the latter alone undergoes decomposition, the former remaining unchanged. The decomposition of the non-nitrogenous part gives rise to the carbonic and sarkolactic acids. During the period of rest it is again built up, the new-formed substance uniting with the nitrogenous part to form inogene.

2. Storage Tissue.—Fat is deposited as drops of oil in the cells of connective tissue. It is a question whether the fat is simply deposited in the cells from the blood, or is manufactured out of their protoplasm. That fat can be formed from something other than fat is seen in the production of *adipocere* in flesh, and in the ripening of cheese, in which cases the source is evidently proteid. Feeding experiments also show that the formation of fat may follow a proteid or carbohydrate diet. How favourable carbohydrates are to the production of fat is a fact of the commonest experience. That the formation of fat in the body is not merely the deposition of that taken in as such, is clearly evident from experiments with fats as foods which differ in their chemical composition from those formed in the body. In such cases the fat formed has the usual composition, and not that of the fat eaten. The presence of large quantities of fat in milk, produced by the activity of the mammary glands, favours the view that fat is formed out of the protoplasm of the cells.

The *Liver*, as before-mentioned, stores *glycogen*, and it is unknown whether it is formed from carbohydrates brought to the liver by the blood, or from the protoplasm of the liver-cells.

The formation of glycogen and bile by the liver shows that it must be the seat of important chemical changes, and on a large scale. That this is the case is supported by the fact that blood leaving the liver is the hottest in the body. In addition to these changes of the protoplasm of the liver-cells forming the complex constituents of bile, there are probably others resulting in the formation of urea and uric acid.

3. Excretory Tissue.—The *liver* comes under this head as far as those constitutents of bile are concerned, which are not re-absorbed but are excreted from the body. The *kidneys*, however, afford the best example of this kind of tissue.

The **Kidneys** are situated one on either side of the vertebral column in the loins, corresponding to the position of the 12th dorsal and first two or three lumbar vertebræ. They are surrounded by a considerable quantity of fat, and have the peritoneum lying in front of them. Their dimensions are, length 4, breadth $2\frac{1}{2}$, thickness $1\frac{1}{4}$ inches. The weight is about $4\frac{1}{2}$ oz. The kidney has the well-known concavo-convex shape. The concavity where the bloodvessels and ureter enter it is termed the *sinus*, and its opening the *hilus*.

Structure of the Kidney. The kidney is enclosed in a strong fibrous connective tissue coat, or *capsule*. Beneath it is an incomplete layer of involuntary muscular fibres. A longitudinal vertical section of the kidney shows it to consist of an outer, or *cortical*, and an inner, or *medullary*, substance. The latter is characterised by conical masses called the *pyramids of Malpighi*, the apices of which are directed inwards towards the hilus. The inner extremities of the pyramids are embraced by small tubes termed the *calices*, which unite to form a funnel-shaped dilatation called the *pelvis*. The pelvis is in communication with the bladder by a long tube, the *ureter*.

The *essential structure of the kidney* consists of a great number of convoluted tubules—**tubuli uriniferi.** These begin in the cortex as closed spherical sacs, or *Bowman's capsules*, and after a very convoluted and tortuous course end in the excretory tubes which open at the apices of the pyramids. The tubules consist of a basement membrane and lining epithelium which varies in different parts of the tubule, as does also the diameter of the lumen of the tubule. The *connection between these tubules and the bloodvessels* is of the greatest importance. The *renal artery*, branching directly from the aorta, on reaching the hilus divides into four or five branches. The branches pass through the medullary substance between the pyramids, and then form incomplete arches at their bases. From these arches *interlobular* arteries pass through the cortex towards the surface of the organ. These give off a number of short branches which almost immediately pierce the capsules of Bowman, and within them break up into a rounded convoluted mass of capillaries forming the **glomeruli** of Malpighi. These capillaries end in a vein of smaller diameter than the corresponding artery which passes out of the capsule close to the point where the artery enters it. This efferent vessel very soon ends in a capillary network which closely surrounds the convoluted portion of the tubule into which the capsule opens. This capillary network ends in a vein, having a course similar to that of the interlobular artery, which ends in one of the venous arches lying between the medulla and cortex. The large veins pass out between the pyramids accompanying the arteries, and ultimately join to form the renal vein which opens into the vena cava inferior.

Composition of Urine.—Urine has a specific gravity of 1·02, an acid reaction, and salt taste. It contains 4 per cent. of solids. Of these the most important and largest constituent is *Urea*, which is present to the amount of about 2·3 per cent. *Sodium Chloride* comes next in quantity, viz., about 1 per cent. There are also small quantities of *Uric Acid*, *Phosphoric* and *Sulphuric Acids*, *Earthy Phosphates*, *Ammonia*, and ·2 per cent. of free acid. About 3 lbs. (1500 grammes) are passed in 24 hours. The colour is due to a yellow pigment called *Urochrome*.

After standing, urine becomes alkaline, due to the conversion of urea into ammonium carbonate.

Urea.—$CO(NH_2)_2$. The interest in the kidney as an excreting organ is largely due to its passing out a nitrogenous body, urea, for there is every reason to believe that all the nitrogenous waste from the body leaves it in this form (excepting a minute quantity of uric acid) and by this channel. It is a neutral, odourless body, soluble in water and alcohol, insoluble in ether. Urea is present in minute quantities in many different parts of the body, *e.g.*, blood, lymph, chyle, liver, lungs, brain, and abnormally in sweat. It doubtless results from the decomposition of the proteid constituents of the tissues or of the food, but the exact steps between these two extremes are not definitely known. About 1 oz. of urea per day is excreted by an adult man. This amount is said to be not increased by muscular exercise—a fact pointing to the conclusion that the proteid constituent of muscle is not a source of urea. This conclusion cannot, however, be regarded as established.

Excretion of Urine.—This is probably effected by a double process of filtration and secretion.

1. *Filtration.* The blood-pressure in the capillaries of the glomerulus being greater than the pressure in Bowman's capsule, there will naturally be a filtration of water, dissolved salts, and possibly other bodies, through the capillary walls into the capsule.

That such a filtration does actually take place is supported by the facts that increase of blood-pressure causes an increased excretion, and diminution of blood-pressure a diminished excretion of urine.

2. *Secretion.* The epithelium lining the uriniferous tubules probably plays a part in secreting certain constituents of the urine—*e.g.*, urea. The epithelium might do this by selecting these constituents out of the blood, or by manufacturing them out of raw material supplied by the blood. The evidence appears to favour the former view, for, (1) as mentioned above, urea is normally present in the blood; (2) in certain cases injection of urea into the blood causes an increase of secretion; (3) the injection of indigo-carmine into the veins is followed by its presence in the epithelium cells and its subsequent passage into the lumen of the tubule; (4) experiments on the frog, in which there is a double blood supply to the kidneys (the glomerule being supplied by the renal artery, the tubules by the renal-portal vein), show that sugar and peptones do not pass when the renal artery is ligatured, thus doing away with the filtration apparatus, whereas urea still passes, for the epithelium of the tubules is still intact.

The knowledge we at present possess concerning the kidneys throws very little light on the metabolism going on in the tissues of the body. Assuming that the tubular epithelium is an important factor in excreting urine, its *modus operandi* is little more than matter for speculation. Observation of the cellular elements of the salivary and gastric glands and of the pancreas shows that during the production of their proper secretion there is an obvious alteration in the physical structure and contents of the cells. This consists in the passage out of the cells into the lumen of granules which have been produced in the cell during the period of rest. This change is accompanied by a diminution in the size of the cells.

Further knowledge is requisite regarding the exact nature of these granules before any certain answer can be given to the question of so much interest and importance, whether the protoplasm of the cells produces the essential constituents of the secretion by a process of selecting them direct from the blood, or whether it manufactures them out of raw material absorbed from the blood, or, lastly, whether they are the products of the decomposition of the complex molecules characteristic of and peculiar to the protoplasm of the cells of these glands.

Metabolism of the Blood.—Contrary to the opinion formerly held, the amount of metabolism actually occurring in the blood is probably very small. There is probably little or no oxidation in the blood. The following facts support this view: (1) The oxidising power of the blood removed from the body is very small; (2) many easily oxidisable substances—*e.g.*, pyrogallic acid—pass largely through the blood of a living body without being oxidised; (3) *Oertman's Experiment*, in which the blood of a frog was replaced by saline solution when oxidation still took place.

Nevertheless the white corpuscles, being independent living cells, must have a certain amount of metabolism going on within them.

ENERGY OF THE BODY.

Source of Energy.—The food contains a store of potential energy, which is transformed into the kinetic form of heat and movement by the changes going on within the body. The oxidation resulting from the union of the oxygen of respiration with the constituent elements of the food or of the tissues gives rise to energy in the form of heat.

Loss of Energy occurs in two ways—

1. *Movement*, or muscular contraction.
2. *Heat*.

The amount of energy lost by a day's work has been calculated to be 150,000 to 200,000 kilogrammetres. This energy is probably the result of the decomposition of the non-nitrogenous constituent of the muscle. That it is not the result of immediate oxidation of the muscular tissue by the oxygen brought to it by the blood is shown by the fact that the absorption of oxygen and evolution of carbonic acid are not necessarily directly dependent on one another. This is proved by carbonic acid being evolved when muscle is thrown into contraction in an atmosphere destitute of oxygen, and also by the fact that during the night, whilst the evolution of carbonic acid is diminished, the absorption of oxygen is actually increased.

Where Heat produced.—Heat is produced wherever oxidation is taking place. It is especially produced in the *Muscles* and *Glands*. Of the latter, the *Liver* is the most important; the blood leaving that organ is the hottest in the body. Also to a slight extent in the *Brain*, and to some extent by the changes the food undergoes in the alimentary canal.

Where Heat lost.—Whilst being thus produced, heat is continually being lost by (1) the *Skin* (77 per cent.); (2) *Lungs* (20 per cent.); (3) *Urine* and *Fæces* (3 per cent.).

Temperature of the Body.—The blood carries heat from where produced to where lost, and in this way equalises the temperature in all parts. In consequence, the temperature throughout the body is remarkably uniform and constant. It lies within the limits of 36°-38° C. (97°-100° F.)—*Axilla*, 36·25°-37·5°; *Mouth*, 36·5°-37·75°; *Rectum*, 38°. The temperature of infants and children is slightly higher, and more susceptible of variation than that of adults. After the 40th year the temperature is somewhat lower. Deprivation of food causes a lowering of temperature.

In *Cold-blooded Animals* the temperature of the body is very little above that of the surrounding medium, which is to be accounted for by a less production or a greater loss. The temperature of the *Frog* is only a small fraction of a degree above that of the surrounding air.

Regulation of Temperature.—This is possible in two ways:

1. By *Variation in Loss*. The *skin* is the most important, as is well seen in *exercise*. The increased production of heat is counteracted by increased loss by the lungs (quickened breathing), and by the skin becoming red and flushed (dilation of blood-vessels to skin).

2. By *Variation in Production*. That such variation is possible under the influence of a nervous mechanism is probable from the facts:

a. That warm-blooded animals and cold-blooded animals differ, in that whilst the temperature of the latter is affected, that of the former is unaffected by the external application of heat and cold.

b. If on exposure to cold the normal temperature is maintained by a production of heat, there ought to be increased metabolism, and such is observed to be the case.

c. The administration of *urari* to warm-blooded animals causes their temperature to be affected by external heat and cold just like cold-blooded ones. This points to the mechanism being nervous.

d. The phenomena of fever point to a distinct production as well as an interference with the loss of heat.

LECTURE XVII.

THE NERVOUS SYSTEM—NERVES.

Use and Importance.—The nervous system renders possible that co-ordination of movement and of function which is so striking a feature in animal life. Its part in the animal economy is to guide, govern, and harmonise the other functions of the body. Accordingly, in proportion as the quantity of motion generated and variety of movements performed are greater, and the functions more numerous and elaborate, so is the quantity of nervous matter and the complexity of the nervous system greater.

Since all other parts of the body are directly or indirectly dependent upon the nervous system for their activity, its importance in the animal kingdom cannot be over-estimated. It may safely be laid down that the more complex and more highly developed the nervous system of an animal, the higher is that animal in the scale of life. The significance of this is seen in the division of the animal kingdom into the two great subdivisions Vertebrata and Invertebrata. The former is distinguished from the latter by that skeletal development known as the vertebral column. Correlated with this vertebral column are its contents—the most important part of the nervous system—the brain and spinal cord.

In the Animal Scale.—Whilst, where first observed in the animal scale (jelly-fish), the nervous system consists merely of a network of scarcely fibrillated nerve-fibres connected with a few centres, in man it forms a most complicated and elaborate mechanism, $\frac{1}{38}$th of the body weight in quantity. The nervous system of *Invertebrate* animals consists of ganglia, arranged singly, or in chains or groups connected by nervous cords. From the ganglia nerves pass to the different parts of the body. In the *Vertebrata* the nervous system becomes more and more complex from fishes to mammalia, the development of the brain becoming more and more marked.

Constituent Parts.—In the human body the nervous system consists of two parts:

1. The **Central Nervous System,** composed of the *Brain* and *Spinal Cord*, together with the *Nerves* connecting them with other parts of the body. The brain and spinal cord together form the *Cerebro-Spinal Axis.*

2. The **Sympathetic System,** consisting of—

   a. The *Trunk of the Sympathetic*, made up of a double gangliated cord, placed one on either side of the vertebral column by the side of the vertebræ. The series of connected ganglia extend on each side upwards to the base of the skull, and downwards as far as the coccyx. The ganglia are thus distributed in the different regions: 3 cervical, 12 dorsal, 4 lumbar, 5 sacral. The two cords come nearer together in the sacral region, and the two last ganglia are connected together through the coccygeal ganglion, by branches passing in front of the body of the first coccygeal vertebra.

   b. *Communicating branches* connecting the ganglia, or intermediate nerve cord, with all the spinal and several of the cranial nerves. The superior cervical ganglion is connected with the four upper cervical nerves, the middle cervical ganglion with the fifth and sixth, and the inferior cervical ganglion with the seventh and eighth cervical nerves. Each thoracic ganglion is usually connected with a spinal nerve by two branches. This double connection is also found in the lumbar and sacral regions.

   c. *Ganglia* and *Plexuses of Nerves* in the thorax (*Cardiac plexus*), abdomen (*Semilunar ganglia*, *Solar diaphragmatic*, *Renal*, *Cœliac*, *Mesenteric*, *&c.*, *plexuses*), and pelvis (*Hypogastric* and *Pelvic plexuses*), connected by nerves with the sympathetic trunk. Of these nerves the largest and most important are the *Splanchnic*, three on either side, termed the *Great*, *Small*, and *Smallest*. The *Great splanchnic* arises from the fifth to ninth thoracic ganglia, and passing through the crus of the diaphragm, ends in the semilunar ganglion, which forms part of the solar or epigastric plexus situated behind the stomach, on the aorta and pillar of the diaphragm. The *Small splanchnic*, arising from the tenth and eleventh thoracic ganglia, ends in the cœliac plexus surrounding the cœliac axis. The *Smallest splanchnic* originates from the twelfth thoracic ganglion, and ends in the renal plexus. The sympathetic nerves are characterised by a preponderance of non-medullated nerve-fibres.

Nervous Tissue.—*Vide* Lecture VII.

Classification of Nervous Structures.—Nervous structures, regarded from a physiological point of view, may be classified as follows:

1. *Conducting Organs* (Nerves).
2. *Centres* (Brain, Spinal Cord, Ganglia).
3. *End Organs* (Organs of Sense).

Structure of Nerves.—Nerves are composed of *nerve-fibres*, which run side by side within the nerve without branching, and without joining one another, when of the medullated kind. Non-medullated fibres may branch and join. An ultimate fibre—or, rather, axis cylinder—may branch just prior to its final distribution. This is well seen in the cornea. The fibres are collected into bundles, or *funiculi*, and these again collected together form the nerve. A nerve is enclosed by a connective-tissue sheath termed the *neurilemma*.

Classification of Nerves.—Nerves may be classified according to their origin as follows:

Spinal Nerves. There are thirty-one pairs originating from the spinal cord. They are named according to the region of the vertebral column whence they issue, viz., 8 cervical, 12 dorsal, 5 lumbar, 5 sacral, 1 coccygeal. They are distributed chiefly to the muscles and integument.

Cranial Nerves. There are twelve pairs arising from the brain. All these, with the exception of the first four, viz., olfactory, optic, third, and fourth, have their primary or deep origin in the medulla oblongata. They are all distributed to the head except the *vagus* and *spinal accessory*.

Sympathetic Nerves, from the sympathetic trunk or ganglia. They consist largely of *non-medullated fibres*. They are connected with the spinal nerves through the communicating branches (*rami communicantes*), and thus receive medullated fibres from, and give non-medullated fibres to, the spinal nerves. They are distributed to the vascular system, the thoracic and abdominal viscera, and to glands.

Origin and Termination of Nerves.—Since a nerve-fibre originates from a nerve-cell in the (*a*) brain, (*b*) spinal cord, (*c*) ganglia, nerves may be said to have their origin in nerve-cells, situated in a *central organ*. At their distal extremity nerve-fibres end in motor end-plates (muscles), electrical organs, secretory cells, other nerve-cells, fine plexuses, or sensory end-organs.

Functions of Nerves.—The great function of nerves is to conduct nervous impulses to and from nerve-centres (especially the brain and spinal cord), and other parts of the body. At its distal extremity a nerve-fibre has one of two properties:

1. *Communicative*, transmitting the impulse, or its effect, to some structure, thereby causing some change or modification in it; *e.g.*, (*a*) muscular contraction, (*b*) secretion, (*c*) inhibition.

2. *Receptive*, receiving impulses as the result of the action of stimuli. These *stimuli may be of different kinds*—(*a*) electrical, (*b*) chemical, (*c*) mechanical, (*d*) thermal, (*e*) natural. *Natural stimuli* can act properly only through *end-organs*, or the mechanisms at the distal extremities of the sensory nerves; *e.g.*, the eye and ear.

Efferent and Afferent Fibres.—A nerve-fibre which conveys impulses *from* a centre to some part of the body is called an *Efferent* or *Motor* Fibre. A nerve-fibre conveying impulses *to* a centre from some part of the body is termed an *Afferent* or *Sensory Fibre*. These terms are not strictly synonymous; for whilst all motor fibres are necessarily efferent, all efferent are not motor; *e.g.*, those conveying impulses to a gland. In like manner, although all sensory fibres must be afferent, all afferent fibres do not convey impulses which give rise to a sensation, or, in other words, are not sensory. Examples of such afferent fibres, not sensory, are seen in those which convey impulses to the spinal cord, thereby causing a reflex action.

A nerve composed solely of motor or efferent fibres is called a *Motor Nerve*; *e.g.*, third, fourth, sixth, facial, and spinal accessory cranial nerves. One composed only of sensory or afferent fibres is termed a *Sensory Nerve*; *e.g.*, olfactory, optic, auditory. A nerve containing both kinds of fibres is a *Mixed Nerve*. Such are the spinal nerves, and the fifth, vagus, and glosso-pharyngeal cranial nerves. The nature of a particular nerve is shown by observing the effects of stimulation (movement, or sensation, or both) of the cut surface of its distal and proximal ends after section.

Anterior and Posterior Roots of Spinal Nerves.—Shortly before the spinal nerves join the spinal cord their constituent motor and sensory fibres part company, and enter that structure separately as the Anterior and Posterior Roots. On the posterior root is an enlargement or *Ganglion*. The motor fibres pass by the anterior roots, the sensory fibres by the posterior roots. This important physiological fact was discovered by Sir Charles Bell (1821) and Majendie (1822).

This fact can be readily demonstrated by experiment, for—

A. When the *anterior root is divided*—

1. The muscles supplied by the nerve cannot be voluntarily contracted, but the parts to which the nerve is distributed are still sensible.
2. *Stimulation of the distal portion* causes the muscles supplied by the nerve to contract. Stimulation of the proximal portion gives rise to no sensations.

B. When the *posterior root is divided*—

1. The muscles supplied by the nerve can still be voluntarily contracted, but the sensibility of the structures to which the nerve is distributed disappears.
2. *Stimulation of the proximal portion* causes evidence of sensation. Stimulation of the distal portion causes no movement.

An exception to the preceding statement is seen in what is called *recurrent sensibility*. This term is applied to the evidence of sensation sometimes observed when the distal stump of the anterior root is stimulated. It appears to be due to some of the fibres of the posterior root turning back into the anterior root soon after they have entered the trunk of the nerve. They soon bend back, and pass into the trunk again.

Nutrition of Nerves.—This is intimately associated with the connection of the fibres with nerve-cells at their central ends, for when a nerve is divided the distal portion soon degenerates, whilst the proximal portion much less readily does so. In the case of the spinal nerves, it is found that whilst the anterior root is dependent for its nutrition on the connection of its fibres with the spinal cord, the posterior root is quite different, for it depends on the *ganglion on the posterior root*.

Section of the posterior root between the spinal cord and the ganglion causes degeneration of only that small part still connected to the spinal cord, whereas its section on the other side of the ganglion causes degeneration of all the sensory fibres of the trunk. This method of experiment affords a means of tracing the course of the motor and sensory fibres respectively, and, from its discoverer, is known as the Wallerian method.

Rate of Conduction of Impulses.—A nervous impulse travels along a nerve at the rate of 26 metres (frog), 35-40 metres (man), per second. This is shown in *motor nerves* by causing a muscle to contract by stimulating its nerve first close to the muscle, and then as far as possible from it. The difference in the length of time which elapses between the moment of stimulation and the moment of contraction in the two cases is the time taken by the impulse to travel over the length of nerve between the two points stimulated.

In *sensory nerves* it can be shown in the human body by a person indicating with a movement of the hand when he feels a stimulus applied to the skin at a point distant from the brain (say the foot), and also at a point nearer (say the thigh) the brain. The difference in time between the application of the stimulus and the movement in the two cases indicates the time taken by the sensory impulse in passing along the length of nerve from the foot to the thigh, from which the rate can easily be determined.

The *personal equation*, or the time taken by the mind to convert the sensation into a volition, is in both cases the same, as also is the time taken by an impulse in passing from the brain to the hand.

Electrical Phenomena of Nerve—

Nerve Currents. In a divided nerve a current passes from the surface to the cut edge outside the nerve; in other words, the cut surface is electrically negative to the sound. This electrical current undergoes a change when an impulse passes along it, viz., by becoming less, or it undergoes a *negative variation*.

The phenomena are essentially similar to those observed in muscle at rest and in contraction (*vide* Lecture VII.). This electrical alteration is the only known change occurring in a nerve when it is transmitting an impulse.

A current passed transversely through a nerve does not excite it.

When a constant current passes along a nerve the natural nerve current in the same direction as this current is increased, that in the opposite direction is diminished.

Electrotonus. When a constant electric current is made to flow along a portion of a nerve its irritability is increased in the neighbourhood of the negative, and decreased near the positive, pole. The nerve is not excited so long as the intensity of the current does not change.

LECTURE XVIII.

NERVE CENTRES—THE SPINAL CORD.

The Spinal Cord—

Shape. It is elongated and cylindrical. In the regions of the neck and loins it is somewhat larger, forming the cervical and lumbar enlargements.

Extent and Size. From 15 to 18 inches in length, it extends from the medulla oblongata above to the first lumbar vertebra below. Its lower termination is conical in shape, the apex of the cone being opposite the first lumbar vertebra. It is continued below this as a slender filament — the *filum terminale.* This terminal filament is surrounded by the sheath of the cord as far as the upper part of the sacrum; then, passing through the dura mater, it is attached below to the coccyx. The spinal cord is rather broader from side to side than from front to back. It measures rather more than one-third of an inch in diameter, except in the cervical and lumbar enlargements, where it is about half-an-inch across.

Membranes. There are three, continuous with those surrounding the brain:—

i. The *Dura mater*, continuous with the membrane lining the skull, hangs freely in the vertebral canal, thus forming a loose investment of the cord. At its lower part there are some small fibrous connections with the vertebræ. It extends some distance beyond the apex of the cone to the upper part of the sacrum. After the roots of the spinal nerves have passed through the dura mater it is continued on the nerve becoming continuous with its sheath. Between the dura mater and the wall of the vertebral canal are connective tissue and fat, and a plexus of veins.

ii. The *Pia mater* is a thin, delicate, fibrous, vascular membrane continuous with that investing the brain. It is, however, not so vascular, is thicker and more closely attached to the substance of the cord. It dips into the anterior and posterior fissures, especially the former. It is continued on the roots of the nerves becoming lost in their connective tissue sheaths.

iii. The *Arachnoid* is a very fine, delicate membrane between the two preceding. Between it and the pia mater is a considerable space—the *subarachnoid space*—continuous with a similar space in the skull, and which is continuous with the ventricles of the brain by the *foramen morgagni.* In the subarachnoid space is a liquid —the *subarachnoid fluid.* Fine bundles of fibres pass across this space, connecting the arachnoid with the pia mater. An imperfect partition—the *ligamentum denticulatum*—divides the subarachnoid space into an anterior and posterior half. It passes from the pia mater between the anterior and posterior roots of the spinal nerves, and is attached by the denticulations to the dura mater; below it becomes fused with the filum terminale. The ligamentum denticulatum thus fixes the spinal cord in a central position.

Fissures. The spinal cord is divided almost completely into two symmetrical halves by two deep fissures, one in front, the other behind. They are known as the *Anterior median* and *Posterior median* fissures. Along each half of the cord, on a line with the posterior roots, is a groove.

Columns. Each half of the cord is divisible by this groove, and the line of origin of the anterior roots into three columns: (1) *Anterior*, (2) *Lateral*, and (3) *Posterior*.

Minute Structure.—The spinal cord consists chiefly of nerve-fibres and nerve-cells having a definite and characteristic arrangement. Besides these essential elements, there is a certain amount of interstitial and supporting connective tissue. A transverse section of the spinal cord shows it to consist of two distinct parts—

1. External *White Matter*, consisting chiefly of nerve-fibres. The two halves of the cord are connected by a certain amount of this matter, passing across the bottom of the anterior fissure, forming the *White* or *Anterior Commissure*. Surrounding and passing between the fibres is a fine network, or *neuroglia.*

2. Internal *Grey Matter*, containing large numbers of nerve-cells. It is somewhat crescentic in shape in each half. From the ends of the crescent—the *cornua* or *horns*—spring the roots of the spinal nerves. The two halves are connected by a thin strand of grey matter at the bottom of the posterior fissure. It is called the *Grey* or *Posterior Commissure*, and in its substance is a

fine canal—the *Central Canal of the cord*. This canal is lined with a layer of columnar ciliated cells. Above it communicates with the fourth ventricle of the brain.

Localisation of Nerve-cells in the Grey Matter. The nerve-cells are especially aggregated in three longitudinal groups—

i. In the anterior cornu forming the *Motor Ganglionic Column*.

ii. *Clarke's* or *Posterior Vesicular Column*, at the inner surface of the base of the posterior cornu. It is best marked in the dorsal region, but extends a short distance up into the cervical and down into the lumbar regions.

iii. *Column of the Intermedio-Lateral Tract* is situated in the middle of the concavity between the two horns. It is present only in the dorsal region.

Origin of the Spinal Nerves. Each spinal nerve springs from two roots, anterior and posterior. They pierce the dura mater separately, and the trunks of the nerves leave the vertebral canal by the intervertebral foramina. The fibres of the roots spring from the respective cornua of the grey matter. The exact course pursued by the fibres after entering the cornua is not thoroughly known. Some end directly in the cells of the anterior cornua; others pass to the opposite cornua; and others again find their way by the commissures to the other half of the cord.

Functions of the Spinal Cord—

The two great functions of the spinal cord are (1) the conduction of impulses to and from the brain and spinal nerves, and to and from different parts of the cord; (2) a centre of reflex action. These two functions are correlated with its structure, for whilst the former is largely, if not wholly, the property of the white matter, the nerve-cells of the grey matter alone form the reflex centres.

A. Conductor of Impulses—

The spinal cord conducts nervous impulses to and from the brain and spinal nerves. This fact, and the paths followed by the impulses are shown by the following experiments—

1. *Transverse section of one-half of the cord* is followed by—
   - *a. Loss of Voluntary Movement*, or Paralysis, on the same side in all parts supplied with nerves originating below the point of section.
   - *b. Loss of Sensation*, or Anæsthesia, on the opposite side of all parts supplied with nerves from below the point of section.
2. *Longitudinal median section* causes—

Loss of Sensation on both sides of all parts supplied with nerves from that part of the cord cut, but no paralysis is produced on either side.

These Experiments show that—

1. *Motor Impulses* pass down the cord on the same side as that from which they are emitted.
2. *Sensory Impulses*, as soon as they enter the cord, pass over to the other side, by which they pass up to the brain.

There has been much difference of opinion regarding the exact paths in the white matter of the nervous impulses. Probably the impulses pass up and down by the *lateral columns*—a view supported by the fact that they form the larger portion of the white matter, and also by their area increasing from bottom to top to an extent corresponding to the united sectional area of the spinal nerves. If this view is correct, the anterior and posterior columns are probably conductors between different parts of the cord.

The area of the grey matter varies according to the thickness of nerves given off. Hence it is much greater in the cervical and lumbar thickenings. This points to its intermediating directly between motor and sensory fibres entering it, or being segmental in its character.

B. Reflex Action—

A reflex action is essentially the conversion of afferent impulses into efferent ones by nerve-cells independently of the will or consciousness.

A reflex mechanism therefore consists of three parts—(1) an afferent nerve, (2) an efferent nerve, (3) a centre connecting 1 and 2. It is in virtue of the spinal cord containing many of these centres that it plays so important a part in reflex actions.

A **Nerve-centre,** here as elsewhere, may be defined as a collection of nerve-cells endowed with the power of controlling or modifying some action or function of the body, either automatically or as the result of the arrival at it of afferent impulses.

In the *modus operandi* of the reflex mechanism the resulting act is dependent on the strength of the afferent impulses, but more so on the nature of the changes taking place in the reflex centre. Reflex actions are very common in the human body, and are of a very useful and purposeful nature. The following examples are indicative of this: Winking, coughing, laughing, swallowing, vomiting, movements from irritation of the skin by an injurious object, contraction of pupil by light.

Primary and Secondary Reflex Actions. Such acts as swallowing, coughing, sucking, &c., are performed independently of volition from the earliest period of life, and are sometimes called *Primary Reflex Actions*, in contradistinction to those acts which for their performance in the first instance require an effort of will, or even repeated volitions, amounting in some cases to an education. Such actions, only after a time becoming reflex, are termed *Secondary* or *Acquired Reflex Actions*. Walking and other more complicated movements are examples.

The evidence showing the spinal cord to be a seat of reflex action is of two kinds—

1. *Experimental.* It is well and easily demonstrated in a frog from which the brain has been removed. The animal is destitute of all voluntary movement, but—

a. If the flank be tickled, a contraction of the flank muscles of that side will take place.

b. If one side be sharply pinched, the leg of the same side will be drawn up and swept over the spot pinched.

c. A piece of blotting-paper moistened with strong acetic acid and placed on the flank will cause the leg of the same size to be raised and swept over it so as to remove the paper.

d. (i.) If the animal be suspended by a hook and the tip of one of the toes be gently pinched, the leg is at once drawn up.

(ii.) If one of the toes be dipped in dilute sulphuric acid, the same result *after a time* occurs. This experiment is explainable on the assumption that the centre stores up weak impulses, each one of which is individually not strong enough to cause the discharge of an efferent impulse, until their combined influence is sufficient to cause the movement. This is called a *Summation* of stimuli.

2. *Pathological.* If by accident or disease the spinal cord is severed from the brain above, stimulation of afferent nerves, although producing no effect on the consciousness of the individual, causes distinct and very complex movements.

Modification of Reflex Action. The importance of the centre as a part of the reflex mechanism is strikingly shown by the profound modification of certain reflex acts produced by nervous impulses affecting the condition of the centres concerned in their production. This modification may be in the direction of stopping or slowing the action (*inhibition*), or of quickening or intensifying it (*augmentation*).

Inhibition.—The following illustrate this :

a. When the *Brain* of a frog is removed reflex action takes place more readily than before. Hence it is assumed that the brain by sending down impulses to the centres of the spinal cord inhibits them. The greater ease with which reflex action occurs in *sleep* illustrates the same point.

b. Crystals of sodium chloride placed in the *Optic lobes* of a frog retard reflex action.

c. Strong stimuli applied to any sensory nerve may inhibit reflex action.

The action is analogous to the *Inhibition of the Heart-beat* caused by stimulation of the vagus nerve (*vide* Lecture X.).

Cold lengthens the time of a reflex action, no doubt, by diminishing the excitability of the centre. *Potassium Bromide*, *Hydrate of Chloral*, and *Atropin* act in an analogous manner.

Augmentation. The possibility of this modification is inferred from the remarkable effect of *Strychnin.* This poison causes the excitability to be so increased that the slightest afferent impulse causes all the reflex centres in the cord to discharge efferent impulses, so that the body is thrown into convulsions. The action may be compared to that of the *accelerator nerves* on the beat of the heart (*vide* Lecture X.).

Time taken for Reflex Action. The changes in the centre occupy ·0555 to ·0471 second.

Ganglia.—In addition to the sympathetic ganglia already referred to, there are *four ganglia in the skull.* These are connected with the sympathetic system, and are hence sometimes included in it. They are—

Ophthalmic or Ciliary Ganglion, situated in the orbit. It is very small, no larger than a pin's head. It has a motor root from the third nerve, a sensory root from the fifth (nasal branch of the ophthalmic division). It is also connected with Meckel's ganglion and with the cavernous plexus, and sends ten to twelve short ciliary nerves to the iris and ciliary muscles.

Spheno-palatine, or Meckel's Ganglion, the largest of the four, triangular in shape, of a reddish colour, is situated in the spheno-maxillary fossa, near the spheno-palatine foramen. Its motor root is from the facial nerve, its sensory from the fifth (spheno-palatine trunk). From it nerves pass to the periosteum of the orbit, to the gums, hard and soft palate, uvula, tonsils, mucous membrane of nostrils and part of pharynx, middle auditory meatus.

Otic Ganglion, oval in shape, is situated just below the foramen ovale. Its motor root is from the facial, and its sensory from the fifth and ninth. It sends nerves to the mucous membrane of the tympanum and Eustachian tube, tensor tympani and palate, and to the cavernous plexus.

Submaxillary Ganglion, situated on the submaxillary gland, is roundish and reddish-gray in colour. Its motor root is from the corda tympani branch of the facial, its sensory from the lingual branch of the fifth, nerve. It sends nerves to Wharton's duct, mucous membrane of the mouth, and to the submaxillary gland.

Physiological Classification of Nerve Centres.—*Nerve Centres* may be said to be *of two kinds:* (1) *Reflex*, (2) *Automatic.* The former are well seen in the spinal cord. It is doubtful whether the latter are present at all in that structure.

It is doubtful whether either reflex or automatic centres are present in the ganglia of the sympathetic or in those just referred to. Considering the presence in these ganglia of nerve-cells and their connection with so many nerves, it would be expected, *a priori*, that they would act as centres. There is, however, very little conclusive experimental evidence on the point. The same applies to the much smaller ganglia found in the heart, intestines, &c. The *Submaxillary ganglion* has been supposed to be a centre of reflex action; the movement of the *Heart* to be due to the *automatic* activity of the microscopic ganglia in its muscular substance; the peristaltic action of the *Intestine* to microscopic ganglia in its walls; the contraction of the arteries to nerve-cells in the vascular walls.

In none of these cases, however, can the evidence be said to be absolutely conclusive, and the question as to how far these ganglia are nerve-centres—reflex or automatic—requires further elucidation.

LECTURE XIX.

NERVE-CENTRES—THE BRAIN.

The Brain.—White and grey nervous matter arranged so as to form an organ of great complexity constitutes the brain, or encephalon. Roughly speaking, the brain may be said to consist of:

1. The *Cerebrum*, or large brain.
2. The *Cerebellum*, or small brain.
3. The parts connecting these with the spinal cord. Of these the most important is the *Medulla oblongata*, or the small portion directly continuous with the spinal cord.

General Arrangement of Parts.—A general idea of the arrangement of the several parts of the brain can perhaps best be obtained by tracing the course of the nerve-fibres from the spinal cord below to the surface of the brain above.

The fibres of the spinal cord pass up into the *Medulla oblongata*, which is its direct continuation. In their course, immediately above the medulla, the fibres are interrupted by others placed transversely. These cross fibres connecting the two halves of the *Cerebellum* are sufficiently numerous to cause a considerable projection just above the medulla. This projection is called the *Pons Varolii.*

Above the pons varolii the fibres spread out somewhat, so as to form two large masses diverging slightly from one another. These are the *Peduncles of the Brain*, or *Crura Cerebri.*

The crura cerebri lose themselves largely in two masses on either side containing a great deal of grey matter. These so-called basal ganglia are placed one in front of the other. The anterior are the *Corpora striata*, the posterior the *Optic thalami.* Some of the fibres pass directly to the surface through the *Internal capsule*, situated between the optic thalamus and the outer nucleus of the corpus striatum.

From the basal ganglia fibres radiate, forming the main internal white matter of the *Cerebral Hemispheres*, and terminate in the convoluted layer of grey matter forming the *Convolutions*.

The most important parts of the brain may be said, then, to be four, viz.: (1) Medulla oblongata, (2) Cerebellum, (3) Basal ganglia; (4) Convolutions of the Cerebrum.

It will be most convenient to consider first the structure of these several parts, and then their functions.

Structure of Parts—

Medulla Oblongata is pyramidal in shape, with its broad end upwards. Its dimensions are: Length, $1\frac{1}{4}$ inch; breadth, 1 inch; depth, $\frac{3}{4}$ inch. In structure it roughly resembles the spinal cord, having anterior and posterior fissures, internal grey and external white matter. The anterior fissure extends up to the pons varolii. The posterior fissure becomes lost above by the back of the medulla opening out to form the lower half of the *fourth ventricle* of the brain a space continuous below with the central canal of the spinal cord. On the floor of the fourth ventricle the grey matter of the medulla is exposed to view. The roof of this part of the fourth ventricle is formed by a thin membrane consisting of pia mater lined with a layer of epithelium.

On either side of the anterior fissure, just below the pons, are two slight projections of white substance called the *anterior pyramids*. These are of great importance, because in them a considerable number of the fibres coming up from the spinal cord cross to the other side before proceeding to the higher parts of the brain. This crossing of fibres is known as the *Decussation of the Pyramids*.

From each side of the medulla a large bundle of fibres, the *Restiform bodies*, passes to the cerebellum constituting its inferior peduncles.

Cerebellum (*Hind* or *Little Brain*).—Dimensions, $4 \times 2\frac{1}{2} \times 2$ inches. It consists of a *body* and *three pairs of peduncles*, or crura, by which it is connected with the rest of the cerebro-spinal axis. The *Peduncles* are (1) *superior* to the cerebrum, forming the sides of the upper half of the fourth ventricle; (2) *inferior* to the medulla (restiform bodies); (3) *middle* to the pons varolii. All these pass into the cerebellum at its fore part.

The Body is composed of two lateral *Hemispheres* joined together by a central portion, the *Vermiform process*. Posteriorly the hemispheres are separated by a depression.

The *Surface* is laminated or foliar, the *laminæ* being nearly parallel.

Structure. Externally there is a layer of grey matter; the white matter within has a curiously branched arrangement, hence the term *arbor vitæ* applied to it. Within the white matter is a small nucleus of grey matter, from its irregular contour termed the *Corpus dentatum.* The *grey matter of the surface* consists of an *outer layer* containing small cells and fibres, and an *inner or granule layer*, largely composed of closely-packed, granule-like cells, $\frac{1}{4000}$th to $\frac{1}{2500}$th inch in diameter. Between these two strata is a single layer of large, highly characteristic cells, the *cells of Purkinje.* They are pear-shaped, $\frac{1}{1800}$th to $\frac{1}{1000}$th inch in diameter, and send processes into both the internal and external layers. In the latter the processes are large and much branched, the branches being connected with the small cells there present.

Pons Varolii forms a projection immediately above the medulla, due to its containing, in addition to the longitudinal fibres on their way to the upper parts of the brain, transverse fibres connecting the two hemispheres of the cerebellum. The transverse fibres are external. Internally there is a strand of grey matter continuous with that of the medulla. Its posterior surface forms the floor of the upper half of the fourth ventricle, the roof here being formed by the valve of Vieussens.

Crura Cerebri.—Each peduncle is divisible into two parts: (1) the *Crusta*, or anterior; (2) the *Tegmentum*, or posterior portion. Between the two is a mass of grey matter, the *Substantia nigra.* The crusta is composed of fibres coming up from the medulla (pyramids), terminating largely in the internal capsule. The tegmentum is composed both of grey matter continuous below with that of the pons and medulla, and of fibres passing above into the optic thalamus. In it also are the fibres from the superior peduncle of the cerebellum. Between the diverging peduncles are the posterior perforated space and the corpora mamillaria.

Corpora Quadrigemina.—Behind the crura cerebri, separated from them by the *aqueduct of Sylvius*, are four hemispherical masses of grey and white matter, arranged in two pairs, anterior and posterior, called the corpora quadrigemina. They correspond to the optic lobes of the brain of lower vertebrates. The anterior pair is connected by fibres with the optic tract.

Basal Ganglia—

Corpus striatum is situated in front and to the outer side of the optic thalamus. It is a large ovoid mass of grey matter streaked with white (hence the name). The greater part of it is embedded in the white substance of the hemisphere, whilst a portion of it comes to the surface in the lateral ventricle. There is thus an intra-ventricular (*nucleus caudatus*) and an extra-ventricular portion (*nucleus lenticularis*). Between the latter and the optic thalamus is a mass of white matter called the *Internal Capsule;* it is composed of fibres passing direct from the crus to the convolutions of the cerebrum.

Thalamus opticus is oval in shape and rests on the peduncle of the cerebrum. The upper surface is white, free, and prominent: in front it is seen in the lateral ventricle. It forms the side of the third ventricle, the grey matter of the two thalami being connected across that cavity by the soft commissure of the third ventricle.

Cerebral Hemispheres—

When looked down upon from above, the cerebrum or large brain covers all the rest of the encephalon. It consists of two symmetrical halves separated by the *great longitudinal fissure.* This fissure passes quite through to the base, both before and behind. In the middle it is interrupted by a large cross mass of white substance, or *Corpus callosum*, which connects the two hemispheres together. The great internal mass of the cerebrum consists of white matter; the layer of grey matter on the surface is often called the *Cortex.*

Surface. It is convoluted, being folded upon itself to form the *Convolutions*, or gyri, marked off from one another by depressions, or *Sulci.* There is thus a great increase of surface, and consequently of grey matter, without increase of size. Into the sulci passes the *Pia mater*, a fine vascular membrane closely investing the surface of the brain, and continuous with the membrane of the same name on the spinal cord (*vide* Lecture XVIII.).

Lobes. The surface is again marked off into five lobes by deeper depressions, or fissures. The lobes are: (1) *Frontal*, or anterior; (2) *Parietal*, or middle; (3) *Occipital*, or posterior; (4) *Tempora-sphenoidal*, or lower; (5) *Central*, or island of Reil.

Fissures. There are three primary or interlobar fissures:

1. *Fissure of Sylvius*, between the temporal and frontal lobes.
2. *Fissure of Rolando*, between the frontal and parietal lobes.
3. *Parieto-occipital,* between the two lobes indicated by the name.

Structure. The internal white matter consists of great numbers of fibres diverging in a fan-like fashion, hence termed the *Corona radiata.* Also of commissural fibres connecting different parts of the cortex of the same hemisphere, and fibres passing to the other hemisphere by the corpus callosum. In the external *grey matter*, $\frac{1}{8}$th to $\frac{1}{4}$th inch in thickness, several strata can be distinguished of alternate lighter and darker colour, due to the different nature and arrangement of the constituent nerve-cells. The most characteristic cells are those forming a thick stratum in the middle part. They are pyramidal in shape, with a large nucleus. They measure $\frac{1}{1800}$th inch across at the base. The cells of the cortex differ in size in different parts, an interesting fact in connection with the question of the functions of the cortex (*vide* Lecture XX.). For example, in the region of the fissure of Rolando (motor centres) the cells are large; in the occipital lobe (sensory region) they are smaller.

The cortex is very abundantly supplied with bloodvessels.

Membranes of the Brain—

Dura mater is a strong, thick connective-tissue membrane, closely attached to the inner surface of the skull. It sends three projections or partitions inwards into the cavity of the skull, viz., (1) the *Falx cerebri*, vertically between the two cerebral hemispheres, extending nearly to the corpus callosum; (2) the *Tentorium cerebelli*, horizontally between the cerebrum and cerebellum; (3) the *Falx cerebelli*, vertically between the hemispheres of the cerebellum. The dura mater consists of two distinct layers, which, becoming separated in certain definite positions, leave spaces termed *Sinuses*, containing blood. There is one along the upper border and another along the lower border of the falx cerebri (superior and inferior longitudinal sinuses). Along the line of attachment of the tentorium cerebelli to the occipital bone is the lateral sinus, and of the falx cerebelli the posterior occipital sinus. Internally the dura mater is lined with a layer of epithelioid cells.

Pia mater is a delicate, highly vascular membrane, closely investing the surface of the brain. It dips into all the sulci. It also passes into the interior of the brain (at what is called the transverse fissure) to the lateral ventricles, over the third ventricle, forming the velum interpositum. It forms also the choroid plexuses. Similarly below it forms the roof and choroid plexuses of the fourth ventricle.

Arachnoid is for the most part in contact with the pia mater, but it does not pass down into the sulci.

The space between the dura mater and arachnoid is called *subdural;* that between the arachnoid and pia mater the *subarachnoid.* The latter communicates with the ventricles of the brain. It contains a liquid, the cerebro-spinal fluid.

Ventricles of the Brain—

The *Fourth ventricle*, bounded in front by the medulla oblongata and pons varolii, and behind by the pia mater and valve of Vieussens, ends above in a small canal, the *aqueduct of Sylvius*, situated between the corpora quadrigemina behind and the crura cerebri in front. At its other extremity this canal opens into a cavity, the *Third ventricle*.

The sides of the third ventricle are formed by the optic thalami, the floor by the *infundibulum*, a funnel-shaped structure, the roof by the *velum interpositum* and *pineal gland*. The third ventricle communicates in front by a Y-shaped aperture, the *foramen of Monro*, with two large cavities, one in each half of the cerebrum.

These are the *Lateral ventricles*. Each lateral ventricle, besides a central part, or *body*, situated beneath the corpus callosum, has an *anterior cornu* descending into the frontal lobe, a *descending cornu*, and a *posterior cornu* in the occipital lobe.

The *Fifth ventricle* is a small cavity situated in the septum lucidum, or delicate double partition between the two lateral ventricles, extending from the corpus callosum above to the body of the fornix below.

The *Fornix* is a longitudinal mass of fibres connecting the anterior and posterior parts of the brain. It is a longitudinal, as the corpus callosum is a transverse, commissure. Its *body* rests upon the velum interpositum, and proceeding from it in front are two *anterior pillars* which arch downwards, and two *posterior pillars* behind, passing down into the descending cornua of the lateral ventricles.

Development—

An acquaintance with the development of the brain makes it easier to understand and remember the somewhat complicated arrangement of its parts.

The brain is developed from what are known as the **cerebral vesicles** in the embryo. They are three in number: anterior, middle, and posterior. These vesicles are transformed into the fore, mid, and hind brain respectively, and the remains of their cavities form the ventricles of the brain.

Anterior Vesicle.—From this are developed the different parts of the *fore brain*. Two hollow prolongations are formed in front, from which are developed the *cerebral hemispheres*. A secondary budding gives rise to the *olfactory lobes*. The outer and under walls of these prolongations thicken to form the *Corpora striata*. Their cavities form the lateral ventricles. The body of the original vesicle forms the *third ventricle* and structures surrounding it, viz., from—

Floor, the *Infundibulum.*
Roof, the *Pineal Body.*
Sides, thicken greatly to form the *Optic thalami.*

Middle Vesicle is modified to form the *Mid brain.*
Roof forms the *Corpora quadrigemina.*
Floor forms the *Crura cerebri.*
The Cavity is transformed into the *aqueduct of Sylvius.*

Posterior Vesicle develops into the *hind brain*, consisting of the *Medulla oblongata* and *Pons varolii* in front, and the *Cerebellum* behind. Its cavity becomes the *fourth ventricle.*

Comparative Anatomy—

In the lowest-known vertebrate (Amphioxus) there is no difference observable between the spinal cord and brain.

The *Optic Lobes* (mid brain) are highly developed in *Fishes* and *Amphibia*, being as large as, or even larger than, the cerebral hemispheres. In *Reptiles* and *Birds*, although still considerable structures, they are by no means so prominent as the cerebrum, This is specially so in Birds. In *Mammals* this portion of the mid brain is reduced to very small dimensions. Four bilaterally-placed small rounded elevations, the *Corpora Quadrigemina*, represent it.

The *Cerebellum* is represented in the lowest *Fishes* and *Amphibia* by a narrow band. In *Reptiles* it is a little larger, and in *Birds* is of considerable size and laminated externally; it is the central part only (vermiform process), and hence there is no pons varolii. It is, however, quite uncovered by the cerebrum. In *Mammals* it becomes more complicated as we rise in the series.

The *Cerebral Hemispheres* increase in size as we rise in the vertebrate scale. In *Mammals* the changes are chiefly connected with the increased development and complexity of the *cerebral convolutions*. As they increase in size the *olfactory lobes* diminish. At the same time the cerebrum extends backwards until the cerebellum is completely covered by it. The surface, at first plain, becomes convoluted, and (with reservations) the convolutions may be said to increase in number, depth, and complexity as the intelligence of the animal increases. The increase in the number of the convolutions indicates an increase in the quantity of grey matter.

Male and Female Human Brain. The comparison of the weights of the brain and body of a great number of adults of both sexes, and the study of these relations at different stages of life, go far to support the view that the difference in weight between the male (48·2 oz.) and the female (43·09 oz.) is simply an expression of the difference in weight of the bodies.

Cranial Nerves.—There are twelve on either side from before back, as follows:

1. *Olfactory* (nerve of smell).
2. *Optic* (nerve of sight). The roots of the two nerves join soon after leaving the skull, forming the optic chiasma.
3. *Oculo-motor*, to all muscles of eye-ball except external rectus and superior oblique. To circular muscular fibres of iris and to ciliary muscle.
4. *Trochlearis*, to superior oblique muscle.
5. *Trigeminus*, a great mixed nerve arising, like a spinal nerve, by two roots—a motor and a sensory. On the latter is a ganglion (Gasserian ganglion). It divides into three great branches: (1) Ophthalmic; (2) Superior maxillary; (3) Inferior maxillary.
6. *Abducens*, to external rectus muscle.
7. *Facial*, to muscles of the face; is hence nerve of expression.
8. *Auditory* (nerve of hearing).
9. *Glossopharyngeal*, a mixed nerve to tongue and pharynx (nerve of taste).
10. *Pneumogastric*, or *Vagus*, a mixed nerve; *efferent* fibres to pharynx, larynx, œsophagus, stomach, intestines, heart (inhibitory); *afferent* fibres to air-tubes, pharynx, gullet, stomach, vasomotor and respiratory centres.
11. *Spinal Accessory*, to sterno-mastoid and trapezius muscles. It receives sensory fibres from cervical nerves. Part of it joins the vagus, giving it efferent fibres.
12. *Hypoglossal*, to muscles of tongue and most of muscles connected with hyoid bone. It is connected with the fifth and vagus, three upper cervical, and sympathetic nerves.

LECTURE XX.

NERVE-CENTRES—FUNCTIONS OF THE BRAIN.

Functions of the Brain.—The functions of the brain are very varied and of the highest importance; for besides being the seat of volition and the psychical faculties, the most important functions of the body are dependent upon and are controlled by nervous impulses descending from this portion of the cerebro-spinal axis. The proofs that the *brain is the organ of mind* have been well summarised by Bain as follows: "1. The physical pain of excessive mental excitement is localised in the head. 2. Injury or disease of the brain affects the mental powers. 3. The products of nervous waste are more abundant after mental excitement. 4. There is a general connection between the size of brain and mental energy. 5. By specific experiments on the brain and nerves, it is shown that they are indispensable to mental functions."

Medulla Oblongata.—This small partion of the brain is of importance in three ways:

1. As a *conductor of impulses.* All impulses passing up and down between the spinal cord and the higher parts of the brain must pass through the medulla. Many of the descending *motor* impulses cross by the decussation of the pyramids. Hence it follows that injury to one side of the brain causes paralysis on the opposite side of the body.

2. All the *Cranial Nerves*, except the olfactory, optic, third and fourth, have their ultimate or *deep origin* in the grey matter of the medulla oblongata. Of these the *Vagus*, or *Pneumogastric*, is the most important, for it is most intimately associated with the three important functions of circulation, respiration, and digestion.

3. It is the seat of very important **nerve-centres.** Amongst these are the centres presiding over and controlling the functions of circulation and respiration (*respiratory and vasomotor centres*). Injury to a certain small part of the medulla between the vaso-motor centre and the calamus scriptorius causes respiration to

cease. The heart's beat is usually at the same time stopped, due to the vagus nerve being connected with the medulla close to this point (*cardio-inhibitory centre*). Death in consequence instantaneously ensues on this spot being injured. For this reason it was termed the *nœud vital* by Flourens. The vasomotor centre extends for about 3 mm. on the floor of the fourth ventricle, from about 5 mm. above the calamus scriptorius to within 2 mm. of the corpora quadrigemina. Besides the foregoing centres there are others connected with *Swallowing*, *Digestion*, and *Secretion*.

Cerebellum—

Physiological experiment (as by injury, removal, and electrical stimulation) and the facts of comparative anatomy and disease point to the cerebellum as being a centre for the **co-ordination of movement** necessary for the **maintenance of equilibrium.**

a. Injury. Injuries cause the movements to be disorderly, and a greater effect is produced when they are lateral or unsymmetrical. Lateral injury gives rise to lateral movements. Injury to the anterior or posterior median portions causes the animal to fall forwards or backwards respectively.

b. Removal. The centre is deep-seated, for the greater the amount removed the more lasting the effect.

c. Electrical Stimulation. Ferrier has shown that electrical stimulation of the surface causes movements of the eyes, and sometimes of the head and limbs. He considers that his results "are such as to bring out the relation of the ocular movements to those necessary for the adjustment of equilibrium generally". They also support the view that the centre in the cerebellum is affected by visual impressions.

Physiological experiment further goes to show that the centre is influenced by afferent impulses from the internal ear (*semicircular canals*), irritation of these structures causing similar results to direct irritation of the surface of the cerebellum. Lastly, the centre is affected by tactile and muscular impressions.

d. Comparative Anatomy. A comparison of different animals points to the conclusion that the cerebellum is developed in proportion to the variety and complexity of the movements of which the animal is capable.

e. Disease. Disease of the cerebellum has been observed to be associated with difficulty in co-ordinating the movements necessary for the maintenance of equilibrium.

Corpora Quadrigemina—

In the animal scale the development of the optic lobes varies directly as the spinal cord, and inversely as the cerebral hemispheres. Experiments by injury and electrical stimulation have failed to thoroughly demonstrate the functions of the corpora quadrigemina. There seems little doubt, however (as their connection with the optic tracts would indicate), that they are in some subordinate manner connected with vision, or at least with visual impulses. These visual impulses are thereby associated with the production of certain movements, *e.g.*, those of the iris and of accommodation.

Basal Ganglia—

It has been supposed that the *corpus striatum* is a *motor centre* for the emission of motor or efferent impulses, and the *optic thalamus* a *sensory centre* for the reception and elaboration of sensory or afferent impulses. In accordance with this theory these ganglia have been regarded as the centres in the cerebrum presiding over those manifestations of activity which take place independently of consciousness and volition; in other words, form a great reflex centre. Such actions are termed *sensori-motor*, in contradistinction to those taking place consciously when the convolutions are called into request, and known as *ideo-motor*.

The evidence, both experimental and pathological, bearing upon this theory is inconclusive. This evidence, however, together with their anatomical relations, points to the corpus striatum being more particularly associated with motor and the optic thalamus with sensory impulses. The localisation of distinct sensory centres in the optic thalamus (Luys) is not generally accepted. Possibly the optic thalamus is a centre of sub-conscious sensation, and the corpus striatum a motor centre corresponding to the motor region of the cortex, in which the different individual parts are less specialised.

Internal Capsule. Section of the anterior two-thirds causes paralysis of motion, of the posterior one-third loss of sensation on the opposite side.

Cerebral Hemispheres—

These are considered the seat of those faculties termed *mental.* Physiology and pathology agree in pointing to *consciousness* being inseparable from the activity of the cerebral hemispheres.

The definite determination of the functions of this important part of the brain has been attempted in several ways:

I. *Observing the* **Effect of Complete Removal.** Generally it may be said that this is followed by absence of sensation, ideation, and volition. The animal is reduced to a mere machine, its activity being called forth only as the result of external stimulation.

a. In a *Frog.* Its movements are just like those of a normal frog, but an external stimulus is required for their production. It maintains its normal position, moves when touched, croaks when its flanks are stroked, swims when thrown into water, and is affected by different degrees of illumination. From this it is evident that there is in some part of the brain, other than the cerebral hemispheres, a central nervous mechanism by which these complex movements can be performed, only some afferent stimulus is required to set this mechanism going. And we may assume as probable and plausible that in the normal animal voluntary movements are produced by this mechanism receiving impulses from the cerebral hemispheres above, and being thus set in action.

b. In a *Bird.* An absence of volition is observed, an external stimulus being required for the production of movement.

c. In a *Mammal.* Whilst volition is absent, movements are caused by tactile, visual, and auditory stimuli. It moves when touched, avoids objects casting a shadow, and follows a strong light with its head, and is affected by sounds. These facts are evidence, if at all, of sensation in only a very restricted sense of that term, for although stimulation of the sensory organs may result in movements, they are probably more akin to reflex actions than anything else. That the sensory impulses do not give rise to perception and ideas is evident from the fact that the animal is unaffected by food or any pleasant or terrible object.

The result of this mode of experimentation is *negative*, and applies to the cerebral hemispheres as a whole. The question may be asked, Does the cerebrum act as a whole, or have certain parts certain definite functions? Is there, in a phrase, a division of labour in the cerebral hemispheres?

Owing to the great influence of Flourens the view was long held that the cerebral hemispheres did act as a whole, and that removal of any part simply caused enfeeblement of all the functions. Scepticism of the justness of Flourens' conclusion has gradually increased, until at present it is very largely rejected. Facts which have tended to this end are—

(1) The very general association of aphasia with a definite part of the cerebral surface. (2) The association of limited paralysis

with limited injury. (3) The connection between epileptiform convulsions and the irritation of certain convolutions. (4) The effects of electrical stimulation of the cortex.

II. **Electrical Stimulation** of the grey matter of the convolutions. The experiments of Hitzig and Fritsch and of Ferrier have shown that there is a distinct connection between electrical stimulation of the cortex and movements. Stimulation of certain definite areas of the cortex by an electric current is followed by definite movements involving the co-ordination of several distinct muscular contractions, and are similar to those produced as the result of volition.

Ferrier, as the result of his numerous and elaborate experiments, has mapped out a considerable portion of the cerebral surface into series of well-defined areas, electrical stimulation of each of which gives rise to a definite movement. These areas he terms **motor centres.** They are chiefly situated around the fissure of Rolando, and the portion of the surface embracing them is known as the *motor region*. These motor centres have a definite and interesting relation to one another, as regards the movements with which they are associated, viz., that the lowest centres are those for the movements of the mouth, tongue, and face; next above these come the centres for the upper limbs, and at the top those for the lower limbs; in the marginal convolution within the great longitudinal fissure are centres for the muscles of the trunk.

Notwithstanding Ferrier's remarks that "the reactions produced by electrical stimulation of the cortex are definite and predictable, and vary with the position of the electrodes—areas close together give different results, certain areas no result," his theory of *localisation of function* in the convolutions, as far as motor centres are concerned, must be taken only in a restricted sense. From I., *a. b. c.*, it is seen that the most complex and elaborate movements may take place in the absence of the cortex, provided there be suitable external stimuli. It is, therefore, plain that the cortex cannot contain motor centres in the sense of being essential to the production of the particular movements with which electrical stimulation shows them to be associated. We may assume, however, that they are the centres called into activity when those movements are produced voluntarily, and to them the term *psychomotor* (which Ferrier has suggested) would be very appropriate.

If the conclusion that these areas are motor centres is correct, we should expect that removal of them would cause paralysis of the movement resulting from their electrical stimulation.

III. **Removal of definite parts** shows that such is the case. When an area corresponding to a motor centre is destroyed, paralysis of the movements caused by its electrical stimulation ensues. Removal of the whole motor region causes general paralysis. This applies to animals, especially the monkey. Of the human body Ferrier says: "There is not on record a single unequivocal case of destruction involving the motor area unaccompanied by paralysis of greater or less extent or limitation; while, on the other hand, there is not another region of the brain which has not been the subject of destructive lesion times without mention, without any motor paralysis whatever".

In some animals the paralysis, after a time, largely, if not altogether, disappears. The recovery is not due to the vicarious action of the same centre of the other hemisphere, for on its removal the paralysis does not return. This question of *recovery* is the chief obstacle in the way of the acceptance of the theory of motor centres. It has been held by some to be fatal to the theory, but Ferrier goes a long way towards removing the objection when he says: "The more the movements are dependent on conscious discrimination and volitional impulse, the more marked and enduring is the paralysis resulting from lesion of the centres . . . the more independent movements are most affected. The varied and delicate movements of the hand are most of all impaired, and are the last to be re-established." In monkeys, he says: "There is not recovery of movements dependent on intelligent volition". Hence the appropriateness of the term *psycho-motor* as applied to these centres.

Sensory Centres.—Removal or destruction of other areas causes loss of sensation. These areas have consequently been termed Sensory Centres. Destruction of the angular gyrus and occipital lobe was followed by loss of sight. This area is hence called the *visual centre.* On similar grounds the *auditory centre* is localised in the superior temporo-sphenoidal convolution. Greater difficulty has been experienced in localising the centres for the remaining special senses. In the case of smell and taste this partly arises from the difficulty of obtaining certain evidence of their absence. Ferrier localises the *olfactory centre* in the hippocampal lobule, and this is supported by its relation to the olfactory nerves, and by the fact that electrical stimulation of this part causes torsion of the lip and nostril on the same side. The *gustatory centre* he places at the lower extremity of the temporo-sphenoidal convolution, an area electrical stimulation of which is followed by movements of the lips, tongue, and cheeks. The *tactile centre*, lastly, is located in the falciform lobe, but no differentiation of this into centres for touch for the different parts of the surface of the body has been made out.

IV. **Disease**—

Localisation of function in the cortex is strongly supported by the disease known as *Aphasia*, which has for a long time been known to be associated with disease of the posterior portion of the third frontal convolution, sometimes called Broca's convolution.

Injury to the cortex from disease or from a fall has often been observed to be followed by convulsions or paralysis of movements corresponding to those resulting from electrical stimulation of the same part. In other words, the convulsions or paralysis arise from stimulation or destruction of the appropriate centres. The theory of localisation has thus enabled the seat of injury of the cortex to be diagnosed, which in some cases has been followed by successful surgical operation.

LECTURE XXI.

SENSATION—TOUCH.

Definition of Sensation.—Physiologically, sensation may be said to be the modification of consciousness following on physical changes taking place in the brain as the result of the arrival at it of sensory impulses. Furthermore, under normal conditions, these sensory impulses are always the result of the stimulation of a definite terminal organ, in which the sensory nerve ends at its distal extremity. These terminal organs are the organs of special sense.

Sensiferous Apparatus.—The sensiferous apparatus or mechanism necessary for the production of normal sensations consists, therefore, of three parts: (1) *Brain*, (2) *End-organ*, (3) a *Sensory nerve* connecting (1) and (2). The *modus operandi* of the apparatus is that an external agent acting upon the end-organ stimulates it in such a manner that sensory impulses pass from it up the nerve to the brain; on arriving there, they cause physical changes within it, producing those modifications of consciousness we call light, hearing, smell, taste, and touch. The brain is the essential part of the apparatus, and, under certain circumstances, sensations may be produced in it independently of the nerve and end-organ (*subjective sensations*). The end-organ and nerve are subsidiary parts of the apparatus especially adapted to enable a particular external agent to produce certain definite physical changes in the brain.

Pain is the strong, unpleasant sensation resulting from the intense stimulation of a sensory nerve. Sensations of pain are not referred to an external object as ordinary sensations are.

Classification of Sensations.—The foregoing description does not include all sensations—not those, *e.g.*, which are of a vague and general character, and are not caused by the stimulation of any external agent. Sensations may hence be arranged in three classes—

1. *Special sensations*, produced by the stimulation of some organ of special sense.

2. *General sensations*, in which the sensation is not referred to any particular locality, nor is there any consciousness of the particular agent producing the sensation. Fatigue, exhaustion, faintness, dejection, are examples.

3. *Internal sensations* are those which result from the stimulation of certain internal organs of the body to which they are more or less referred. Thirst and hunger are referred more or less distinctly to the digestive organs, though they arise from a general want all over the body. They may be said to be intermediate between special and general sensations. Suffocation, and, less distinctly, the exhilaration from inhaling an invigorating atmosphere, are referred to the respiratory organs. Repletion, indigestion, and nausea are referred to the organs of digestion.

Law of Eccentric Sensation is applied to special sensations being referred to the sense-organs at the terminations of the nerves, *i.e.*, to the point where the external agent acts, notwithstanding that the sensation really occurs in the brain on the arrival there of the sensory impulses. This is strikingly illustrated by the effect of stimulation of the nerve stump of an amputated limb. To explain this, it seems necessary to assume that the imaginative faculty is entirely formed by experience.

Limen.—A stimulus acting upon the end-organ must reach a certain intensity before it can be felt, or, in other words, give rise to a sensation. This minimum intensity is termed the *limen*. It is constant in the same individual. This intensity of stimulus must be increased a certain proportional amount before a difference in its intensity can be appreciated, or, in other words, a different sensation can be produced. The necessary increase, or *sensible increment*, is proportional to the previous stimulus. The ratio of the sensible increment to the previous stimulus differs in different cases—*e.g.*, for light, it is 1 to 100; for sound only, 1 to 3; for touch, 1 to 30.

Touch.

The End-organ is situated on the surface of the body, especially in the skin, for the structure of which *vide* Lecture III. The sensory nerves to the surface of the body have been observed to terminate in the following structures:

Tactile corpuscles, situated in the papillæ of the skin. They are oval bodies, $\frac{1}{300}$th inch long and $\frac{1}{800}$th inch broad. One or more nerve-fibres enter each corpuscle. The corpuscle appears transversely marked, due partly to the coiling around it of the fibre on its way to the top of the corpuscle, and partly to an external covering of connective tissue with oblong nuclei placed transversely to the axis.

End-bulbs are spheroidal bodies, $\frac{1}{600}$th inch in diameter, found in the lips. They have a simple nucleated sheath continuous with the sheath of the fibre, and in the middle a soft granular core.

Pacinian bodies are large terminal structures at the extremity of sensory nerves in the fingers, toes, joints, &c. They are visible to the naked eye, being $\frac{1}{10}$th inch long and $\frac{1}{20}$th broad. Each body has a stalk in which a nerve-fibre passes to the centre or core of the corpuscle, which is surrounded by 40 to 50 membranous capsules, the inner being more closely placed than the outer.

Nerve plexuses. This mode of termination is well seen in the *cornea*, where the axis cylinders of the nerve-fibre divide and subdivide to form a very fine network or plexus.

Tactile Sensations may be arranged under the following heads:

Pressure.—Organs adapted for touching are endowed with mobility. When two or more sensations follow one another, as the result of stimuli applied to the same spot, at a sufficiently short interval, they are fused into one.

A pressure sensation quickly reaches its maximum, and immediately after decreases. The intensity of a sensation is affected by the pressure on contiguous parts—*e.g.*, a finger dipped in mercury.

The additional increment of pressure necessary to be felt, or, in other words, produce a new sensation, is for the fingers $\frac{1}{30}$th the previous pressure. It appears to be more for other parts.

Some parts of the skin are less sensitive to pressure than others. The greatest sensitiveness is on the forehead, temples, and back of hand and forearm; next the fingers; then the nose, chin, and abdomen.

Sensiferous Apparatus for Touch in its simplest form may be said to consist of (*a*) brain nerve-cell, (*b*) nerve-fibre, (*c*) tactile corpuscle. Its *modus operandi* will be that pressure in the skin stimulates the tactile corpuscle, causing an impulse to pass up the fibre to the nerve-cell in the brain. The impulse on arriving at the cell causes certain physical changes in the cell, of the nature of which we are entirely ignorant. All we know is that those changes are followed by the modification of consciousness we call touch. Whether the former is caused by the latter is probably at bottom a barren question. As far as we know the one never exists without the other, a connection which all analogy would point to being best explained as one of cause and effect. If we imagine that under certain circumstances the physical changes (say, molecular redistributions) produced in the cell by the nervous impulse on arriving at it, are rendered permanent or fixed, we have a physical basis of memory.

The *after effect* is very distinct, especially with heavy weights and after long application.

Temperature—

Although it is difficult or impossible to determine absolute temperature, a difference of $\frac{1}{4}°$ C. can be perceived through the finger. The more sudden the change in temperature of the skin, the more intense the sensation produced.

Those portions of the skin most sensitive to variation of pressure are not identical with those most sensitive to variation of temperature. This, together with the fact that nerve-trunks are not affected by heat, so as to give rise to the sensation of heat, has suggested that in the skin there are special end-organs for temperature alone, apart from pressure, and that they are connected with separate parts of the central organ by separate nerve-fibres. In other words, that there is a special sense of temperature. Pathological cases have also been brought forward in support of this view.

Locality—

When a portion of the skin is touched we are able with more or less accuracy to say where the spot touched is. We are able to *localise pressure sensations.* This power of localisation is not the same on all parts of the skin. This can be shown by experimentally determining how far apart two points applied to the skin must be to be felt as two—*i.e.*, give rise to two distinct sensations. The distances in the several parts of the body are as follows :—Tip of tongue, 1·1 ; finger tip, 2·2 ; centre of palm, 8 ; tip of nose, 6·6 ; cheek, 15·4 ; back of hand, 29 ; sternum, 44 ; back, 66 mm. If at these places the two points are nearer together than the above, they are fused into one ; they give rise to only one sensation. The experiments can be carried out with a pair of compasses, though a more elaborate apparatus has been devised for the purpose.

The two sensations are more easily produced the lighter the pressure ; on the other hand, they are distinguished with greater difficulty if there are pressure sensations being produced in neighbouring parts simultaneously.

Sensory circles are imaginary figures on the skin, within the circumference of any one of which two points give rise to only one sensation. They are smaller the more sensitive the part. They cannot be explained by assuming that one nerve-fibre supplies each circle. A more probable explanation is that there are a number of isolated fibres distributed to each sensory circle, and that a certain number of spaces supplied by these isolated fibres must intervene between the two points of irritation in order that a double sensation may be produced. The sensory circles vary in size at different times. Practice diminishes their size. The circles of the blind are smaller than those of other people. From this it is evident that the property of the skin of measuring the distance between two points is really a property of the brain. The sensory circles are not situated really in the skin, but in the brain. The improvement of the sense of touch by practice may therefore be explained by the sensory areas in the brain becoming more defined and restricted.

Muscular Sense—

In calculating the weight of a body there are two sensations involved—(1) sense of presssure, (2) the muscular sense. It is by aid of the latter especially that we are able to distinguish the difference in weights of bodies. A difference of one-fortieth can thus be distinguished. We are always conscious when we put forth muscular exertion. It is a question whether this consciousness results from changes taking place *in the first instance* centrally in the brain, or peripherally in some end-organ ; in other words whether there is or is not a true muscular sense. In favour of the former view may be adduced the following facts :

1. *Anatomical.* Afferent nerves have been shown to end in muscles in fine plexuses.

2. *Physiological.* (*a*) Muscular sense is experienced when muscles are thrown into contraction by electrical stimulation. (*b*) After section of the posterior roots of the spinal nerves movements have all the appearance of lacking the guidance of the muscular sense.

3. *Pathological.* (*a*) The keen pain experienced in *cramp.* (*b*) Loss of tactile sensibility while muscular sense still remains. (*c*) *Locomotor ataxy*, or impairment of power of co-ordinating the movements of the limbs, may occur without diminution of cutaneous sensibility.

LECTURE XXII.

SMELL—TASTE—VOICE.

The End-organ of Smell is the simplest of all the end-organs of the special senses. It consists of the mucous membrane lining the upper part of the nasal cavity. By the inward projection of two curved bones (*turbinate bones*), the nasal cavity is divided into three passages. The *olfactory nerve* is distributed only to the mucous membrane lining the two upper of these passages. Here the fibres of the olfactory nerve are believed to end in peculiar spindle-shaped cells (*olfactory cells*) situated between the ordinary columnar epithelium of the mucous membrane. These cells therefore constitute the real end-organ of smell. The olfactory nerve-fibres arise from the *olfactory lobes*, from which they pass to the nostrils by piercing the cribriform plate of the ethmoid bone. In order that they may excite the end-organ, the odorous substances must be in the form of gas or vapour, or at least be conveyed in a gaseous medium. The epithelium of the mucous membrane lining the lower (non-olfactory) portion of the nostril is ciliated.

Sensiferous Apparatus for Smell in its simplest form consists of (*a*) nerve-cell of brain, (*b*) nerve-fibre of olfactory nerve, (*c*) olfactory cell in nasal mucous membrane. Its *modus operandi*—an odorous particle stimulating (*c*), causes an impulse to pass up (*b*) to (*a*), producing in it physical changes followed by sensation of smell.

Sensations of Smell.—The delicacy of the sense of smell far surpasses that of the other senses. It has been calculated that $\frac{1}{300000000}$th of a grain of musk can be perceived.

Sensations of smell can only be roughly divided into pleasant and unpleasant. Most substances of an unpleasant odour are injurious to the animal economy.

Sensations of smell may be produced subjectively. Mental changes are more tenaciously associated with smell than with any other sense.

From the greater acuteness of the sense of smell in some animals there seems reason to believe that the larger the olfactory surface the more intense the sensations of smell.

The mucous membrane of the nose may as the result of excitation give rise to sensations other than those of smell; *e.g.*, ammonia excites the terminations of the fifth nerve distributed to the nasal mucous membrane.

TASTE.

The End-organ of Taste is situated in the tongue, a muscular organ covered with mucous membrane, which is looser and smoother on the under surface and at the sides. The mucous membrane has a thick stratified epithelium. Along the middle line on the upper surface is an irregular slight furrow, or *Raphe*, terminating about half-an-inch from the base in a depression—the *foramen cæcum* of Morgagni. On the upper surface are numerous **Papillæ** which gradually become smaller towards the edges, and are altogether absent from the under surface. The papillæ are of three kinds, viz., Circumvallate, Fungiform, Filiform or Conical.

1. *Circumvallate Papillæ.* These are the largest, and, seven to twelve in number, are arranged somewhat in a **V**-shaped manner, the arms meeting towards the foramen cæcum. They derive their name from the fact that each papilla is surrounded by a wall, or vallum, separated from it by a depression, or fossa. The epithelium is thick and stratified, and the substance of the papilla consists of dense connective tissue like that of the dermis. Along the sides of these papillæ, embedded in the thick epithelium, are oval or flask-shaped bodies called *taste-buds.* The base of each taste-bud rests upon the substance of the papilla, while the apex, appearing as an orifice when seen from above, emerges between the ordinary epithelium cells.

A **Taste-bud** is composed of two parts, viz.—

a. Cortical, or outer part, made up of long, flattened cells, with pointed ends, in contact by their edges. They extend from base to apex, and are called the *cover-cells.*

b. Central part, composed of spindle-shaped cells (*rod-cells*). The upper process of each rod-cell extends to the apex, and a fine styliform extremity projects at the orifice; the lower passes down to the substance of the papilla, where it is said to be connected with a plexus of fine nerve fibrils. In these rod-cells, then, we have the real end-organ for taste, and they are hence often called the *gustatory cells.* Taste-buds are also found on the fungiform papillæ, on the soft palate, uvula and epiglottis.

2. *Fungiform Papillæ.* These, as their name suggests, are narrowed at their point of attachment. They are most numerous at the apex and edges. They are red, being very vascular.

3. *Filiform Papillæ* are the most numerous and smallest. They are minute conical, tapering, or cylindrical eminences.

Nerve of Taste.—The base of the tongue is supplied by the *glossopharyngeal nerve*, which is connected at its terminations with the taste-buds. The back of the tongue is undoubtedly a seat of taste, and hence the glossopharyngeal is regarded as especially the gustatory nerve. The front of the tongue is supplied by the *lingual branch of the fifth nerve*, and it is regarded as the nerve of taste for that portion of the tongue.

Sensiferous Apparatus for Taste may be said in its simplest form to consist of (*a*) nerve-cell of brain, (*b*) nerve-fibre of glossopharyngeal nerve, (*c*) rod-cell of taste-bud. Its *modus operandi* will be that a sapid substance stimulating (*c*) causes an impulse to pass up (*b*), which on arriving at (*a*) causes in such changes as result in the modification of consciousness called taste.

Taste Sensations may be classified as *bitter*, *sweet*, *salt*, and *acid*. Those sensations which cannot be referred to one of these probably result from the combination of taste-sensations with those of smell and touch. The union of taste and smell gives rise to what is called the *flavour* of a substance.

In order that the end-organ may be stimulated it is essential that the stimulating substance be in solution. The larger the *surface* acted upon, the more intense the sensation. A temperature of 35° to 40° C. is that most favourable to the production of taste-sensations. Sensations of taste can be produced by stimuli other than sapid substances—*e.g.*, mechanical stimuli and the passage of an electrical current, when there is a sensation of acidity at the positive and of alkalinity at the negative pole.

The sense of taste is not so delicate as that of smell: $\frac{3}{100}$ths of a grain of sulphuric acid can be detected.

SOUND, VOICE, SPEECH.

As a preliminary to the study of the next sense, viz., Hearing, it is desirable to know something of the nature of *Sound*, its production and transmission, and especially of that kind of sound called *Voice.*

Sound—

Production of Sound. Sound is produced by the vibration of bodies, *e.g.*, *Air* (organ pipe), *Strings* (violin), *Membranes* (drum, vocal chords).

Propagation of Sound. Sound is transmitted through any elastic medium as waves or undulations. When the medium is the atmosphere these *sound-waves* consist of alternate condensations and expansions of the air. In an unenclosed medium, a series of spherical waves alternately condensed and rarified is produced around each centre of disturbance. Sound thus propagated travels at a *velocity* of 1100 feet per second.

Intensity of Sound varies inversely as the square of the distance of the sonorous body from the ear.

Classification of Sounds. Sounds are either non-musical (noises) or musical. The latter are termed *tones.* Tones are produced when the vibrations are periodical—*i.e.*, occur and recur at regular intervals. Tones are either simple or compound. *Compound tones* are produced by the union of vibrations of different rates of frequency.

Characteristics of Tones. A musical note or tone has three qualities—

1. *Intensity*, dependent on the amplitude or extent of the vibrations.

2. *Pitch*, dependent on the number of vibrations occurring in a given time.

3. *Quality*, or *Timbre*, due to the number, intensity, and relative preponderance of the harmonics or overtones which accompany the primary tones.

Harmonics. When any given note is sounded, not that tone only is produced, but a series of tones, each being of less intensity than the one preceding. These are called the *harmonics of the primary tone*; *e.g.*, if C, the primary tone, be represented by unity, then 1, 2, 3, 4, 5, 6, 7, &c., represents the whole series. The harmonies of the primary C are its octave, then the fifth to that octave, second octave, the third, fifth to the second octave, &c.

Voice—

Voice is produced by the vibration of the *vocal chords.* These are two elastic membranes situated in the larynx, the box-like expansion at the top of the trachea or windpipe.

The **Larynx** is composed of four cartilages, joined together by membranes and ligaments and connected by muscles. The cartilages are—

(1) The *Thyroid*, a large V-shaped cartilage, the open part being at the back. The point of the V in front forms what is felt in the neck as "Adam's apple". The posterior edges end above and below in projections termed the superior and inferior cornua. The superior cornua are connected by ligaments to the great cornua of the hyoid bone; the upper edge of the thyroid is connected by a ligament to the body of the hyoid.

(2) The *Cricoid*, situated below the thyroid, is in shape like a signet ring, the thicker portion being behind. Posteriorly it is partly overlapped by the sides of the thyroid, to which its upper edge is attached at the sides and in front by ligaments. Its lower edge is similarly connected to the first cartilage of the trachea. On the outer surface on each side posteriorly is a smooth depression where the inferior cornua of the thyroid is jointed. On the upper border of the deeper posterior part there is on either side of the middle line an articular surface to which are jointed

(3) and (4) The two *Arytenoid* cartilages. These are pyramidal in shape, the base of the pyramid entering into the aforesaid joint. Each arytenoid has three lateral surfaces—posterior, external, and internal, and at the base three angles—anterior, external, and posterior. *To the anterior angles are attached the posterior ends of the vocal chords, which are attached close together in front at the re-entering angle of the thyroid.* The arytenoids are connected together by muscle, and their angles to the cricoid and thyroid also by muscles. By the contraction of these muscles the arytenoids can be moved on the cricoid, with the result of approaching or separating the anterior angles, and thereby the posterior ends of the vocal chords.

Muscles of the Larnyx. Crico-thyroid, from external surface of thyroid forwards and downwards to the front part of lateral external surface of cricoid. There are two views regarding its action: (1) that it pulls down the thyroid, thereby rendering tense the vocal chords; (2) that it pulls up the front of the cricoid, thereby depressing its posterior part, and thus putting the vocal chords on the stretch. *Thyro-arytenoids*, from anterior angle of arytenoid to angle of thyroid lying immediately external to the vocal chords. Their action is supposed to be to raise up the thyroid after its depression by the preceding muscle and thereby slacken the chords. It may also act directly upon the vocal chord, rendering tense limited portions of it. *Lateral Crico-arytenoids*, from external angle of arytenoid downwards and forwards to the external surface of the cricoid. By their contraction they move forwards the external angles, thereby causing the anterior angles of the arytenoids to come nearer together, and in consequence the vocal chords to become more parallel. *Posterior Crico-arytenoids*, passing from the external angles down and back to the posterior surface of the cricoid, by their contraction produce exactly the opposite result to the last muscle, viz., a separation of the vocal chords. *Arytenoids* pass from the posterior surface of one arytenoid to that of the other, and by their contraction are said to cause the arytenoids to come nearer together. Whether their action will cause the anterior angles, and hence the vocal chords, to come nearer together, or just the reverse, seems doubtful, probably the latter.

Glottis. The opening from the œsophagus into the larynx is called the glottis. At the opening, attached to the back of the tongue, at the top of the larynx, is a spoon-shaped piece of cartilage, or *Epiglottis.* During swallowing the epiglottis is bent down so as to cover over the glottis.

Vocal Chords are composed of yellow elastic connective tissue, covered over by a closely-attached mucous membrane. Their free edges, which by their vibration produce voice, are sharp and straight, and are directed upwards. The surfaces below face inwards towards one another. Just above the vocal chords, separated from them by a space, the ventricle, are two marked folds of the mucous membrane, forming the *false vocal chords*, for they take no active part in the production of voice.

Conditions of Voice Production.—When at rest the vocal chords are separated by a considerable space, which becomes wider the stronger the inspiratory act. In order that they may produce voice, two conditions are necessary, viz. :—

1. That they shall be made *parallel.*
2. That they shall be rendered *tense.*

These conditions are brought about by the contraction of the preceding and perhaps other muscles. "The action of these several muscles is excessively complicated, and anyone who should be able fully and exactly to describe it would dispel the mystery which still surrounds the whole subject of voice production" (Morell Mackenzie).

The action of the chief muscles is probably as follows :

Parallelism—Lateral Crico-arytenoids.

Separation—Posterior Crico-arytenoids : Arytenoids.

Tension—Crico-thyroids.

Relaxation—Thyro-arytenoids.

The blast of air necessary to throw the chords into vibration is supplied by the lungs, and hence normal vocalisation takes place only during expiration. The vocal organ is essentially a *reed instrument*, the lungs being the bellows, the trachea the pipe, the larynx the reed-box, the vocal chords the reeds, and the pharynx, nose, and mouth the resonator.

Characters of Voice. As of musical sounds generally, so of the voice. It varies in—

1. *Loudness*, dependent on the force with which air is expelled from the lungs, or on the amplitude of vibration of the chords.

2. *Pitch*, dependent on the length and tension of the chords, for on this depends the number of vibrations in a given time.

3. *Quality*, or *Timbre.* This depends on the number and character of the over-tones accompanying the fundamental tone. The chief factor in determining the timbre of a voice is the size and shape, &c., of the *resonance chambers*, amongst which must be counted the cavity of the chest, the pharynx, the mouth, and the nasal cavities.

Speech—

Speech is the voice modified by the palate, tongue, lips, and teeth, these structures being therefore sometimes called the *organs of speech.* Voice may exist without speech, and speech may exist without voice (*i.e.*, voice produced by the vocal chords), as in whispering. Speech sounds are distinguished as vowels and consonants.

Vowel sounds are due to particular over-tones accompanying the fundamental tone produced by the vocal chords. The different over-tones of the different vowels are caused by the resonance chamber (pharynx and mouth) taking different shapes. The essential alteration appears to be in the length of the resonance tube (mouth). In sounding, for example, the vowels ē, ā, ah, o, oo, in the order named, a gradual lengthening of the tube of the mouth will be observed. The production of vowel sounds is therefore essentially a question of quality or timbre. In fact, by combining a fundamental tone with the appropriate over-tones, Helmholtz has been able to artificially produce the vowel sounds by synthesis; and Kœnig, by his ingenious manometrical flame apparatus, shows in a graphical manner how there is a particular form of flame-picture for each vowel, and how it varies with the pitch. By a combination of this method with a series of resonators, he is also able to analyse a vowel sound into its fundamental tone and overtones.

Consonants are not produced by the vocal chords, but by the outrush of air being interrupted or modified in passing through the throat and mouth. Consonants are classified in several different ways: (1) Liquids and mutes; (2) according to the mechanism of formation into explosives, aspirates, vibratives, and resonants; (3) according to the *place where the interruption of the outrush of air takes place* into—

a. Labials when at the lips; *e.g.*, B, P.

b. Dentals at the teeth; *e.g.*, T, D.

c. Gutturals at the throat; *e.g.*, K, G.

Defective Speech. Stammering is due to the abnormal action of the diaphragm, thereby interfering with the appropriate respiratory movements on which the production of the voice is dependent. *Stuttering* is due to inability to normally manipulate the larynx so as to produce the appropriate sounds. It is accordingly much more difficult to overcome than stammering. *Aphasia* is due to disease of the brain (*vide* Lecture XX.).

LECTURE XXIII.

HEARING.

To understand this sense we have to consider first the Ear, or end-organ, and then the way in which it is acted upon by sound-waves so as to produce the sensation.

I. The Ear.—The human ear is composed of three parts—an outer, middle, and inner ear.

External Ear.—This consists of two parts:

1. The *Auricle*, or the feature usually known as the ear. It is an irregular mass of cartilage covered with skin, exhibiting elevations and depressions the purpose of which is probably to reflect the sound-vibrations into the other part of the external ear. In the human ear this is probably a very subsidiary function of the auricle compared with the same structure in some of the lower animals.

2. The *Auditory Canal*, or *External Auditory Meatus*. This tube, about $1\frac{1}{4}$ inch long, is partly cartilaginous and partly osseous. It is slightly narrower in the middle than at either end. It is closed internally by a membrane, the *membrana tympani*. At its outer part are a number of modified sweat-glands, the *ceruminous glands*, which secrete a waxy substance.

Middle Ear.—The *Tympanum*, or *Drum*, is a cavity in the petrous portion of the temporal bone of the skull. It is an irregularly-shaped cavity, separated from the outer ear by the

Membrana tympani, a thin fibrous membrane, almost circular in shape, attached at its circumference to the bone. It is a little over $\frac{1}{3}$ inch in diameter. The fibres are arranged radially on the outside, circularly on the inside. Externally it is covered by a thin layer of skin, internally by a mucous membrane with squamous epithelium. All the rest of the tympanum is lined with ciliated epithelium. The membrane is directed downwards and inwards. It is not flat, but bulged in towards the tympanum, where the handle of the malleus is attached to it. It is thrown into vibration by sound-waves. "The membrani tympani has the remarkable property of answering equally well to tones of any pitch within the range of tones perceptible to our ear: to tones of about 60 to 4000 vibrations per second, which is impossible with an ordinary stretched membrane."

The *Tympanum* is ½ inch high, and 2 lines broad. Above, it is separated from the brain by a thin piece of bone, and below similarly from the jugular vein; posteriorly it is continuous with the *mastoid cells;* in front it communicates with the pharynx by the *Eustachian tube*, a canal about 1½ inch long, said to be normally closed, but is momentarily opened during the act of swallowing. In the inner wall of the tympanum are two minute openings communicating with the internal ear. One of these is oval in shape, and is called the *fenestra ovalis;* the other, round, is the *fenestra rotunda*. They are both closed by membrane. To the membrane of the former is attached the bottom of the stapes, or stirrup-bone.

Ossicles of the Ear. There are three minute bones in the Tympanum, viz.:

The *Malleus*, or hammer-bone, is fixed by its handle-process to the inner surface of the membrana tympani; its head is jointed to

The *Incus*, or anvil-bone, which in addition to a body has two processes—one short by which it is fixed to the wall of the tympanum, another longer which at its extremity is joined to

The *Stapes*, or stirrup-bone. This is firmly joined to the membrane, closing up the fenestra ovalis.

These bones are so connected as to move as one lever, and as a result any vibration of the membrana tympani is communicated through them to the membrane of the fenestra ovalis.

Internal Ear, or *Labyrinth.*—This is the essential part of the ear, for in it terminates the auditory nerve. It consists of a series of channels hollowed out in the substance of the petrous portion of the temporal bone. It is divisible into three parts, viz.—

1. The *Vestibule*, or central part. Into this opens the fenestra ovalis.

2. The *Semicircular Canals*, three in number, placed posteriorly to the vestibule with which they communicate.

3. The *Cochlea*, in front of the vestibule, also opening into it. Within these bony spaces, often spoken of together as the bony or *Osseous Labyrinth*, are membranous structures of similar shape, forming the *Membranous Labyrinth.*

Between the osseous and membranous labyrinths is a liquid, or *Perilymph*. Within the membranous labyrinth is another liquid, or *Endolymph*.

The Vestibule.—The membranous vestibule consists of two fibrous sacs, called the *Utricle* and *Saccule*. Into the former, which is much the larger, open the membranous semicircular canals. The latter is continuous with the central canal of the cochlea. The utricle and saccule communicate with one another by a narrow canal.

The Semicircular Canals are designated according to their position superior, posterior, and external. The superior and posterior are vertical, and meet one another at an angle, the former lying transversely, the latter antero-posteriorly. The external canal is horizontal and communicates with the vestibule by two distinct openings; whereas the superior and posterior canals have each only one independent communication with the vestibule, the other being common to both. At one end of each canal, just where it joins the vestibule, there is an enlargement called the *Ampulla*.

The *Membranous Semicircular Canals* have a similar shape. They are only about one quarter as wide as the osseous canals, and are attached at one side to the bony wall. Their connections with the utricle correspond to those of the bony canals with the vestibule.

Terminations of Auditory Nerve.—The auditory nerve divides into two branches, distributed respectively one to the cochlea, the other to the vestibule and semicircular canals. The *Vestibular portion* divides into five branches, viz., one to each ampulla, to the saccule, and to the utricle. On the internal surface of each membranous structure, corresponding to the place of termination of the branch of the nerve, is a cushion-like elevation covered by a columnar epithelium, surmounted by fine cilium-like processes, which project stiffly upwards. These so-called *auditory hairs* do not, however, project freely into the endolymph, for they are covered by a gelatinous mass containing numerous minute calcareous bodies called *otoliths*. This auditory epithelium is the real *end-organ*, for the columnar cells are connected at their base with the final terminations of the auditory nerve.

The Cochlea is a dome-shaped organ about $\frac{1}{4}$ inch in height, and the same in breadth at the bottom. It is composed of a conical tube $1\frac{1}{2}$ inch long and $\frac{1}{10}$th inch wide at its beginning, where widest, coiled upon itself $2\frac{1}{2}$ times. There is a central bony axis, the *modiolus*, or column of the cochlea. This tube, forming the osseous cochlea, is divided into two compartments by a partition, partly bony, projecting out from the column, forming the *spiral lamina of the cochlea*, and partly membranous, connecting the spiral lamina to the outer wall, forming an important structure, the *Basilar membrane.*

The two parts into which the cochlea is thus divided are termed respectively the *Scala tympani* (the lower), opening by the fenestra rotunda into the tympanum, and the *Scala vestibuli* (the upper), because it communicates at the bottom with the vestibule. These two compartments communicate with one another at the apex of the cochlea, and they contain perilymph.

A small triangular part of the scala vestibuli is cut off by a fine membrane (*membrane of Reissner*), passing upwards and outwards to be attached to the bony wall. The portion thus divided off is termed the duct or **Central Canal of the Cochlea.** Of its three walls, the upper and lower are membranous, and the outer bony. It is the membranous cochlea. At the bottom it communicates with the saccule by a fine canal (*canalis reuniens*), at the top it ends blindly. It contains endolymph continuous with that in the saccule. The inner surface of the central canal is lined with epithelium; and this on the basilar membrane undergoes modification to form the remarkable **Organ of Corti.** The central part of this complicated structure is formed by the *Rods of Corti.* These are inclined towards one another in pairs, meeting at their heads, which project up into the central canal of the cochlea. In this way they form a tunnel, extending along the whole length of the basilar membrane, which is filled with endolymph. The inner rods are more numerous than the outer in the proportion of 6000 to 4500. Internal and external to the rods are rows of columnar cells surmounted by stiff hairlets. The *inner hair-cells* form a single row; the *outer hair-cells* are arranged in four rows. The hairs on the latter project through rings formed by fiddle-shaped structures connected with one another at their ends, the most internal being connected with the tops of the rods. A *reticular lamina* is thus formed, covering this part of the organ of corti like a wire net. On either side the cells forming the epithelium gradually diminish in size until they resemble the cubical cells lining the canal generally.

The whole organ is covered by the *tectorial membrane*, which projects from the spiral lamina.

Termination of the Auditory Nerve.—The branch of the auditory nerve to the cochlea passes up the central column and sends fibres through the spiral lamina to the organ of corti. In what part of that complicated structure the fibres actually terminate is a matter of some uncertainty. They have been described as ending in the hair-cells, which from analogy are certainly the part of the structure we should expect to be the *end-organ*.

Sensiferous Apparatus for Hearing.—In its simplest form the sensiferous apparatus for hearing may be said to be (*a*) nerve-cell in brain, (*b*) nerve-fibre of auditory nerve, (*c*) hair-cell of utricle, ampulla, or cochlea. Its *modus operandi*—that sound agitating (*c*) causes an impulse to pass up (*b*), which on arriving at (*a*) produces in it such physical changes as to bring about the modification of consciousness called hearing. We have now to consider how the agitation or excitation of the hair-cell or end-organ is caused by sound-waves.

II. How End-organ excited by Sound.—Those vibrations of the air from a sounding body, called sound-waves, passing down the auditory canal, fall on the membrane tympani and set it vibrating. The vibration of this membrane (connected to the handle of the malleus) is communicated to the ossicles of the ear, which, acting as one lever, rotate round an axis, passing through the heads of the incus and malleus. Their movement throws into vibration the membrane closing the fenestra ovalis. Since the handle of the malleus is half as long again as the stapedial process of the incus, it follows that the movement of the stapes will be only two-thirds as great as that of the malleus. But, on the other hand, although there is a loss in the extent, there will be a corresponding gain in the force of the movement communicated to the membrane closing the fenestra ovalis. The vibration of this membrane agitates the perilymph of the labyrinth. This, causing a disturbance of the endolymph, will agitate the auditory hairs projecting from cells connected with the terminal fibres of the auditory nerve.

Sound may be conveyed to the perilymph through the bones of the head. Such sound is much less perfectly referred to the external world than that which acts through the membrana tympani.

Muscles of the Tympanum. The vibration of the membrana tympani is controlled and modified by the *tensor tympani muscle.* This muscle, arising in the Eustachian tube, is inserted into the malleus near the top of the handle. By the strong contraction of this muscle, the membrana tympani may be rendered so tense as not to respond to sonorous vibrations. In this way very loud sounds would be prevented from communicating their vibrations to the inner ear, and thereby injuring the delicate end-organ. Again, by varying the degree of its contraction, the tension of the membrane may be varied so as to alter its fundamental tone, thus enabling it to take up more readily the vibrations produced by sounds of different pitch and intensity. There is another muscle, the *stapedius*, inserted into the head of the stapes. By its contraction it tends to fix the stapes, and thereby prevents too strong vibrations from being communicated to the perilymph.

The lowest sound recognisable as musical is produced by about 32, and the highest by about 32,000, vibrations per second.

Functions of different parts of Internal Ear.—There is very little certain knowledge concerning the functions of the several parts of the internal ear. From the striking differences in structure of the three parts, Vestibule, Semicircular Canals, and Cochlea, they doubtless have different functions.

Vestibule. From its simplicity, and from the fact that it is the first to appear in the animal scale, the vestibule probably gives rise to the sensation of sound as such.

Semicircular Canals. From their position and arrangement these have been supposed to enable us to learn the direction of sounds. Experiment goes to show that they are intimately associated with the *co-ordination of movements* and maintenance of equilibrium (*vide* Lecture XX.).

Cochlea. From its remarkable complexity, the cochlea must have an important function. What that function is, however, it is impossible to say with certainty. The remarkable *Organ of Corti* has been supposed to be the organ through which we are enabled to appreciate the pitch and quality of musical sounds. This is suggested by the number and arrangement of the *rods of Corti*, for they vary regularly from the bottom to the top of the cochlea in length and in the span of their arch. There are, however, the following objections to the view that the rods of Corti constitute the organ by which we analyse musical sounds:

1. The nerve-fibrils end in the hair-cells, not in the rods.
2. The variation in length of the rods is not sufficient.
3. They are absent in birds.

In view of these objections, the *basilar membrane*, considered as a series of tense parallel strings, may be the organ required.

It increases in width gradually from the bottom to the top of the cochlea.

Judgments of distance and of *direction* of sounds are by no means easy or precise. They appear to be more certain and exact for noises than for musical sounds.

Comparative Anatomy.—There is considerable doubt whether auditory organs exist in the lower Invertebrata. In *Cœlenterata* and *Vermes* a small capsule containing minute hard particles (otoliths) has been regarded as a rudimentary ear. From the sounds produced by many *Insects*, they are probably endowed with the sense of hearing.

In *Crustacea* there appears to be an undoubted organ of hearing which may be compared to the utricle of the human ear, for it consists of a sac lined with hairs and containing otoliths. The vestibule is apparently the only part of the ear represented in the auditory organ of Invertebrata. In *Vertebrata* the vestibule and semicircular canals are present in all classes from fishes upwards. The cochlea in *Fishes* is merely a small projection; in *Birds* it is short, conical, and straight, except for a bending at the extremity forming the lagena. In *Mammals* it is essentially the same as in man.

LECTURE XXIV.

THE EYE—LIGHT.

To understand the sense of sight, three things are necessary :

1. That form of energy called *light*.
2. The structure of the *eye*.
3. The way in which light acts upon the eye, so as to cause vision.

I. Light is held to be due to the vibratory disturbance of an exceedingly tenuous medium pervading all space—the *luminiferous ether*. A luminous body gives a rapid undulatory motion to the molecules of this ether, which motion is propagated as spherical *waves* in all directions. The smallest conceivable portion of light is called a *ray*. It is represented by a straight line. A *pencil* of light is a collection of rays from the same source : it may be *parallel*, *divergent*, or *convergent*.

Refraction. When a ray of light passes obliquely from one medium to another (*e.g.*, air to water, or air to glass), it is bent or *refracted*. Refraction takes place when light passes through a *lens*. The straight line which passes through the two centres of a *biconvex lens* is called the *principal axis*. All rays of light parallel to the principal axis, falling on a biconvex lens, are so refracted as to be brought to one point behind it, called the *principal focus*. All the rays of light proceeding from any luminous point (beyond a certain distance from the lens) are refracted so as to be brought to a *focus* after passing through it.

Images. Any object, being virtually a series of luminous points, when placed in front of a biconvex lens, beyond the principal focus of the lens, has a luminous representation of it formed behind the lens. This luminous representation is termed an *image*. The image in this case is reversed.

Camera. A camera is a box within which by means of a lens images of external objects are formed clear and distinct upon a screen. In a photographic camera this screen is movable, so that images of objects at different distances may be formed upon it at different times. The eye is a camera, images of external objects are formed by a biconvex lens (the *crystalline*) on a screen (the *retina*).

Colour.—Sunlight can be decomposed by a prism into a number of colours, comprising all the simple colours, and which, when combined, produce all the colours which occur in nature. The sum of the colours thus obtained by decomposing sunlight is called the solar *spectrum*. That the colours of the spectrum are simple may be shown by cutting off all the colours except one by means of a screen. When this remaining colour is allowed to pass through a prism, it emerges unbroken. By re-combining the different colours of the spectrum by allowing them to fall on a reversed prism white light can be reproduced.

Colour of Bodies. The colour of a body depends on that portion of the spectrum which it reflects or transmits. The two extremes are the case in which a body reflects or transmits all colours in the proportion in which they exist in the spectrum, when it is white, and that in which it transmits or reflects none, when it is black.

Fundamental Colours. This term has been applied to *red*, *green*, and *violet*, for by combinations of these three all possible colours can be formed.

Quality of Colour depends on (1) the part or parts of the spectrum reaching the eye, (2) the intensity of this light, (3) the amount of white light mixed with the coloured light.

Mixed Colours are the impressions of colour resulting from the coincident action of two or more colours on the same part of the retina. This impression is single, and cannot be resolved into its constituents. This is a physiological combination, and is quite different from the effect produced by the mixture of differently coloured pigments.

Complementary Colours. If a portion of the spectrum be cut off, the remaining portions give a definite colour; if, on the other hand, the latter be cut off, the former give another definite colour. These two resulting colours, when combined, give white, and they are termed, in consequence, complementary colours. The following are examples of complementary colours: Red and Greenish-blue; Orange and Light-blue; Green and Purple.

Properties of the Spectrum—

Luminous. The rays of the spectrum consist of light vibrations of different wave lengths which diminish from the red to the violet. Since the different kinds of light travel with equal velocity, violet makes more vibrations in the same length of time than red light; the former about 667 billions, the latter 456 billions per second. All the light rays of the spectrum differ solely in the wave lengths of their vibrations, and possess no other special mark of distinction.

Colorific. The spectrum has no defined limit at either end, but passes gradually into black, the transition being more gradual at the violet than at the red end. The greatest heating effect is produced by the ultra-red rays.

Chemical. The violet rays are more powerful, chemically, than the rest of the spectrum. This action extends beyond the visible portion of the spectrum. To these invisible rays the term *actinic* is applied.

II. The Eye—

Comparative Anatomy.—The pigment spots of some *Actiniæ* (sea anemones, &c.), have been supposed to be rudimentary eyes. In its simplest form an eye is little more than a lens fixed on the end of a nerve. Such an eye is found in *Insects.* In these animals the eye consists of one or more six-sided lenses placed at the end of a nerve. In the *Cuttle-fish* (Cephalopoda), an eye of great complexity is found. In the eye of this invertebrate animal all the main parts of the human eye are represented.

Structures surrounding the Eye—

The *Eyelids* consist of a mass of dense connective tissue (*tarsus*), covered externally by skin, and internally by the conjunctiva. Opening on the edge of the lids are a number of sebaceous glands, the so-called

Meibonian glands, imbedded in the substance of the eyelid. The extent of separation of the eyelids determines what is usually called the "size of the eye".

Conjunctiva is the delicate continuous mucous lining of the inner surface of the eyelids, and the anterior surface of the eyeball: over the cornea it consists simply of epithelium.

Lachrymal apparatus for the secretion and passing off of the liquid by which the exposed surface of the eyeball is kept moist consists of—

The *lachrymal gland*, of the racemose variety, about the size of a small almond, situated at the upper and outer part of the orbit, a little behind the anterior margin. Its upper surface is attached to the periosteum by fibrous bands. From it pass 12 to 14 ducts which open on the surface of the conjunctiva.

The *lachrymal canals* are two small tubes beginning at two orifices—the *puncta lachrymalia*—at the inner angle of the eyelids. They open internally into

The *lachrymal sac*, situated at the side of the nose imbedded in a deep groove in the superior maxillary bone. It opens below into

The *nasal duct*, about a half-inch long, in a groove of the superior maxillary bone. It descends to the fore part of the lower meatus of the nose. It is lined by a ciliated epithelium, as is that of the lower portion of the nostril.

The **Eyeball**, globular in form, measures about one inch in all diameters except the antero-lateral, which is a little less. It is kept in position in the orbit by the optic nerve behind, the eyelids in front, a mass of fat, and six muscles by which its varied movements are produced.

Chambers. Its interior is divided into parts, or *chambers*, by a dark opaque screen (*iris*), in the centre of which is a round aperture (*pupil*), and the crystalline lens, situated just behind the pupil. The posterior chamber, forming the greater part of the eyeball, is filled with a gelatinous fluid—the *vitreous humour;* the anterior chamber, much smaller, is filled with a similar fluid—the *aqueous humour*.

Coats of the Eye—

(*a*) The eyeball is enclosed by a strong, thick membrane, the posterior, $\frac{5}{6}$ths of which is white and opaque. This is the **Sclerotic.** The anterior, $\frac{1}{6}$th slightly more convex than the rest, is transparent, and is known as the **Cornea.** Together they form the corneo-sclerotic, or *outer coat*.

(*b*) Lining the internal surface of the sclerotic is the second, or *middle coat*, the **Choroid.** It consists of a dense network of fine bloodvessels, amongst which are numerous branched cells, containing *pigment* granules; hence the choroid has a black colour. In front it is continuous with the iris at a line corresponding with that of the junction of the sclerotic with the cornea. Just before joining the iris, the substance of the choroid is thickened, so as to form a fringe of projections—the *ciliary processes* of the choroid.

The **Iris** consists of a framework of fibres and muscular tissue, with pigment-cells scattered through it. The amount of pigment present determines the "colour of the eye". Posteriorly, it is covered with pigment-cells—*uvea*—continuous with the hexagonal pigment-cells of the retina. There are two sets of muscular fibres; one arranged circularly—*sphincter*—which, by their contraction, diminish the size of the pupil; the other arranged radially—*dilator*—causing by their contraction the pupil to enlarge. By the action of these muscular fibres, the amount of light entering the eye is diminished or increased: this action is wholly reflex.

(*c*) Lying on the inside of the choroid is the third or inner coat of the eye, the **Retina.** It is the essential part, the end-organ. The retina extends only about two-thirds as far forwards as the choroid. It ends in an irregular border, or *ora serrata*. Beyond this the retina is represented merely by a single stratum of elongated columnar cells, with the pigmentary layer external to them (*pars ciliaris*). The middle point of the retina is slightly tinged with colour, and is hence known as the *yellow spot*, or *macula lutea*. The centre of the yellow spot is slightly depressed, forming the *fovea centralis*, the part of the retina most sensitive to light. The retina may be regarded as an expansion of the *optic nerve* which pierces the sclerotic coat at the back of the eyeball a little to the nasal side of the middle point.

Crystalline Lens.—This is situated immediately behind the pupil, and is invested by a very fine membrane continuous with the *hyaloid membrane*, surrounding the vitreous humour. The portion of the membrane passing from the edge of the lens to the hyaloid is called the *zonula of Zinn*, or *suspensory ligament of the lens*. It keeps the lens in position, and in a slightly stretched condition. The crystalline lens is biconvex, the posterior convexity being slightly greater than the anterior. It is firmer and more strongly refractive in its central part. It is $\frac{1}{3}$ inch in diameter, and $\frac{1}{5}$ inch thick. It is made up of *concentric laminæ*, composed of long *riband-shaped microscopic fibres*, $\frac{1}{5000}$ inch broad. These adhere together by their edges, which are often serrated.

Ciliary Muscle, or *Tensor Choroideæ*. This muscle arises by a thin tendon from the fore part of the sclerotic, close to the cornea. Its fibres spread out, and are directed backwards to be inserted into the choroid opposite the ciliary processes, and partly further back. When this muscle contracts, it draws the choroid forward, and thereby renders less tense the suspensory ligament of the lens. The crystalline lens then, in virtue of its elasticity, becomes more convex (*vide* Accommodation Lecture XXV.).

The **Retina**—

This is the essential part of the eye, for in it terminate the fibres of the optic nerve. It is the end-organ for vision. Although very thin and delicate, being little thicker than a piece of thick paper, it has a very complex structure. No less than eight layers can be distinguished in it. These are from within out—

1. *Layer of nerve-fibres*, being the terminal fibres of the optic nerve.

2. *Ganglionic layer*, composed of nerve-cells.

3. *Inner molecular layer*, probably of the nature of a fine network.

4. *Inner nuclear layer*, containing numerous large nuclei.

5. *Outer molecular layer*, a thin stratum, apparently similar in nature to (3).

6. *Outer nuclear layer*, containing large nuclei connected with the constituents of

7. The *Bacillary layer*, or layer of rods and cones.

8. A layer of *hexagonal pigment-cells*.

In addition to this proper substance of the retina, there is a *supporting tissue*. Internally, this forms a fine limiting membrane —*membrana limitans interna*. Immediately internal to the bacillary layer, it forms another limiting membrane—the *membrana limitans externa*.

In the centre of the optic nerve is a small artery. It branches out, forming a network of bloodvessels in the innermost layers of the retina.

Rods and Cones.—These are the most important part of the retina, for they are the part sensitive to light. They form, in fact, the *real end-organ*. The rods and cones are continuous through the intermediate layers with the nerve-fibres of the innermost layers. In the *yellow spot there are only cones*, which are here much longer and narrower, especially in the fovea. All the other layers are very much thinned at the fovea, and the layer of nerve-fibres is absent.

That the *cones are the real end-organ for vision* is supported by the following facts :

1. The *blind spot* (where the optic nerve enters) has no rods and cones, but only nerve-fibres. This spot is not excited by light.

2. The centre of the *yellow spot*, or fovea, the part most sensitive to light, has this layer highly developed at the expense of the others. Here there are only cones, no rods.

3. The experiment of *Purkinje's figures*.

4. The distance at which two points can be distinguished, *i.e.*, give rise to two sensations, corresponds very nearly with the diameter of a cone.

Sensiferous Apparatus for Sight.—In its simplest form this may, therefore, be said to consist of (*a*) nerve-cell in brain, (*b*) fibre of optic nerve, (*c*) a cone of the retina. Its *modus operandi*, that waves of light having traversed the eyeball and other layers of the retina on reaching the bacillary layer excite the cone, and, in consequence, an impulse passes up the fibre of the optic nerve to the nerve-cell, in which it produces such physical changes as are followed by the modification of consciousness called sight.

Optical centre of the eye lies in the crystalline lens, not, however, exactly in its centre, but between that point and the posterior surface of the lens.

The *optic axis* is the straight line joining the object observed and the retina which passes through the centre of the crystalline lens.

Optic angle is the angle formed by the two optic axes from the same object.

Visual angle is the angle under which an object is seen. If the visual angle, formed by straight lines from two objects to the eye be less than 60 seconds, they appear as one.

LECTURE XXV.

VISION.

III. How Light acts upon the Eye—Formation of the Image—

Light, from an object passing through the transparent cornea, by which it is refracted, the aqueous humour and the pupil, falls upon the anterior surface of the crystalline lens. Refracted by the lens, an image of the object is formed behind it within the eye. In a normal (*emmetropic*) eye the image (unless the object be nearer than five or six inches) is always formed on the retina and on the yellow spot. This is rendered possible by the power possessed by the eye of *Accommodation.*

Inverted Image. The image upon the retina is reversed, yet we see every object in the field of vision upright. Much discussion and mystery have been thrown around this fact. "The true scientific answer is found in what is called the 'Law of Visible direction'." This law may be thus stated: "When the rays from any radiant strike the retina, the impression is referred back along the ray line into space, and therefore to its proper place" (Le Conte). This is only in keeping with the way in which other sensory impressions are referred to some outside object in a definite direction.

Accommodation is affected by an alteration of the convexity of the anterior surface of the crystalline lens. This alteration is brought about by the contraction of the tensor choroideæ muscle (*vide* Lecture XXIV.). When contracted, this muscle draws forward the choroid, thereby rendering less tense the suspensory ligament, and thus gives free play to the elasticity of the lens. That accommodation is produced in this way is proved by observing the three reflected images of a luminous object seen in an eye when accommodated for long and short distances. These images are formed by the anterior surface of the cornea, the anterior convex and posterior concave surfaces of the crystalline lens. During accommodation only the middle image undergoes a change. In accommodation for far objects it becomes longer, for near objects shorter, showing that the anterior surface of the lens is more convex in the latter than in the former case. That the tensor choroideæ is the muscle of accommodation can be shown experimentally by stimulation of the ciliary nerves going to the muscle, and by the action of atropin, which paralyses it.

Near limit of accommodation. The nearest point at which an object can be seen distinctly is called the near limit of accommodation. For the normal eye it is 5 to 6 inches, for the myopic eye 2 to 3 inches, for the hypermetropic eye at some distance. The near limit is easily determined by *Scheiner's experiment.*

The Pupil. In accommodation for near objects the pupil contracts; in accommodation for far ones it dilates, thus appropriately altering the amount of light entering the eye.

Long and Short Sight.—If the crystalline lens or cornea be more than normally convex, or if the antero-posterior diameter of the eyeball be too great, the image is formed in front of the retina. This defect is called short-sightedness, or *Myopia.* It is corrected by concave spectacles. If, on the other hand, the surfaces of the cornea and lens are too flat, or the antero-posterior diameter of the eyeball too small, the image is formed behind the retina. This is long-sightedness, or *Hypermetropia.* It is corrected by convex spectacles. Normal vision is termed *Emmetropia.*

Binocular Vision.—Under ordinary circumstances both eyes are used, and there must therefore be two images of any object observed. The two images give rise to a single perception because they fall on *corresponding points* of the two retinas. If this is prevented, as by squinting, we see double.

Horopter. The horopter is an imaginary figure in space comprising all those points projected on to corresponding points of the retinas.

Judgment of solidity depends on binocular vision. It is shown by the *stereoscope* to be due to the blending of two slightly dissimilar images on the two retinas.

Judgment of distance is also connected with binocular vision, for it is partly due to the sensation of muscular effort necessary to bring the axes of the two eyes to the proper convergence. The sensation of effort of accommodation, no doubt, also assists.

Movements of the Eyeball.—These are produced by *six muscles,* all, with one exception (inferior oblique), having their origin in the osseous wall of the orbit near the point where the optic nerve enters it. Four muscles pass directly to the eyeball. They are the straight or *Recti* muscles, denominated from their position external, internal, superior, and inferior. The two others are attached to the eye in an oblique direction, and hence termed *Oblique*. One above is the superior, and is peculiar in its anterior tendon working through a pulley-like loop, so that the direction of its action is at an angle to the direction of the main part of the muscle; the other below, the inferior. As regards *their action*, they are *divisible into two groups*. (1) External and internal recti rotating the eyeball round its vertical axis. (2) Superior and inferior recti and the two oblique acting together (rectus superior with obliquus inferior, and rectus inferior with obliquus superior) rotate the eyeball round its horizontal axis. The straight line connecting the apex of the cornea with the fovea centralis is called the *visual axis*. All rotations of the eyeball take place round axes —*axes of rotation*—which meet the visual axis at right angles about 1·7 mm. behind its middle point (Listing).

Observation of the Interior of the Eye.—Part of the light reaching the retina is reflected. The reflected light returns along nearly the same paths as those by which it arrived. If by a mechanical arrangement this reflected light be made to pass into the eye of an observer, he is able to see the interior of the observed eye. An instrument invented by Helmholtz, called the **Ophthalmoscope,** is such an arrangement. The brilliancy of the eyes of some animals is due to the reflection of light by a carpet of glittering fibres, called the *tapetum*, lying behind the retina.

After Effect.—The retina continues in an excited condition for some time after the stimulus ceases. There is an *after effect*. In other words, the sensation lasts longer than the stimulus. **After-images** result from this. When they are continuations of the sensation, they are termed *positive after-images*. A practical application of this is seen in the toy called the *zoetrope*. The positive after-images are followed by images just the reverse, *i.e.*, what was dark is light, what was light is dark; or if coloured, by an image having its complementary colour. These succeeding images are termed *negative after-images*, and are explained as the result of exhaustion.

Colour Sensations.—The theory of colour vision generally accepted, named after its originator and chief supporter the *Young-Helmholtz Theory*, supposes that there are *three primary colour sensations*—red, green, and violet—and that all other colour sensations are due to a combination of these. Further, that every visual unit of the retina (every cone) contains three terminal elements, one of which is most excited by red rays, another by green, and a third by violet rays. All three are more or less excited by all the rays. These three terminal elements are assumed to be connected with three sets of fibres. Combinations of these fundamental colour sensations may be made by the *colour top*. If one or more of the primary colour sensations are absent, *colour blindness* results. The edge of the retina is often colour blind for red rays.

Hering's Theory. This theory is opposed by *Hering*, who has put forward an ingenious view, that colour sensations are due to two antagonistic processes in the visual substance, one of a constructive nature, or *assimilation* (black, green, blue), the other of a destructive character, or *disassimilation* (white, red, yellow). The visual substance of the retina, according to this view, is composed of three constituents, viz., a white-black substance, decomposed by white light, reconstructed in darkness; a green-red substance, decomposed by red, reconstructed by green rays; and a blue-yellow substance, decomposed by yellow, reconstructed by blue rays. This theory affords a good explanation of complementary coloured after-images, and also of colour blindness.

Retinal Purple. The retina is coloured by a violet-red colouring matter—the *retinal or visual purple*—which is bleached by light. Its connection with vision is unknown, for it is found only in the rods, *not in the cones*, and, therefore, not in the fovea, where vision is most distinct.

Optical Illusions.—Examples of these are seen in (*a*) *Zöllner's figures*, (*b*) *Irradiation*, (*c*) Parallel horizontal and vertical lines in the form of a square giving rise to illusion as to length and depth, (*d*) *Colour illusions*, or the *simultaneous contrasts* of Helmholtz.

Imperfections of the Eye—

1. *Colour blindness*, before alluded to.

2. *Astigmatism*, due to the curvature of the cornea being less in the vertical than the horizontal direction. In consequence, the horizontal and vertical portions of the image are not at exactly the same level.

3. *Aberration*, *spherical* and *chromatic*. The former due to the different degree of refraction of the rays falling upon the circumferential and more central portions of the cornea and lens; the latter to dispersion, caused by the refractive media. Normally, these defects are discoverable only by making experiments on the eye.

4. *Entoptic phenomena*, or shadows of objects floating in the humours of the eye, thrown upon the retina. They usually have the form of round particles or bands, forming the so-called *muscæ volitantes*.

Summary—

A luminous body throws the luminiferous ether around it into a concentric series of waves or undulations. These ether waves —only $\frac{1}{50000}$th inch long—travel towards the eye with a velocity of 186,000 miles per second. They make up the rays of light which travel in straight lines, and on reaching the transparent cornea pass through it. After traversing the aqueous humour, they pass through the pupil, and immediately fall upon the crystalline lens. By this lens they are so refracted that an image of the object is formed upon the retina, especially that part of it called the yellow spot. The light waves have the peculiar power of exciting that characteristic structure in the retina known as the layer of rods and cones, especially, if not exclusively, the cones. These bodies are connected through the other layers of the retina with the most internal layer of nerve-fibres forming the termination of the optic nerve. The excitation of the cones is thus transmitted to the optic nerve, up which it passes as a nervous impulse to the brain. On arriving at that organ, it so affects it as to produce that state of consciousness known as vision.

APPENDIX.

METRIC SYSTEM OF WEIGHTS AND MEASURES.

This system is almost universally adopted in scientific calculations.

It has the advantages (1) of being a decimal system, and (2) its units being constants.

The *unit of Length* is the **Metre.** A metre is 39·37 inches in length. It is very nearly $\frac{1}{10000000}$ part of a quadrant of the earth's circumference, *i.e.*, the distance from the pole to the equator.

The dimensions and multiples of a metre are as follows:

$\frac{1}{10}$ metre = 1 decimetre.
$\frac{1}{100}$ metre = 1 centimetre.
$\frac{1}{1000}$ metre = 1 millimetre.
10 metres = 1 decametre.
100 metres = 1 hectometre.
1000 metres = 1 kilometre.

The *unit of Volume* is the **Litre** = 1 cubic decimetre. Its divisions and multiples are precisely similar to those of the metre, decilitre, centilitre, millilitre, decalitre, hectolitre, kilolitre.

A litre = 61·027052 cubic inches (rather less than a quart).

The *unit of Weight* is the **Gramme.** A gramme is the weight of 1 cubic centimetre of pure distilled water at a temperature of 4° Centigrade.

A gramme = 15·432349 grains. A kilogramme weighs 2·2046 lbs.

Divisions and Multiples of the gramme are:

$\frac{1}{10}$ gramme = 1 decigramme.	10 grammes = 1 decagramme.
$\frac{1}{100}$ gramme = 1 centigramme.	100 grammes = 1 hectogramme.
$\frac{1}{1000}$ gramme = 1 milligramme.	1000 grammes = 1 kilogramme.

The **Thermometer** usually employed in scientific experiment is the Centigrade. The *Centigrade Thermometer* differs from that in general use in this country (*Fahrenheit's*) in the freezing point being zero or 0° instead of 32°, and boiling point being 100° instead of 212°. Putting C. for Centigrade, F. for Fahrenheit,

0°C. corresponds to 32°F.
100°C. ,, 212°F.

Therefore, 100 divisions of the C. corresponds to 180 of the F.
Or, 5 ,, ,, ,, 9 ,,
Or, 1 ,, ,, ,, $1\frac{4}{5}$,,

With these data, it is very easy to convert a Centigrade into a Fahrenheit reading, or *vice versâ*.

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