BLACKIE'S SCIENCE TEXT BOOKS.

·ELEMENTARY·PHYSIOLOGY.·

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BLACKIE'S SCIENCE TEXT-BOOKS.

AN ELEMENTARY TEXT-BOOK OF PHYSIOLOGY.

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BEING AN ENLARGED EDITION OF MURCHE'S "ANIMAL PHYSIOLOGY," SPECIALLY ADAPTED TO THE REQUIREMENTS OF THE ELEMENTARY STAGE OF THE SCIENCE AND ART SYLLABUS.

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PREFACE.

The original edition of this book was designed specially as a text-book for elementary schools. While it has proved admirably adapted and been widely used for that purpose, it has also found a place in classes studying the first stage of the Science and Art course in Physiology, so far as its scope allows. It is by request of a number of teachers of such classes that a FOURTH PART is now added to the book, to suit it more completely for their requirements. The new part may be regarded as a Supplement, since it deals with those subjects which are included in the curriculum of the Science Syllabus, but are either not discussed at all in the earlier parts of the book, or are not treated with sufficient fulness in them.

To render the book convenient for use, references have been inserted from paragraphs in the earlier parts to the pages in PART IV. where the same subjects are dealt with.

HUMAN PHYSIOLOGY.

BOOK I.

THE BUILD OF THE HUMAN BODY—NAMES AND POSITION OF THE INTERNAL ORGANS—THE PROPERTIES OF MUSCLE.

THE SCIENCE OF PHYSIOLOGY, which concerns us all so closely, cannot fail to be of the most interesting and instructive nature. We think, breathe, talk, see, hear, and feel; we eat, drink, and sleep; we perceive the regular beat beat of the heart, as it day by day carries on its incessant work; and perhaps no subject can be more alluring as a study than that which investigates the laws which govern all these wonderful but everyday phenomena.

Human Physiology is the science which treats of the functions or uses of the various parts of the human body while in a healthy state.

Physiology in its wider sense does more than this. It makes clear to us certain laws which are necessary to health, so that by observing these laws we may hope to spend happier and more useful, because healthier, lives. The Physician has to study the body when subject to disease and disorder. This study constitutes another science called *Pathology*. We cannot study Physiology without to some extent touching upon its kindred science Anatomy.

Anatomy is the science which treats of the structure, form, and position of the various parts of the body. The first part of this little volume will be devoted almost exclusively to the description of the different parts of the body, in order that we may afterwards learn the manner in which each performs its special work.

The young child soon learns by experience many things about such parts of his body as the eye, the ear, the nose, the hands and feet, the tongue, and so on; and you, I have no doubt, are already aware that there are other distinct parts inside your body, although you cannot see them. You have doubtless heard of some of these parts, such as the heart, the brain, the stomach, the liver, and the lungs. It is usual to speak of these as the *organs of the body.*

Organ. An organ is a special part of the body which performs a special work. Thus the eye is the organ of sight, the nose of smell, the ear of hearing, the stomach of digestion, the lungs of breathing, and so on.

The special work which an organ has to do is said to be the *function of that organ.*

We speak of the body as being an *organized structure* because it consists of a number of organs, each performing some function necessary to the whole. One important fact must be borne in mind. Although each of these organs is placed in a distinct part of the body, and has its own special work to do, yet none exists and works for itself alone. The special work which each performs is necessary for the general well-being of the body as a whole, and cannot be carried on by another organ. Some of the organs are more intimately connected with the life of the body than others. We often speak of them as the *Vital Organs*, from a Latin word *vita*, which means *life.* If any one of these be diseased or injured, so that it cannot carry on its proper work, the rest of the organs sooner or later suffer too, cease to perform their functions, and death ensues.

Tissue. The organs and other parts of the body are composed of a variety of substances or materials. These we shall call the tissues of the body, and may be compared to the timber, stone, bricks, mortar, iron, lead, glass, and other materials, which, properly arranged, make up this school. The principal tissues which make up your body are *bone* or *osseous tissue*, *muscle* or *muscular tissue*, *cartilage* or *gristle*, *fat* and *nerve tissue.*

Just one thought more before we proceed further. Look on the back of your hand or along your arm, and you will see some dark branching lines just under the skin. These are the *blood-vessels* (tubes or pipes which carry blood). They are found not only in the hand and arm, but in every part of the body, from the crown of the head to the sole of the feet. Some of them are as big as your fingers, but they get smaller and smaller, until at last they are as fine as hairs; and yet they all carry blood, which you will learn by and by is to restore and build up the tissues. This blood is in fact the material which is to make bone, muscle, gristle, fat, nerve—every portion of the body.

We shall now proceed to study the human body under the following heads:—

1. The Skeleton, or bony framework.
2. The Muscles, or fleshy parts.
3. The Digestive organs.
4. The organs of the Circulation of the Blood.
5. The organs of Respiration or breathing.
6. The Brain and Nervous System.
7. The Senses (touch, taste, smell, hearing, and sight).

The Skeleton or bony framework (Fig. 1) consists, if we include the teeth, of 249 separate bones, of various shapes and sizes. This bony framework serves several purposes: (*a*) it forms the chief support of the body; (*b*) it incloses and protects the internal organs; (*c*) it enables us to move. Just turn for a moment to the picture of the skeleton on p. 10. Here you see the strong firm bones, forming the main support or framework of the body from the feet upwards. Without that strong framework, the body would be utterly unable to support itself in any position. Now, notice again the head and chest, and we shall soon see how it is that these bones protect the internal organs. That important organ the *brain* is lodged in the skull, and that is why the bones of this part of the skeleton are made to form a strong box. In much the same way that bony cage which forms the chest is designed specially to protect those delicate organs the heart and lungs within it. Now, notice lastly the bones of the arms and legs. These bones have to do most of the work in moving the body. Hence we find them surrounded so thickly with flesh that we cannot see the shape of them. The flesh, as you will learn by and by, has to do the work of moving the bones one upon another. Hence, where much work has to be done, there we find the greatest amount of flesh or muscle.

Bone tissue. Bone consists partly of animal matter (cartilage or gristle) and partly of earthy or mineral matter. In infancy there is a very small quantity of earthy matter in the bones—indeed the skeleton of an infant can scarcely be called bone at all. This explains why it is so easy to bend or twist a young child's bones out of shape. You have all seen a child bow-legged or bandy. The child was not born like that, but bad nursing and allowing him, too soon, to stand on his feet have bent the soft gristly substance which in time is to become bone.

In adult age human bone contains about one-third its weight of animal matter and two-thirds mineral matter (chiefly phosphate of lime). The effect of this mineral matter is to harden the bones. As we advance in years the bones become still more deeply impregnated with these earthy matters, and in old age they thus become very brittle. Hence in elderly persons a slight slip will often cause a broken limb, and it is then a very difficult matter to set the bone. A child you see is not likely to break its bones by a fall because they are too flexible, and rather become twisted out of shape, while an old man's bones are brittle, and will easily snap. Two simple experiments will prove to you the composition of bone:—

1. Place a bone on a bright red fire, and let it remain there and burn for some time. When you take it out you will find that it is lighter—indeed that it has lost about one-third of its weight. All the animal matter has been burned away, and what remains is the mineral or earthy matter. If you drop this on the stones it will break into pieces.

2. Place another bone in some dilute muriatic acid, and let it remain in the acid for a few days. (This acid is often called spirit of salt, and can be purchased at the chemist's.) When

taken out, the bone will be found to have lost about two-thirds of its weight. The acid dissolves the mineral matters in the bone, and nothing remains but the animal matter (gristle). The bone is now soft and flexible, and may be easily twisted into any form. Indeed it now resembles the bones in an infant. This shows how careful elder brothers and sisters should be in nursing baby.

It is important to remember that all bones are abundantly supplied with blood-vessels, and thus although bone as we generally see it is almost white, yet living bone has a reddish colour owing to the blood in these vessels.

The bones are enveloped in a thin tough membrane or skin known as the **periosteum.** The blood-vessels branch off from this membrane, and extend in every direction through the pores of the bone.

Bones are usually divided into three kinds, viz.:—*hollow*, *flat*, and *irregular* bones.

The Hollow or Long Bones are found in the limbs, and consist of a long, cylindrical shaft and two rounded ends covered with pads of gristle. (See Figs. 13, 14, and 16.) The hollow interior of these bones is filled with a fatty substance called the marrow. You have all no doubt seen the bone in a leg of mutton or in a piece of leg of beef, and you probably have seen your mother break the bone in order to get this marrow out.

The Flat Bones generally consist of two layers of hard bony tissue, having a light, spongy kind of bony substance between them. The principal flat bones are those forming the skull.

The infinite wisdom of God is manifest in this beautiful arrangement. The skull has to lodge and protect the brain, and this delicate organ is secured from injury by the peculiar *spongy* structure of these flat bones. A blow on the head is not so likely to injure the brain, as it would be if the skull bones were of the same density throughout. The force of the blow, instead of being transmitted through the bones, as it would be if they were solid, is broken up and diffused through the spongy internal part.

The Irregular Bones cannot be described as a class because they vary so much in form. The principal irregular bones are the vertebræ of the back-bone or spine.

Cartilage or Gristle is a very firm, tough, and elastic substance varying in colour from pearly white to yellow. It is not so hard as bone, and contains fewer nerves and blood-vessels. The ends of all the movable bones are protected by cushions of gristle. The lower portion of the nose, as well as the ears, and the larynx consist of soft cartilage or gristle, which you can feel for yourselves.

The Muscles, as we have already stated, are the fleshy or lean parts of the body, and they together with the fat give to the body its general form and proportions. They consist of bundles or separate masses of red flesh capable of contracting and expanding. Every movement we make is due to the contraction of some of these muscles, while the work of breathing and blood-pumping is carried on by muscles which never stop. The muscles will be more fully described farther on.

The Organs of Digestion. Digestion is the work of separating the useful or nutritious from the useless or innutritious parts of the food we consume and changing them into blood; this work is performed by the stomach and the intestines. To put it more simply, *digestion is the process of blood-making.* The beef, potatoes, and pudding, and the tea and coffee and other things we eat and drink are of no use to us until they are changed into blood. This is done by the process of digestion.

The Organs of Circulation. We have already had our attention called to the blood-vessels (the tubes or pipes which carry blood). It is very essential that from the outset we clearly understand something of the nature of these blood-vessels. In the first place the blood in them is not still and stagnant, but is in constant motion. It may perhaps help you to understand how rapidly it surges along, when I tell you that the blood makes a complete journey through your body every three or four minutes. The organs concerned in the circulation of the blood are the **heart**, the **arteries**, the **capillaries**, and the **veins**. The heart is the great centre of the circulation. It is in fact *a pump*, and from the dawn of life till death lays his cold hand upon us, this pump never stops or rests from its task. It is constantly at work pumping blood into the arteries, or great blood-vessels, which lead from it into all parts of the body. These *arteries* as they extend through the body split up again and again into finer and finer tubes, until at last they become so fine that they resemble mere threads or hairs, and can only be examined by the aid of the microscope. Nevertheless they are still hollow tubes, and the blood passes along them in its course through the body. The blood is thus being always forced *by the heart* along the **arteries** into the hair-like tubes called **capillaries.** The rest of the course is performed by the *veins*, which collect up the blood from the *capillaries* and carry it along back to the heart. This course of the blood through the body is called the Circulation. By placing your finger on your wrist you may feel the jerk caused by the flow of the blood, and you will find that this jerk is repeated at regular intervals.

The Organs of Respiration. Respiration is the act of breathing. It is carried on chiefly by the lungs. These are therefore called the organs of respiration.

The Nervous System. The brain is the great centre of the nervous system. It is contained in the cavity of the **cranium** or **skull.** It is continued through the vertebræ or bones of the back, and called the **spinal cord.** The brain and spinal cord send off minute, silvery-looking fibres or threads (the nerves) to all parts of the body. By means of these nerves we move, see, feel, hear, taste, and smell, while the brain itself is the head-centre of the mind and the agent of thought.

The Senses. We generally speak of the faculties of touch, taste, smell, hearing, and sight as the five senses. The various organs concerned in these senses will be described in the third book.

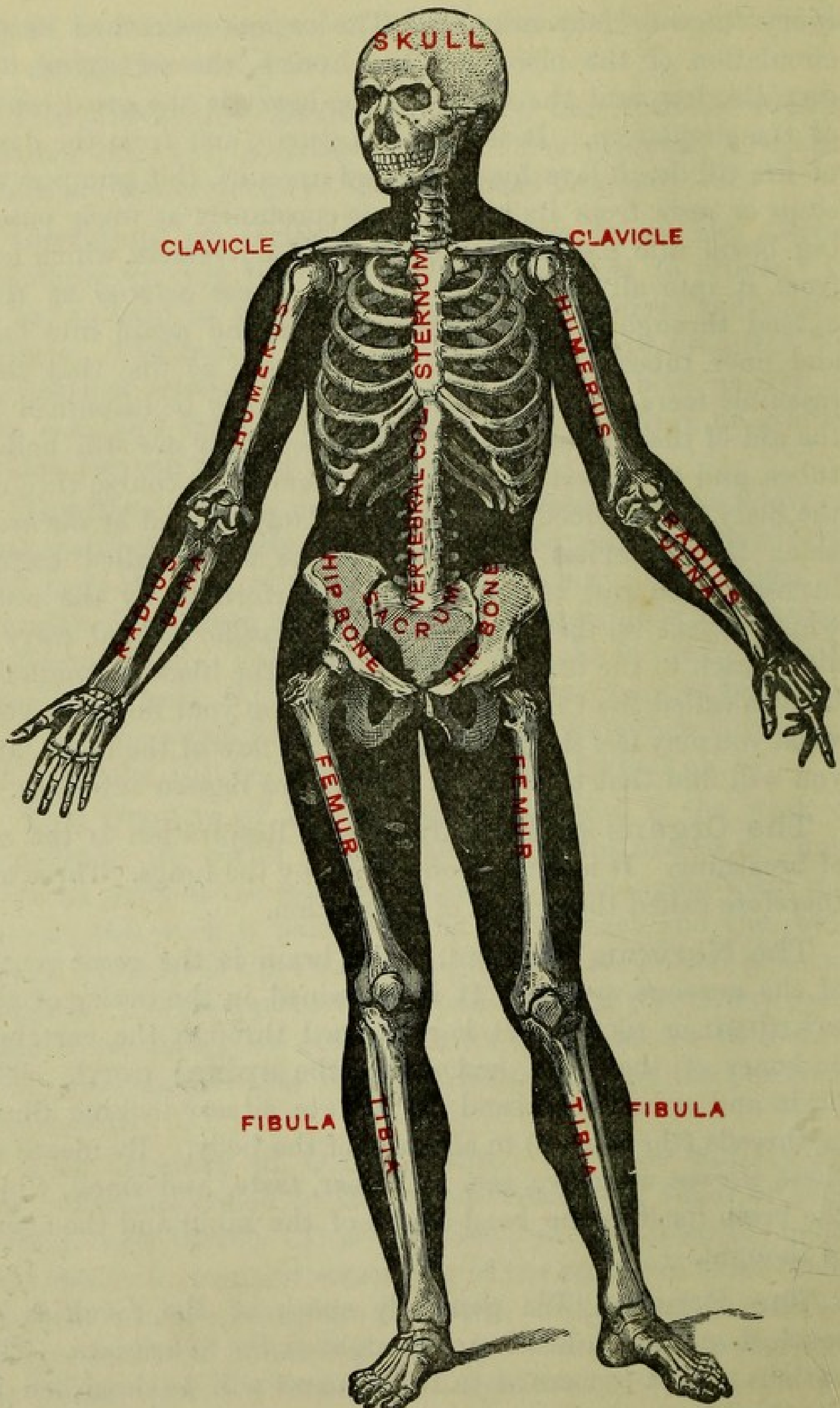


Fig. 1.—Skeleton.

THE SKELETON.

The **Skeleton** consists of the bones of the head, the trunk, and the limbs. The bones of the head include those of the cranium or skull, and those of the face.

The Cranium or brain-case (Fig. 2) is a kind of oval bony shell, which contains and protects the brain. It is formed by eight bones—

One Frontal bone.	One Occipital bone.
Two Parietal bones.	One Sphenoid bone.
Two Temporal bones.	One Ethmoid bone.

The Frontal bone forms the forehead.

The Parietal bones form the side-walls, top and back of the skull.

The Temporal bones lie round each ear, and form the Temples.

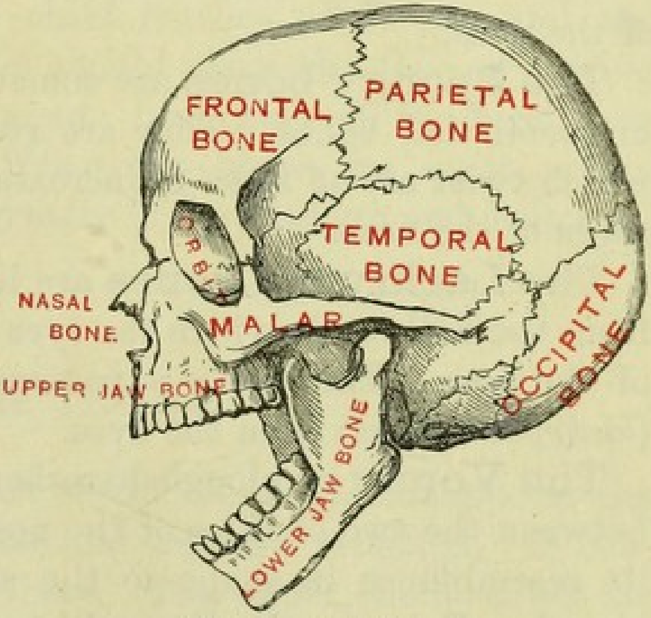


Fig. 2.—The Cranium.

The Occipital bone forms the lower part of the back of the skull.

This broad flat bone rests on the topmost vertebra of the backbone (*atlas vertebra*), and is pierced by a large hole called the **occipital foramen.** Through this hole, a long cord of whitish marrow passes from the brain-case into the **spinal canal,** and runs down the whole length of the **vertebral column** or backbone. This white marrow is known as the **Spinal Cord.**

The Sphenoid or **wedge-bone** is situated at the bottom or flooring, so to speak, of the skull. Indeed it is between the bones of the face and those of the cranium, and serves to lock together fourteen of those bones.

The Ethmoid or **sieve-like bone** is so called because it is perforated with holes like a sieve. It is situated between the bones of the cranium and those of the face, just at the root of the nose. It thus forms part of the floor of the cranium. Through the holes in this bone the nerves of smell pass from the brain into the cavities of the nose.

The Face contains fourteen bones, viz.:—

Two Nasal bones.
Two Spongy bones.
Two Lachrymal bones.
One Vomer or Ploughshare-bone.
} All these are in the nose. (See below.)
Two Malar or cheek-bones.
Two Upper Maxillary or upper jaw-bones.
Two Palate bones forming the roof of the mouth.
One Lower Maxillary or lower jaw-bone.

The Nasal bones form the bridge or hard upper part of the nose.

The Spongy bones are sometimes known as the twisted or turbinated bones. They are really small scroll-like bones which twist about so as to increase the length of the air-passages of the nose.

The Lachrymal bones are little bony channels running from the hollows in which the eyes are placed into the cavities of the nose. They form a passage for carrying off the tears (*lachrymal fluid*) from the eyes.

The Vomer or ploughshare-bone is the wall of separation between the two cavities of the nose. It takes its name from its resemblance in shape to the steel share of the farmer's plough. Between the Frontal bone, the cheek-bones, and the nasal bones are the *orbits of the eyes.*

The Orbits are the hollow, bony sockets in which the eyes are placed. In the back of each socket is a hole through which the nerve of sight passes from the brain to the eye.

Each **Upper Maxillary** or **Upper Jaw-bone** in an adult person contains eight teeth, and is immovable.

The Lower Jaw-bone contains sixteen teeth, and moves up and down and from side to side by means of a joint in front of the ears. (All these bones may be found and examined in a Sheep's head.)

Before leaving the Head we must notice the peculiar way in which its bones are joined together. The edges of the bones of the cranium and face are shaped somewhat like the teeth of a saw. In adults these edges fit into each other and grow together, slightly resembling the dove-tailed joints in a cabinet-maker's work. When grown together these joints look almost as if they had been *sewed*. Hence they are called *Sutures*, from a Latin word which means a sewing or a seam. These sutures may be seen in Fig. 2. In infancy the bones of the skull do not meet, and you may see the throbbing of the brain at the top of the head. Boys and girls should be very careful not to press the top or indeed any part of the baby's head, as it might easily cause serious injury to the brain. The bones of the skull grow at their edges, and gradually adapt themselves to the growth of the brain. They are not completely joined till the child reaches adult age and the brain its full size, and this should show the folly of boxing children's ears as a punishment; for a blow on the head may produce serious results. When the bones are quite grown together these *sutures* add greatly to the strength and resistance of the brain-case.

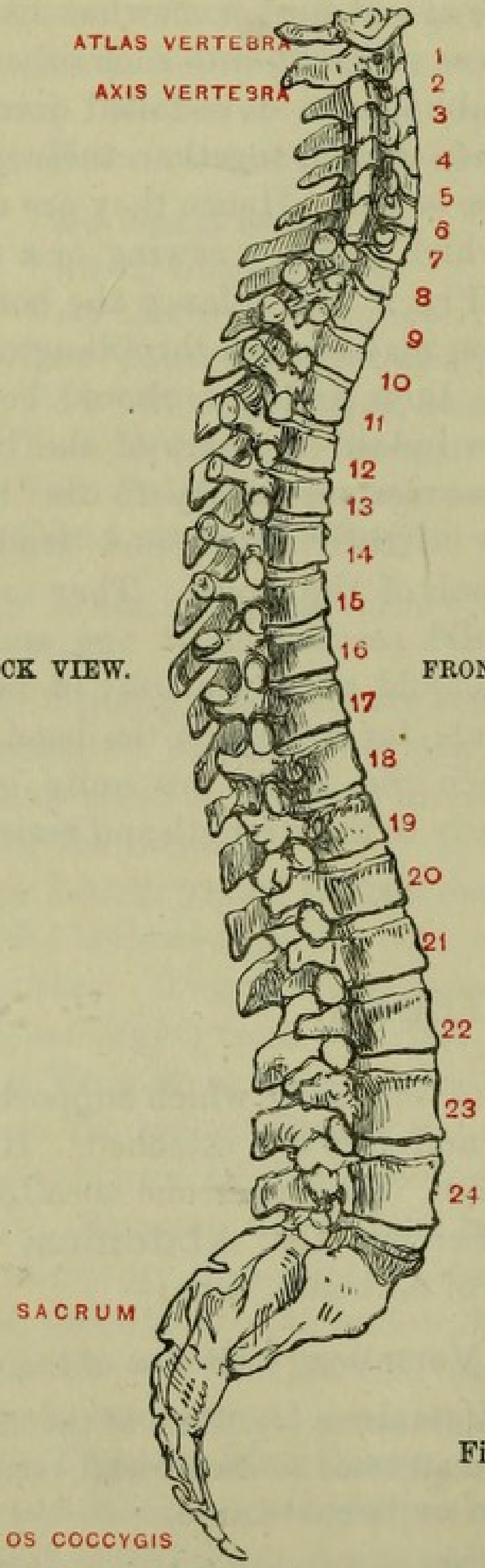
THE TRUNK.

The Trunk is that part of the body which supports the head, and to which the arms and legs are attached. It contains two cavities or chambers. The upper one is called the **Thorax or chest**, the lower one the **Abdomen**. The skeleton of the trunk consists of 53 bones, thus:—

The **Neck** contains **7 Cervical Vertebræ** (vertebræ of the neck).

The **Thorax** contains 37 bones in all.	**12 Dorsal Vertebræ** (vertebræ of the back). **24 Ribs** (two attached to each dorsal vertebra). **1 Sternum or breast-bone.**
The **Abdomen** contains 9 bones in all.	**5 Lumbar Vertebræ** (vertebræ of the loins). **1 Os Sacrum.** **2 Ossa innominata** (hip-bones). **1 Os coccygis.**

In adult age the four last bones unite and form a bony girdle called the **Pelvis.**



The first seven Vertebræ form the neck, and are called Cervical Vertebræ.

The next twelve Vertebræ are known as the Dorsal Vertebræ.
Twelve ribs are joined to these on each side.

BACK VIEW. FRONT VIEW.

The remaining five Vertebræ are called Lumbar or Loin Vertebræ.

Fig. 3.—The Vertebral Column.

The Sacrum, although generally reckoned as one bone, actually consists of five distinct vertebræ, which grow together, however, and form a single bone in adult age.

The Os Coccygis also consists of four distinct vertebræ, which are united into one in the adult.

From this classification we see that the trunk is supported by 33 separate bones or *Vertebræ* (Fig. 3.) These vertebræ resting one on the other pass down the middle of the trunk, forming the **Vertebral Column** or Spine. This column supports the head. Each **Vertebra** is pierced with a hole through its centre, and the separate bones are so placed that these holes form a continuous tube or canal from the head to the lower extremity of the trunk.

Imagine a number of reels of cotton placed one on the other. The central hole through each would be exactly over the other, and there would be one long tube or channel through the whole string of reels. This is just like the arrangement of the vertebræ of the backbone.

The **Spinal Cord** passes from the cranium along the entire length of this canal, which is therefore called the **Spinal Canal.** Through small passages between the vertebræ, the Spinal Cord sends out its nerves in all directions. The whole string of vertebral bones is also called the *Spinal Column.*

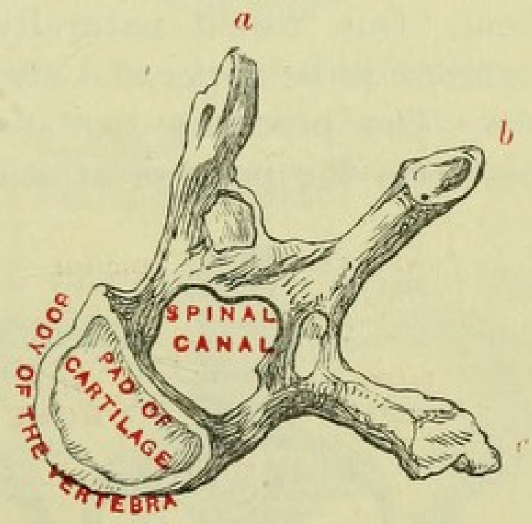


Fig. 4.—Top view of a Single Vertebra, showing the processes (*a*, *b*, *c*), the Spinal Canal, and the Pad of Cartilage.

b, the spinous process.
a and *c*, the two transverse processes.

The Vertebræ belong to the class called irregular bones. Each **Vertebra** consists of a body and a number of projecting points called **processes** (Fig. 4). The body of the vertebra is the solid central portion. This part of each vertebra is protected with smooth tough pads or cushions of cartilage (gristle). Each vertebra thus rests upon its pad or cushion, and not directly on the vertebra below it. If you look at Fig. 3, you will see the pads of gristle between the vertebræ.

The processes of the vertebræ are the three projections shown in Fig. 4. The middle one is called the **spinous** process; those on each side of it are termed the **transverse** processes. The row of spinous processes along the whole length of the vertebral column forms a ridge which we may feel down the middle of the back.

The powerful muscles for supporting and bending the body are firmly attached to these processes of the vertebræ.

The vertebral column being thus composed of separate little bones, considerable freedom is afforded for bending the body, while the pads of gristle prevent any grating or friction of one bone on another. These bones again are prevented from yielding too much by strong tough **ligaments** or cords which stretch between the processes of the vertebræ. If the vertebræ were allowed too much freedom of movement the spinal cord in the interior would be crushed or twisted and immediate death or paralysis would ensue.

It will be readily understood that the lower vertebræ of the backbone have a greater weight to support than those above them. One would naturally expect therefore these lower vertebræ to be larger and stronger in proportion, and so they are. The processes too are larger and stronger, because they form the point of attachment for the powerful muscles of the loins. If you turn to Fig. 3, you will notice that each vertebra is larger than the one above it.

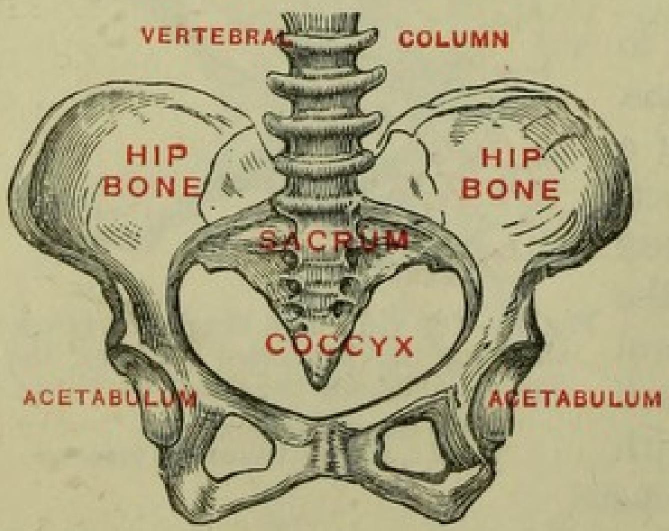


Fig. 5.—The Pelvic Bones.

There are two great classes in the animal kingdom, one including those animals which have a backbone, the other those which have not.

Animals which have a backbone belong to the class called **vertebrate animals.** Those which have no backbone are classed as **invertebrate animals.** Among the invertebrate animals are snails, slugs, oysters, mussels, lobsters, crabs, &c.

The Pelvis consists of four immovable bones joined together so as to form a kind of basin at the lower extremity of the trunk (Fig. 5). These four bones are the two **Hip-bones** (ossa innominata); the **Sacrum**, and the **Coccyx**. In the lower animals the coccyx is lengthened to form a tail. In the outer side of each hip-bone is a deep cup or socket called the **Acetabulum.** Into this socket the rounded head of the thigh-bone fits. In Fig. 13 is shown the corresponding socket for the upper bone of the arm.

The two topmost vertebræ are worthy of special notice.

The Atlas or first vertebra rests on the **Axis** or second vertebra; these vertebræ are shown in Figs. 6 and 7. The Atlas carries the head, which is joined to it by a double hinge-joint. This hinge allows the head to nod backwards and forwards, while ligaments similar to those just mentioned prevent its moving too far. On the upper surface of the Axis bone is a peg or process called the **Odontoid** Process. This peg fits into a hole in the Atlas, and thus *the Atlas, with the head*, is enabled to turn from side to side. Ligaments here also prevent the Atlas from turning round too far.

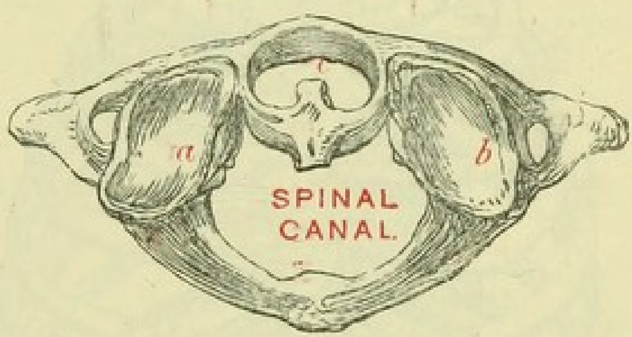


Fig. 6.—Top view of Atlas Vertebra.

a, b, the two smooth hollows in which the Skull rests.
c, the hollow or groove in which the odontoid peg of the Axis fits.

It may be interesting to know that the topmost vertebra is called the Atlas from the fabled Atlas of the ancients. In old times people believed that the earth was supported on the shoulders of a huge giant called Atlas. As therefore the head is supported by this bone it received the name of Atlas after the fabled giant of old.

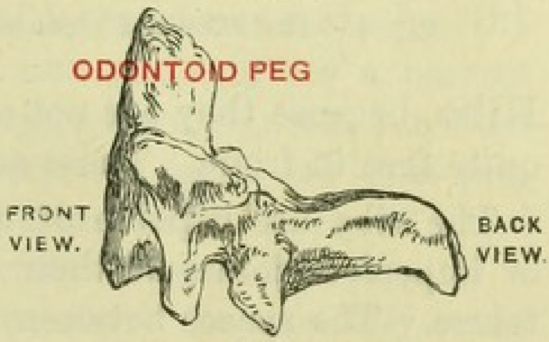


Fig. 7.—Axis Vertebra.

The Ribs. To each of the 12 **Dorsal Vertebræ** is attached a pair of long, flat, curved bones,—the ribs. There are thus 12 ribs on each side, and they pass round and strengthen the **Thorax,** resembling somewhat the hoops of a barrel. Most of these ribs are also attached by cartilages directly or indirectly to another bone in the front of the Thorax called the **Sternum.**

The ribs are therefore usually divided into **7** pairs of **true ribs,** and **5** pairs of **false ribs.**

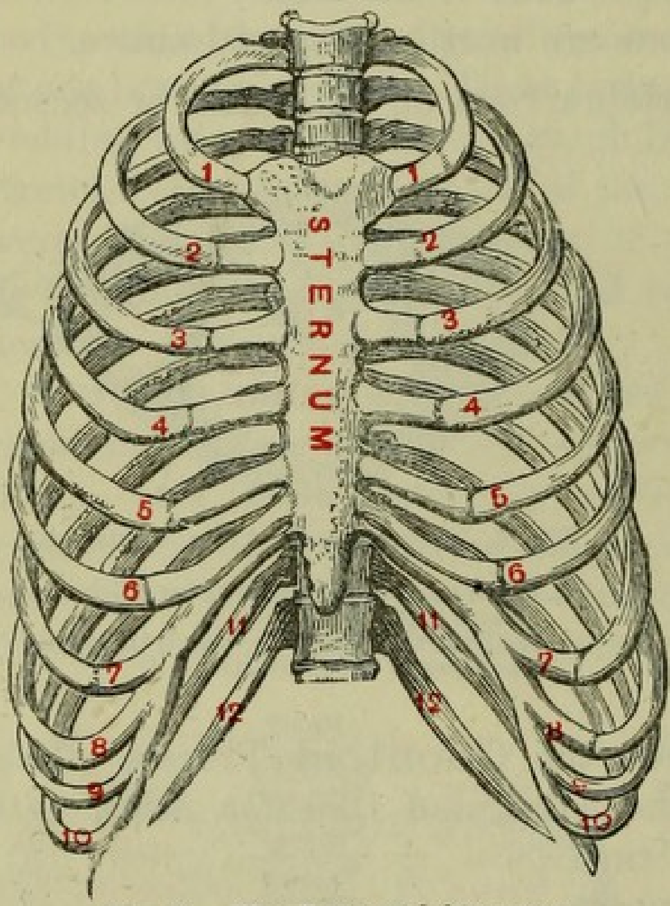


Fig. 8.—The Ribs and Sternum.

The True Ribs are the first seven pairs counting from the neck. They are all joined by their own special cartilages directly to the Sternum. See Fig. 8.

The False Ribs are the five lower pairs, and they are not joined to the **Sternum** at all. Cartilages connect them with each other, and with the last of the **true ribs.** The two lowest pairs of these False Ribs, Nos. 11 and 12, are often known as the **Floating Ribs,** because they are not even joined by cartilages, but are quite free in front. These are clearly seen in Fig. 8.

The ribs are capable of moving up and down by means of imperfect joints at their connection with the Dorsal Vertebræ. The spaces between the ribs are occupied with strong muscles termed the **Intercostal Muscles.** One set of these muscles raises the ribs, the other set depresses them. This movement of the ribs is of the utmost importance to the work of breathing, and may be easily observed every time one breathes. When the ribs are raised the cavity of the Thorax is enlarged, and the lungs (which are situated in the Thorax) expand and take in a deep draught of air. The ribs are then depressed and this movement diminishes the cavity of the Thorax, so that the lungs being pressed together are compelled to send out some of the air through the mouth and nostrils.

We cannot well leave the ribs without saying a word or two about the stupid but prevalent custom of tight lacing.

Fig. 9 shows you the ribs in a natural and healthy state. Now look at Fig. 10, which represents (but does not

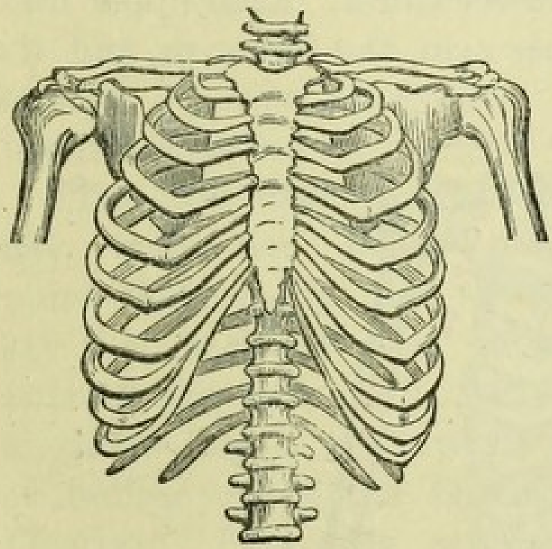


Fig 9.

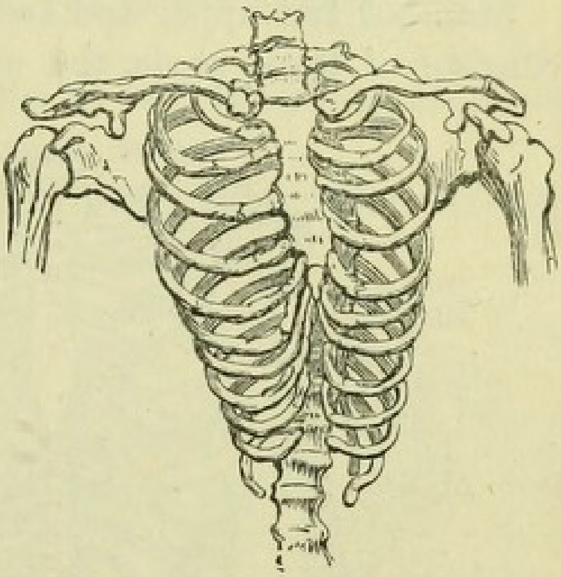


Fig. 10.

exaggerate) the effects of tight lacing. In the one case you will observe that the cavity of the Thorax is a large and spacious one, and affords ample room for the healthy movements of a healthy pair of lungs. In the distorted one you will see a narrow confined chamber in which the lungs have no room for their necessary expansions. Those precious organs are thus prevented from carrying on their all-important work of blood purifying, and gradually but surely become the prey of a dreadful devouring disease. You cannot too carefully avoid every kind of tight-lacing—stays, corsets, or indeed anything which confines or presses the ribs and breast-bone.

The Sternum or **Breast-bone** is the long flat narrow bone which may be felt in the middle of the front of the chest. In shape it is somewhat like an ancient sword or dagger. It is connected with the ribs and with another bone called the **Clavicle or Collar-bone.** See Figs. 8 and 11.

We now see that the vertebral column, the ribs, and the sternum form a kind of conical, bony cage. The space inclosed by these bones is called the cavity of the Thorax, and as it contains the heart and lungs we can understand why it is protected by such strong walls.

THE LIMBS.

Man has two upper and two lower limbs. Each upper limb consists of three parts, the upper arm, the fore-arm, and the

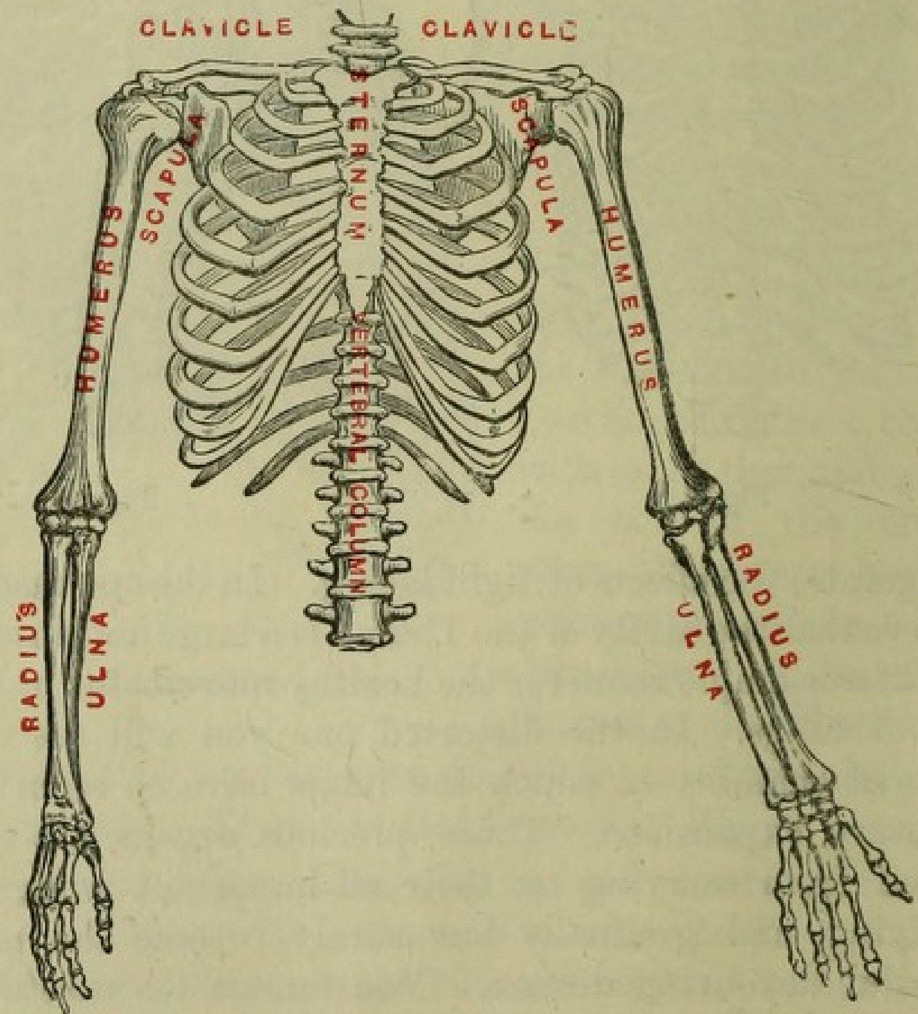


Fig. 11.—Sternum, Clavicle, and Bones of the Arm.

hand. Each lower limb also consists of three parts, the thigh, the lower leg, and the foot. In speaking of the bones of the upper extremities, however, it is usual to include the two

Scapulæ or **shoulder-blades**, and the two **Clavicles** or **collar-bones.**

Each upper limb therefore contains the following bones:—

Upper arm	Scapula. Clavicle. Humerus.
Fore-arm	Ulna. Radius.
Hand	8 Carpal (wrist) bones. 5 Metacarpal bones. 14 Phalanges of the fingers.

making 32 bones altogether. Fig. 11 will show how all these bones are placed with regard to each other.

The Scapula or **Shoulder-blade** (Fig. 12) is a large flat triangular bone, placed point downwards, and situated at the back of the thorax, outside the ribs. At its outer angle it has a shallow cavity or hollow called the **Glenoid Cavity.** Into this cavity or socket the rounded head of the humerus fits. You may see this for yourselves in the bones of a shoulder of mutton.

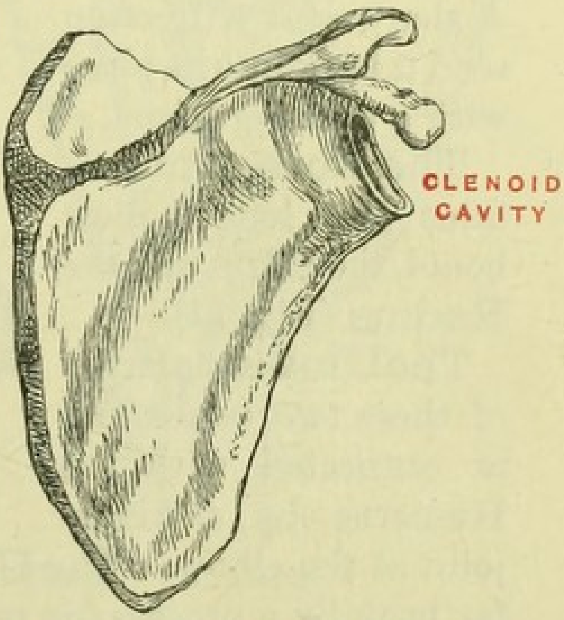


Fig. 12.—The Scapula or Shoulder Blade.

The Scapula is also connected with another bone, the Clavicle or Collar-bone, which keeps it in its place.

The Clavicle or **Collar-bone** (Fig. 11) is a long curved bone which stretches from the outer angle of the Scapula to the top of the Sternum. This bone thus forms a kind of arch which serves to protect the upper part of the cavity of the Thorax. It is attached to both the Sternum and the Scapula, and holds the Scapula firmly in its place, thus preventing the arms from falling forwards to contract the chest. The whole of this beautiful arrangement is shown in Fig. 11, where the humerus may be seen attached to the scapula, while the clavicle acts as a kind of rigid bar between the sternum and the scapula, which is thus held firmly in its place.

The Humerus is the long hollow bone of the upper arm. It has a rounded head which fits into the glenoid cavity of the Scapula, as shown in Fig. 13.

When you hear that a person has dislocated his shoulder, it means that the head of the Humerus has slipped out of the socket or hollow in the Scapula. A sharp jerk will often send it back into its place with a clicking sound.

The Fore-arm contains two long hollow bones, the **Ulna** and the **Radius** (Fig. 14).

The Ulna is the larger of these two bones, and is connected with the Humerus by a hinge-joint at the elbow. The **Ulna** is prevented from moving too far back by a process (or projection) termed the **Olecranon Process**, as shown in the figure.

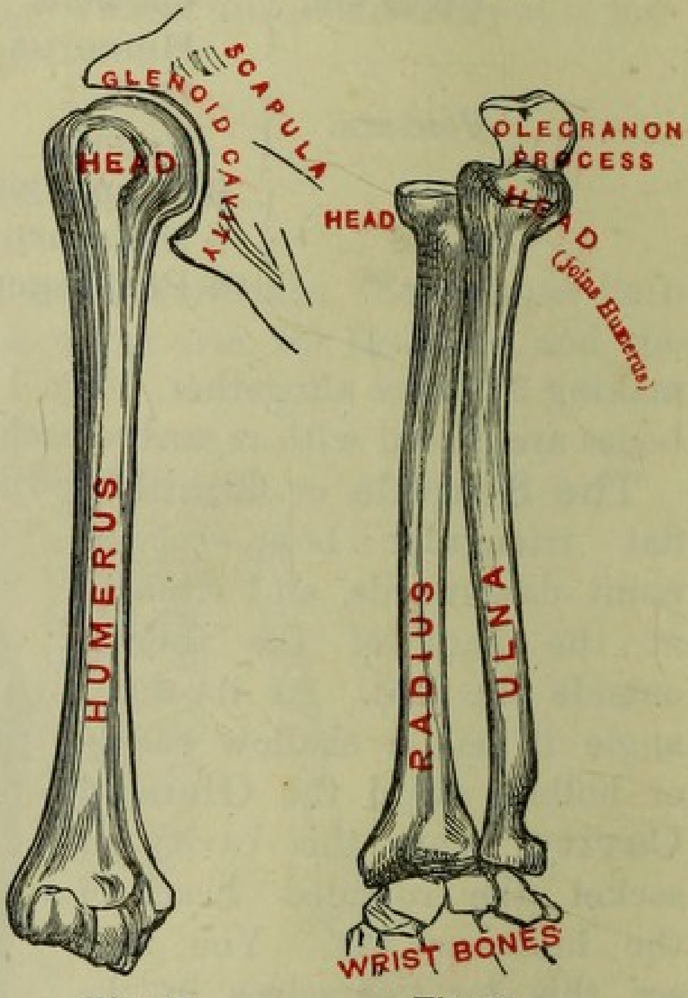


Fig. 13. Fig. 14.
Long Bones of the Arm.

The Radius is the long, slightly curved, outer bone of the fore-arm. It is smaller than the Ulna. Its upper end is attached to both the Ulna and the Humerus. Its lower end is much larger than its upper, and carries the hand.

THE HAND.

The Hand consists of three parts, the **wrist**, the **palm**, and the **fingers**. These contain in all 27 bones, which are distinctly shown in Fig. 15. The eight **Carpal or wrist bones** are arranged in two rows, and connected together by ligaments.

The Metacarpal bones are the five long bones which form the palm of the hand. They are attached to the carpal bones of the wrist, and to the phalanges of the fingers.

The Phalanges of the fingers are the fourteen small hollow bones which are attached end to end to form the fingers. Each finger contains three bones; each thumb two. The bones of the fingers are arranged in three rows, as you may see by closing the hand.

The Carpal bones, Metacarpal bones, and the Phalanges of the fingers, are all united by strong but flexible ligaments. By this beautiful contrivance the greatest strength and elasticity are given to the hand, which is thus fitted for all kinds of duties, from driving heavy hammers to handling the pen and brush.

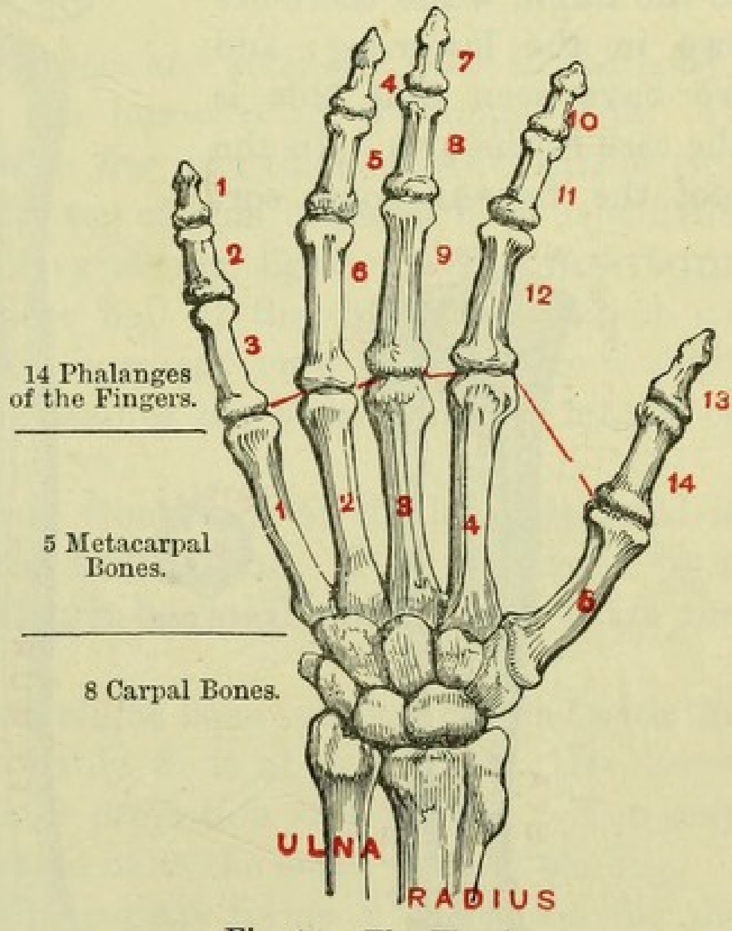
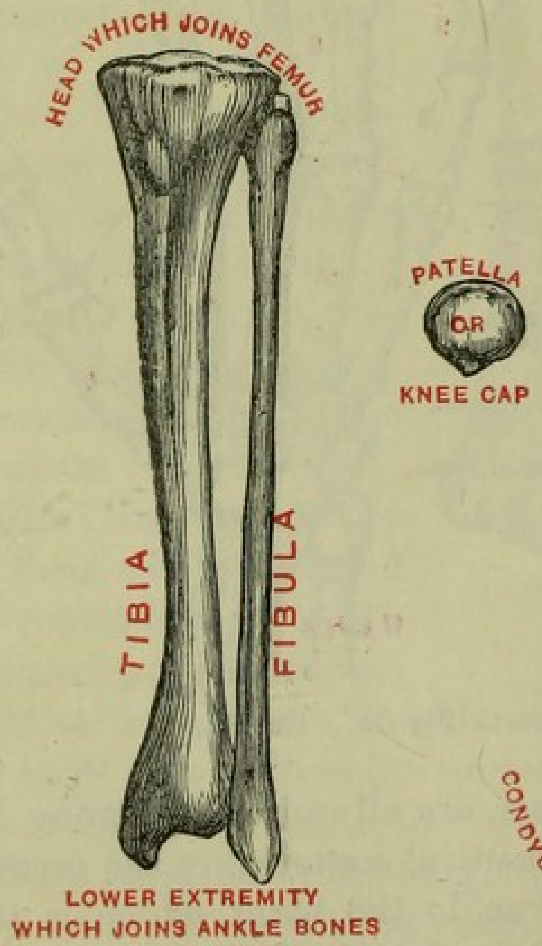


Fig. 15.—The Hand.

As the hand thus consists of so many parts, the effect of a blow is, as it were, broken up among the various bones, and no harm is done. If it were not for this the concussion caused by using a hammer or other tool would shatter the hand.

THE LOWER LIMBS.

The general structure and number of the bones of the legs bear a remarkable similarity to those of the arms. Thus the leg (like the arm) consists of three parts, the **thigh**, the **lower-leg**, and the **foot**. There is but one bone in the thigh, while there are two in the lower-leg; and we have seen that this is the case in the arm. In the foot the **tarsal** bones cor-



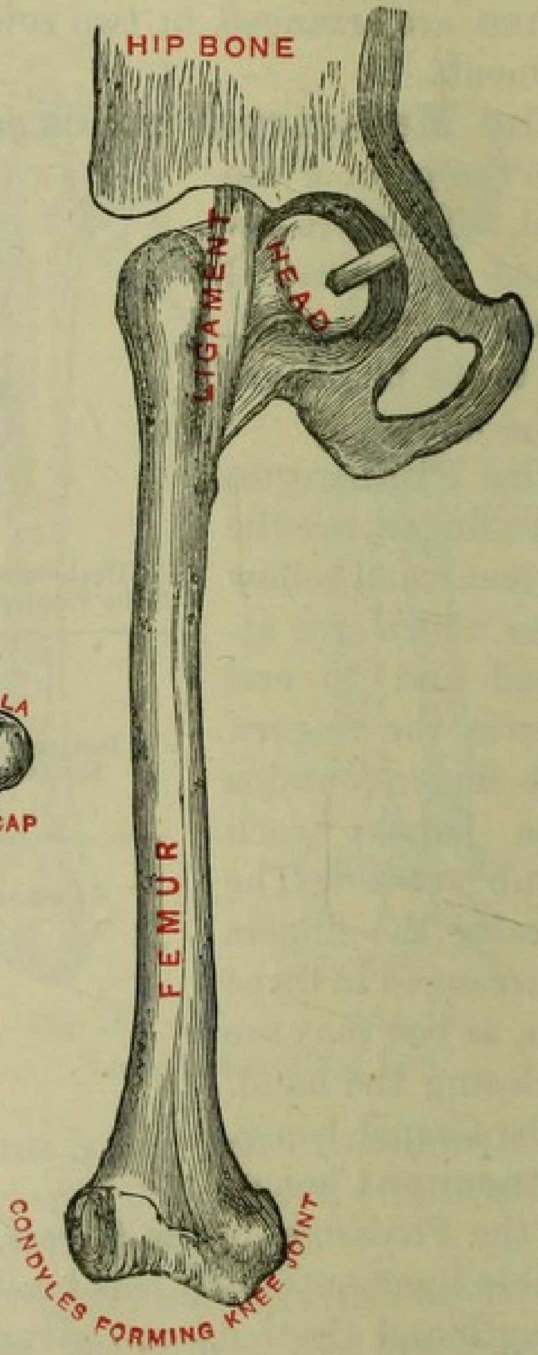


Fig. 16.—Femur, Tibia, and Fibula.

respond with the carpal bones of the wrist, while the **metatarsal bones** and the **phalanges of the toes** take the place of the metacarpal bones and the phalanges of the fingers. We shall note the points of difference as we proceed.

The bones of the leg are:—

Thigh	**Femur** (thigh-bone).
Lower leg	**Patella** (knee-cap). **Tibia** (shin-bone). **Fibula** (splint-bone).
Foot	**7 Tarsal bones** (ankle-bones). **5 Metatarsal bones** (bones of instep). **14 Phalanges of the toes.**

making 30 bones in all.

The Femur is the largest and strongest bone in the body, and corresponds with the humerus of the upper arm. It has a rounded head which fits into the **acetabulum** or cup of the hip-bone. In the top of this rounded head is a little hollow from which a very strong ligament (**ligamentum teres**) passes, to hold the ball of the thigh-bone well in its socket. In Fig. 16 this ligament may be seen like a short round cord between the head of the Femur and the middle of the Acetabulum.

The Tibia is the long front bone of the lower-leg, and is commonly known as the **shin-bone**. It is connected by a hinge-joint with the **thigh-bone (Femur)**, and bears the weight of the body.

The Fibula is a long slight bone running parallel with the Tibia, and fixed immovably to it at both ends. Its lower extremity forms the outer projection at the ankle. You may have often heard it spoken of as the small bone of the leg.

The Patella or **knee-pan** forms a protection for the knee-joint. It is a flat three-sided bone, and is held in its place by fourteen stout ligaments.

THE FOOT.

The Foot, like the Hand, consists of three parts, the bones of which are known as the **tarsal bones**, the **metatarsal bones**, and the **phalanges of the toes** (Fig. 17).

The Tarsal bones are seven in number, and form the heel, the ankle, and part of the sole of the foot. The heel-bone is called **os calcis**, and is connected with the great muscle of the calf of the leg by a strong tendon called **the Tendon of Achilles.**

The Metatarsal bones are five in number, and form the lower instep of the foot. They are the connecting link between the ankle-bones and the phalanges of the toes.

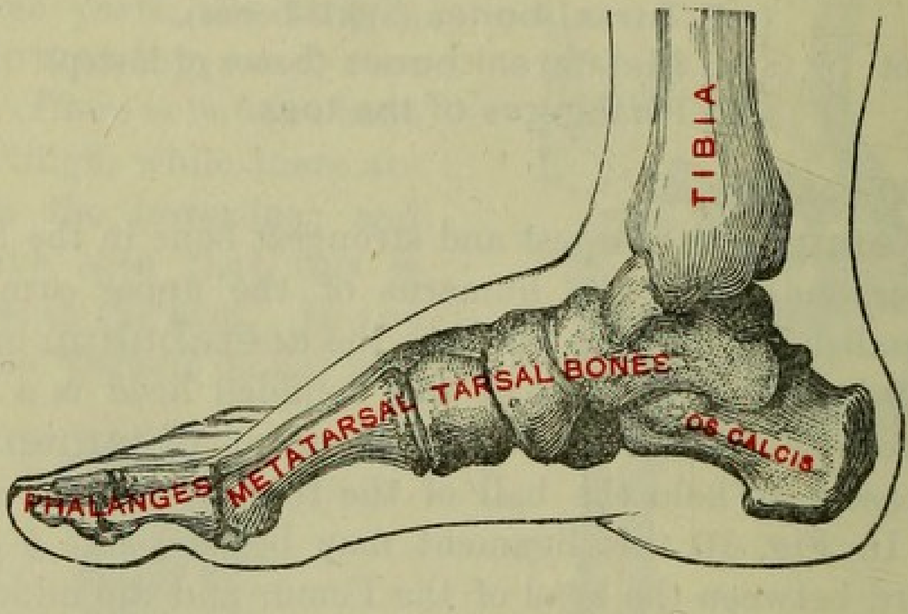


Fig. 17.—The Human Foot.

There are 14 phalanges of the toes, but these are shorter than those of the fingers, and allow of less freedom of motion. Fig. 18 shows the bones of the foot viewed from above; and if we compare this with Fig. 15 on page 23, we shall see many points of difference in the structure of the hand and the foot. In the hand the carpal bones are small, and the phalanges are very long and slender. The thumb too is made to move in the opposite direction to the fingers, and thus the hand becomes adapted for grasping purposes. Indeed the hand may be either a most delicate pincer or a powerful vice, while its flexibility can nowhere be better seen than in the rapid movements of the *skilful* musician on the key-board of his instrument.

Now look at the bones of the foot. The tarsal bones have a heavy clumsy appearance, and all the hollow bones (that is, the metatarsal bones and the phalanges of the toes) are short, thick and heavily jointed. It is at once clear that strength and not flexibility is the object of these bones, and of course the feet which are to support the entire weight of the body are better adapted to perform their office than they would be if constructed of slight long bones like those of the hand.

Just take one more look at Fig. 17. You see that the under part of the foot is arched, and you know that when you walk the middle of your foot never touches the ground. You walk really on the heel and the ball of the foot. This arch, which is known as the **Plantar arch**, is of great assistance in walking, for it acts like an elastic spring when the weight of the body falls upon the foot. The result of this is that we are enabled to walk and run without shaking or jolting our bodies at every step.

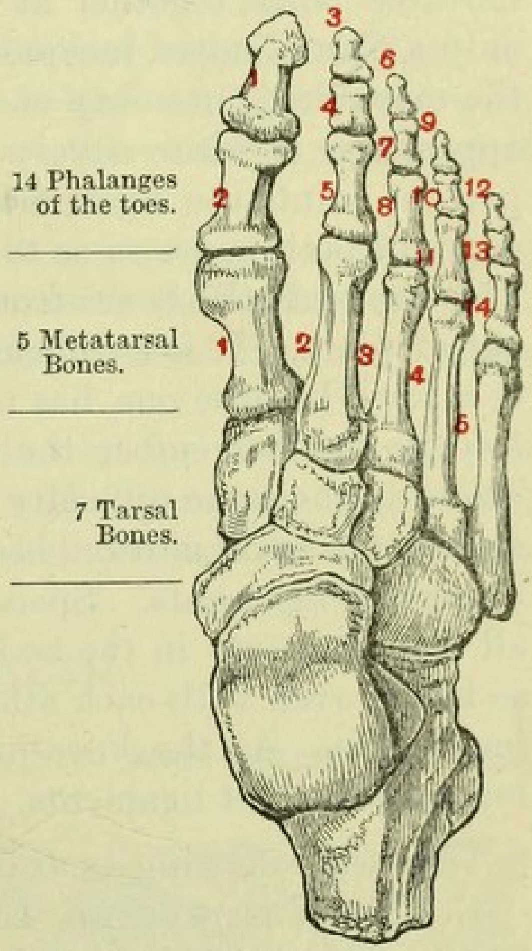


Fig. 18.—The Human Foot, viewed from above.

The Clavicle, Humerus, Radius, and Ulna of the arm; the Femur, Tibia, and Fibula of the leg; as well as the metacarpal and metatarsal bones, and the phalanges of the hands and feet, all belong to the class called long or hollow bones. (See page 7.) At all the joints the bones are protected from friction by thin smooth pads of cartilage, and held in their places by ligaments. Both the cartilages and the binding ligaments are kept moist and smooth by a white somewhat sticky fluid called the **Synovia.** The fluid is something like the white of an egg, and is secreted by a membrane called the **Synovial sac** which lines the joint. You may often hear this lubricating fluid spoken of as **joint oil.** This oil sometimes dries up through over-eating or intemperance, and the person cannot move without pain and a grating sound in his joints. The best way to avoid rheumatism, gout, and other disorders of the joints is to eat moderately of simple plain fare, to abstain from drinking spirits, and to take plenty of exercise. It is quite evident that the joints were made for use or they would never have been supplied with their lubricating joint oil. Use the limbs then in work and exercise, and do not abuse them with gluttony, drunkenness, or laziness.

LIGAMENTS.

Ligaments are tough flexible bands or straps which bind the movable bones together at the joints. They allow the bones only a fixed limited movement. They may be seen in any of the movable joints—say of a rabbit or a sheep, and have the appearance of white silvery-looking strings. At the most important joints the ligaments are bound completely round the edges of both bones so as to inclose the joint in a kind of cap. This prevents the bones from being easily dislocated or slipped out of place. It is a difficult matter to carve a goose, turkey, or a fowl, because one has to cut through these ligaments before he can dismember the body to serve it out in portions. There is the same difficulty in separating the two bones in a shoulder or leg of mutton, because they are held firmly together by strong ligaments. Space will not allow of the mention of all the ligaments in the body—indeed they are in some parts so interwoven with each other that the task would be almost impossible. At the knee-joint alone there are no less than fourteen distinct ligaments.

Take the following as examples of the most important:—

1. **The Transverse Ligament of the Atlas Vertebra**, which binds the Atlas to the Axis Vertebra. We have already described the way in which the head performs its movements. You remember, of course, that the act of turning the head round from side to side is performed by the rotation of the Atlas on the Odontoid Peg of the Axis Vertebra. You know, too, that the spinal cord, that extremely delicate marrow, runs through the centre of these vertebræ. The least twist or injury to that cord would perhaps cause death. This powerful ligament therefore holds the Atlas firmly in its place, and will not allow it to move round too far, either to the right or left.

2. **The Glenoid Ligament**, which holds the head of the humerus firmly in the glenoid cavity of the scapula.

3. **The Ligamentum Teres,** which is a very strong round ligament, like a cord, passing from the top of the ball of the femur to the middle point in the hollow of the acetabulum. Besides the **Ligamentum Teres** there is, at this joint, a strong **capsular ligament** binding the outer edges of the bones firmly together. Both these ligaments were shown in Fig. 16.

The whole of the bones in the spinal column are held together by short strong ligaments, which are interwoven with each other between the processes of the vertebræ, and impart strength and flexibility to the spine.

You perhaps know how difficult it is to separate the bones in a loin of mutton or even the bones in the back of a rabbit. This is because they are so strongly attached together by ligaments.

The wrist and ankle too, and indeed the whole of the foot and hand, are literally crowded with ligaments, which bind their little bones together, giving both strength and flexibility to those parts.

THE TEETH.

An adult person has 32 teeth, 8 in each upper jaw-bone, and 16 in the lower jaw. Their position in the jaws will be better understood from Fig. 19. These teeth are known as the **Permanent Teeth.** They do not begin to appear till between the age of six and seven, when they take the place of the child's first set (the **milk teeth**). Infants usually begin to cut their milk

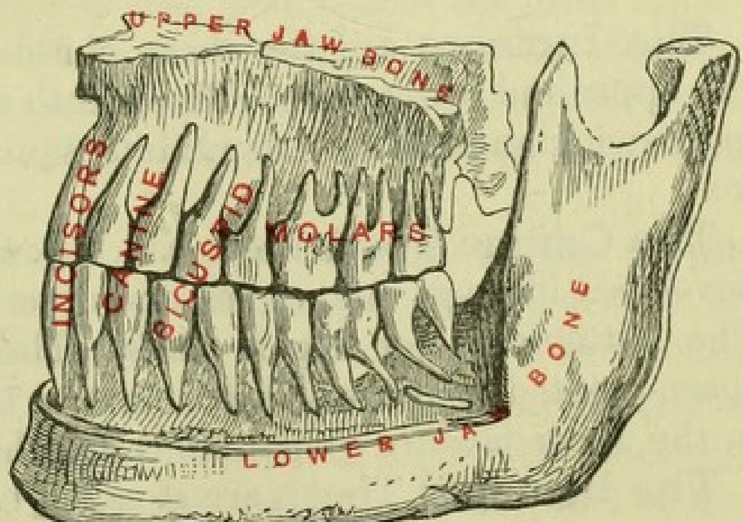


Fig. 19.—Side view of Jaw with Teeth.

teeth when they are between six and nine months old, and the full number of these teeth is 20. They have no roots, and fall out to give place to the Permanent Teeth as soon as the latter are formed.

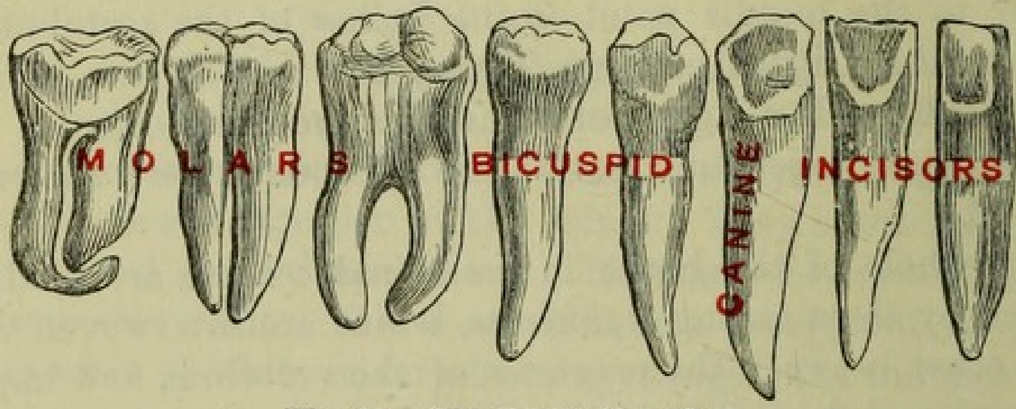


Fig. 20.—The Teeth Classified.

This figure shows the eight teeth in each half of the upper and lower jaw. Hence although there are but 3 molars, 2 bicuspids, 1 canine, and 2 incisors in the figure, there are actually four times as many of each in the whole set of teeth.

The last to appear of the Permanent Teeth are the four **molars** commonly called the Wisdom Teeth, because they are not usually cut until the twenty-first year.

Teeth have different shapes (see Fig. 20), and they are divided, according to the work they have to do, into—

8 Incisors or cutting teeth.
4 Canine teeth.
8 Bicuspid or false grinders.
12 Molars or true grinders.

The Incisors are the sharp chisel-like teeth in front of the upper and lower jaws. These teeth are strongly developed in gnawing animals such as rabbits, squirrels, rats, the beaver, &c.

The Canine Teeth are so called because they are strongly developed in dogs, cats, tigers, and other flesh-eating animals. The Latin word for dog is *canis.* These teeth are long and sharp-pointed, and are situated next to the incisors. The two in the upper jaw are sometimes called the **Eye Teeth.**

The Bicuspid Teeth are so called because they have two cusps at the top for grinding the food. They are situated between the canine teeth and the true molars. Those in the upper jaw have one fang deeply set.

The Molars are the true grinding teeth. These teeth have broad crowns with four or five cusps or ridges for grinding. They have also two or three roots or fangs. All animals which live on corn, grass, hay, or herbs have very large grinding teeth. In this class of animals come the elephant, ox, horse, sheep, rhinoceros, &c.

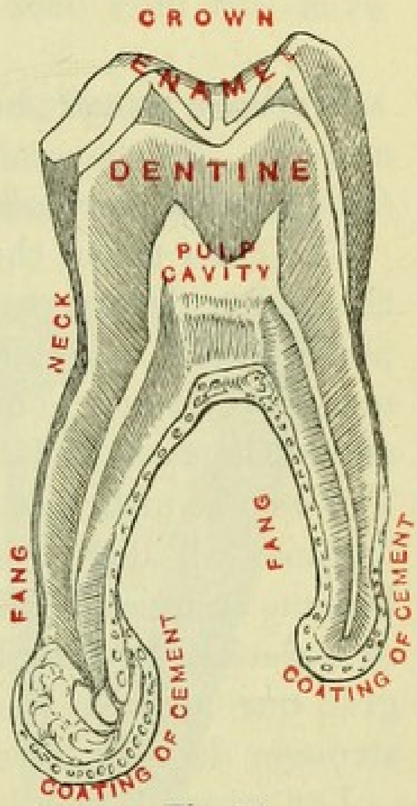


Fig. 21.
Section of a Tooth.

Each tooth consists of three parts:—the **root** or **fang**, which is fastened into the jaw-bone; the **neck**; and the **crown**. (See Fig. 21.) The incisors and the canine teeth have only one fang, the molars sometimes two, sometimes four. The nerves and blood-vessels enter the teeth at the end of the fangs.

Teeth, although sometimes classed with the bones, are not of the same structure. They consist mainly of a hard substance resembling bone and called **dentine**. The dentine is covered on all the exposed parts with an exceedingly hard, white, and brittle substance called **enamel**. Blood-vessels traverse all parts of the teeth except the enamel. If, therefore, this outside covering becomes chipped or damaged, it does not grow again. In the centre of the tooth is a cavity filled with the **tooth-pulp**, a mass of nerves and blood-vessels. The fang is secured in the jaw-bone by a thin coating of a substance known as **cement**. See Fig. 21.

Good teeth, besides being most essential to the proper digestion of our food, and therefore to our health, are one of the greatest natural adornments of our person. We should therefore be careful to preserve them. A tooth-brush and a little water (neither too hot nor too cold), night and morning, will do all that is required in this respect. The enamel of the teeth, however, will not stand unfair usage,hard as it is. Cracking nuts and biting anything very hard should be avoided, as well as too many sweets. Picking the teeth with pins and needles is also very hurtful. When the enamel is once broken the softer dentine underneath it decays, the tooth becomes hollow, and we are racked with the distracting pain of toothache.

MUSCLES.[1]

We have already had occasion to mention muscular tissue or muscle. *This muscular tissue is the flesh which covers the bony framework of our bodies.*

The chief use of this flesh or muscle is to cause movement in the body. Every part of the body which is capable of motion performs its movements by means of its own special set of muscles. Hence you will readily understand that the largest and strongest muscles must be sought for in the arms and legs. The blacksmith has very heavy work to do in swinging his hammer all day; and this is why the muscles of his arms become so much thicker and firmer and more solid than those of a clerk. By and by you will learn that the more work we give our muscles the better they like it, and the larger and stronger do they develop.

Let us see how all this movement is brought about. Suppose you take two long pieces of wood, and join them together by a sort of peg at one end so as to allow them to move up and down on each other. I daresay your teacher will show you what I mean. If now you fasten a stout piece of elastic by its ends to the two bars I think I can make you understand how a muscle acts. The bars of wood represent two bones joined by a sort of hinge; the elastic represents the muscle. If you stretch them out, and then remove your hand, the elastic will contract and pull the two bars together. This, although not a perfectly exact comparison, is the best one you can have, for muscles cause the movements of the body simply by contracting or drawing themselves up just as the elastic did.

Muscles are of two kinds, **Voluntary** and **Involuntary.**

Voluntary Muscles are those which can be made to act *under the influence of the will.* Such muscles constitute the bulk of the fleshy parts of the body and form a covering for the bony skeleton.

When a piece of lean meat is bought from the butcher per-

[1] See also pp. 162–167.

haps you have little idea that it consists of parts of several distinct muscles. It looks to you like a solid mass. With the aid of the anatomist's knife, however, these muscles may be readily separated, and then each will have the following form:—

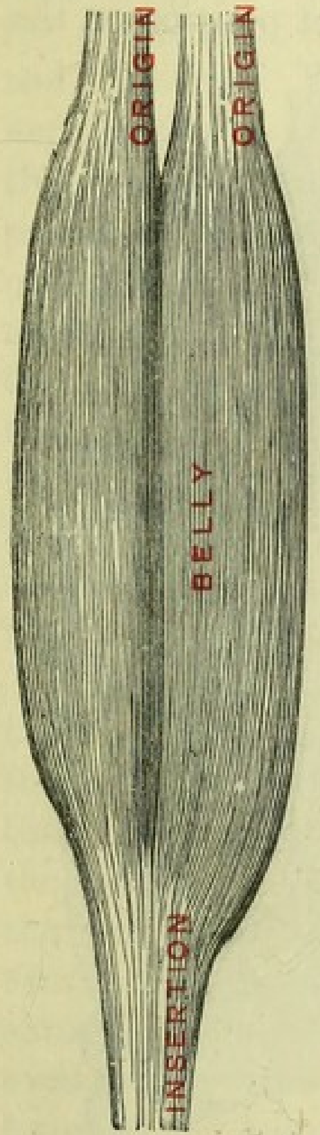


Fig. 22.—Biceps Muscle of the Arm.

1. A middle or thick part called the **belly.**

2. Two tapering ends, one attached to the fixed bone and called the **origin**; the other connected with the movable bone and called the **insertion** of the muscle. These tapering ends of the muscles are attached or inserted into the bones by means of tendons or sinews. Fig. 22 is a representation of the **biceps muscle** of the arm. At its origin it is attached to the Scapula or Shoulder-blade by two tendons; hence its name Biceps—*bi* meaning two. At its lower end it is inserted into the Radius bone of the fore-arm.

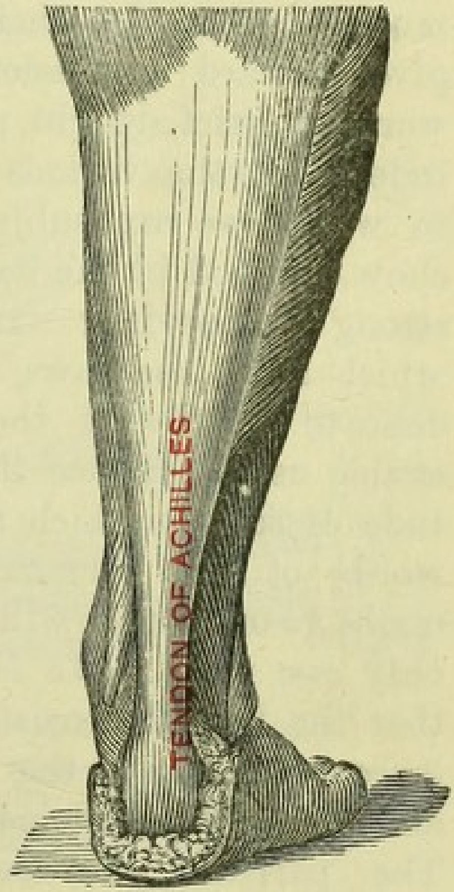


Fig. 23.
Lower portion of the Leg.

The number of muscles in the human body is very great, probably there are as many as 500 altogether. We can mention only a few of the most important. The great muscle known as the **gastrocnemius muscle,** which forms the calf of the leg, is perhaps the most important one in the body, and is of very great strength (Fig. 23). It is inserted into the heel-bone by the Tendon of Achilles, and is also joined to the thigh-bone above. In the act of walking, at every forward step this muscle and its powerful tendon have to raise the entire weight of the body.

Strong muscles support the head in the erect position on the neck, and turn it in every direction *at the command of the will.* The face too consists of a great number of closely interwoven muscles, which by their action give outward expression to inward joy, grief, delight, pain, and indeed all the various feelings to which we are subject. We chew our food by the help of the strong **chewing muscles** which move the jaws, and the delicate muscles of the tongue enable us to produce the multitude of sounds which form the words of our language. We might go on, but we will mention only one more. We have seen that the **trunk** consists of two large chambers, the Thorax above and the Abdomen below. The partition between these two chambers is formed by a large flat muscle called the **diaphragm.** This important muscle thus forms the floor of the Thorax, and every time we breathe that chamber is enlarged by the contraction of the diaphragm. See Fig. 24.

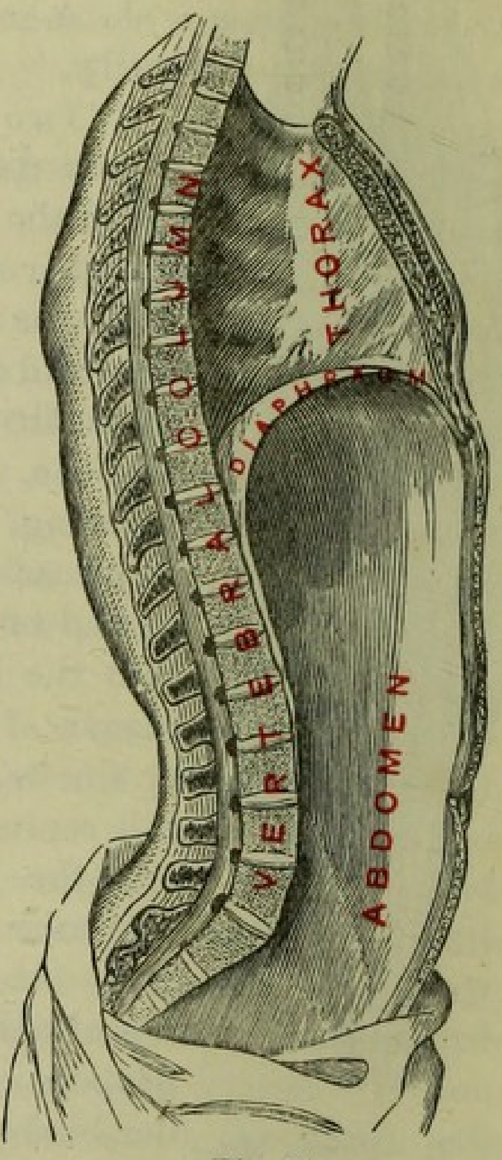


Fig. 24.
Showing the Diaphragm separating the Thorax and Abdomen.

As a muscle acts only by contracting, each movable bone must be supplied with at least two opposing muscles. One of these contracts and draws up the limb. This is called a **flexor muscle.** The other, on the opposite side, by contracting stretches out the limb. This is called an **extensor**

muscle. Take for instance the muscles of the arm. When we bend the arm we notice that the muscle in front of the upper arm swells up and becomes hard. Indeed this muscle (which is the Biceps muscle mentioned above) has contracted (*in obedience to the will*), and by its contraction has drawn up the fore-arm. When we wish to straighten the arm, we do not accomplish this by the mere relaxing of this muscle; for if that were the case the arm would simply *fall* into the straight position. The **triceps muscle**, however, at the back of the upper arm, now contracts (*in obedience to the will*), and by its contraction straightens the arm. It will be readily seen from Figure 25 that the Biceps acts as a flexor muscle and the Triceps as an extensor.

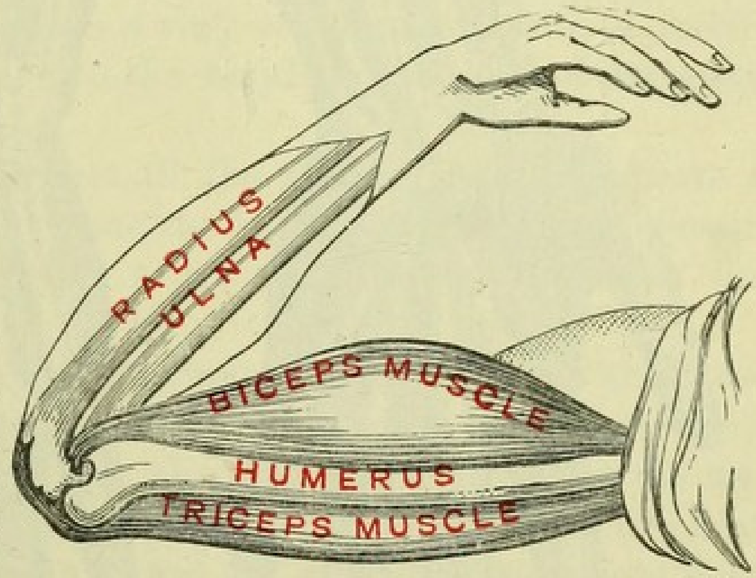


Fig. 25.—Biceps and Triceps Muscles.

This figure shows the Biceps Muscle contracting so as to draw up the arm. When the arm is again straightened the Triceps has a swollen appearance, because it has contracted and become thicker.

The Involuntary Muscles are those which carry on their work without the interference of the will—indeed we cannot prevent them acting. They act even when we are asleep. Among these muscles we may mention those of the stomach, the intestines, the gall-bladder, the lungs, the heart, and the iris of the eye. These muscles have no **tendons.** The involuntary muscles found in the walls of the arteries, the heart, the stomach, the gall-bladder, &c., are sometimes known as **organic muscles.** When they contract they force along the contents of these organs and vessels. In this way the blood is forced out of the heart, the food out of the stomach, the bile fluid out of the gall-bladder, and so on. If these muscles were not entirely independent of the will they would cease to act immediately we fell asleep, and death would be the result. As it is, the organs of circulation, respiration, and digestion continue their work at all times because the will has no power over them.

If we examined a muscle very closely we should find that it consists of bundles of red parallel fibres enveloped in a most delicate sheath or membrane. You have no doubt seen a piece of mutton or beef boiled, as we say, to rags. If so you must have noticed that it has a stringy or fibrous appearance.

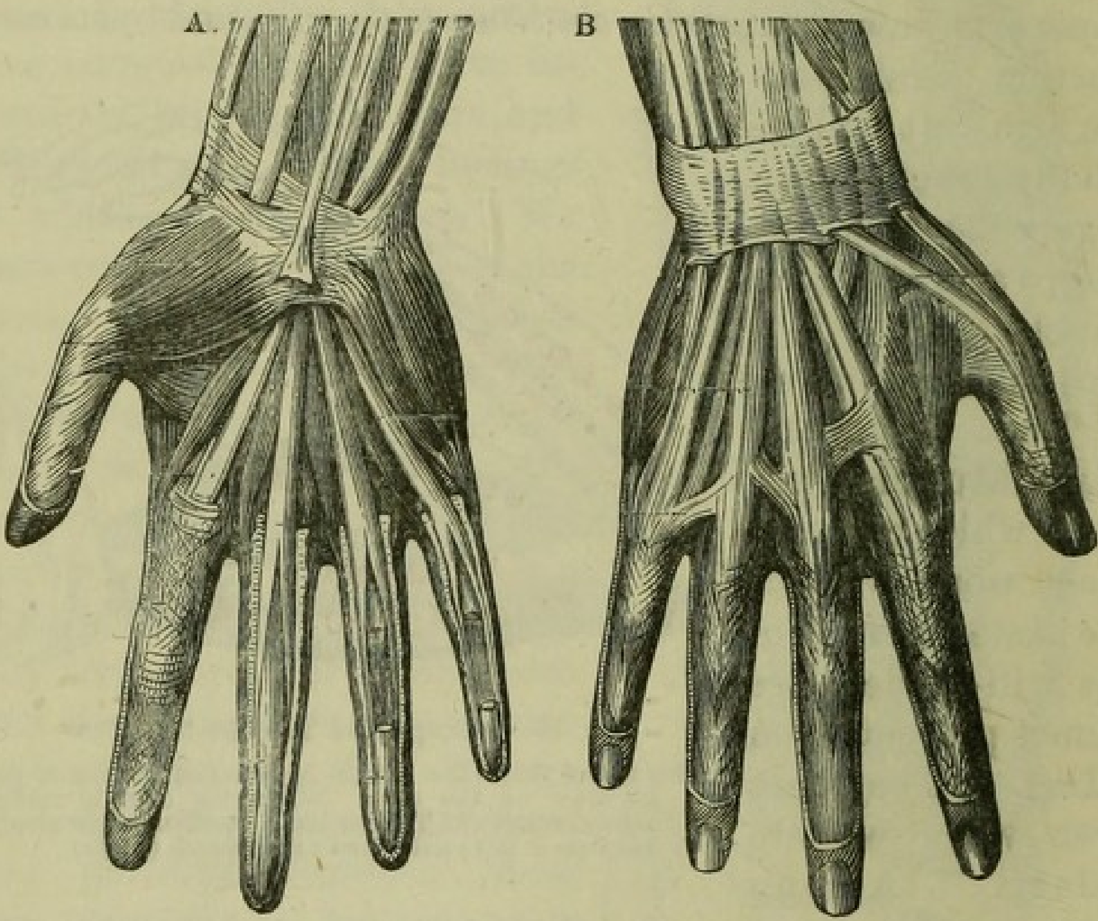


Fig. 26.—Showing the Muscles and Tendons of the Hand.

Each fibre is supposed to be made up of a great number of very minute fibres visible only with the aid of the microscope. Muscular fibre is of two kinds, *smooth* and *striped.* The Voluntary Muscles consist wholly of striped muscular fibre; the smooth or unstriped muscular fibre is found in the involuntary and organic muscles. We have noticed that the voluntary muscles are joined to the bones by tendons or sinews.

The Tendons are tough, white, shining cords which connect the muscles with the bones. They may even be considered as a continuation of the muscles. They are exceedingly strong but flexible. You have often perhaps seen the foot of a fowl, a rabbit, or some other animal, and have amused yourselves with moving the toes by pulling a white cord in the leg. This cord is a tendon. The tendon which corresponds to it in the human body is the most important one of all, and is called the Tendon of Achilles. It connects the great muscle in the calf of the leg with the **os calcis** of the heel, as shown already in Fig. 23.

Fig 26 shows the muscles and tendons of the hand; A showing the palm, B the back of the hand. These numerous muscles and tendons form a very complicated piece of mechanism, and help to give to the hand its marvellous dexterity and flexibility.

It is worth noticing that all the muscles shown in figure A are **flexors**—*i.e.*, they close the hand, as in the act of grasping, while those in figure B are **extensors**, and open the hand.

Fat. Intermixed with the muscles, and between the muscles and the skin, there is in all persons a more or less thick layer of fat. The fat gives plumpness and beauty to the figure, and as it is a bad conductor of heat it prevents the heat of the body from passing away. If a healthy man were kept without food, the fat in his body would be gradually absorbed by the blood, and burned up to maintain the requisite heat of the body. This loss of fat would soon begin to show itself in the sharp and pinched features which so infallibly denote starvation.

Only a moderate quantity of fat is necessary for the health of the body. Very great corpulence in persons is generally the result of some disease.

THE SKIN.

The outer covering of the body consists of three distinct layers, which may be readily separated with the aid of the anatomist's knife. The most internal layer is known as the **Cutis** or **True Skin**; on this rests a thin layer called the

Basement Membrane; and the outer layer is called the **Cuticle** or **Epidermis.**

The Cutis, Dermis or **True Skin.** This innermost layer is of a very complex structure, and consists of fibres crossing and recrossing each other in all directions. It is so abundantly supplied with minute hair-like blood-vessels that it appears to be almost entirely composed of them. A closely interwoven net-work of nerve fibres is intermingled with the blood-vessels. The result of this is that the slightest prick with a needle will draw blood by injuring some of these vessels, and give pain by irritating some nerve. The nerves become enlarged at the surface of the cutis, and form curved ridges. These may be seen on the palms of the hands, the tips of the fingers, and the soles of the feet. On the surface of the tongue and the tips of the lips the ridges give place to tiny swellings or pimples. The sense of touch is most acute in these parts of the body.

The Basement Membrane is a delicate gauze-like layer on which lies a soft pulpy substance which gives the peculiar colour to the skin. This pulpy substance is black in the negro, copper-coloured in the American Indian, yellow in the Chinese, and so on.

The Cuticle or **Epidermis.** This outer layer is a thin, horny membrane, which serves to protect the more delicate structures beneath. It is semi-transparent, and when seen under the microscope looks very much like the scales of a fish or a snake. It is this layer which is raised by a scald or a blister. It contains neither nerves nor blood-vessels. It is therefore quite insensitive to pain, and does not bleed when pricked.

It is important to remember that in the process of tanning skins to make leather, the outer layers are scraped off and nothing is left but the cutis or true skin.

The skin, however, is not only a covering for the body; it is an organ of excretion—indeed one of the most important organs of the body. By the term *excretion* is meant the collecting up or separating of waste poisonous substances from the blood and throwing them off from the system. This is just what the skin does by means of the Perspiration or Sweat Glands.

The skin contains millions of these **Sweat Glands,**[1] set close side by side, and opening out on its surface in little holes (the pores of the skin). The little tubes are about a quarter of an inch long and are coiled up somewhat like a corkscrew. If placed end to end, these tiny sweat pipes would make a tube thirty miles long. They are the drain-pipes of the human system. The sweat or perspiration which they excrete from the blood is a watery fluid containing certain waste matters which, if not allowed to escape, would soon poison the body and cause disease. You will readily understand that such a wonderful system of drain-pipes was not designed without some great purpose. They are always at work draining off these impure matters from the blood, night and day, sleeping and waking. You might think, as you sit quietly in your places in school, that your sweat glands can now have little or no work to do. Your skin does not feel damp in the least. But even at these quiet times the work of the little drain-pipes is still going on. Indeed without undergoing any violent exercise you lose nearly a pint of sweat through the sweat-glands every day.

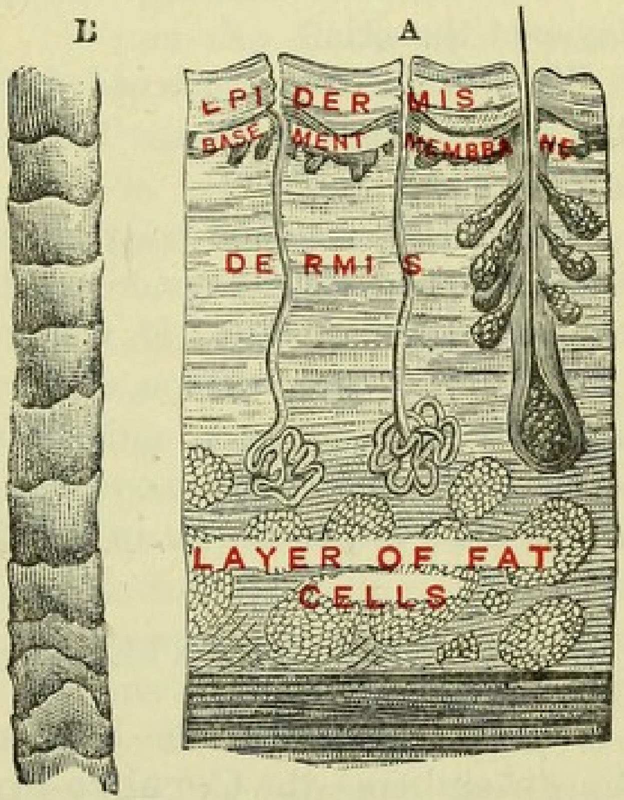


Fig 27.
A, Section of the Skin, under the microscope.
B, Hair seen under the microscope.

You may hence judge for yourselves what a great quantity of perspiration is thrown off by a man who works hard all day in the hot sun or at the blacksmith's forge. Since the skin with its sweat-glands and tubes forms a drain for carrying off the impurities from the blood, we should be careful to keep the body clean, and not allow the pores to be choked and blocked up with dirt. Unless we do this the skin will cease

[1] See also pp. 176–179.

to do its work effectually, and we cannot expect to continue in health. There are two of these sweat glands and tubes shown in Fig. 27.

The skin is kept soft and moist by another set of glands and tubes which pour out a fatty or oily fluid over its surface, and so prevents its drying and cracking. These glands are called the **Sebaceous** or **Fat Glands.**

The Nails and **Hair** are simply modifications of the outer layer of the skin.

The Nails are hardened epidermic cells, condensed into the form of horny plates. They consist of a root, a body, and a free edge.

The Hairs on the body are set in an oblique direction in the bottom of little bags or pouches in the innermost layer of the skin (the dermis). If we examined a hair with the aid of a powerful microscope we should find that it consists of an outer layer or bark, and an inner pith. The outer layer seems to consist of scales overlying each other like the tiles or slates of a roof, as shown in Fig. 27, B.

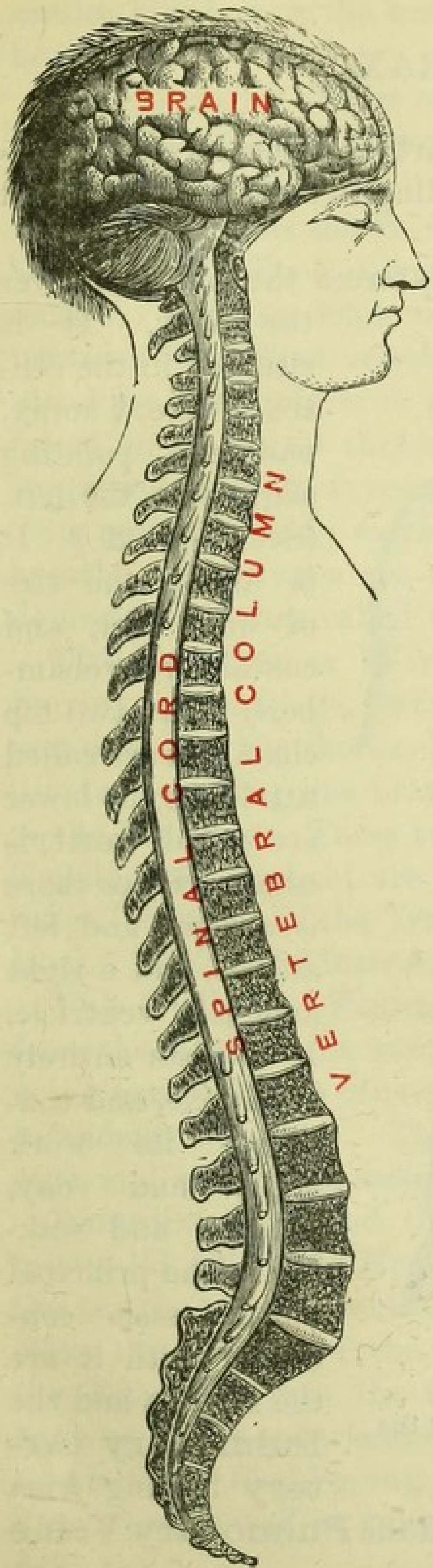
THE INTERNAL ORGANS.

We have seen that the head and trunk contain three distinct chambers—the **Cerebro-spinal Canal,** which extends from the cranium through the whole string of vertebral bones; the **Thorax,** or upper cavity of the trunk; and the **Abdomen,** or lower cavity of the trunk.

THE CEREBRO-SPINAL CANAL.

The whole of the cavity of the skull is filled with the Brain, which you know is the head-centre of the nervous system and the mind.

The **Brain** consists of a number of masses of gray or pinkish-gray nerve tissue. It is divided into two hemispheres by a deep cleft or fissure from front to back, and has a peculiar convoluted or folded-up appearance. The average weight of a man's brain is about 3½ lbs. It consists of three distinct



parts — the **Cerebrum** or **brain proper**, the **Cerebellum** or **lesser brain**, and the **Medulla Oblongata**.

This nerve matter is continued along the whole length of the Spinal Canal, and is called the Spinal Cord.

From the Brain and Spinal Cord, nerves pass off in all directions. These nerve-trunks divide and sub-divide into extremely fine threads, and run into every part of the body. You cannot prick your skin anywhere with a needle without feeling pain. This is because there are nerves all over your body and they give rise to the sensation of feeling. Some of the nerves too pass into the organs of the body, such as the eyes, the ears, the nose, the tongue, the stomach, the lungs, the heart, &c. There they act as masters, foremen, or gangers, and see that the work of each organ is properly carried on. They give their orders, and the organs merely do as they are told. If the attention of these overseers be diverted (that is, if the nerves become deranged) the work at once flags, and disease must follow sooner or later.

Fig. 28.—Showing the Cerebro-spinal nervous centre. Along the whole length of the Spinal Cord may be seen the roots of the spinal nerves.

THE THORAX.

This chamber contains the heart and the largest blood-vessels, the lungs and air-pipes leading to them, and the gullet or food-pipe.

The Heart is the organ which forces the blood all over the body. It is situated in the centre of the Thorax, one end pointing slightly to the left. (See Fig. 29.) It is about the size of one's fist, and contains four chambers. The two top chambers are called **auricles**, the lower are called **ventricles.** Hence there is a right and left auricle, and a right and left ventricle. It consists entirely of muscle, and continues its work night and day, sleeping and waking. The principal blood-vessels connected with it are the **Aorta** and the **Pulmonary Artery** leading *from* the heart, and the **Venæ Cavæ** and the **Pulmonary Veins** leading *to* the heart.

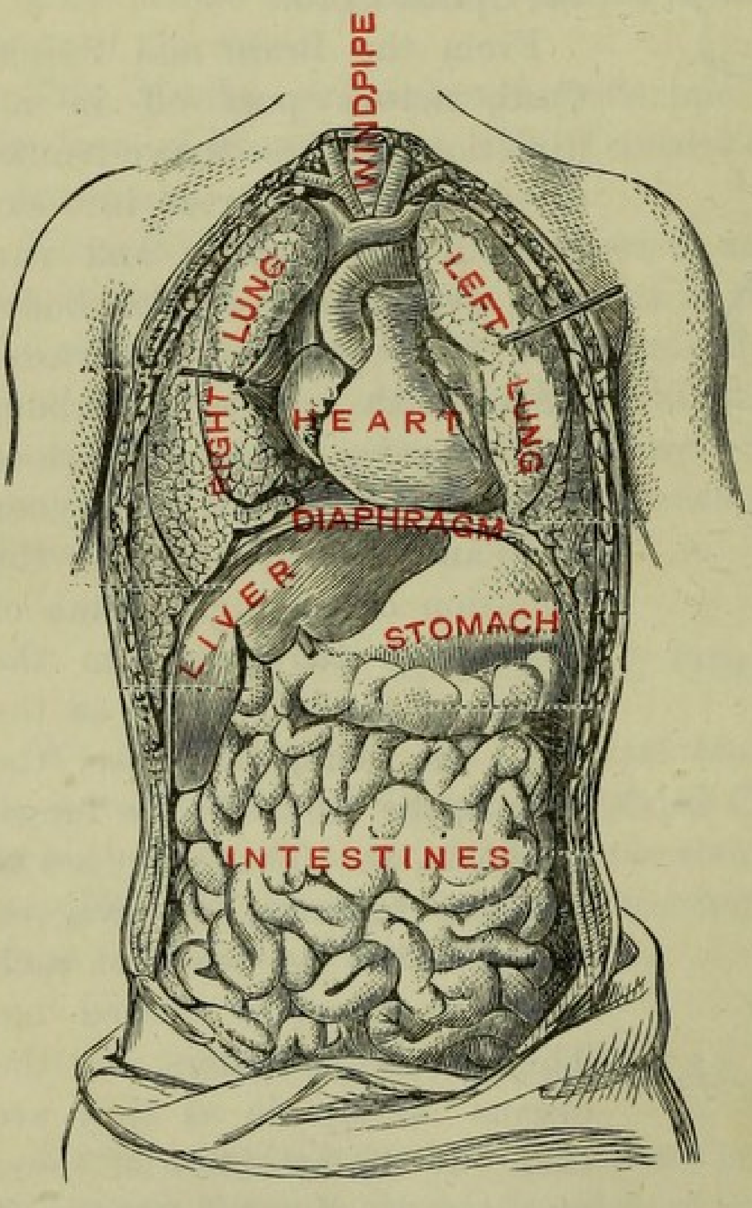


Fig. 29.

Showing the two cavities of the Thorax, and the Abdomen, separated by the Diaphragm.

We may here notice that an *artery* is a blood-vessel which carries blood *from* the heart, while a *vein* carries blood *to* the heart.

The Lungs. There are two lungs, one on each side of the heart. These large organs occupy the whole of the thorax which is not taken up by the heart, the great blood-vessels, and the gullet, as shown in Fig. 29. The butcher calls them the "lights." Their colour is pink, and they are of a spongy nature. They are made up entirely of closely interwoven air-passages and blood-vessels. Their function is to purify the blood by taking from it the poisonous substances it has collected in its course through the body, and at the same time supplying it with oxygen from the air which surrounds us. This work is being carried on by the lungs every time we breathe. The lungs are contained in two bags formed of a delicate membrane called the **Pleura.**

The Trachea or **Windpipe,** a long stout pipe protected by rings of cartilage, leads down from the back of the mouth and nose into the thorax. After entering the thorax this pipe divides—sending one branch to the right lung, and the other to the left lung. These two pipes are called **Bronchi.** The Trachea and Bronchi are thus the air-passages leading to the lungs. The top of the Trachea forms the **Larynx** or **voice-box.** This is the instrument which produces the voice.

The Gullet or **Food-pipe** is the long pipe which passes from the back of the mouth to the stomach. The food after being masticated is conveyed along this pipe into the stomach to undergo digestion. The Gullet is at the back of the windpipe, and is thus not seen in Fig. 29.

Immediately behind the root of the tongue is an elastic gristly lid called the **Epiglottis.** In the act of swallowing, the tongue pushes back the Epiglottis and thus effectually closes the opening of the larynx. The food then passes over the Epiglottis into the Gullet behind the windpipe. You have no doubt experienced the unpleasant sensation caused by a particle of food "going down the wrong way." It is very dangerous as well as vulgar to laugh and talk with the mouth full.

THE ABDOMEN.

The abdomen is the lower chamber of the Trunk, and is separated from the Thorax by the Diaphragm, as shown in Fig. 29. This *diaphragm* is, as we have seen, the floor, so to speak, of the Thorax. It is made of muscle, and is capable of moving up and down so as to enlarge and diminish the Thorax during the act of breathing. The abdomen contains the stomach, the small and large intestines, the liver and gall-bladder, the spleen, the pancreas, the kidneys, and the bladder. You see from this that it is not correct to call this part of the body the *stomach.* The *stomach* is merely one of the organs contained in the abdomen.

The Stomach is a kind of curved bag with two openings, one called the **cardiac orifice**, where the gullet terminates, the other the **pylorus**, which leads to the small intestines. The stomach is situated immediately under the diaphragm, and on the left side of the abdomen. (See Fig. 29.) It is the principal organ of digestion. In the stomach the food which we take is broken up and dissolved, so that it is in a fit state to enter the blood-vessels, and become actual blood ready to nourish the body. The gullet in passing down to join the stomach pierces the centre of the diaphragm.

The Intestines consist of a long tube or canal which winds about in different directions and fills the greater part of the abdomen. (See Fig. 29.) If stretched out in a line this tube would measure about 12 yards. The intestines are divided according to their size into large and small. The small intestines form the beginning of the tube and join the pylorus at the right end of the stomach. The large intestines form the end of the tube, and consist of three parts, the ascending colon, the transverse colon, and the descending colon.

The Liver[1] is the large reddish-brown organ situated immediately under the diaphragm, and occupying the upper part of the right side of the abdomen. (See Fig. 29.) It is the largest gland in the body, is about 12 inches long, and between 6 and 7 inches across, and weighs about 5 lbs. The liver

[1] See also pp. 169–176.

secretes from the blood a greenish fluid called **bile**, which is most important for the work of digestion. This bile is stored up in a kind of little bag in the liver itself, called the **gall-bladder**, and poured from the gall-bladder into the first part of the small intestines.

The Pancreas is a smaller gland than the liver, and usually measures from 6 to 8 inches in length. The butcher calls it the "sweetbread." It secretes a fluid termed the **Pancreatic Juice**, which is necessary for the work of digestion. It is situated in the upper and hinder part of the abdomen behind the stomach. A short canal or tube **(the Pancreatic Duct)** carries the pancreatic juice from it into the small intestine just where the gall-bladder pours in the bile.

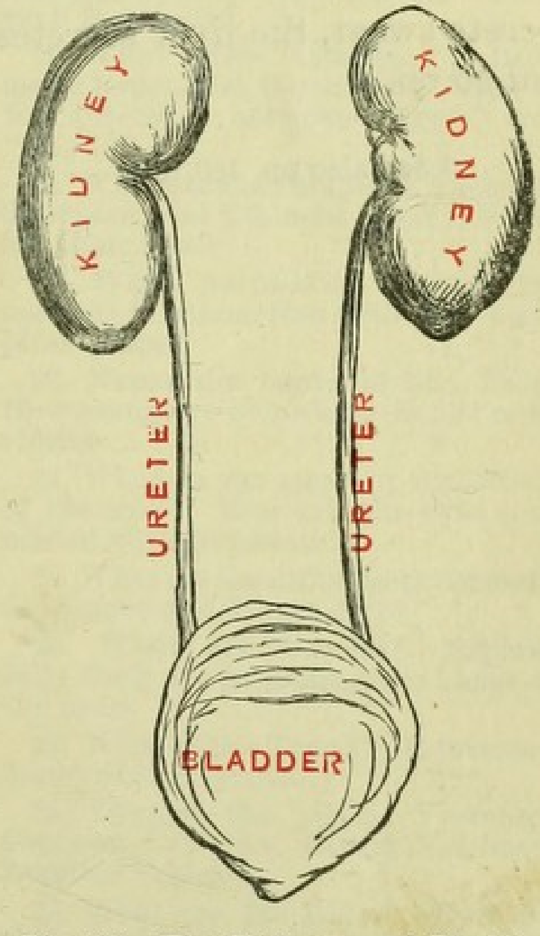


Fig. 30.—The Kidneys and Bladder.

The Spleen is situated on the left side of the abdomen behind the stomach. It is sometimes spoken of as the "milt" by the butcher. It is of a dark purple colour, and of a soft pulpy nature. Its function has not yet been determined. The Pancreas and Spleen being behind the stomach cannot be seen in Fig. 29.

The Kidneys.[1] These two important glands have something of the shape of a French bean, and are of a brown colour. They are about four inches long, and two inches across. They are embedded in fat, and situated one on each side of the upper lumbar vertebræ. (See Fig. 30.) The function of the kidneys is to purify the blood by carrying off from it a poisonous waste substance called the **urea**. The kidneys lie behind the intestines, and cannot be seen, therefore, in Fig. 29.

[1] See also pp. 176–179; and pp. 179–186.

The Bladder[1] is simply a kind of bag or reservoir for holding the urine which has been secreted from the blood by the kidneys. It is situated at the bottom of the abdomen in the basin formed by the pelvis.

Gland.[2] As the term gland has been used several times, you must remember that this name is given to all those organs of the body which have the power of secreting or taking up certain substances from the blood. Thus the sweat-glands secrete sweat, the liver secretes bile, the kidneys secrete urine, and so on.

1 See also pp. 180,181. 2 See also pp. 167–169.

QUESTIONS FOR EXAMINATION.

1. What do you understand by Physiology? What good is to be gained by studying this subject?

2. What do you mean by the term "organ?" Name some of the principal organs of the body.

3. We sometimes speak of the body as an "organized structure." Why is this? Explain the word "inorganic."

4. What do you understand by the "Function of an organ?" Give examples.

5. What are the Tissues of the body? Name some of them.

6. What do you mean by "Skeleton?" How many bones are there in the human body? What are the uses of the skeleton?

7. Describe the composition of bone.

8. Explain why we should be careful in nursing infants.

9. Suppose a baby and an elderly person have a serious fall: what will be the probable result to each, and why?

10. How would you prove the composition of bone?

11. What is the "Periosteum," and what are its uses?

12. We generally classify the bones of the body into long, flat, and irregular. Explain and give examples of each.

13. What is Cartilage? Say where it is chiefly found, and what are its uses?

14. What are the Muscles?

15. What do you understand by the term "Digestion?" Name the organs of digestion.

16. What do you mean by the Circulation of the Blood? What are the organs concerned in this circulation?

17. What is Respiration? Name the organs concerned.

18. Describe briefly the Brain, Spinal Cord, and Nerves.

19. What are the five Senses? Name the organs concerned, and say where each is situated.

20. What is the "Cranium?" How many bones does it contain? What is the difference between "head" and "skull?"

21. What are the Temporal, Parietal, Sphenoid, and Ethmoid bones? What are their uses?

22. What peculiarity do you remember in connection with the "occipital" bone?

23. Name the bones of the Face. How many are contained in the nose alone?

24. What do you mean by the Orbits of the eyes? How are the eyes connected with the Brain?

25. What are the differences between the Upper and Lower Jaw?

26. What are Sutures? Explain fully their use in joining the bones of the head.

27. What is the Trunk? How many bones does it contain?

28. Explain the terms: Vertebra, Cervical Vertebra, Dorsal Vertebra, Lumbar Vertebra.

29. What are the Ribs? What are their uses? How are they joined in front and at the back?

30. What is the Sternum? To what bones is it joined?

31. Describe the "Pelvis."

32. Describe the Spinal or Vertebral Column.

33. How are the Vertebræ prevented from wearing away by rubbing against each other?

34. Describe the two topmost vertebræ of the neck.

35. What is the Thorax? What bones form it?

36. Explain fully the terms: True, False, and Floating Ribs.

37. How are the ribs raised and de-

pressed? What is the result of this movement?

38. What is the Clavicle? What are its uses?

39. Name the bones in each upper limb. Say to which class of bones they belong respectively, whether long, flat, or irregular bones.

40. Compare the bones in the upper and lower extremities.

41. Name the bones in each lower limb. Classify them as in Question 39.

42. Say exactly where is each of the following bones:—(*a*) Femur, Frontal bone, Scapula, Fibula, Os calcis. (*b*) Sphenoid, Clavicle, Humerus, Tibia, Sternum. (*c*) Patella, Os innominatum, Tarsal, Ulna, Ethmoid.

43. Name six of the largest bones of the body. Say where they are.

44. What is Synovia? What are its uses?

45. What do you understand by the term "ligament?" Name some of the principal ligaments. What are their uses?

46. How many teeth has an adult person? Why are they called the Permanent Teeth?

47. What are a young child's teeth called? How many has he?

48. Describe the Milk Teeth. What are the Wisdom Teeth?

49. How are the teeth arranged in the jaw?

50. What animals have strong incisors, canines, and molars respectively?

51. Describe the structure of a tooth.

52. Explain dentine, tooth-pulp, cement, enamel, fang, neck, crown.

53. Describe briefly the different kinds of muscle.

54. Where do we find involuntary muscle?

55. Give a general description of one of the great muscles of the body.

56. What are the Tendons? Name one.

57. Name some of the great muscles in the body. Say what bones they move.

58. What is the Diaphragm? What is its use?

59. Explain the terms Flexor and Extensor Muscle. Give examples of each.

60. What is the object of fat in the body?

61. Give a brief description of the skin. What gives the peculiar colour to the skin of the European, the Negro, the Chinese, and the American Indian?

62. Explain the term "Excretion." The skin is an excretory organ. Explain this.

63. What are the Sebaceous Glands? What are their functions?

64. Describe briefly the nails and the hair.

65. Explain "Trunk," "Thorax," "Abdomen," "Diaphragm."

66. Name the organs contained in the Thorax. Say exactly where each is.

67. Give a short description of the Heart.

68. What are Auricles, Ventricles, Arteries, Veins, Capillaries?

69. Say what you know of the Lungs. What is the Pleura?

70. Explain Trachea, Bronchi, Gullet. How is food prevented from passing down the Trachea?

71. Name and give positions of all the organs contained in the Abdomen.

72. Give a short account of the Stomach and Intestines.

73. Describe the Liver. What is its function?

74. Explain Gall Bladder, Bile, Pancreas, Pancreatic Juice.

75. What is the Spleen?

76. Describe the Kidneys and Bladder. What are their uses?

HUMAN PHYSIOLOGY.

BOOK II.

THE MECHANISM OF THE PRINCIPAL MOVEMENTS OF THE LIMBS AND OF THE BODY AS A WHOLE—THE ORGANS AND FUNCTIONS OF ALIMENTATION, CIRCULATION, AND RESPIRATION.

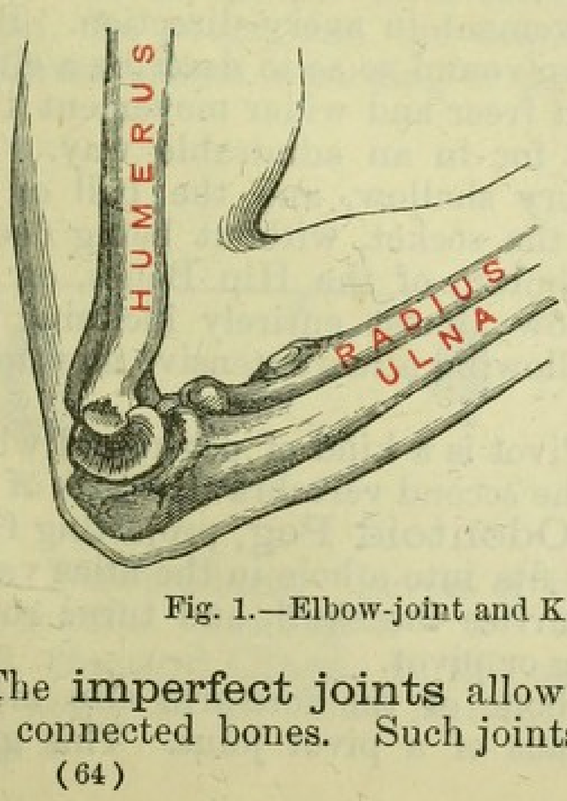
PART I.

MECHANISM OF THE SKELETON.

WE have seen that the muscles and tendons are the machinery (so to speak) which move the bony levers of the body.

We shall now proceed to investigate (1) the different kinds of joints, (2) the bony levers themselves, (3) the mechanism of some of the principal movements of the body.

I. The different kinds of joints. The movable joints of the body are of two kinds, imperfect and perfect.



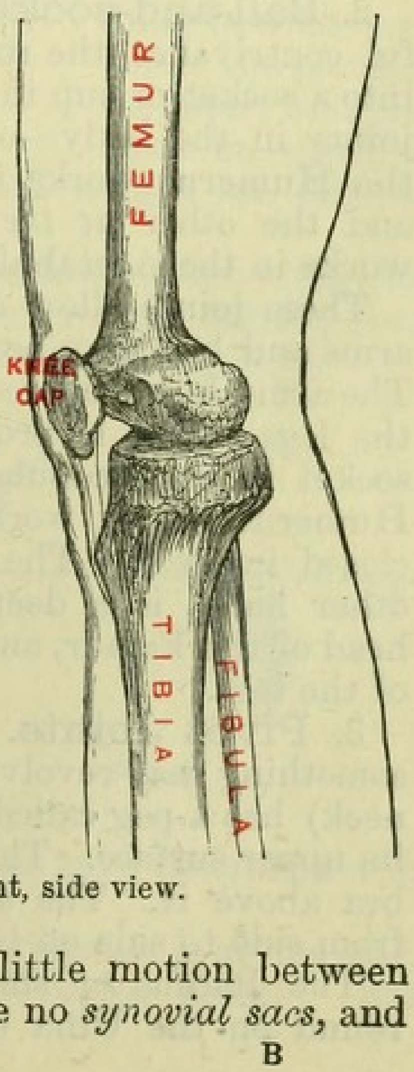


Fig. 1.—Elbow-joint and Knee-joint, side view.

The **imperfect joints** allow very little motion between the connected bones. Such joints have no *synovial sacs*, and no smooth cartilages at their edges. The best instances of imperfect joints are the vertebræ of the spinal column.

The **perfect joints**, on the contrary, are protected with a lining of cartilage, and are kept moist by the *synovia* from the *synovial sacs.*

The **perfect joints** may be divided into Hinge joints, Ball-and-socket joints, and Pivot joints.

1. **Hinge Joints** allow of the same backward and forward movement as the hinge of a door. These joints are the most numerous in the body. Among them are the knee, the elbow, the wrist, the ankle, the joints of the fingers and toe, and the skull on the *Atlas vertebra.*

The thumb is allowed a kind of double movement. It can move not only backwards and forwards, but from side to side. This is accomplished by means of a peculiar kind of hinge joint between the metacarpal bone of the thumb and the Trapezium bone of the wrist. The joint is commonly called a *double hinge joint,* and the ends of both bones are shaped somewhat like a saddle, so that the roundness of one bone fits into the hollow of the other.

2. **Ball-and-socket Joints.** In these joints, by a beautiful contrivance, the rounded head of one bone is made to fit into a socket or cup in the other. There are two pairs of these joints in the body—one *at the shoulders,* where the head of the Humerus works in the Glenoid Cavity of the Scapula; and the other *at the hips,* where the head of the Femur works in the Acetabulum or hollow of the Hip Bone.

These joints allow of movement in every direction. Both arms and legs may be thrown round so as to describe a circle. The arms, however, require a freer and wider movement than the legs. This is provided for in an admirable way. The socket in the Scapula is very shallow, and the ball of the Humerus simply works in the socket, without being deeply closed in by it. The acetabulum of the Hip Bones, on the other hand, is a deep hollow almost entirely inclosing the head of the Femur, and so allowing a less extensive movement of the legs.

3. **Pivot Joints.** A Pivot is a kind of peg round which something may revolve. The second vertebra (the axis of the neck) has a peg called the **Odontoid Peg,** projecting from its upper surface. This peg fits into a hole in the atlas vertebra above it. The atlas carries the skull, and turns round from side to side on this peg or pivot.

The Radius or smaller bone of the fore-arm also moves round on the Ulna by means of a pivot joint. This gives us the power of turning the palm of the hand upwards and downwards. It is important to remember that in this movement the radius bone, as well as the wrist and hand bones, turn round.

II. **The Bony Levers.** The term *lever* is taken from the science of mechanics, and means simply a rigid bar or rod which moves about a certain fixed point. The fixed point is called the *fulcrum.* You have all seen a man trying to raise a heavy stone with a crow-bar. He places one end of the bar under the stone, and presses down the other end. In this case the bar is a *lever,* and the ground under the bar the *fulcrum;* the pressure which the man applies is called the *power,* and the stone to be lifted is called the *weight.* You have the same thing in a see-saw, where the plank is the *lever,* and the block on which it rests the *fulcrum;* while the power and weight are first at one end and then at the other.

Fig. 2.

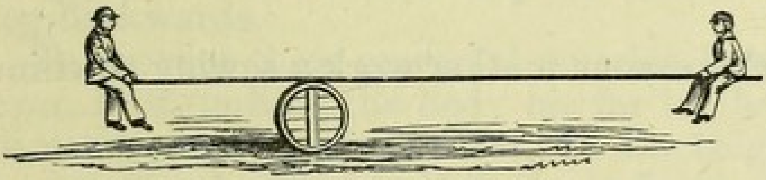


Fig. 3.

In a lever, then, we have three things to consider,—the *fulcrum,* the *power,* and the *weight.* Levers are divided into different classes, according to the position of these three.

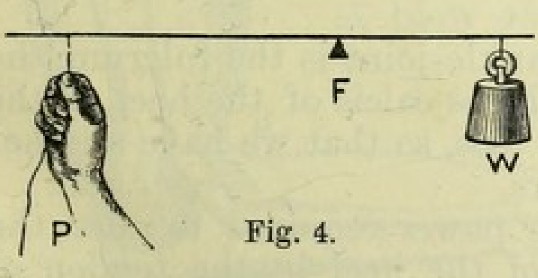


Fig. 4.

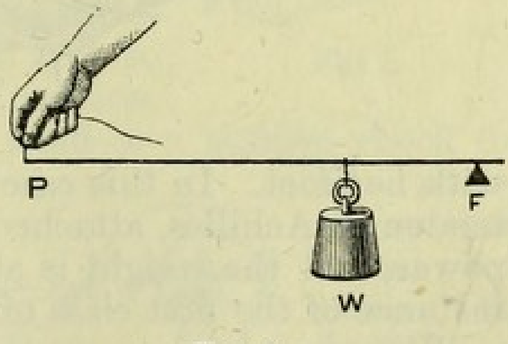


Fig. 5.

1. **First Class.** Levers of this class have the *fulcrum* in the middle. See Fig. 4.

2. **Second Class.** In this case the *fulcrum* is at one end, the *power* at the other, and the *weight* in the middle. See Fig. 5.

3. Third Class. In this case the *fulcrum* is at one end, the *weight* at the other, and the *power* between them. See Fig. 6.

In the various movements of the body we have instances of all three kinds of levers.

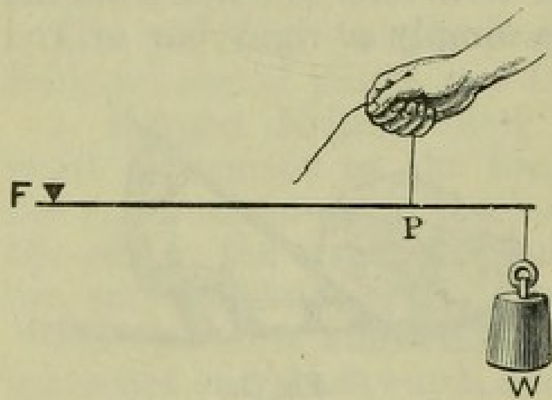


Fig. 6.

The *skull*, as it nods backwards and forwards upon the atlas vertebra, is an instance of the first class of levers. It is like the see-saw we spoke of above.

The *ulna*, moved by the *triceps muscle* at the back of the upper arm, is another instance of the first class of levers. Here in the act of straightening the arm, as shown in Fig. 7, the elbow-joint is the fulcrum, the triceps muscle the power, and the fore-arm the weight.

You have seen perhaps your mother work a sewing-machine

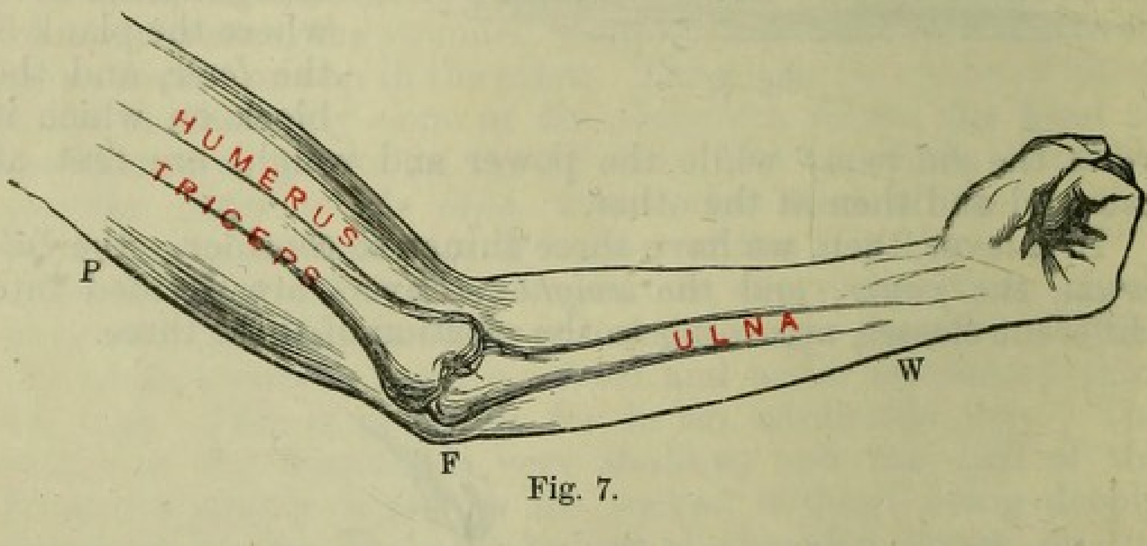


Fig. 7.

with her foot. In this case the ankle-joint is the fulcrum, the tendon of Achilles, attached to the os calcis of the heel, is the power, and the weight is at the toes, so that we have another instance of the first class of levers.

When we stand on tip-toe, the power required to raise the body is applied to the *os calcis* of the heel by the tendon of Achilles. The toes are the fulcrum, and the bones of the foot support the weight. We have in this case a lever of the second class. See Fig. 8.

When we bend the fore-arm upward, the radius bone becomes a lever of the third kind. We have in this case the *fulcrum* at the elbow, the *weight* about the middle of the arm, and the *power*, applied by the *biceps muscle*, at its insertion in the radius. See Fig. 9.

III. We have now noticed most of the principal movements of the limbs; it remains to explain how the body, as a whole, maintains its erect position, and performs such movements as walking, running, jumping, &c.

The body is supported in the erect position by a somewhat complex arrangement of muscles, which balance each other, some pulling backwards and some forwards; thus:—

The weight of the body falls on the tarsal bones of the foot; and there is a tendency for the leg to fall forward over the foot. This is prevented by the contraction of the great muscles of the calf, which pull the leg backwards.

To prevent these powerful muscles, however, from pulling the body too far in that direction, the muscles in front of the thigh now contract and so pull the body forward.

The same thing is then repeated by the muscles of the buttocks and back, which tend to pull backwards; and by those in front of the abdomen and throat, which balance that effort by pulling the body forward again.

Thus the combined action of these opposing muscles balances the body and so keeps it in the erect position.

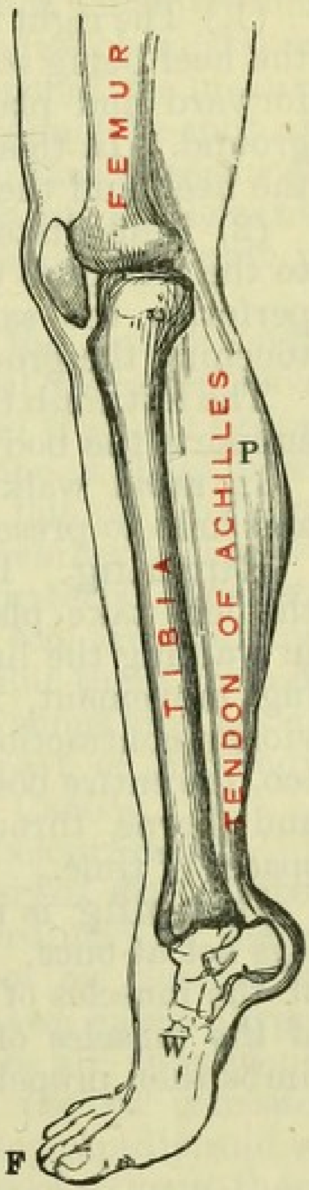


Fig. 8.

A blow on the head or a sudden shock to the nervous system causes the person to fall in a heap, because the great overseer, the will, has for the time lost its power over the muscles, and they cease to contract.

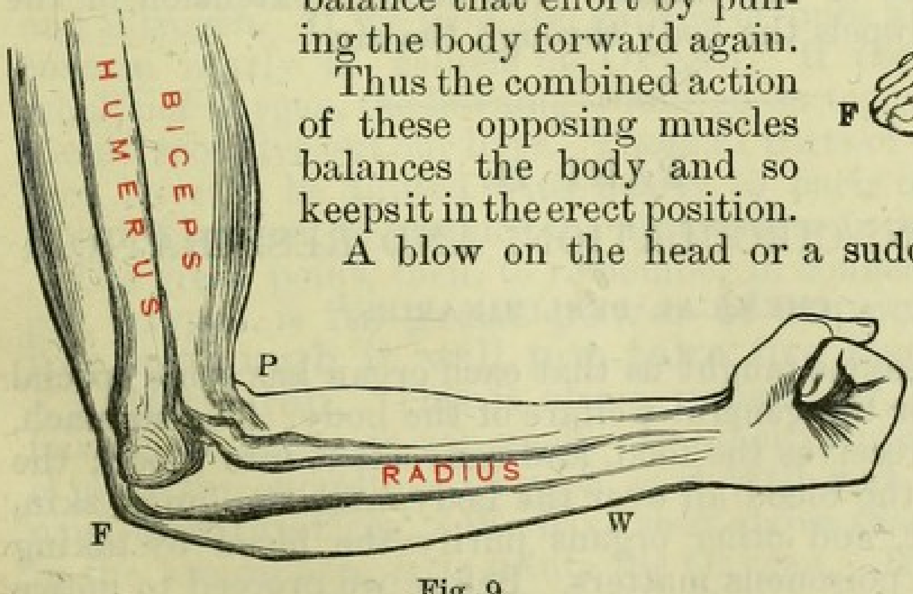


Fig. 9.

Walking. In walking, the body is supported by only one foot at a time, while the other is swinging forward. There are two principal movements.

(1.) The right limb touches the ground at the ball of the foot, the heel being somewhat raised, while the left limb is carried forward and placed with the sole of the foot resting on the ground. In this act the left foot touches the ground first at the heel, and the weight of the body is thrown forward.

(2) Immediately the weight of the body is thus thrown on to the left limb the right is raised by bending the knee, and performs the same kind of pendulum-movement forward, touching the ground in its turn first with the heel.

The left limb then swings forward as before, while the right supports the body; and so on.

In rapid walking the arms swing in unison with the legs and help to preserve the equilibrium.

Running. In running, the same alternate movements of the legs take place, only in more rapid succession; and while in walking the limbs are carried forward with a simple swinging movement, in running their action is caused by the violent contraction of the muscles. During the act of running, too, the entire body is repeatedly being raised from the ground and borne through the air, during the shortest possible spaces of time.

Jumping is really a kind of running step in which both legs act at once. It is accomplished by a violent contraction of the muscles of both calves, and a simultaneous contraction of the muscles of the thighs. The sudden extension of the limbs then propels the body through the air.

PART II.

DIGESTION, CIRCULATION, AND RESPIRATION.

CHEMICAL PRELIMINARIES.[1]

Our early lessons taught us that each organ has some special work to do for the general welfare of the body. The stomach, for instance, receives the food, and converts it into blood; the heart pumps the blood all over the body, and the lungs, skin, kidneys, liver, and other organs purify the blood by taking from it waste poisonous matters. Before we proceed to notice how all this is done, it will be well to learn something of the materials of which our bodies are composed.

It has been ascertained that all the things which make up

1 See also pp. 145-159.

this great world of ours—its rocks, its soil, its water, its atmosphere, and the plants and animals which live upon it—are built up or composed of a certain number of simple substances or materials which we call *elements.* The science which teaches us this is Chemistry, and the person who studies chemistry is called a Chemist. When we speak of an element we mean a substance in its simplest state, or one which cannot be split up or separated into anything else. Water, for instance, seems at first sight a very simple substance; but it is not an element, because, as you will learn by and by, the chemist can split it up into two simpler substances.

Our present work has to do simply with the human body and not with chemistry generally. We shall therefore have to notice only a few of the *elements.* We find that our bodies are made up of about *fourteen elements.* None of these, however, exist in the simple state in the body, but only in combination with others. All that we need remember is that we are made up of fourteen different sorts of material variously combined with each other. Many of these, too, are comparatively unimportant to the young student. But there are four elements which it is very desirable to learn something about, for they form the material of the greater part of the body. They are Oxygen, Nitrogen, Hydrogen, and Carbon.

1. **Oxygen.** Oxygen is a transparent, colourless gas. It has neither taste nor smell. **It is a powerful supporter of life and combustion (burning).** Ordinary air seems, like water, a simple substance; but it is not an *element,* for the chemist is able to prove that it contains two gases, oxygen and nitrogen. If we took 100 gallons of pure air, they would contain nearly 21 gallons of Oxygen. If the air consisted wholly of oxygen, the burning would go on too rapidly, and we should soon live out our lives. These 21 parts of oxygen, therefore, have to be diluted with nearly 79 parts of another gas called Nitrogen, to produce the atmosphere in which we live.

The great point, then, to remember in connection with this gas, Oxygen, is **its great power of supporting burning, although it will not take fire itself.**

2. **Nitrogen.** This is also a transparent, colourless gas, having neither taste nor smell. In other respects, however, it is quite the opposite of Oxygen, as **it will not support life and combustion.** We have seen above that its chief uses in the atmosphere is to dilute the Oxygen. If you had two glass jars, one filled with oxygen and the other with nitrogen, you might easily prove to yourselves the properties of these two gases. Suppose you put a lighted candle into each jar.

That in the oxygen would burn with a brilliant white flame, while the other in the nitrogen would be extinguished. If all the oxygen could be separated from the atmosphere, so that nothing but nitrogen were left, every animal and plant would die, because nitrogen cannot support life.

Strange as it may seem, although Nitrogen will not support life, when breathed in a pure state into the lungs, yet it enters very largely into the composition of the tissues of the body, and we cannot live without consuming a certain quantity of it every day as food. We shall speak more of this, however, further on.

3. **Hydrogen.** This also is a gas resembling oxygen in some points. It differs from oxygen, however, in being very inflammable, that is in easily catching fire. Nevertheless, it will not support combustion or animal life. Hydrogen gas is the lightest body in nature.

Hydrogen burns with an intense heat, and combines with Oxygen to form water. Every particle of water, wherever it is met with, is found to be composed of these two gases, Hydrogen and Oxygen.

4. **Carbon.** Carbon is a solid substance which is found in many varieties. It is the chief chemical basis of the vegetable kingdom, and the chief constituent of coal; while at the same time it exists in a pure state as the diamond, and the mineral plumbago (black-lead). The most common examples of carbon are soot and coke and charcoal. Charcoal may be prepared both from burned bones and wood. **When we burn carbon in oxygen, we produce a gas called carbonic acid.** Carbonic acid gas, in an undiluted state, cannot be breathed *by animals* without producing certain death. On the other hand, *all plants* require this gas for their very existence. Indeed they suck in this carbonic acid; take away from it all the carbon it contains; and then return the oxygen to the air. The plant uses the carbon to build up its own substance, while the oxygen, which is thrown off into the air, becomes again *the supporter of animal life and combustion.* When we remember that every time we light a fire, and every time we breathe, we produce large quantities of this gas (*carbonic acid*), which would in time render the air unfit for breathing, we can see the wisdom and goodness of God in forming plants which take away for their own substance the very gas which would poison animals, while they give out (as useless to themselves) the valuable life-preserving oxygen, which is so necessary to every form of animal life.

By this admirable example of divine goodness and wisdom, the balance is held between the necessities of both animal and plant life.

It is important to add that at night, plants, being in a half dormant state, do not perform their ordinary functions, and the result is that they then give off carbonic acid. Hence, plants must not be kept in a bed-room during the night.

ALIMENTATION OR DIGESTION.[1]

Work and Waste. I daresay you remember my mentioning the fact that the more work we give our muscles the better they like it, and the larger and stronger do they become. Now I am going to give you a very great surprise. What will you think when I tell you that every act we perform destroys some portion of our bodies—that in fact our bodies are daily, hourly, dying. Yet this is an undoubted truth. We cannot lift our little finger; we cannot utter a single word; we cannot think, look, or even move an eyelid, without using up some of the tissues of the body. These worn out, or used up tissues are henceforth of no use in the body. Indeed, if allowed to remain, they would become a positive evil. They would be as injurious in the body as a rotting putrefying heap of rubbish would be in our houses, or at our back-doors. They would poison all the rest of the body, and disease and death would speedily follow. It is then in the highest degree essential that these waste matters be got rid of as quickly as possible. Let us see how this is accomplished.

All the tissues of the body contain **Carbon, Hydrogen, and Nitrogen.** You will learn farther on, that the blood carries **oxygen** through the body.

Now our little talk about the chemical elements showed us that when oxygen and hydrogen come into contact they have such a strong affinity for each other that they rush together, and combine to form a new substance—water. So with oxygen and carbon. They combine, or, in other words, the *oxygen* burns up the *carbon*, and forms a new substance, *carbonic acid gas.* Besides these there is another waste product *urea*[2] formed by this internal burning. This *urea* is a sort of complex product formed by all four elements, carbon, hydrogen, nitrogen, and oxygen. All these waste products are being constantly thrown off by the lungs, the skin, and the kidneys.

You must form a clear notion of this burning which takes place in the body. It is entirely distinct from the burning of ordinary fire—there is no blaze, no light, no smoke. You have seen, perhaps, a gardener make what he calls a hot-bed

 [1] See also pp. 159-162. [2] See also pp. 185, 186.

of a heap of decaying weeds or leaves. These leaves, if left lying singly on the ground, would decay. The fact is, the oxygen in the air would seize upon particles of the leaves and slowly burn them up. There would be heat, although we should not be able to detect it. When, however, the gardener makes a heap of these leaves, and the same thing goes on with each leaf, the accumulated amount of heat produced by this burning may be easily detected by thrusting the hand into the heap of leaves.

Again, suppose we throw a number of oily rags into a heap. The oxygen in the air will slowly burn away (or oxidize) the oil, and a great amount of heat will be produced. This heat you may feel by thrusting your hand among the rags. If the rags were allowed to remain for a long time, so much heat would at last be accumulated that they would actually catch fire and burn with smoke and flame.

This is commonly known as spontaneous combustion. Ships have been known to take fire in this way. So much heat has been accumulated by the insensible burning or oxidizing of the heaps of coal in the hold, that at last actual fire with smoke and flame has broken out.

The same thing sometimes happens to hay-stacks.

By this burning, then, the lungs, the skin, and the kidneys throw off daily from the system about 4000 grains (or more than 9 ounces) of Carbon, in the form of carbonic acid, and about 250 grains of Nitrogen, in the form of Urea. The amount of Hydrogen given off, varies very much under different circumstances.

Thus the body is being constantly worn away, and must be constantly built up again with food. The food, too, must contain the same things (*Carbon*, *Hydrogen*, and *Nitrogen*) as the body has lost.

The blood is the stream which conveys this material for restoring the waste tissues of the body. Indeed the blood is that material itself; it is simply the food we have eaten in another form.

Alimentation or Digestion is the process by which the useful or nutritious parts of the food we consume are separated from the useless or innutritious parts, and changed into blood. In one word, digestion is the process of blood-making.

The next chapter will explain how the bread and butter, beef, potatoes, and pudding become blood, capable of being carried along through the most delicate hair-like tubes to every part of the body.

The chapter on circulation will then show how this nourishing fluid is whirled along through the body, giving up to brain, muscle, and bone just what each requires for its special work, and taking away waste matters which, if allowed to accumulate, would cause disease and death.

FOOD.[1]

We consume a great variety of articles as food day by day, but they all contain or should contain one or both of the following substances, which we call Food-stuffs, viz.:—Proteid matters or Flesh-forming food, and Heat-givers or Fuel-food.

Articles which contain neither of these are not, properly speaking, food, for they cannot restore the waste or keep up the heat of the body.

Proteids or Flesh-forming Foods contain, as their name implies, all the materials requisite for restoring the waste tissues. They are all rich in one or more of the following organic substances:—Albumen, Casein, Fibrin, Gelatin, Syntonin, Gluten, and Legumen.

Albumen is familiar to all as the "white of egg." You know that when it is boiled it has a white, opaque appearance. It is this which gives it its name (albumen), from the Latin word "albus," white. The serum of blood is very rich in albumen, and so is flesh-meat.

Casein you all know as cheese. It is one of the chief constituents of milk.

Fibrin exists largely in blood and in flesh-meat. In some respects it resembles albumen. It will be described more fully in the chapter on the blood.

Gelatin is an important constituent of gristle, bone, and skin, and may be easily obtained by boiling. You may have seen your mother boil calves' feet to make jelly for the sick-room. The familiar substances Glue and Size are simply gelatin obtained by boiling the hoofs, horns, and skin, &c., of animals.

Syntonin resembles fibrin, and is, like it, one of the chief constituents of muscular fibre (flesh meat).

Gluten is really a kind of vegetable fibrin. It exists largely in the cereals, wheat, barley, oats, and rye.

Legumen is a substance resembling casein or cheese. It is the nitrogenous principle of peas and beans. You will understand how much it resembles casein when I tell you that the Chinese make a kind of cheese from peas.

Each of these substances, if analysed, would be found to

[1] See also pp. 186–189.

contain all four elements—Nitrogen, Carbon, Oxygen, and Hydrogen. They are especially rich however in Nitrogen, and are hence often called Nitrogenous foods.

Nearly every kind of vegetable contains more or less of these nitrogenous or flesh-forming materials. The most nutritious of all are peas and beans, while the potato contains less flesh-forming material than any other vegetable food. Oat, wheat, and barley flour are all rich in flesh-formers, oatmeal being the richest.

Heat-giving or Fuel Food contains much Carbon, and is hence often called *Carbonaceous Food.* It also abounds in Hydrogen, but contains no Nitrogen. Such food cannot completely restore the waste tissues; but it serves as a kind of fuel which is burnt up by the Oxygen in the body. The combustion of these fuel-foods develops and sustains the necessary heat of the body, and the strength or vital energy which enables us to perform our various duties. The chief fuel-foods are starch, sugar, gum, and fat.

Starch is the chief constituent of wheat, barley, oats, rye, rice, maize, tapioca, arrowroot, sago, potatoes, &c.—in fact it probably stands first in importance among the various vegetable foods. We have already noticed that the cereals wheat, barley, oats, and rye contain an amount of the nitrogenous principle *gluten.* The *starchy matters,* however, in these are largely in excess of the *gluten.* Taking wheat, for example, we find it contains almost 70 per cent of starch, and not more than 10 per cent of gluten.

You may very easily separate these two constituents by tying up a little flour in a piece of coarse muslin, and then squeezing it for some time in a bowl of water. After a time you will observe that the water has become thick and milky-looking. This is because you have squeezed the *starch* of the flour into it. The gluten is of a tough and somewhat sticky nature and holds together within the muslin like a ball. After leaving the water for a time you will be able to collect the *starch,* which has settled at the bottom like a white powder.

Starch in its natural state would be useless as a food, because it is insoluble. It is only after it has been acted upon by the saliva of the mouth and converted into *sugar*, that it becomes soluble, and is capable of being sucked up by the blood.

Sugar is now too common to require any description here. You know that it is *soluble,* because you see it disappear in your cup of tea or coffee as it is dissolved.

Gum is another vegetable food similar to starch, and differing from it only in being soluble.

Fats include not only the ordinary fat of meat, but a large number of animal and vegetable oils. They are very combustible, and are hence the most important of the fuel foods.

It may be useful to notice here that, in the cold, dreary polar regions, the Esquimaux consumes about 20 lbs. of blubber fat daily, besides drinking deep draughts of train-oil. This fat is necessary as the fuel to keep his inward fires going, or he would perish from cold.

Before leaving this chapter on food it will be well to notice the two simple foods which nature supplies to nourish the young.

First, in the case of birds, you know that the little chick is nourished and supported by a store of food laid up in the egg. This food, as you know, consists of two distinct substances. The white of the egg is the nitrogenous substance we have spoken of before as *albumen*. The yolk, although it also contains a large amount of *albumen*, is chiefly made up of an *oily or fatty material* and certain mineral substances. It is from the nitrogenous matter that the tiny thing obtains the materials for forming its flesh, bones, blood, feathers, &c.; while the fatty parts of the yolk supply it with heat, and the energy which enables it at length to break its shell and begin the world.

Again, let us notice milk, which is Nature's food for all young animals belonging to the class called Mammals.

(1.) If we allow some new milk to stand for a time, we get, as you know, a thick layer of cream on the top. This cream consists of fatty or oily matter, and may be churned into butter.

(2.) If we poured a little rennet into some milk, we should cause a solid substance (the curd) to separate from it. This is the nitrogenous substance *casein*, the chief constituent of cheese.

(3.) The liquid which is left behind after taking away the curd is called *whey*. It contains certain mineral matters for building up the bones, and a kind of sugar, known as milk-sugar, besider various salts which assist digestion.

We can now see how it is the baby grows so rapidly. The nitrogenous *casein* of the milk with which it is fed affords the material for building up the muscles, skin, and internal organs, &c., and for restoring what is continually being destroyed; while the cream and the milk-sugar are the fuel foods which develop and sustain the animal heat and create the energy or strength which the child uses.

Advantages of a Mixed Diet. We noticed in the beginning of the chapter that about 4000 grains of Carbon and 250 grains of Nitrogen are daily given off from the body. It is necessary, then, that just these quantities of the two elements should be supplied in the shape of food, if the body is to be kept in its natural condition, weight, and temperature.

Now, if a man lived entirely on potatoes, he would have to eat 13 lbs. every day in order to get the requisite amount of Nitrogen. In eating such a large quantity of potatoes, however, he would get a great deal more Carbon than he required; as potatoes are very rich in Carbon, but contain little Nitrogen.

Again, if he lived on lean meat alone, he would have to eat about 6 lbs. a-day in order to get the requisite amount of Carbon. This large quantity of meat again would give him very much more Nitrogen than he would require, because flesh-meat is rich in Nitrogen.

Hence it has been found judicious to use one kind of food with another, or in other words, to have a *mixed diet*. This is just what Nature has taught us in her two foods which we described above; and it will perhaps explain to you why we eat meat and potatoes, bacon and beans, or bread and cheese together; why you have butter or treacle on your bread; why your mother puts suet (which is a kind of fat) with the flour to make a pudding, and so on. In the same way the starch foods, rice, sago, and tapioca, are of very little use alone. In making a pudding with these your mother would put some milk, eggs, sugar, and butter with the tapioca or rice. You can now tell why she does this.

It may be as well to notice here that beer, wine, and spirits are not useful as foods. They contain little or no nitrogenous or flesh-forming materials, and can neither nourish the body nor develop true animal heat.

THE ORGANS OF DIGESTION.

The food-passage, from the mouth to the lowest part of the intestines, is sometimes called the *Alimentary Canal.* The upper part of this tube, which is at the back of the mouth, is the *Pharynx*. Lower down it receives the name of the *Gullet.* The Gullet passes through the *Thorax*, pierces the *Diaphragm*, and after entering the *Abdomen* opens into the *Stomach*. The remainder of the Alimentary Canal consists of the small and large intestines.

The **Mouth.** In the mouth the teeth form the mill which crushes up the food, while the tongue performs its part of the work by bringing every particle of the food in turn under the mill. In the mouth are the openings of three pair of small glands called the *Salivary Glands.*[1] The two principal of these Salivary Glands lie just behind the lower jaw-bone, and under each ear. Sometimes they become inflamed and swollen by what we call "the mumps," and then they form a great lump below the ears. The tongue, too, is studded with a great number of small glands called *Buccal Glands.* Both the Salivary and the Buccal Glands pour out into the mouth a clear, thin, watery fluid called the *Saliva* or *Spittle.*

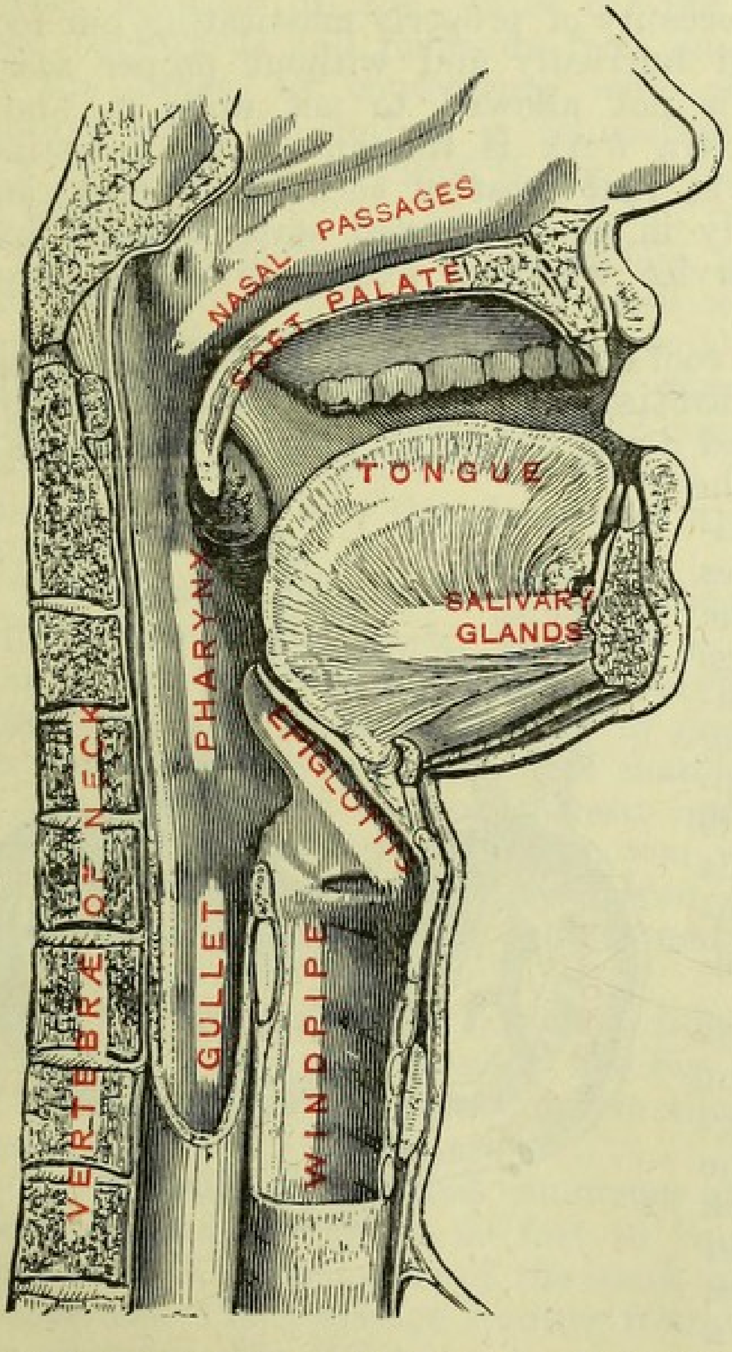


Fig. 10.—Section showing the nasal passages, the mouth, pharynx, larynx, gullet, and windpipe.

The work of crushing the food, and of moistening it with Saliva, is called *mastication* or *chewing.* **The Saliva has the power of acting upon all starchy matters in the food, and changing them into sugar.** These starchy matters, before they are saturated with saliva, are insoluble, but when converted into sugar they are quickly dissolved in the stomach, and absorbed into the blood.

[1] See also pp. 167–169.

You may easily prove that the saliva changes starch into sugar. Hold some boiled starch or a little arrowroot in your mouth for a few minutes. You will find that it gradually loses its thick, pasty nature, and becomes thin and watery, while at the same time it acquires a sweet taste. The fact is, *the saliva has acted on the starch and converted it into sugar*, in order to render it soluble.

This shows the necessity of properly masticating our food. By swallowing food hurriedly and without proper mastication, the saliva is not allowed to act upon it, and a large amount of extra work is thrown on the intestines. The result of this is, that most of such badly masticated food leaves the body in an undigested state, without having been of any service whatever except to create severe pains.

At the back of the root of the tongue is a kind of hard gristly flap called the **Epiglottis.** See Fig. 10. In the act of swallowing, this flap is forced down by certain muscles, and made to close the entrance to the windpipe. The masticated food then passes over the flap into the *Gullet*, the flap springs up to its usual position, and breathing (which has been stopped for the time) is resumed. All this may be clearly understood from Fig. 10.

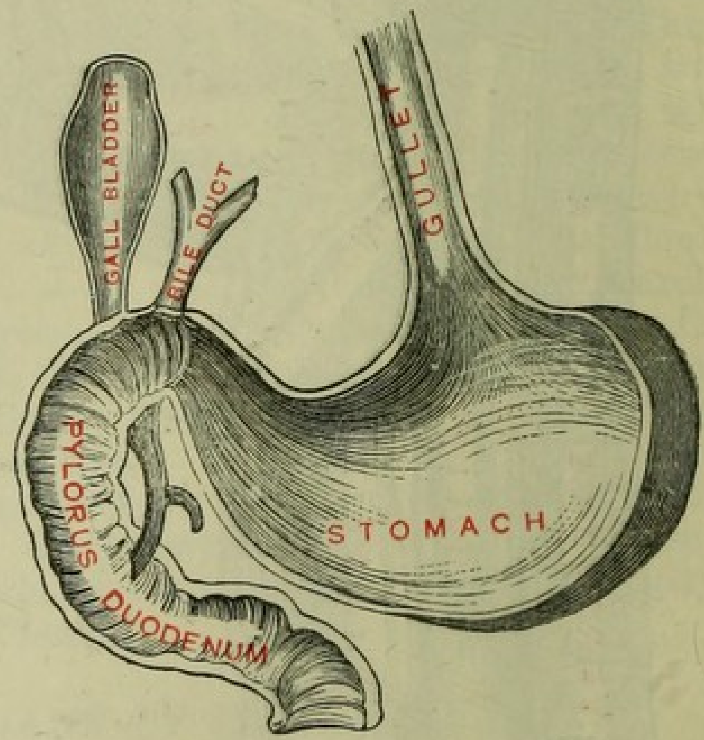


Fig. 11.

The **Gullet** or food-pipe is a tube about 9 inches long, hanging loosely behind the windpipe. Its thick walls are provided with circular muscles, which contract with a wave-like motion, and so push the food along towards the stomach.

The **Stomach** is a large bag or pouch capable of holding about two quarts of liquid. It is placed across the upper part of the Abdomen, and on the left side, immediately under the Diaphragm.

It has two openings; one on the top where the Gullet ends, and the other at its right extremity where the intestines begin. See Fig. 11.

The walls of the Stomach consist of *four* coats:—

1. A tough outer coat of fibrous tissue, which protects and strengthens the organ.

2. A coat of smooth or involuntary muscular fibre. These muscles of the walls of the stomach force the food backwards and forwards, from one end of the stomach to the other, by contracting with that same wave-like motion which we noticed in connection with the Gullet.

3. A third coat, in which the blood-vessels and nerves begin to break up.

4. An innermost coat, whose surface is honey-combed with millions of little pits. You have all seen this in tripe. In the floor of each of these tiny pits about six tubes open. These tubes, during the process of digestion, are constantly pouring into the stomach a peculiar liquid called the *Gastric Juice.*[1] It is calculated that from 3 to 4 quarts of this juice are poured into the stomach of a man during twenty-four hours.

The **Gastric Juice** is a clear, almost colourless liquid, with a sharp acid taste. It has scarcely any effect on starchy matters, but **acts as a solvent upon proteid matters**, such as are contained in meat, cheese, bread, &c. So powerful a solvent of proteid matters is this juice, that if you put a piece of cooked meat into a basin with some gastric juice, and kept it warm, you would find the meat gradually disappear. The juice, even out of the stomach, would rapidly dissolve the proteid matter, leaving only the fat floating on the top.

The **Intestines.** The bowels or intestines form the lower part of the Alimentary Canal. See Fig. 12. The total length of the intestinal tube is about five times the length of the body.

The **Small Intestines** commence at the right end of the stomach, and are about 20 feet in length, and $1\frac{1}{4}$ inch in diameter. The first part of the small intestines is called the *Duodenum.* The passage leading from the stomach into the Duodenum is the *Pylorus.*

The **Large Intestines** commence at the *Ileum* or lower extremity of the small intestines, and consist of three parts, the *ascending*, the *transverse*, and the *descending colon.* This tube, which is about 6 feet long, and from 2 to 3 inches in diameter, first passes up the right side of

[1] See also pp. 167–169.

the abdomen, then across under the liver and the stomach, and lastly descends on the left side of the abdomen to the rectum.

The **Stomach** and **Intestines** are completely enveloped in a kind of loose, double membrane called the *Peritoneum.*

The **Mesentery** (a portion of this membrane) keeps the small intestines in their proper place, by binding them to the *Vertebral Column.*

The Intestines are protected from cold and injury by being packed in large quantities of fat.

Two small pipes or ducts enter the Duodenum or first part of the small intestines. One of these pipes comes from the Gall-bladder, and brings a greenish-yellow, bitter fluid called *Bile.* You know that this Bile is prepared by the Liver.[1] It is an alkaline fluid—that is, it possesses the properties of soda. You have seen your mother cleanse a bottle which has held oil. She puts in some soda and water, and then shakes the bottle. The soda dissolves the oil and produces a kind of creamy mixture, with the oil separated into the most minute particles. This is exactly what the Bile accomplishes with the fatty parts of the food.

The other pipe comes from the *Pancreas,* and brings the *Pancreatic Juice.* This juice very closely resembles the Saliva. It acts chiefly upon the starchy matters of the food which have escaped the saliva, and changes them into sugar. At the same time, however, it follows up the work of the Gastric

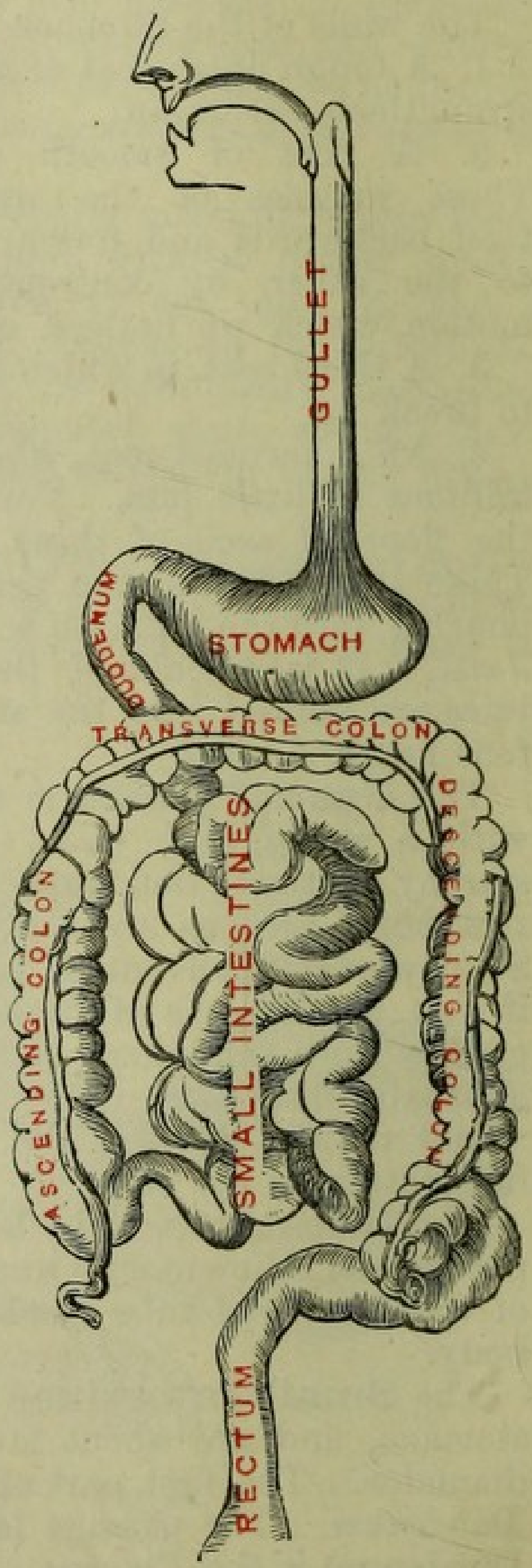


Fig. 12.—Alimentary Canal—including Gullet, Stomach, Large and Small Intestines.

[1] See also pp. 169–176.

Juice in dissolving any proteids which have not been dissolved in the stomach.

The inner surface of the intestines also pours in a liquid called the *Intestinal Juice*, which, like the Saliva, acts upon the starchy matters. At the same time, however, this juice acts as a solvent on any proteid matters or fats still undissolved.

In fact, this Intestinal Juice has the properties of Saliva, Gastric Juice, Bile, and Pancreatic Juice, all in one. It is intended to act upon *all matters* in the intestines still left undissolved by the other juices, so that no part of the food may be wasted.

The walls of the intestines, like those of the stomach, are

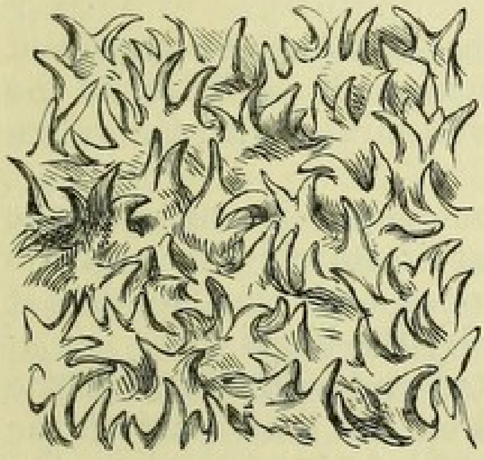


Fig. 13.—Piece of Inner surface of Intestine, showing the Villi.

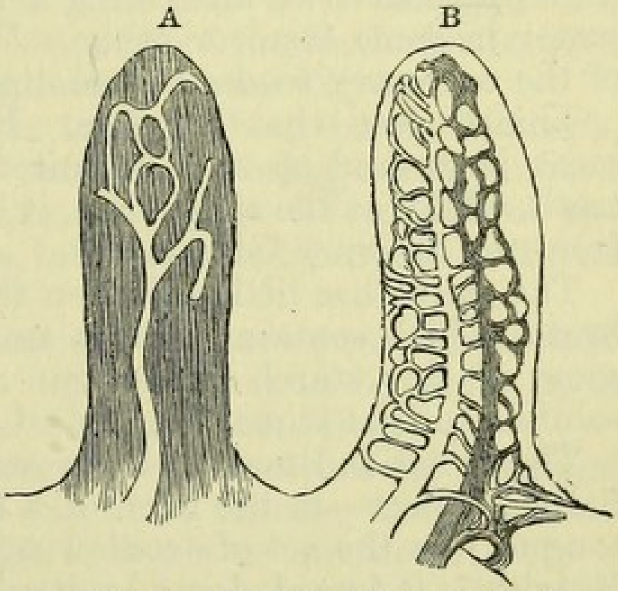


Fig. 14.—Villi greatly magnified.
A, Showing Lacteal.
B, Showing Artery, Capillaries, and Veins.

formed of four coats, the two principal being, as before, the muscular and the inner coats.

The muscles of the intestines, like those of the stomach, are almost perpetually at work. They perform the same undulatory motion as we noticed in the Gullet and Stomach.

The whole intestinal tube is constantly surging along in a manner somewhat resembling the motions of a worm, and all this time it is squeezing and forcing forward its contents. In this way the whole of the food is acted upon by every part of the intestines in its turn.

The innermost surface of the small intestines is raised up into millions of little thread-like processes termed *Villi*. These give to it the appearance of the pile on velvet, see Fig. 13. You are, of course, familiar with this appearance in tripe.

Each **Villus** is a kind of finger-like projection. It contains, not only a close network of blood capillaries, but an extremely fine central tube called a *Lacteal*, see Fig. 14.

The **Lacteals** commence at the ends of each of these Villi, and, after uniting into larger tubes, pass through the coats of the intestines and then through the membrane spoken of above as the Mesentery. From this membrane the Lacteals proceed to a kind of pouch in the loins, which extends upwards along the Spinal Column, under the name of the *Thoracic Duct*.

Having thus briefly described the organs of digestion, let us now see how each performs its share of the work of nourishing the body, and what becomes of the various food-stuffs. Let us suppose that we are taking a meal of bread and meat and water in some form or other. We shall then have all three of the necessary food-stuffs to digest.

This is just what happens. Each mouthful of bread and meat is ground up and separated into small particles by the teeth, while, at the same time, it is well mixed with the saliva from the Salivary Glands.

The saliva has little effect on the meat, but it acts upon the bread, which contains a large amount of starch. It converts some of this starch into sugar at once, and thus renders it soluble, so that it may be sucked up by the blood.

The bread and meat, well masticated and softened with the Saliva, collect—in the form of a ball on the back part of the tongue. In the act of swallowing, which now takes place, the Epiglottis is forced down by its muscles, so as to form a kind of bridge over the top of the Windpipe, and the ball or *bolus* passes over this bridge into the Pharynx. The muscles round the walls of the Pharynx then contract one after another like a number of elastic rings, seize hold of the ball, and force it downwards into the Gullet. In the same way it is carried along into the stomach by the contraction of the ring-like muscles of the Gullet.

It is important to remember that, in swallowing, the food and drink do not simply *fall* down the gullet; but are forced along by the contraction of its muscles as we have described. Even in swallowing a pill there is the same process, and consequently the smaller the pill the greater the difficulty in swallowing, because the muscles have more trouble in laying hold of it. You may have seen an acrobat stand on his head, and eat and drink in that position. This shows plainly that the food and drink do not *fall* into the stomach.

Passing into the stomach, the masticated particles of bread and meat are at once hurried and tossed to and fro by the continued action of the muscles of that organ. At the same time, the inner coat of the stomach continues to pour in large quantities of the Gastric Juice.

The **Gastric Juice** at once seizes upon and gradually dissolves the *proteids* contained in the bread and meat, which rapidly seem to vanish under its action. Some of these dissolved proteids, together with some of the starchy matters dissolved by the Saliva, are at once sucked up into the blood by the blood-vessels in the walls of the stomach. The remainder of the mass, consisting of a thick, pulpy substance, resembling gruel, is called *Chyme.*

Chyme contains more or less proteid matters, together with those starchy elements which have not been changed into sugar, and all the fat. This last part of the food may be seen floating in large drops on the surface of the Chyme.

All the while the Chyme is tossing about in the stomach, more and more of its proteid matters are being eagerly sucked up by the hungry blood. At last, it is forced out of the stomach, through the Pylorus, into the Duodenum, or first part of the small intestines.

Here the Bile and Pancreatic Ducts are pouring in their juices, and the Chyme is at once acted upon by them, as it passes along the folded tubes of the small intestine.

The **Bile-fluid** seizes upon the still undissolved fats, and rapidly breaks these up into the most minute morsels, small enough to be sucked up by the Lacteals we mentioned above.

The **Pancreatic Juice** finishes the work which the Saliva began. It takes hold of the starchy matters which still remain undissolved, and changes them into sugar. It also assists in dissolving the proteids which were not dissolved in the stomach by the Gastric Juice.

The Chyme thus acted upon by the Bile and Pancreatic Juice has the appearance of a thick, yellowish-white cream, and is called *Chyle.*

As this creamy-looking **Chyle** is slowly forced along the intestines by the contraction of their ring-like muscles, all the nutritious parts are drop by drop sucked up by the Lacteals. The Lacteals are chiefly occupied in sucking up the fatty matters, but no doubt some of the proteids and sugar also pass into them.

The term Lacteal comes from a Latin word which means "milky." The tiny tubes in the Villi of the intestines are called Lacteals, because they have a white, milky appearance, from sucking up the fatty matters of the chyle from the intestines. The Lacteals, as we have seen, convey the substances they have sucked up to the Thoracic Duct.

The **Thoracic Duct** pours its contents into the left *Subclavian Vein*, and thus, at last, after a roundabout course, the fats we have eaten pass into the blood.

The remainder of the Chyle, consisting largely of starch, which has been changed into sugar by the Saliva and Pancreatic Juice, is readily and at once absorbed into the blood by the capillaries in the walls of the intestines.

The same thing, to a great extent, happens to the proteid matters. After they are dissolved by the gastric juice in the stomach, the blood greedily sucks them up.

Water requires no digestion, but passes at once into the blood-capillaries, which are spread out along the whole inner surface of the Alimentary Canal.

All other mineral foods, too, are readily and easily dissolved either in the mouth or the stomach, and in the same way pass at once into the blood.

From this short account of the process of blood-making as we termed it, we can see that the blood is constantly being loaded and enriched with substances necessary for renewing the waste tissues, and this from apparently two sources.

First, as it rushes along in the hair-like capillaries of the stomach and intestines, it sucks up, *directly*, rich stores of proteid and sugary matters.

Again, the Thoracic Duct is constantly pouring into the blood, *indirectly*, the rich, white, creamy fluid which the Lacteals have absorbed from the *fatty matters in the Chyle* in the intestines.

Thus we see that the tissues of the body are destroyed by mental and physical exertion; that the blood restores those waste tissues; and that the food we eat supplies the blood with the substances necessary for that work.

THE BLOOD.

The Blood has been beautifully called "the river of life." Every part of the body, both solid and fluid, is formed from the blood. It must therefore contain in itself all the substances of which the body is composed. We have seen, in the last chapter, that it does contain these substances, and that they are prepared by the process of digestion from the food which we consume.

Blood, as it is drawn from the body, is a red, somewhat *sticky fluid*, thicker than water, and apparently all of one substance. If, however, we let fall a small drop of freshly-drawn blood upon a piece of glass, and examine it under a very powerful microscope, we shall see that this fluid **is not all of one substance**, but consists of—

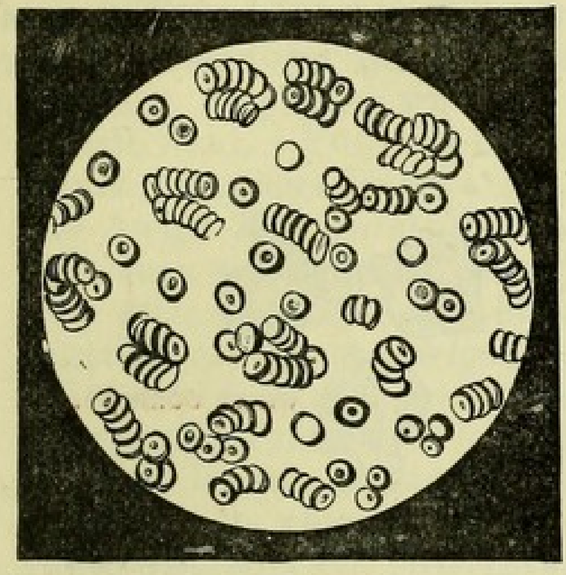


Fig. 15.

1. An almost colourless liquid called the "*liquor sanguinis.*"

2. An enormous multitude of minute bodies termed "*corpuscles*" floating in the liquid, see Fig. 15.

These corpuscles are of two kinds, red and white.

The **Red Corpuscles** are by far the more numerous. You may form some notion of their size and number from the fact that ten millions of them would probably just cover a square inch. In shape they resemble somewhat the round, flat discs we use in playing draughts, see Fig. 16. They may even be compared to a muffin, only that they are slightly hollowed in the middle.

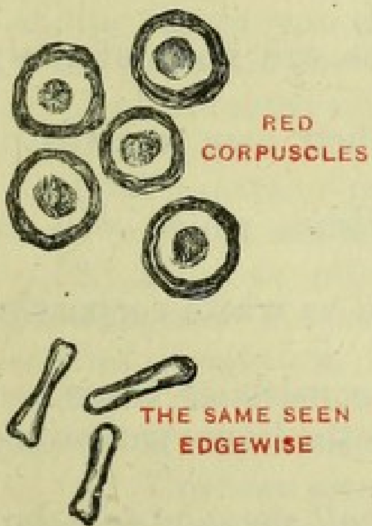


Fig. 16.

They are not hard and solid, but rather resemble tiny pieces of red jelly than anything else.

The Red Corpuscles absorb oxygen in the lungs, and carry it for distribution to the various tissues of the body. As we proceed, we shall see that the presence of oxygen, in every part of the body, is of the utmost importance. The blood in the arteries is abundantly supplied with oxygen, and it is the combination of the oxygen with a substance in the red corpuscles called *Hæmatin* which gives arterial blood its bright scarlet colour.

The blood in the veins contains very little oxygen, because it has parted with it to the tissues of the body. The colour of blood in the veins is dark purple. This blood is unfit to nourish the tissues.

Let us again examine a drop of blood by means of the microscope. As we continue looking at it through the microscope, we shall notice the red corpuscles rolling and tumbling about in the clear liquid; and after a time they will arrange themselves in long rolls, like piles of tiny coins. See Fig. 17.

The **White Corpuscles** are slightly larger than the red, and are not flattened. Indeed they cannot be described as of any special shape. As we watch them, by means of the

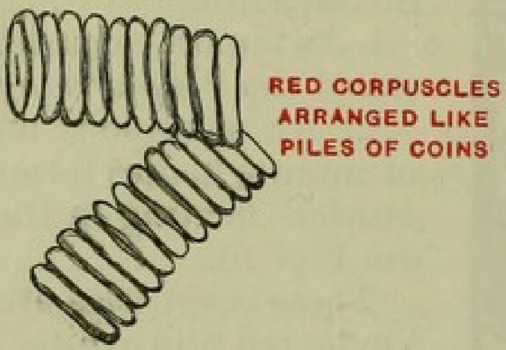


Fig. 17.

Fig. 18.

microscope, rolling and tumbling about, we shall see that at one time they are round like a ball, and of such a size that about 2500 of them would just reach one inch. Immediately afterwards, however, they begin to change their form, and become pear-shaped, triangular, square, and so on, in endless variety. See Fig. 18.

The functions of the white corpuscles are not definitely known, but they are probably—

1. To form the red corpuscles from their own nucleus or centre.

2. To prepare the substance called *fibrin*, which will be spoken of below.

There are nearly 500 times as many red as white corpuscles in the blood.

About one-half the bulk of the blood consists of these red and white corpuscles, the remaining half is the liquor sanguinis, the clear fluid in which they float.

This **Liquor Sanguinis**, again, *is not all one substance*, but consists of two distinct parts—the *serum* and the *fibrin*.

These two substances can be best seen in the process of Coagulation.

Coagulation or **Clotting.** Blood, although fluid (like water) while it is in the blood-vessels, becomes quite solid soon after it is drawn from the body. We say it forms a *clot*, and in this state it may be picked up in lumps and handled.

You may all perform the following experiments for yourselves. Get the butcher to give you enough freshly-drawn blood to fill two small basins. Let one of the basins stand undisturbed for some time, and with a bundle of twigs keep slowly stirring the blood in the other basin. In a few minutes you will find that the blood which has been standing appears to have become a nearly solid jelly. In other words, it has begun to *coagulate,* while that which you have been stirring is still fluid. You will notice, however, that the twigs themselves are covered with a soft red sticky substance. Take now the twigs and carefully wash them under the tap. You will then see the red colour disappear, and what remains will be a soft, white, delicate, stringy substance, matted and bound together among the twigs like a kind of network. This stringy substance is *fibrin,* one of the constituents of the liquor sanguinis. You may now leave the blood which has been stirred, for any length of time, *and it will not become solid.* This proves to us that the **fibrin is the real cause of the coagulation of the blood.**

After some hours you may look again at the blood which had begun to clot or coagulate. You will then see that the solid jelly in the middle has become firmer, and has shrunk in size, and that it floats in a clear yellowish fluid. This fluid is not the liquor sanguinis, but only part of it, the *serum.* Take the clot or solid lump out of the basin, and wash it carefully at the tap as you did the twigs. In a little while you will wash away all the corpuscles, and will have nothing left but some of the same soft, white, stringy material which we noticed on the twigs. We see from this, then,

(1.) *That when freshly-drawn blood is left to stand it coagulates or forms a clot.*

(2.) *That in this coagulation the delicate threads of fibrin bind together the corpuscles into a solid mass, inclosing them in a kind of network.*

(3.) *That if we take away this fibrin by whipping or stirring the blood, there will be no coagulation.*

(4.) *That the serum of the blood (the yellowish fluid in which the clot floats) is what remains of the liquor sanguinis after the fibrin is taken away.*

The power of coagulation is of the most vital importance. When a person receives a severe wound, he would probably bleed to death, unless coagulation set in. Nature in this way plugs up the wound with clots of blood, and prevents excessive bleeding.

In the last chapter, page 59, we noticed that the blood is rich in Albumen. If you took some of the Serum of blood, and tried to boil it, you would find that it would soon become quite white and solid like the "white of egg." This is because it consists chiefly of albumen, as does also the white of egg. In its natural state, as well as after boiling, the serum of the blood resembles the "white of egg." You know that albumen is a Proteid, and contains nitrogen, carbon, hydrogen, and oxygen.

Although we have hitherto spoken of the blood as consisting of red and white corpuscles, serum, and fibrin, the student of chemistry would find in the blood small quantities of such elements as sulphur, phosphorus, iron, sodium, potassium, calcium, and chlorine. You can imagine, then, what a wonderful fluid the blood is.

The **Functions** of the **Blood**:—

1. The blood carries nourishment to the various tissues, to build them up or repair them after they have been broken down by exertion.

2. It absorbs large quantities of oxygen in the lungs, and carries it into every part of the system. You all remember that the great property of this gas is its power of supporting combustion. Notice, now, what takes place in the body. Certain tissues, we will suppose, have been worn away or destroyed by some mental or physical exertion. These worn-out tissues thus become waste, poisonous matters, and if allowed to remain in the body would speedily produce disease and death. Hence they must be got rid of. It is important to remember that the tissues of the body all contain carbon, nitrogen, and hydrogen. When, therefore, oxygen is brought, by the course of the blood, into contact with these worn-out tissues, it seizes upon them and a burning takes place. The carbon and oxygen, in burning, produce carbonic acid; the hydrogen and oxygen combine and form water; while a complex product called *Urea* is formed by all four, carbon, hydrogen, nitrogen, and oxygen.

3. The blood is the drain or stream which carries away all the waste products from the body. After the oxygen has converted the various waste matters into carbonic acid, water, and urea, they are readily sucked up by the blood and carried away, to be expelled from the system.

4. The constant combustion going on in the body produces a large amount of heat. The blood then acts like the hot-water pipes of a large building, and distributes the heat equally to all parts of the body.

5. The blood supplies the material for forming certain juices which act an important part in the work of digestion. Thus

the salivary glands of the mouth form or secrete the saliva from the blood; the coats of the stomach secrete the gastric juice; the liver the bile, and so on.

THE CIRCULATION OF THE BLOOD.

We finished the last chapter by enumerating the various functions of the blood. The present chapter will explain how this "river of life," as we called it, is made to keep up its constant flow through every nook of the human system.

Circulation of the Blood. The blood is carried by the arteries from the heart to the various parts of the body, and it returns by the veins from all those parts back to the heart. This continual flow of the blood through the body, to and from the heart, is called the *Circulation.*

The organs of the circulation of the blood are the heart, the arteries, the capillaries, and the veins. See Fig. 19.

The **Heart.** The heart is a hollow muscular organ, somewhat like a pear in shape. (See Fig. 20.) It is about the size of one's closed fist, and is composed of involuntary muscular fibre. It is the head-centre of the circulatory system, and is, in fact, a kind of force-pump for propelling the blood along the arteries. From the first dawn of life it carries on its incessant work, night and day, sleeping and waking; it never rests for one moment, till death stops it for ever. It is enveloped in a membrane called the *Pericardium.*

The **Pericardium** is one of the serous membranes. It secretes or gives out a fluid somewhat like the serum of the blood, and known as the *serous fluid.* This fluid is constantly being poured out over the surface of the heart, to reduce friction.

The Heart is situated in the centre of the Thorax, immediately behind the breast-bone, and between the two lungs. A good view of its position is given in Fig. 24, on page 88.

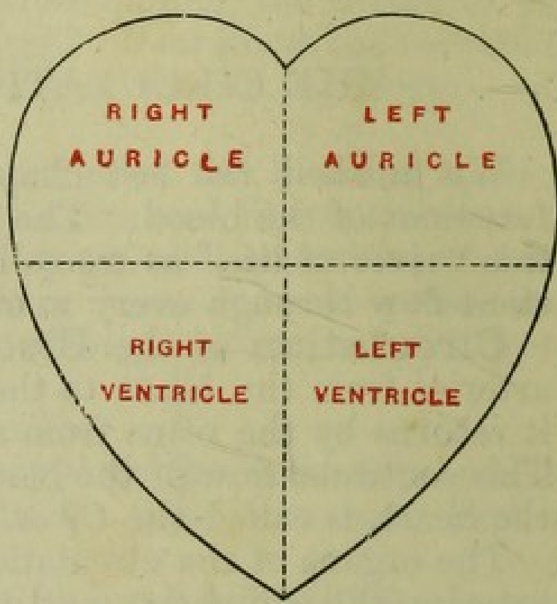
Its base or broad end is turned upwards, and to the right; and its apex or point is directed downwards, forwards, and to the left.

A muscular wall from the base to the apex divides the heart into two equal parts.

The right half of the heart contains impure venous blood, the left half pure arterial blood.

Each half of the heart is again divided by another muscular wall, into an upper and a lower chamber.

Hence there are two upper chambers called *Auricles*, and two lower chambers called *Ventricles.* The walls of the Ventricles are stouter and stronger than those of the Auricles; and those of the Left Ventricle are much stouter than those of the Right Ventricle.



The **Right Auricle** communicates with the Right Ventricle and the **Left Auricle** with the Left Ventricle; but there is no connection between one side of the heart and the other.

The passages, however, between the auricles and ventricles are provided with *valves,* which have the power of effectually closing the communication. These valves may be roughly compared to folding-doors or gates, which, by opening only one way, allow the blood to flow in that direction, and prevent its flowing in any other. They are formed of thin, three-sided flaps of tough membrane, which hang down from the edges of the passage into the ventricles. The valve on the right side of the heart consists of three such flaps, and is called the *Tricuspia Valve;* that on the left side consists of two flaps, and is called the *Bicuspid Valve.* This one is said to resemble a bishop's mitre in shape, and is hence often called the Mitral Valve.

These valves allow the blood to flow through the passages, *from the auricles to the ventricles*, without offering any resistance. As soon, however, as the blood attempts to return from the ventricles into the auricles, it gets behind the flaps of the valves, and drives them together, so closing the passage.

No doubt you will wonder why the flaps are not forced right back into the auricles, so as to open up the passage again the wrong way. The reason is this. Those corners of the flaps which hang down into the passage, are attached to the walls of the ventricles by a great many fine threads or tendons called *Chordæ Tendinæ.* These slender threads are only just long enough to allow the flaps to close together, and no force of the blood pushing against the valves can send them farther back, as the threads themselves will not stretch. The more, then, the blood in the ventricles pushes against the valves, the tighter the threads become, and the closer the flaps are brought

Fig. 19.

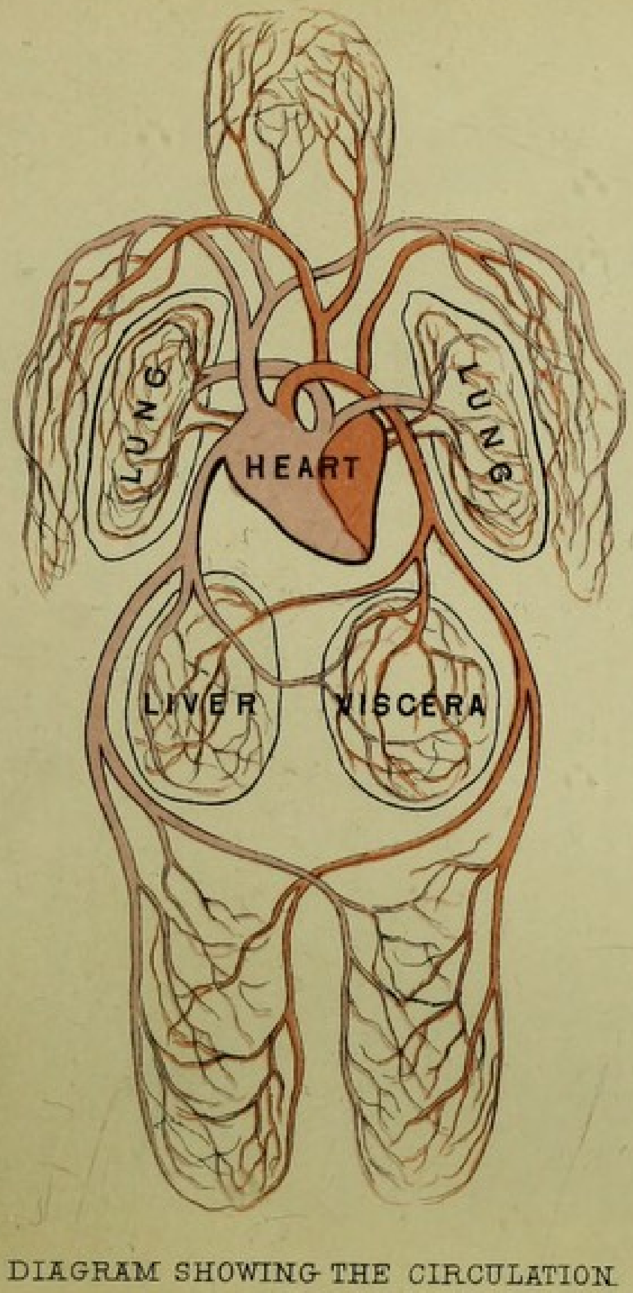
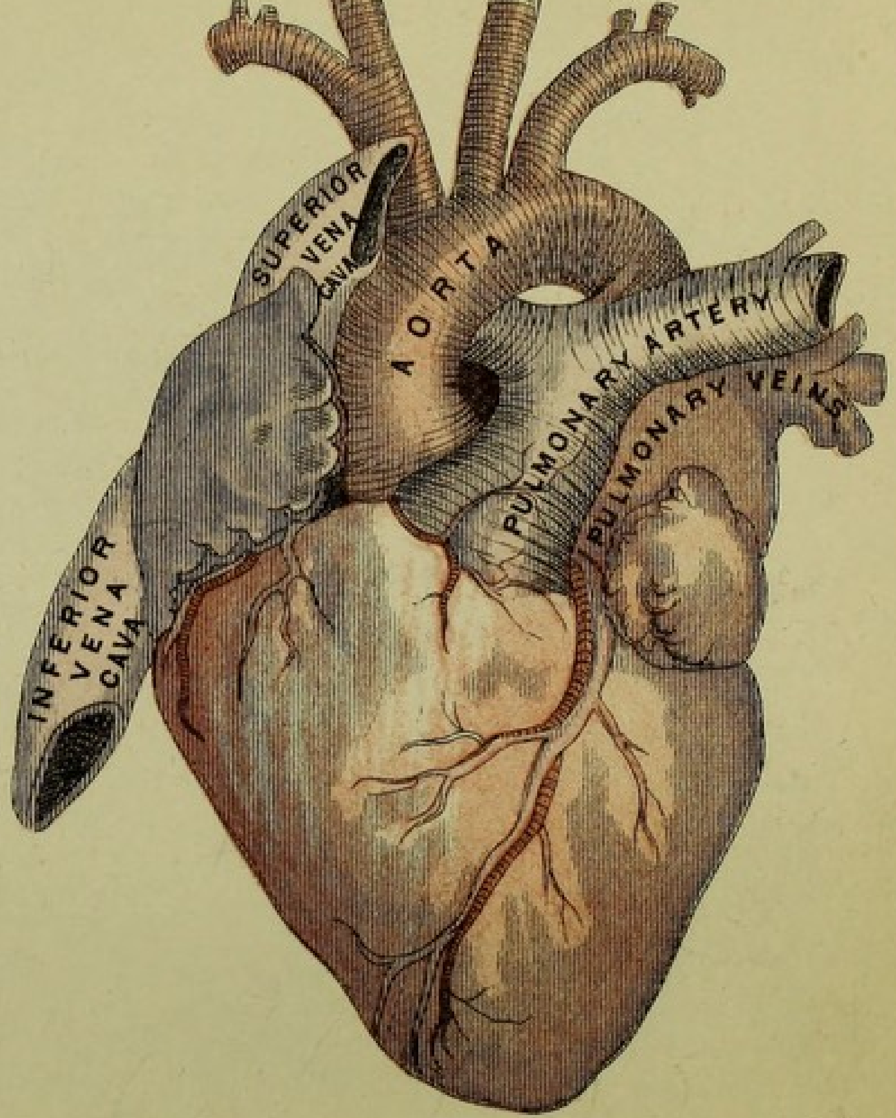


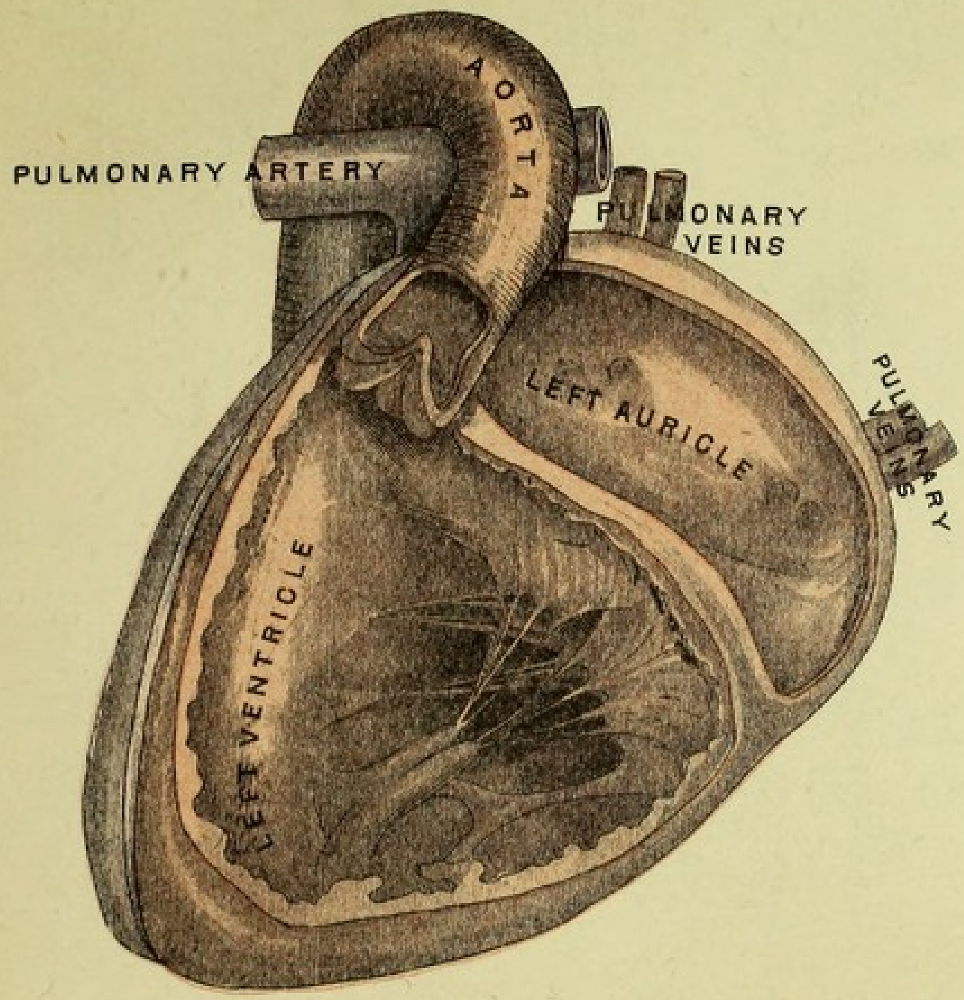
DIAGRAM SHOWING THE CIRCULATION OF THE BLOOD.

Fig. 20.



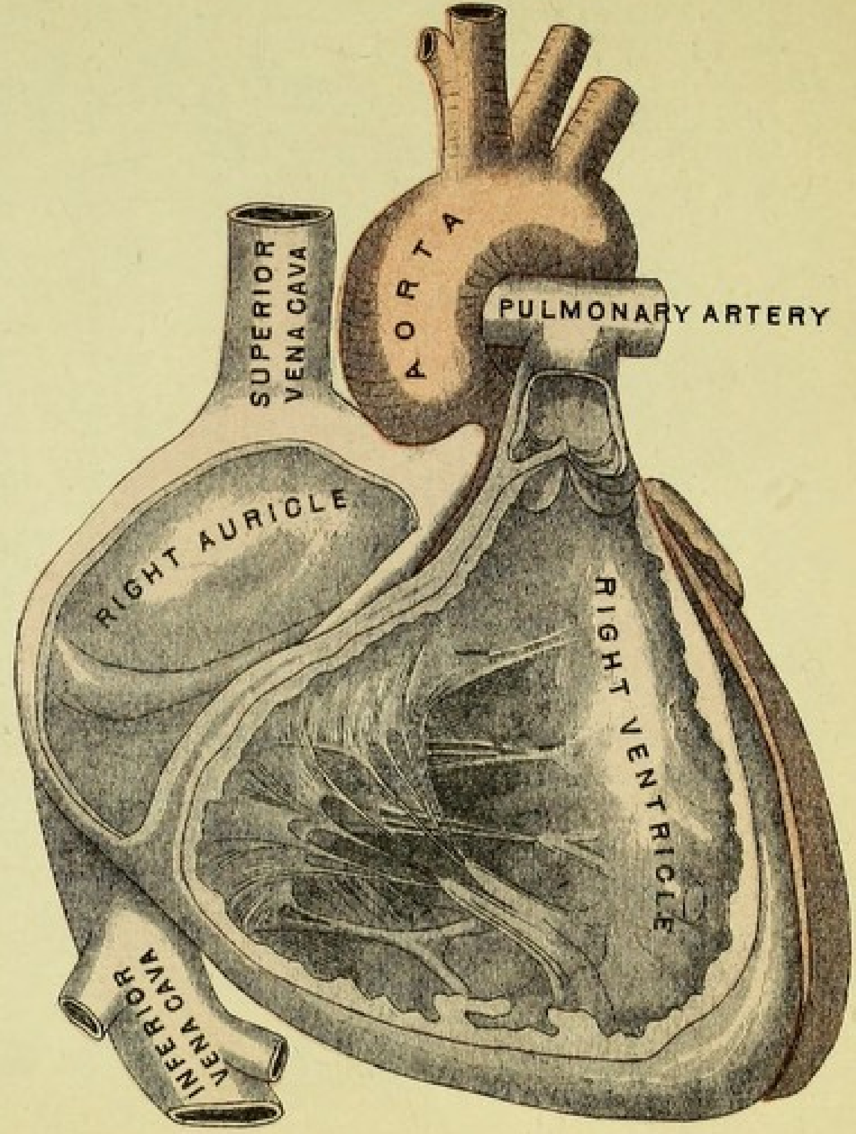
EXTERNAL VIEW OF HEART.

Fig. 21.



LEFT SECTION OF HEART.

Fig. 22.



RIGHT SECTION OF HEART.

together, till the way is completely blocked up. This may be clearly understood by studying Fig. 22.

Blood-vessels connected with the **Heart.** The two largest veins in the body open into the Right Auricle. These are the *Superior Vena Cava* and the *Inferior Vena Cava.*

The entrance of the Inferior Vena Cava into the auricle is guarded by a valve called the *Eustachian Valve.* This valve opens into the auricle and allows the blood to flow *from the vein into the auricle, but not back again.*

Both of these great veins pour into the Right Auricle the dark, impure purple blood, which has been collected up in various parts of the body by the smaller veins.

The **Superior Vena Cava** *brings venous blood from the head* and upper parts of the body.

The **Inferior Vena Cava** *brings venous blood from all the lower parts.*

The **Pulmonary Artery** springs from the Right Ventricle. Its entrance is guarded by a valve called the *Semi-lunar Valve.*

This valve is not like those between the auricles and ventricles. It is formed of three little pouches or pockets, *each shaped somewhat like a half moon.* Hence the valve is called a *Semi-lunar Valve.* The mouths or openings of these pockets are turned towards the artery. When, therefore, the blood is passing from the Ventricle into the Artery, the valve allows an easy passage. As soon, however, as the blood attempts to return from the Artery into the Ventricle, it fills the three little pockets, their edges are forced together, and the passage is entirely blocked up.

The Pulmonary Artery, soon after leaving the heart, splits up into two pipes. One goes to the *Right Lung,* the other to the *Left Lung.*

This Artery carries from the heart to the lungs the dark, impure purple blood, which has been brought to it by the great veins. In the lungs such blood is purified and sent out again heavily charged with the life-giving gas, Oxygen.

The **Four Pulmonary Veins** open into the Left Auricle. Two of these veins come from the Right Lung, and two from the Left Lung. They all bring back to the heart the blood which has been purified in the Lungs. This blood, as we noticed before, is of a bright scarlet colour, and is laden with oxygen.

The **Aorta** springs from the Left Ventricle. It is the largest artery in the body, and is about as big round as one's thumb. Its entrance is guarded by a Semi-lunar Valve similar to that at the entrance of the Pulmonary Artery. The valve allows the blood to flow from the Ventricle into the Aorta, but prevents its returning again into the Ventricle.

This great artery carries out from the heart the pure bright life-giving blood, which is to be distributed all over the body.

You now see that the great veins open into the auricles, and that the arteries spring from the ventricles of the heart.

The rule is, that all arteries carry pure, bright scarlet blood, and all veins, dark, impure purple blood. This is not so, however, with the Pulmonary arteries and veins.

The Pulmonery Artery carries *the impure blood* from the right ventricle of the heart to the lungs.

The Pulmonary Veins bring back *pure blood* from the lungs to the left auricle of the heart.

The **Movements** of the **Heart.** You already know that the heart is an extremely thick muscle, which alternately contracts and relaxes of its own accord, without any interference of the will.

In childhood these movements of the heart take place at the rate of from 100 to 140 in a minute.

In the prime of life their rate varies from 60 to 75 a minute.

In old age they become still slower.

In fevers the heart sometimes makes nearly 200 of these movements per minute.

The two auricles always contract together, and at the same time the two ventricles expand. Then both the ventricles contract while the two auricles expand, and this is continually being repeated.

Let us now suppose that the two auricles have been charged with blood from the venæ cavæ and the pulmonary veins. As soon as they are full, both of these chambers begin to contract, and thus squeeze or drive their contents through the valves into the ventricles. The ventricles at the same time expand to receive the blood.

When the ventricles have in this way been charged with blood, they in their turn begin to contract. The blood in the ventricles is thus forced back against the Tricuspid and Mitral Valves, and effectually closes them.

There is no way of escape from the ventricles but by the Aorta and Pulmonary Artery, and hence the blood rushes up these two pipes to leave the heart. With the contraction of the ventricles, however, there has been an expansion of the auricles. These upper chambers have thus again been charged with blood from the great veins, and the same thing goes on perpetually.

The Beat of the Heart. Every time the ventricles contract, the apex of the heart is drawn upwards and forwards, and strikes upon the front walls of the thorax. It is this which we feel when we place the hand on the chest.

The Blood-vessels. The blood-vessels of the body consist of the arteries, veins, and capillaries. These are all tubes or pipes, but they differ in many respects.

Arteries. The Arteries are the blood-vessels which carry blood from the heart to the lungs and the various parts of the body.

Most of the principal trunks of the arteries are deeply placed in the body, but the smaller branches extend into every part of the system. They are all protected with strong tough muscular walls. The Aorta is the largest artery in the body, and after leaving the heart it splits up into smaller vessels, and these into still smaller, like the branches and twigs of a tree.

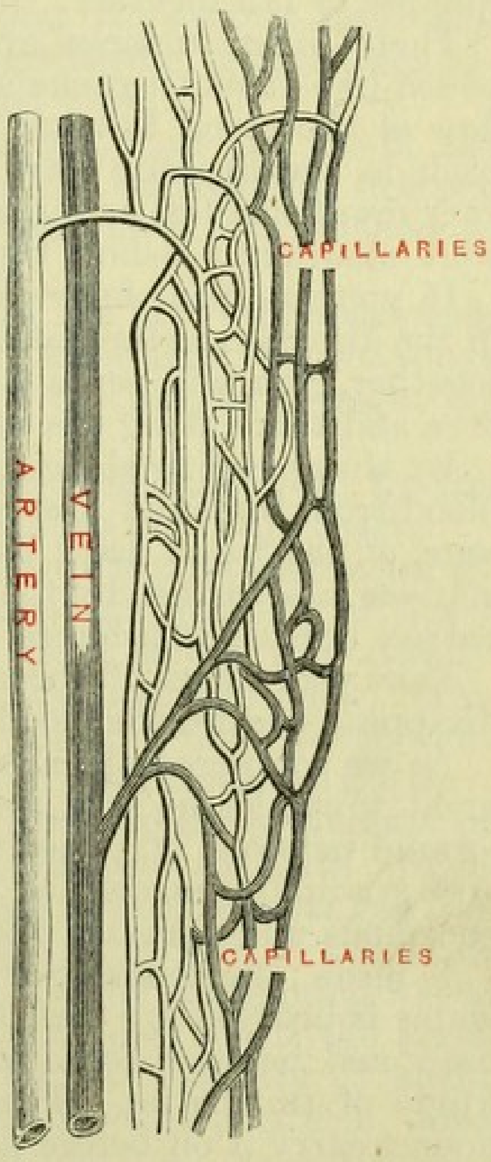


Fig. 23.

The arteries might be compared to the underground network of pipes belonging to one of the great water companies of a town. The heart itself would then represent the great pumping-house at the waterworks, where the pumps are going night and day, forcing good wholesome water along the pipes for the supply of the town. The aorta would represent the great main which leaves the water-works; and just as this great pipe sends off smaller ones along the various roads, and these again still smaller ones into the streets, and lastly these again to the individual houses, so it is with the aorta and its various branches.

Veins. The Veins are the blood-vessels which carry back the blood to the heart from the lungs and the various parts of the body.

Veins generally lie near the surface of the body, just beneath the skin. You may see some of them in almost any part of your body. They commence in exceedingly minute tubes, and gradually unite (like a river and its tributaries) into larger and larger vessels, until they at last form the great veins which open into the auricles of the heart.

The walls of the veins are thin and flabby, and not muscular like those of the arteries.

If the veins were emptied of their blood, their sides would collapse or fall together.

Their inner surfaces are abundantly supplied with little pouch-like folds or pockets, which act as valves to direct the flow of the blood towards the heart, and prevent its turning back in the opposite way. They are exactly the same (only very much smaller) as the semi-lunar valves of the heart which were mentioned a short time ago.

If you run your finger along one of the veins in your arm, in the direction of the hand, so as to press the walls of the vein together, you will see a number of little knots or swellings here and there along the vein.

By thus pressing along the vein, you prevent the flow of the blood from the hand towards the shoulder. Indeed you force some of the blood back towards the hand. The knots which you see are caused by the blood filling the little pouches or valves, because it is forced back.

Take your finger off the vein, and the knots will immediately disappear, because the blood is allowed to flow towards the heart.

As we compared the arteries to the water-supply pipes of a great town, let us now compare the veins to another underground network of pipes, which commence in small channels and gradually increase as they unite, until they at last form enormous underground passages.

I mean the system of sewerage. The pure, wholesome water is brought by the company's pipes to each house. It is used, and becomes contaminated with dirt, and waste, and all kinds of impurities. Then the drains from the individual houses carry it off before it can work any harm. You can imagine a sewer-pipe running under the middle of your street, and receiving smaller drain pipes from the various houses. You can then imagine the still larger channel or sewer which runs under the main roads, and receives the pipes leading from the various streets. You can imagine all these great channels uniting at last into one immense main-sewer, which carries away this unwholesome river of impurities, and gets rid of it many miles from the town.

The veins of the body resemble this very much. The pure, wholesome blood is brought by the arteries. It is used by the tissues of the body, and becomes contaminated with impurities. The veins are then the drain-pipes of the system to carry away the impure blood from the tissues.

Capillaries. The Capillaries are the minute hair-like tubes which form the connection between the end of the finest arteries and the commencement of the finest veins. They therefore form a close network in every part of the body. So close-set are these tiny vessels, that you cannot prick any part of your skin, even with the finest needle, without wounding one or more of them and drawing blood.

These little tubes are invisible except with the aid of the microscope. Their walls consist of an exceedingly delicate membrane, which allows the liquor sanguinis of the blood to pass through into the tissues beyond.

It is in this way that the tissues of the body are nourished, strengthened, and restored. At the same time, the worn-out tissues are seized and burned up by the oxygen brought by the blood in the capillaries.

The products of this burning are then caught up by the blood, and sent along to the veins, and so on to the heart.

PULSE. It is important to notice here that at each contraction of the ventricles of the heart a certain quantity of blood is squeezed into the aorta. That great artery was already full of blood before it received this additional quantity. The blood once in the aorta, however, cannot return to the ventricle because the semi-lunar valve shuts and blocks up the way. In order, then, to make room for this additional volume of blood, that part of the aorta nearest the heart expands. (You remember that all arteries have strong muscular walls.) After it has stretched to its fullest extent, this portion of the aorta begins to contract to its former size, and by contracting forces some of the blood forward. The next portion of the aorta must now expand to make room for the quantity of blood which has been sent forward, just as the other part did. Also after expanding it will contract and force the same quantity of blood forward to the next portion of the aorta. This will send to the next, and that to the next, until the smaller arteries end in the tiny capillaries.

This alternate swelling and contracting of the arteries you may feel by placing the finger on the arteries of the wrist, the ankle, the neck, and the temples. It is commonly called the Pulse.

It has taken some time to tell this story of the circulation, but in the meantime the blood in your body has made several complete journeys to and from the heart.

It is calculated that the blood rushes along the main arteries at nearly twelve inches in a second. This rapid rate becomes diminished as the arteries divide and subdivide, until in the capillaries the blood moves along at the slowest creeping pace.

The course through the capillaries, however, is a very short one, probably in no case more than from half to three quarters of an inch; and the rate again increases as the veins unite into larger and larger trunks, so that the whole circuit through the body occupies only about thirty seconds.

If any artery be cut, the blood gushes from it in jerks corresponding to the Pulse.

If you wish to stop the bleeding, you must bind up the artery on the side of the cut nearest the heart, because the blood comes from the heart along the artery.

When a vein is cut, the blood flows in a kind of trickling stream without any jerk.

To stop the bleeding in the case of a vein, you must bind up the vein on the side of the cut farthest from the heart, because the blood is coming from the capillaries along the vein.

Course of the **Blood** through the **Heart.** In following the course of a quantity of blood through the heart, let us commence at the Right Auricle, where the Superior and Inferior Venæ Cavæ are busy filling the Auricle with dark, impure purple blood.

As soon as the Auricle is full it begins to contract. The blood cannot get back into the great veins, because it is urged forward by the great body of blood behind it. The passage, however, leading to the Right Ventricle lies open, and through that the blood passes until the ventricle is full.

When the ventricle is full it begins in its turn to contract. The Tricuspid Valve at once closes, and blocks up the way back to the Right Auricle, and the blood rushes up the Pulmonary Artery through the Semi-lunar Valve which stands open.

The Pulmonary Artery by its alternate swelling and contracting propels the blood along to the Lungs.

In the Lungs the blood gives up its impurities and absorbs a large amount of oxygen. It comes back to the heart in a purified state by the Pulmonary Veins, which pour it into the Left Auricle.

At the next contraction of the auricles the blood is forced through the Mitral Valve into the Left Ventricle.

As soon as the Left Ventricle is full it begins to contract. The Mitral Valve at once closes and blocks up the passage into the Left Auricle, and the blood has no other way open but through the Semi-lunar Valve into the Aorta.

The Aorta then, as you know, distributes the blood through the body.

The Circulation of the blood is generally treated under four heads—

1. The Greater Circulation, or the circulation through the body.

2. The Lesser or Pulmonary Circulation, the course of the blood through the Lungs.

3. The Portal Circulation, which is simply a branch of the Greater Circulation, and carries blood through the stomach, spleen, pancreas, and liver.

4. The Coronary Circulation, or course of the blood through the muscles of the heart itself.

1. The **Greater Circulation.** The pure bright arterial blood, rich with nourishing and life-giving properties, is forced out of the left Ventricle into the Aorta.

From the Aorta it passes along the Arteries, which get smaller and smaller continually. Reaching the capillaries in the various parts of the body, it creeps along at almost a snail's pace, giving up all the time to the tissues outside the walls of the tiny tubes the nutritive materials it has received from the food as well as the oxygen it has absorbed in the lungs.

The most important part of all takes place here, when the oxygen seizes upon the waste tissues and consumes them, forming carbonic acid, water, and urea.

These waste products are sucked up by the blood as it crawls slowly along in the capillaries, and completely change its character and appearance. It is now collected up by the smallest veins and conveyed by them to larger and larger trunks, until at last these pour it into one or other of the great veins which open into the Right Auricle of the heart. The course of the blood then in the greater circulation may be briefly stated as—

Left Ventricle, Aorta, larger artery, smaller artery, capillary, smallest vein, larger vein, Inferior or Superior Vena Cava, Right Auricle.

2. The **Lesser** or **Pulmonary Circulation.** In this course of the blood through the Lungs the **Pulmonary**

Artery starts from the Right Ventricle bearing impure purple blood from the heart to be purified. This artery soon splits into two branches, one going to each Lung. After entering the Lung the Pulmonary Artery divides and subdivides into smaller and smaller arterial trunks until at last they form the pulmonary capillaries. These tiny tubes surround the air-cells of the Lungs and an exchange takes place. The blood gives off carbonic acid and watery vapour to the air in the air-cells, and in return sucks up a great deal of its oxygen.

When the blood has been collected up by the Pulmonary Veins, it leaves the lungs entirely different in character and appearance from what it was when it entered them by the Pulmonary Arteries.

The four Pulmonary Veins (two from each lung) **finally bring back the bright scarlet blood to the Left Auricle of the heart.** This constitutes the Lesser Circulation. It may be briefly put—

Right Ventricle, Pulmonary Artery, smaller and smaller branches, Pulmonary Capillaries, smallest Pulmonary Veins, larger veins, four Pulmonary Veins, Left Auricle.

3. The **Portal Circulation.** This, as before stated, is simply a branch of the Greater Circulation. Certain arteries leave the main trunk carrying blood to nourish the stomach, the intestines, the pancreas, and the spleen.

In the chapter on Digestion we saw how the blood in the capillaries of the walls of the stomach and intestines is being constantly enriched with materials from the digested food.

The blood, after performing its office in these organs, is collected up by a number of veins, which at last unite and form a great vein, *the Portal Vein.*

This blood is carried by the Portal Vein to the *Liver*, and affords the material from which that organ prepares the Bile fluid.

Entering the substance of the Liver, the Portal Vein breaks up into smaller and smaller tubes and capillaries. The Liver takes from the blood in the capillaries what it requires for its work of Bile-making.

The blood is then again collected up by the *Hepatic Vein* and conveyed to the Inferior Vena Cava. The course of the blood through Portal Circulation is briefly—

Veins from stomach, intestines, spleen, and pancreas, Portal Vein, Capillaries of the Liver, smaller Hepatic Veins, main Hepatic Veins, Inferior Vena Cava.

4. The **Coronary Circulation.** This represents the

shortest journey a drop of blood can make from leaving the Left Ventricle, to returning to that chamber again. The arteries, capillaries, and veins of this system simply pass through the structures of the heart itself.

The two **Coronary Arteries** leave the Aorta just above the Semi-lunar Valve, and divide and subdivide through the substance of the heart, bringing blood to nourish that organ itself. They form capillaries, and the capillaries finally re-unite to form veins as in the other circulations. The Coronary Vein at last pours its impure blood into the Right Auricle.

A valve, called the Coronary Valve, guards the entrance of the *Coronary Vein* into the Right Auricle. The course of the blood through the Coronary Circulation is—Left Ventricle, Aorta, Coronary Artery, smaller and smaller Arteries, Capillaries, small Coronary Veins, Coronary Vein, Right Auricle.

PROOFS OF THE CIRCULATION OF THE BLOOD.

The following facts will prove very conclusively that the blood does circulate through the body:—

1. If an artery be cut, the bleeding may be stopped by binding up the artery between the cut and the heart, while binding up the part farthest from the heart will have no effect, because, as you know, the blood is coming *from the heart* along the arteries.

2. If a vein be cut it is necessary to bind up the part farthest from the heart if we wish to stop the bleeding. A bandage between the cut in the vein and the heart will not stop it, because the blood is now making its return journey *to the heart.*

3. If you press your finger along a vein in the direction leading from the heart, you will stop the flow of the blood, and the valves of the vein will swell up into little knots.

4. When a person is bitten by a venomous snake, the suffering is not confined to the spot where the teeth of the creature pierced the skin. Within a few seconds the poison from the fangs is to be found in every corner of the victim's body. It has been carried along by the course of the blood.

5. Alcohol taken into the stomach in the form of spirituous liquors, may be easily discovered in the blood drawn from any part of the body soon afterwards. This is only to be accounted for by the fact that the blood does circulate, and that these poisons are carried along in its stream.

THE LYMPHATIC SYSTEM.

Any account of the Circulatory System would be incomplete without a short notice of the Lymphatic System.

In describing the blood capillaries we mentioned that the liquor sanguinis of the blood oozes through their delicate walls, and bathes and nourishes the tissues beyond.

Some of this fluid is not used up by the tissues in the work of repairing their waste. This surplus *lymph*, as the fluid is called, is collected up by a system of tiny tubes invisible to the naked eye. These tubes commence in and lead from every part of the body, and are called Lymphatics. They unite into somewhat larger tubes, which finally convey the lymph to the Thoracic Duct, the main trunk of the Lymphatic System.

The **Thoracic Duct** is a tube about 20 inches in length and not much thicker than your penholder. It is placed along the front of the vertebral column, and pours the lymph into a great vein near the heart. By this arrangement all that part of the liquor sanguinis which is not required and used up to nourish and restore the tissues, is absorbed by the lymphatics and conveyed as lymph by separate channels to the blood again. It is supposed that the quantity of fluid in the tissues is constantly pushing forward that in the lymphatics so as to cause a regular circulation in those vessels towards the Thoracic Duct.

In the chapter on Digestion you learned how the Lacteals in a similar way proceed from the Intestines to the Thoracic Duct, and convey to the blood the chyle which they have absorbed from the intestines.

The Lacteals may be called the Lymphatics of the Intestines.

RESPIRATION.

DIFFERENCE BETWEEN ARTERIAL AND VENOUS BLOOD.

You have now seen the bright scarlet blood, loaded with oxygen, pass along the arteries into the capillaries in every part of the body.

You have also seen the veins, at the other end of the capillaries, collecting up the blood again to take it back to the heart.

You have noticed the change which has taken place in the capillaries. The blood in the vein is no longer bright scarlet, but of a dark purple colour.

You know that it has not only given up its oxygen, but that it has sucked in carbonic acid, water, and urea.

You know, too, that these waste matters are the product of a perpetual burning in the tissues, and that the burning could not go on without the aid of the oxygen brought by the blood. To carry on the burning, then, the blood must be constantly replenished with oxygen from some source.

The work of replenishing the blood with oxygen is performed chiefly by the lungs during the process of Respiration or breathing.

Respiration is the process by which the impure purple blood is purified in the lungs. During this process the blood gives off a certain quantity of carbonic acid and watery vapour and takes in fresh supplies of oxygen.

Although we generally associate the act of breathing with the lungs, it is important to remember that **the skin is also a breathing organ**, and carries on the work of respiration. The skin takes from the blood the same waste products (only in different quantities) as the lungs, and by means of the skin the blood takes in oxygen from the air as it does in the lungs.

CHANGES EFFECTED IN THE BLOOD BY RESPIRATION.

When following the course of the Pulmonary Circulation you noticed that the blood, as it entered the lungs by the Pulmonary Arteries, was of a dark, purple colour, and loaded with impurities. You then saw it collected up again and carried back to the heart by the Pulmonary Veins after it had given up these impurities and absorbed large quantities of oxygen in the lungs. This exchange of poison matters for fresh supplies of oxygen is shown even in the colour of the blood as it returns to the heart, for it is now a bright scarlet.

DIFFERENCES BETWEEN PURE AND RESPIRED AIR.

Now since the blood, as it passes through the lungs, is constantly throwing off its impurities and taking in oxygen, there must necessarily be considerable difference between the air which we exhale from our mouths and nostrils and that around us. Let us see what these differences are.

1. Pure atmospheric air contains nearly 79 per cent of nitrogen and about 21 per cent of oxygen, together with a mere trace of carbonic acid.

In other words, out of every 100 gallons of pure air nearly 79 gallons are nitrogen and 21 gallons oxygen.

Air which has passed through the lungs contains between 16 and 17 per cent of oxygen and from 4 to 5 per cent of carbonic acid. That is, this air has lost 4 or 5 per cent of oxygen and gained the same quantity of carbonic acid. The nitrogen remains unaltered.

2. Ordinary air, too, contains a slight quantity of watery vapour; but air, as it leaves the lungs, is saturated with watery vapour.

3. Air, as it leaves the lungs, is much hotter than the surrounding air. It is generally about 98° Fahrenheit.

4. It also contains a small quantity of decaying animal matter.

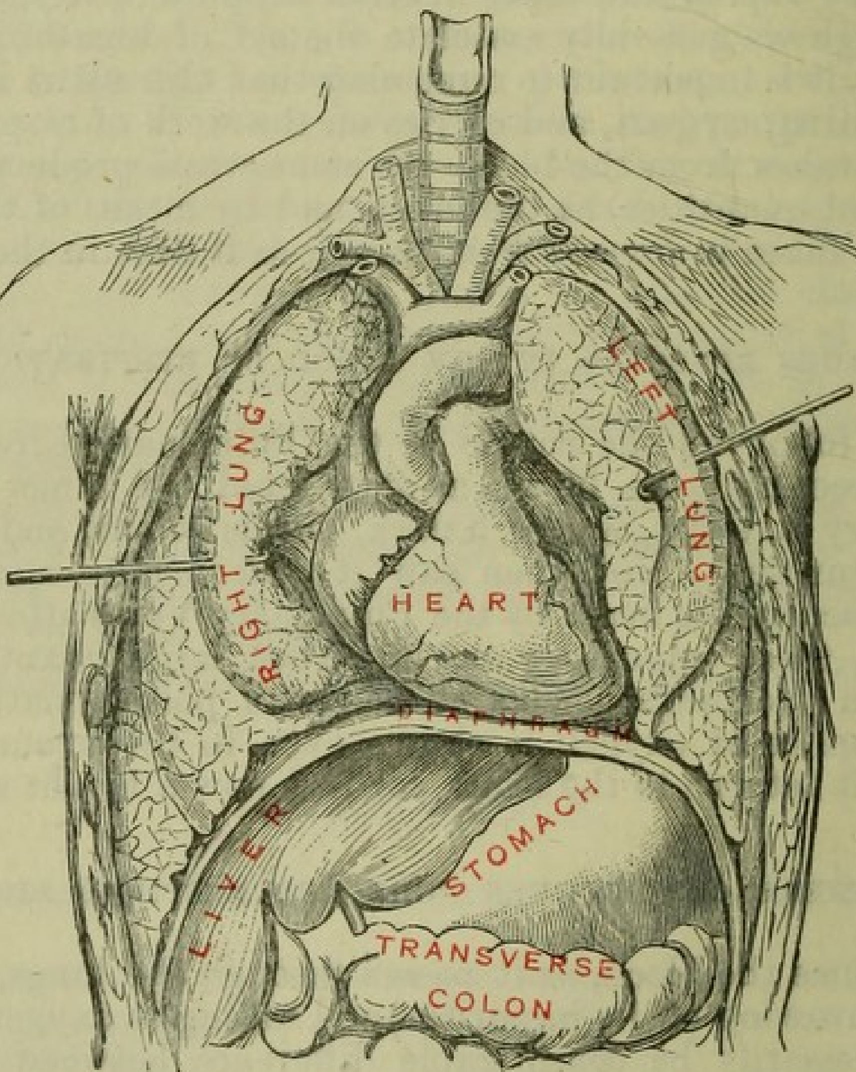


Fig. 24.

You may prove these differences by the following experiments:—

1. Take a small tumbler, about one-third full of clear lime-water, and breathe for a little while into it. Make each expiration as long as you can. You will see the water gradually become white and thick. The fact is, you have been sending carbonic acid into the lime-water, and the carbonic acid has seized on some of the lime, and combined with it to

form white carbonate of lime or chalk. This proves that carbonic acid is given off by the lungs.

2. If you breathe on the bright steel blade of your knife or on any cold polished surface you will see it become covered with minute drops of water. This proves that watery vapour is given off by the lungs.

3. You need no experiment to prove that the air as it leaves the lungs is hot. You know how on a cold day you blow your fingers to warm them.

4. The presence of organic matter in the breath may be proved, but the experiment is a very dangerous one, and must not be tried except by a skilful chemist. He would take a small quantity of strong oil of vitriol in a glass, and gently breathe into it until the organic matter of the breath turned the vitriol black.

Think for a moment of some great chimney-shaft which is constantly belching out clouds of smoke from the great fires down below. Our mouth is really a chimney, which is constantly sending out, night and day, sleeping and waking, volumes of the foul, poisonous products of our internal fires.

Let us now endeavour to see how all this is brought about.

Structure of the Lungs. The lungs are the two large, pinkish, spongy organs which surround the heart, and occupy almost all the remainder of the cavity of the Thorax. (See Fig. 24.) The right lung is the larger of the two, and is divided into three lobes. The left lung has only two lobes.

The lungs are protected by a serous membrane called the *Pleura*, similar to the Pericardium which surrounds the heart.

The internal structure of the lungs is really a collection of air-passages, arteries, capillaries, and veins.

THE AIR-PASSAGES OF THE LUNGS.

The **Windpipe** is the principal air-tube of the lungs. It is about 4 inches in length, and is protected on the front and sides by stout rings of gristle. These rings do not pass round the back of the tube. But for them the windpipe would close with the slightest pressure and cause suffocation. The internal walls of the windpipe are lined with a mucous membrane, which gives out a thick slimy substance called *mucus* or *phlegm* to keep the passages moist.

This membrane is covered with little thread-like processes termed *Cilia*, which resemble somewhat the pile in velvet. They wave to and fro like the waving of a cornfield in a breeze. Their office is to receive and pass upward towards the back of the mouth the mucus, together with all dust which has been sucked in with the air. Unless the cilia removed these substances they would speedily accumulate in the air-cells and produce disease.

The Windpipe, after entering the Thorax, divides into two branches called *Bronchi,* sending one to each lung.

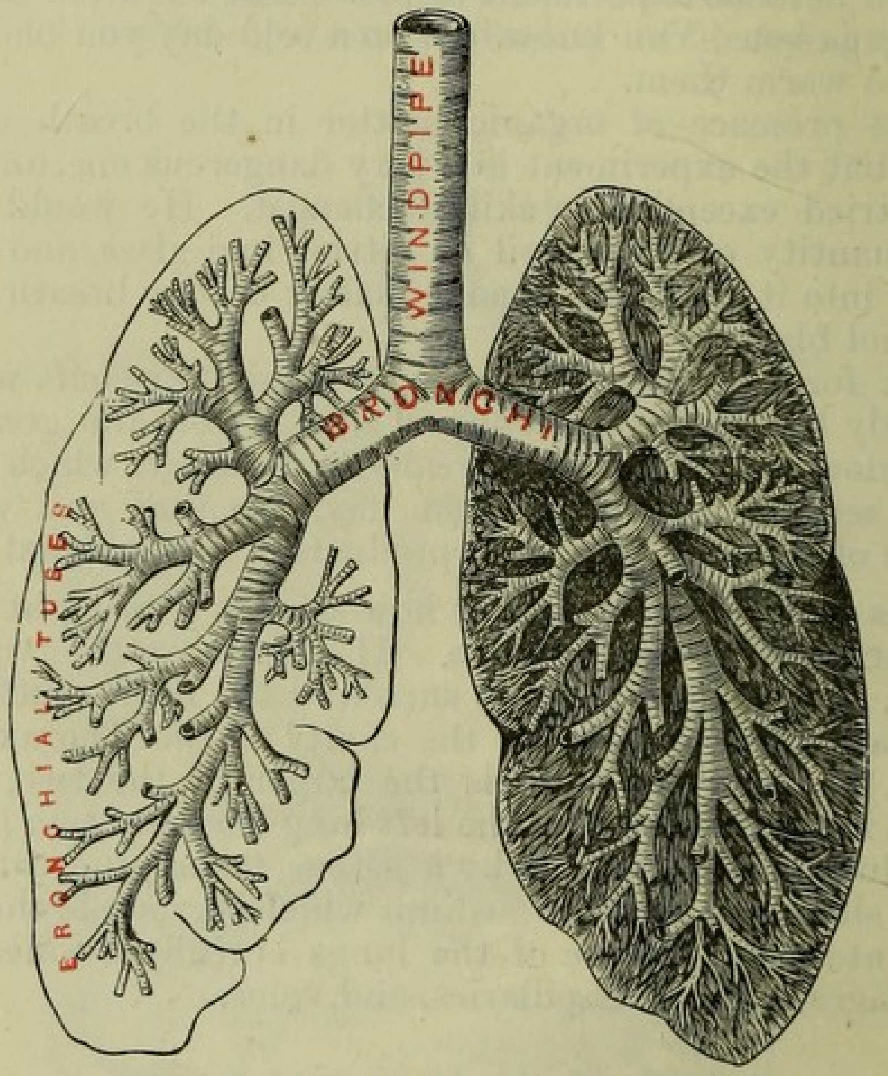


Fig. 25.—Section showing the ramifications of the Bronchi in the Lungs.

Each **Bronchus** branches out in the lungs into a large number of *Bronchial Tubes;* each Bronchial Tube divides again into smaller branches; these again into smaller; and so on down to the veriest twigs. See Fig. 25.

If you will only remember that all these tubes, great and small, are hollow, we may conveniently compare the whole system to a short bush or tree, of which the Windpipe is the trunk.

The smallest Bronchial Tubes end at last in the Lung-sacs. See Fig. 26.

Each **Lung-sac** bears some resemblance to a bunch of grapes, and is so small that forty of them would barely reach an inch.

Just as the bunch of grapes, however, contains a large number of individual grapes, so every Lung-sac consists of a large number of tiny hollow bladders called *Air-cells.* Each Lung-sac is said to consist of about 1700 Air-cells. The walls

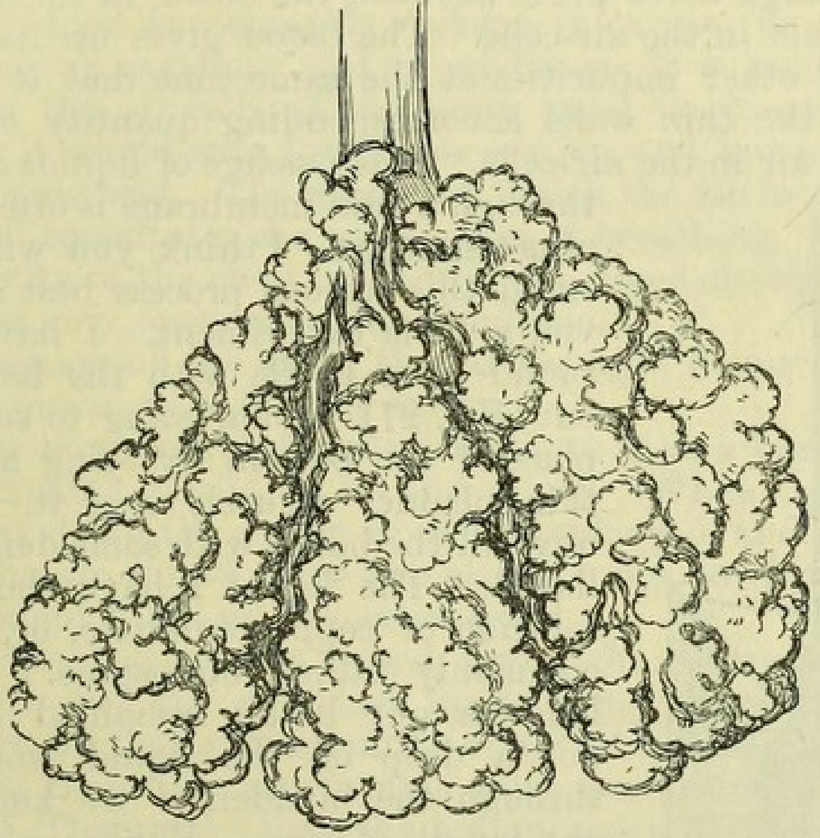


Fig. 26.—Lung-sacs and Bronchial Tube.

of the air-cells are exceedingly thin and delicate, but they are also very elastic.

The lungs, then, consist of millions of these tiny Air-cells, packed closely together, each Air-cell communicating with the Windpipe, and so with the atmosphere in which we live.

Course of the Air in Breathing. When in a quiet, calm posture we generally breathe through the nostrils alone, but during rapid motion we breathe through mouth and nostrils. In both cases the air first passes into the Pharynx, thence through the Larynx or voice-box at the top of the Windpipe, then along the Windpipe, Bronchi, and Bronchial Tubes into the air-cells of the lungs.

THE BLOOD-VESSELS OF THE LUNGS.

The Pulmonary Arteries, bringing dark, impure blood to the lungs, branch out into finer and finer tubes, and at length form a close network of extremely fine capillaries round every air-cell. You may compare this close network of capillaries round the air-cell to the network of string which is sometimes put round a child's india-rubber ball. The walls of the capillaries, as well as the walls of the air-cells, are of the finest and most delicate nature. It is through these delicate walls that the exchange takes place between the blood in the capillaries and the air in the air-cells. The blood gives up its carbonic acid and other impurities at the same time that it sucks up through the thin walls a corresponding quantity of oxygen from the air in the air-cells. This passage of liquids and gases through a thin membrane is often spoken of as **osmosis**. I think you will understand this curious process best if I show you a little experiment. I have here a round glass bottle with the bottom cut out (Fig. 27). I am going to supply the place of the bottom by tying a piece of thin bladder securely over it. I shall next fill the bottle with some dense heavy liquid. The liquid I have chosen is a solution of copper sulphate, or, as it is commonly called, blue-stone. Now, so long as our bottle remained air-tight, not a drop of the liquid would leak through the bladder, if we kept it for any length of time. But see what takes place when I plunge the bottle into this vessel of water. The clear water is becoming tinged with blue, which shows you that some of the copper sulphate is passing out of the bottle, through the bladder, and mingling with it. In other words *osmosis* is taking place. Not only, however, is the dense blue liquid passing out into the water, but the water itself is making its way through the bladder into the bottle. We may say that the blue solution is passing out of the bottle by *ex-osmosis;* and the water is entering into the bottle by *end-osmosis.*

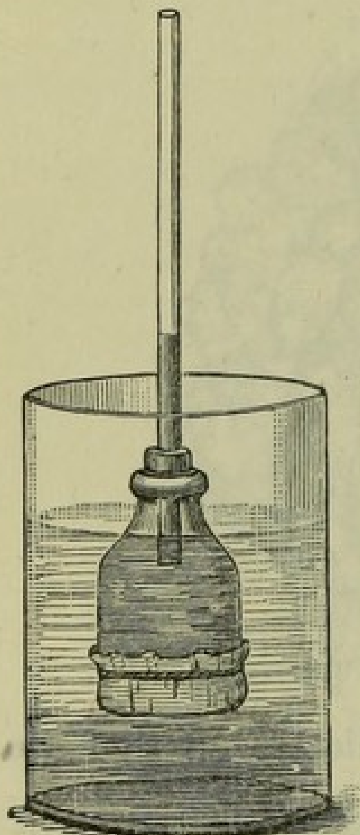


Fig. 27.

It is by *osmosis* that the blood in the capillaries all over the body passes out of those delicate vessels to nourish the tissues. It is by *osmosis* that the various glands secrete their fluids from the blood. It is by *osmosis* that the blood sucks up nourishment from the digested food in the stomach and intestines.

When the blood has been thus purified it is collected up again by the smallest of the Pulmonary Veins and sent by them into the heart by means of the four large Pulmonary Veins which lead from the lungs to the heart.

THE MOVEMENTS OF RESPIRATION.

As the blood is constantly sucking in oxygen in this way, and giving up carbonic acid in exchange, it is evident that the air in the air-cells of the lungs must be constantly renewed, or it would soon lose all its oxygen, and become loaded with carbonic acid. The means by which the air in the lungs is renewed constitutes the mechanism of breathing.

The cavity of the chest or Thorax is a closed air-tight chamber, whose only opening is the Windpipe.

The pressure of the air in the air-passages keeps the lungs stretched out so as to fill this cavity.

Imagine now such a chamber as this to have a kind of false bottom, capable of sliding up and down. When the bottom was pulled down the cavity would be enlarged, and the pressure of the air would cause the elastic lungs to expand to a greater extent to fill up the extra space.

When the bottom was raised again, the cavity would be diminished, and the stretched lungs being diminished also, would give up the extra quantity of air which they took in.

Suppose these two movements were performed at regular intervals. Then every time the bottom was pulled down there would be a rush of air down the air-passages to the lungs, and every time it was raised that same quantity of air would be driven out of the lungs again.

This is exactly what happens during the process of breathing. The bottom or floor of the Thorax is formed, as you know, by a large flat muscle called the Diaphragm.

When this muscle contracts it is pulled down, and the cavity of the chest is enlarged.

When it relaxes, and consequently rises again, that chamber is diminished.

These two up-and-down movements of the Diaphragm are the chief movements in ordinary quiet breathing.

The cavity of the chest, however, is enlarged in another way.

The walls of the Thorax are formed by the ribs, which encircle it, so as to join the breast-bone in front.

The spaces between the ribs are occupied by a set of strong muscles called the Intercostal Muscles.

One set of these Intercostal Muscles contract and pull up the ribs, which are fastened to the Vertebral Column, behind, by a joint. When the ribs are raised they push out the breast-bone in front, and thus the cavity of the chest is enlarged all round.

This enlargement, by means of the side walls, takes place at the same time as the Diaphragm descends, so that the Thorax is enlarged on all sides. An extra quantity of air then rushes into the lungs, and we get an *inspiration*.

Immediately following the inspiration the Diaphragm relaxes and of course rises, and at the same time another set of intercostal muscles begin to pull the ribs and breast-bone down.

These combined movements diminish the cavity of the chest, and consequently the same quantity of air is driven out. This constitutes an *expiration*.

A healthy man in a quiet position breathes about 18 times in a minute; an infant about 40 times, and children about 25 times a minute.

The breathing becomes more rapid during violent exertion, especially during running.

QUESTIONS FOR EXAMINATION.

1. What do you understand by a lever? Explain the three classes of levers.

2. Give instances of the three kinds of levers in the body.

3. Distinguish between perfect and imperfect joints.

4. What are Hinge joints, Ball-and socket joints, and Pivot joints? Give examples of each.

5. What is the difference between the joints at the shoulders and the hips?

6. Explain how the palm of the hand is turned first upwards and then downwards.

7. What are Oxygen, Nitrogen, Carbon, Hydrogen?

8. What is the great property of Oxygen?

9. Describe the composition of pure atmospheric air.

10. What is the use of Nitrogen in the air?

11. What is Carbonic Acid? How is the air naturally cleared of carbonic acid?

12. What do you understand by the oxidizing of the tissues?

13. What are the products of this burning?

14. What is the object of taking food?

15. What do you mean by Alimentation or Digestion?

16. Certain substances are called Food-Stuffs. Explain this.

17. Classify the Food-Stuffs.

18. What are *Albumen*, Casein, Fibrin, Gluten, Legumen?

19. What are Flesh-Formers? Name some of the best flesh-forming foods.

20. What is the use of the Fuel-Foods? Name some kinds of Fuel-Foods.

21. Explain why it is economical to use a mixed diet.

22. Show why alcoholic liquors are not useful as foods.

23. Name the principal organs of digestion.

24. What are the Salivary Glands? Where are they situated? What is their function?

25. What effect has the Saliva on the food? How would you prove this?

26. Where and what is the Pharynx?

27. Explain the use of the Epiglottis.

28. How is the food sent along the Gullet to the Stomach?

29. Give a short description of the Stomach.

30. Explain the movements of the Stomach during digestion.

31. What is the Gastric Juice? What is its function?

32. What are the Intestines? What is the Peritoneum?

33. What is the Gall Bladder? What is its function?

34. Describe the Bile and its uses.

35. Describe the Pancreatic Juice and its uses.

36. Say what you know of the Intestinal Juice.

37. Describe the Villi of the intestines.

38. What are the Lacteals? Where do they end? What work do they accomplish?

39. What is Chyme? Where is it found?

40. What is Chyle? What becomes of most of it?

41. What are Proteid matters?

42. What is the Thoracic Duct?

43. Give a brief description of the Blood.

44. Describe what you would see if you examined a drop of blood under a microscope.

45. Describe fully the Red Corpuscles.

46. Say what you can about the White Corpuscles and their functions.

47. What is the Liquor Sanguinis?

48. Explain clearly what you mean by Fibrin. What is the difference between liquor sanguinis and the serum of the blood?

49. What do you mean by the coagulation of the blood?

50. What causes the blood to coagulate? How can you get this substance from the blood?

51. Describe the chief functions of the blood.

52. What do you understand by the Circulation of the blood? Name the organs of circulation.

53. Give a short description of the Heart.

54. Explain the terms Auricle, Ventricle, Valve, Pericardium.

55. Describe the action of the valves of the heart.

56. What are the *Chordæ Tendinæ*? What are their uses?

57. Name the blood-vessels connected with the heart; say with which part of the heart each is connected.

58. What is the great difference between the Pulmonary circulation and the Greater circulation?

59. Describe the Aorta.

60. Give a short account of the mechanism of the movements of the heart.

61. What do you mean by the beat of the heart?

62. Explain the terms Artery, Vein, Capillary.

63. Note the differences between the Veins and Arteries.

64. Describe the valves of the veins.

65. What is the Pulse? What causes it?

66. How long is a portion of blood between leaving and returning to the heart?

67. How would you stop a bleeding artery? How would the blood flow?

68. Describe the course of a drop of blood through the heart.

69. How many circulations are there? Name them.

70. Describe each.

71. Explain how the oxygen leaves the blood in the capillaries and gets into the tissues.

72. How would you prove the Circulation of the blood?

73. Describe briefly the Lymphatic system.

74. What is "*Lymph?*"

75. Say why Oxygen is constantly required in every part of the system.

76. What do you understand by Respiration?

77. Explain what changes are effected in the blood by respiration.

78. Give the composition of Pure Air. Say how respired air differs from pure air.

79. How would you prove that Carbonic Acid is given off by the lungs?

80. Give a short description of the Lungs.

81. Describe the Air-passages of the lungs.

82. What are the Cilia? Give their uses.

83. What are the Lung-sacs?

84. What course does the air take to reach the air-cells of the lungs?

85. Describe the Blood-vessels of the lungs.

86. Explain how the blood is purified in the lungs.

87. Describe the mechanical movements of Respiration.

HUMAN PHYSIOLOGY.

BOOK III.

THE GENERAL ARRANGEMENT OF THE NERVOUS SYSTEM—THE PROPERTIES OF NERVE—REFLEX ACTION—SENSATION—THE ORGANS AND FUNCTIONS OF TOUCH, TASTE, SMELL, HEARING, AND SIGHT.

THE NERVOUS SYSTEM.

Introduction.—We have studied the human body as a kind of living machine; we have examined its various parts and found each adapted to perform some particular work essential to the well-being of the whole. But beyond all this there is a higher and even more wonderful agency—*the Nervous System*—which directs and governs every part of the body.

The Nervous System, in fact, is to the organs of the body, what steam is to the steam-engine. Shut off the steam and the rods, and wheels, and bands, which a moment before were whirling round, immediately become inert and useless. So with the body, any injury to the Nervous System paralyses some or all of the various organs and eventually produces death. The Nervous System is therefore the highest structure in the organism of the body. Our study of the Nervous System will moreover explain to us how it is that we are able to think, to learn, to understand, and to remember; how it is that we rely upon the five senses of touching, tasting, smelling, hearing, and seeing, to teach us about the objects around us; how it is that we are able to make up our minds to do a certain thing, and at once set about it; how it is that we are capable of loving, hating, fearing, rejoicing, sorrowing, and so on; and lastly, how it is that each organ is guided, directed, and governed by an overseer, which keeps it strictly to its work throughout life.

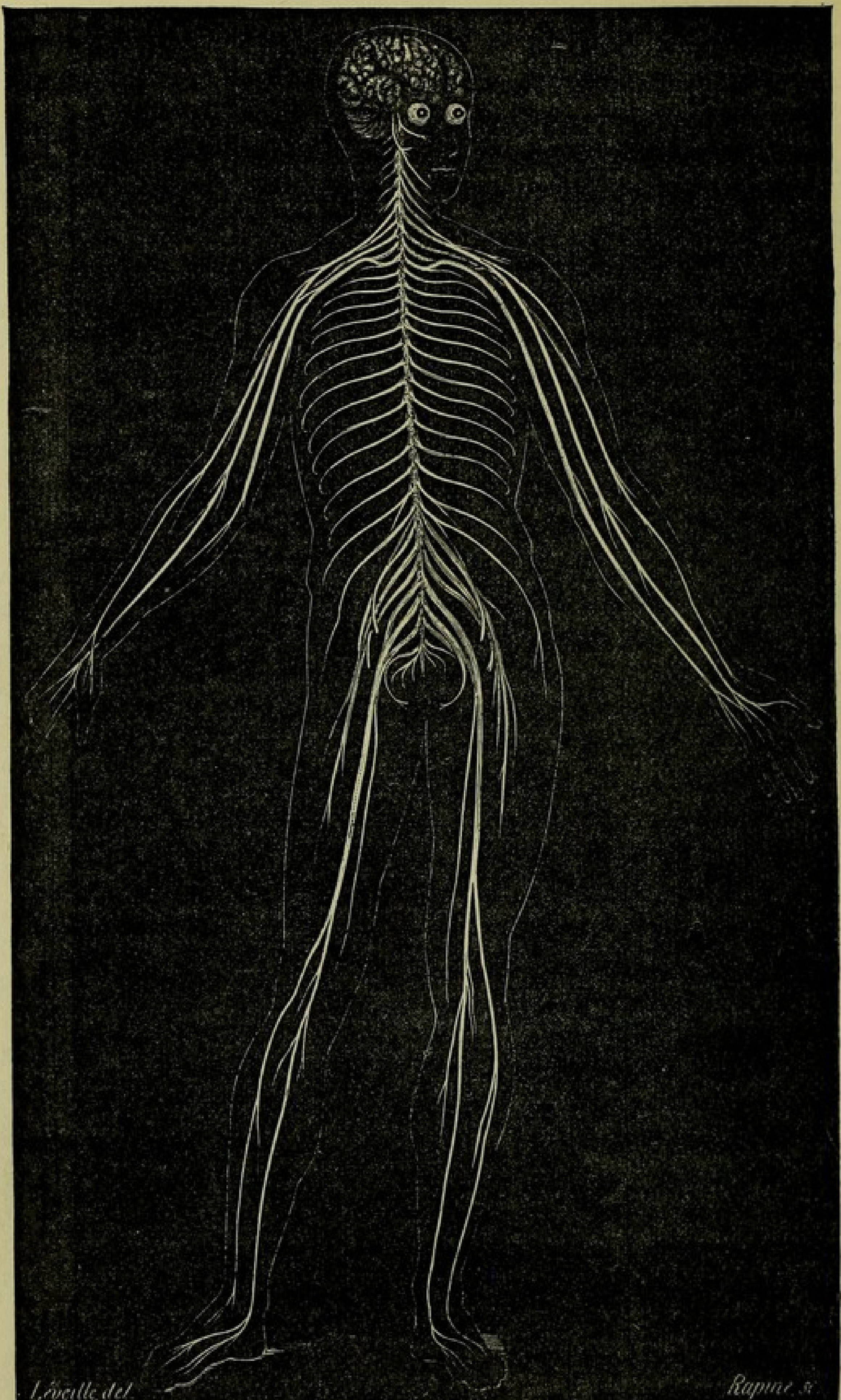


Fig. 1.—Nervous System.

The Nervous System consists of two distinct parts:—

1. The **brain, spinal cord,** and **cerebro-spinal nerves,** which form an unbroken connection between the external parts of the body, the muscles, the sense-organs, and the brain.

2. The **sympathetic system,** which is connected with the organs of digestion, circulation, and respiration.

The Nervous System may be compared to nothing so aptly as to a complete telegraphic system. The brain itself is the head office, and the multitudes of nerve-fibres branching from it to all parts of the body form the telegraph wires. Strange to say, this is not a mere accidental resemblance, for it has been ascertained that the nervous action of the body is, in some mysterious way, closely related to the action of electricity.

By means of these nerves telegraphic messages are constantly being sent to the brain, to inform it of what is going on in various parts of the body. The brain on receiving the intelligence immediately sends back its commands as to what must be done in each case.

Thus if a person says something funny or witty, it seems a very simple and natural thing for us to laugh, and yet it is really a most complex mechanism which produces the laugh. In the first place the nerves of hearing catch up the words and convey them to the brain; and then the brain immediately issues its commands by means of another set of nerves to the muscles of the face, which in obedience contract and give outward expression to the feelings of amusement produced in the brain.

Again, suppose in walking home an offensive smell assailed your nostrils. You would rush past the place to get away from it. Why? Because the nerves of smell have conveyed to the brain the unpleasant sensation, and the brain has immediately issued its orders to the muscles of the legs, causing them to contract and hurry you from the spot.

The same may be said of picking up a red-hot cinder or a hot iron. You know how quickly you drop it, and yet exactly the same process has brought about the apparently simple action. A message has been sent from the hand along the nerves to the brain, and when the brain learns that the hand is being burned it hurries off its orders, *along another set of nerves,* for the hand to drop the burning cinder.

We might multiply these examples to almost any extent, for every voluntary act we perform is carried out under the direction of the nervous system, and by the same process, although it may occupy the most infinitesimal space of time.

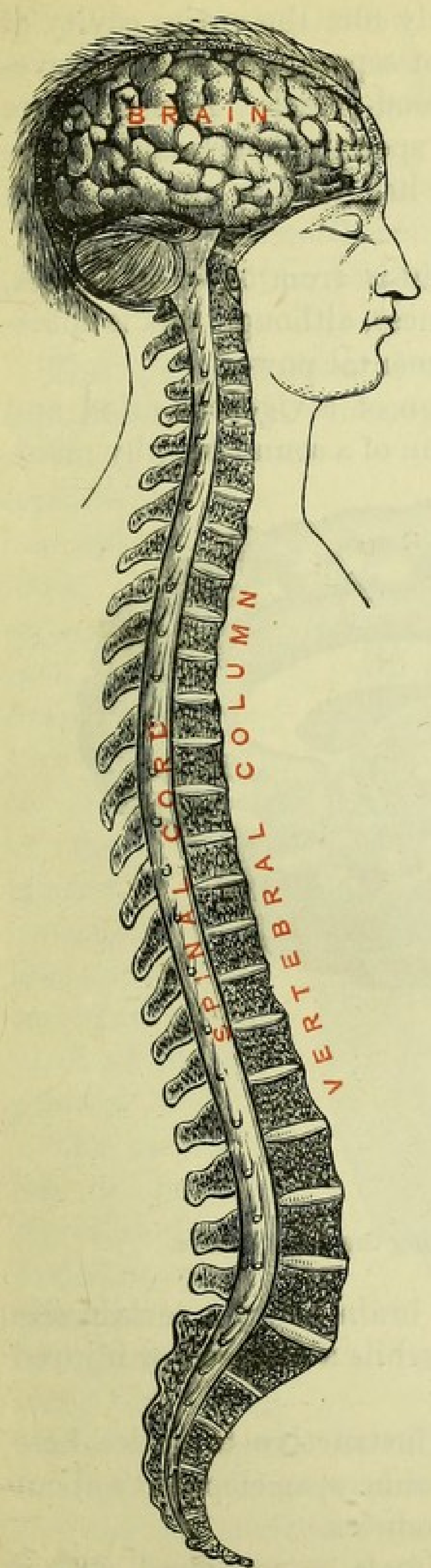
Nerve Tissue is the soft marrow-like substance which forms the principal bulk of the brain, the spinal cord, the sympathetic ganglia, and the nerves. In the brain the inner part is white, and the outer layer a gray or grayish-pink colour; while in the spinal cord the inner part is gray and the outer white. The Nerves themselves consist entirely of the white matter. The gray or grayish-pink matter is more abundantly supplied with blood-vessels than the white.

You no doubt remember that all muscular action is produced by the oxidation or burning up of the substance of the muscles themselves, and just in the same way the brain performs its functions by the oxidation or burning up of its nerve tissue, so that every thought, every sensation, every effort of the will which proceeds from the brain destroys part of its substance.

Nerve Fibres are really so many parts of the brain and spinal cord extending into almost every corner of the body. They have the appearance of microscopic, slender, silvery-white threads.

A certain number of these fibres, enveloped in a gauzy sheath or covering, form what we call a nerve. Some of the nerves are coiled round and among the muscles of the body, and carry to them the commands of the brain, thus causing them to contract. These are called **Motor Nerves.** Others proceed from the various parts of the body to the head-centre and convey to it numerous impressions or sensations. These are the **Sensory Nerves.**

A sensory and a motor nerve generally run side by side, forming one main trunk—each continually sending off numerous branches on all sides.



The only parts of the body which are not supplied with nerves are the hair, the nails, cartilage, and the epidermis of the skin. You know that you can cut your nails or your hair without causing pain, and this could not be if these parts contained nerves.

THE BRAIN AND SPINAL SYSTEM.

The Brain is the organ of the mind, or in other words the seat of sensation, the intellect and memory, the will, the affections, and the emotions. We have already spoken of these powers without giving them any distinct names. Let us now proceed a little further.

(1.) That which enables us to think, learn, understand, and remember, is the *intellect*.

(2.) That which teaches us to observe things around us by one or other of the five senses is *sensation*.

(3.) That which gives us the power of voluntary action is the *will*.

(4.) That which produces in us love, hate, fear, joy, sorrow, &c., is *emotion*.

All these powers then are lodged in the brain.

Fig. 2.—Showing the Cerebro-spinal Nervous Centre. Along the whole length of the Spinal Cord may be seen the roots of the spinal nerves.

This important organ of the body fills the entire cavity of the skull, and consists of a number of separate masses of nerve-matter abundantly supplied with blood-vessels. Each separate mass is the head-centre for some special department of the work of the Nervous System, and has little or no connection with the other parts.

The usual weight of a man's brain is from 52 to 56 ounces, and of a woman's from 44 to 47 ounces, although this is sometimes exceeded in persons of great mental power.

As a rule a large brain is the sign of a vigorous mind and superior faculties, and a healthy brain of a sound healthy mind.

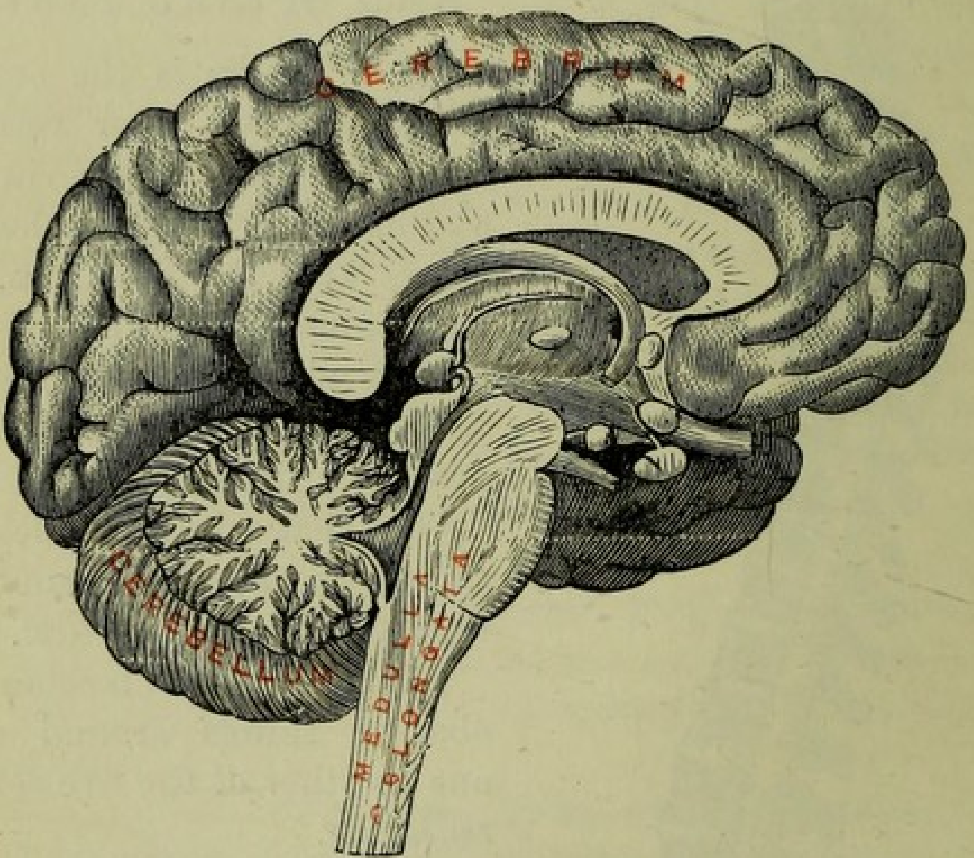


Fig. 3.—Section of the Brain along the great fissure.

On the other hand, a person with a brain below a certain size can never be anything but an idiot, while a diseased or injured brain produces insanity.

It may be interesting as well as instructive to notice here that a horse's brain weighs about 19 ounces, an elephant's about 150 ounces, and a whale's about 80 ounces.

Considering the size of these animals as compared with a man, it is easy to see how much larger in proportion to the body is a man's brain than the brain of any other animal. It is this very fact which raises man above the lower animals.

The three principal masses which compose the brain are:—

1. The Cerebrum or Brain Proper.
2. The Cerebellum or Lesser Brain.
3. The Medulla Oblongata.

The Cerebrum or Brain Proper comprises nearly seven-eighths of the entire mass, and fills the whole of the upper part of the skull. It consists of two hemispheres, almost entirely separated from each other by a deep cleft or fissure from front to back. Each of these hemispheres again consists of three lobes, so that the cerebrum is made up of six distinct parts or lobes.

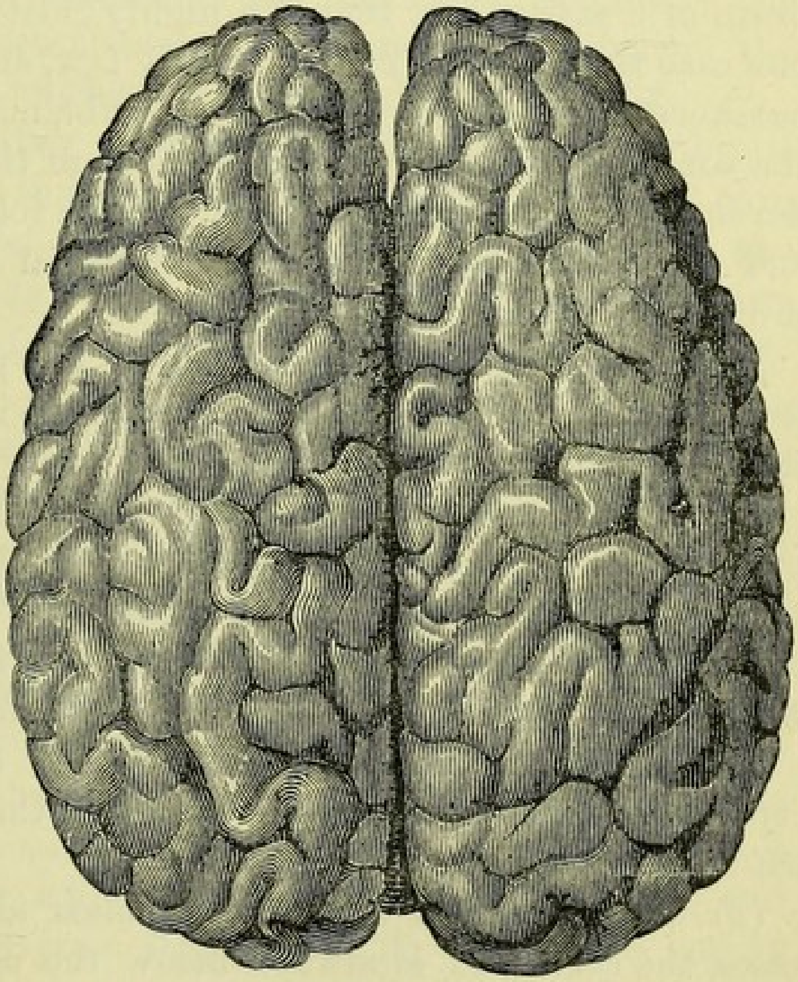


Fig. 4.—Upper Surface of the Brain.

The cerebrum has a peculiar convoluted or folded up appearance, its various folds being separated by deep clefts or fissures. See Fig. 4. Some of these fissures are nearly an inch deep. The object of the folds is probably to increase the surface of the cerebrum.

The interior portion of the brain consists of the white nerve matter spoken of above. This is surrounded on all sides by an outer layer of pinkish-gray nerve substance, about one-eighth of an inch in thickness.

The active powers of the cerebrum are supposed to reside in this outer layer, and these powers are great or small according to the number of folds, the extent of surface, and the thickness of that layer. If the folds of the cerebrum were spread out they would show a surface of about 670 square inches.

It is a peculiar fact that in the lower animals the brain has no folds, and as we pass from these to animals of a higher grade the folds begin to appear. In man they become most numerous, although there is a marked distinction between the brain of a savage and that of a highly cultivated man. In the one case the folds are comparatively few, and the brain in appearance has a somewhat close resemblance to the brains of the common animals. In the other case the folds are highly developed. From this it appears that the folds of the cerebrum and the mental powers of the individual bear a remarkable proportion to each other.

Function of the Cerebrum.—The powers of the intellect, the will, and the emotions are lodged in the cerebrum, as the following facts will prove:—

(1) The other day a young man met with his death at foot-ball. He received a blow on the top of his head, which caused severe injury to the cerebrum. The poor fellow was carried out of the field, and lay for some hours quite unconscious, and without any power of moving. Then he died.

The injury to the cerebrum, you see, had destroyed the *intellect*, the consciousness and therefore the *emotions*, and the *will*.

(2) Some children are born hopeless idiots, and in these cases the cerebrum is always below the usual size. On the other hand, in men of vigorous intellect the cerebrum is always very large. Just as a blacksmith's arm, too, is more muscular than a clerk's, because he uses it more, so is the *cerebrum* of the educated and thinking man greater than that of the ignorant and slothful. The diligent boy who works hard and regularly at his school lessons is developing his *cerebrum*, and laying up a store of *mental power*, which will

not end with his school days, but will act upon his future life.

(3) Sometimes a softening of the cerebrum sets in, and this destroys the intellect, and plunges the sufferer into blank insanity or idiocy.

(4) It is this part of the brain which is affected by intoxicating drinks, and when so affected the person loses his ordinary intelligence, and perhaps consciousness, while, unless he discontinue the use of alcohol, he will soon be the prey of temporary insanity.

Membranes of the Brain and Skull.—Between the outer surface of the cerebrum and the inner surface of the skull are three important membranes, one above another: the **Pia Mater**, the **Arachnoid**, and the **Dura Mater.**

1. **The Pia Mater** is an exceedingly delicate membrane which closely lines the folds of the cerebrum. In this thin membrane the blood-vessels break up before entering the substance of the brain. The entire membrane indeed consists of a close network of blood-vessels held together with connective tissue.

2. **The Arachnoid Membrane** is a thin membrane which loosely surrounds the pia mater, and lies between it and the dura mater, the outermost of the three membranes. It belongs to the class called Serous Membranes, because it secretes a fluid (the serous fluid) for keeping the inner surfaces moist.

3. **The Dura Mater** is the tough, whitish membrane which lines the inner surface of the skull, and forms a loose outer covering for the brain. It is full of arteries and veins carrying blood to and from the brain. Just think for a moment of the care which has been taken in inclosing and protecting the brain from injury, and it will enable you to form some idea of the vast importance of this precious organ. Not only is it shut up completely in a strong bony box, the skull, but the skull itself is covered with the *scalp*, and thatched, so to speak, with hair. Then within the box, as we see, are those three important membranes, the Dura Mater, the Arachnoid Membrane, and the Pia Mater, each forming a complete covering, one within the other.

The Cerebellum or Lesser Brain lies beneath the back part of the cerebrum, from which it is separated by a fold of the dura mater. Its weight is about one-tenth of the entire brain. It consists of two halves or hemispheres, each formed by a number of layers of gray and white nerve matter curiously disposed, so as to present when cut through a peculiar tree-like appearance, as shown in Fig. 3.

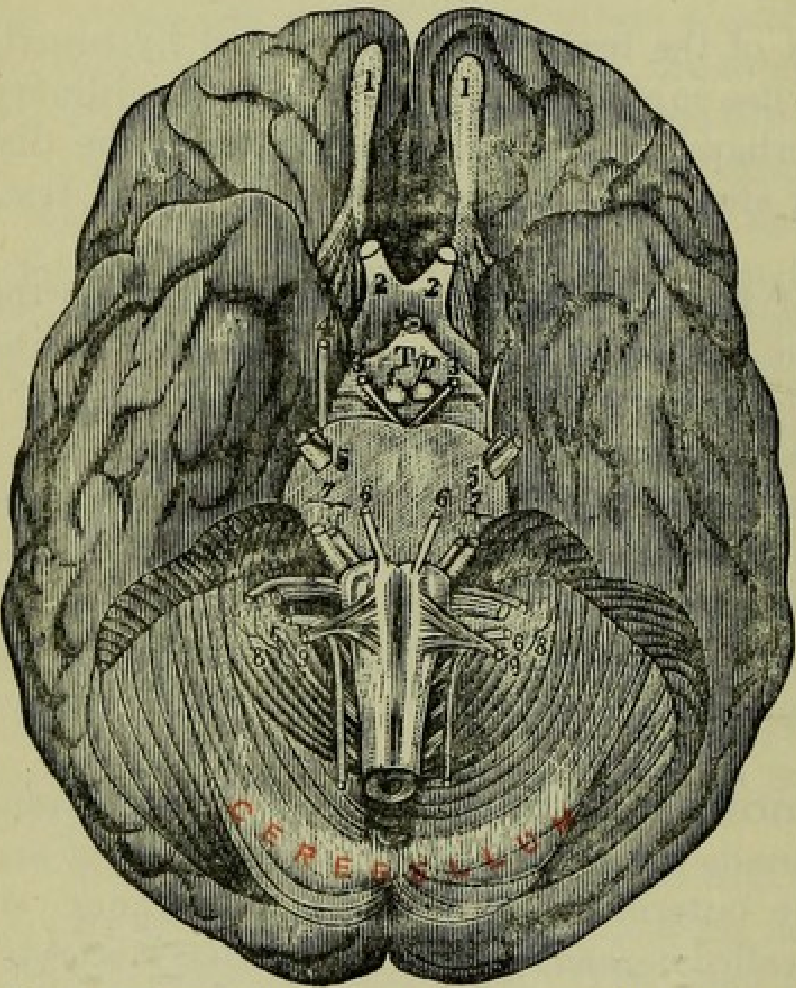


Fig. 5.—Lower Surface of the Brain. The numbers refer to the pairs of nerves. (See Fig. 6.)

The Functions of the Cerebellum are not yet known with certainty. It is supposed to exercise an influence over the muscles of the body so as to regulate their movements. If this supposition be correct the cerebellum acts as a sort of assistant to the *Will*. By the powers of the Will we perform various actions at our pleasure. Some of these actions are the resultant of the combined action of many muscles. The simple act of *standing upright* is, as you know, brought about by the united work of a great many muscles which are all supposed to be held in control by the cerebellum. *Walking*, *Running*, *Speaking*, *Singing* are all actions of a similar kind in which many muscles are brought into play at the same time, and are probably under the control of the cerebellum. At all events, when disease attacks the cerebellum, the sufferer is no longer able to perform such actions as these when he pleases.

In certain diseases of the cerebellum the sufferer spends his time in almost incessantly turning round and round.

The Medulla Oblongata is the thick upper portion of the Spinal Cord which is contained within the cavity of the skull. It is situated immediately under the cerebellum, and forms the link between the brain and the spinal cord. It is nearly an inch and a half long, and from half an inch to three quarters of an inch thick at its upper part. (See Fig. 3.) In this part of the brain, as in the spinal cord, the exterior consists of the white and the interior of the gray nerve matter,

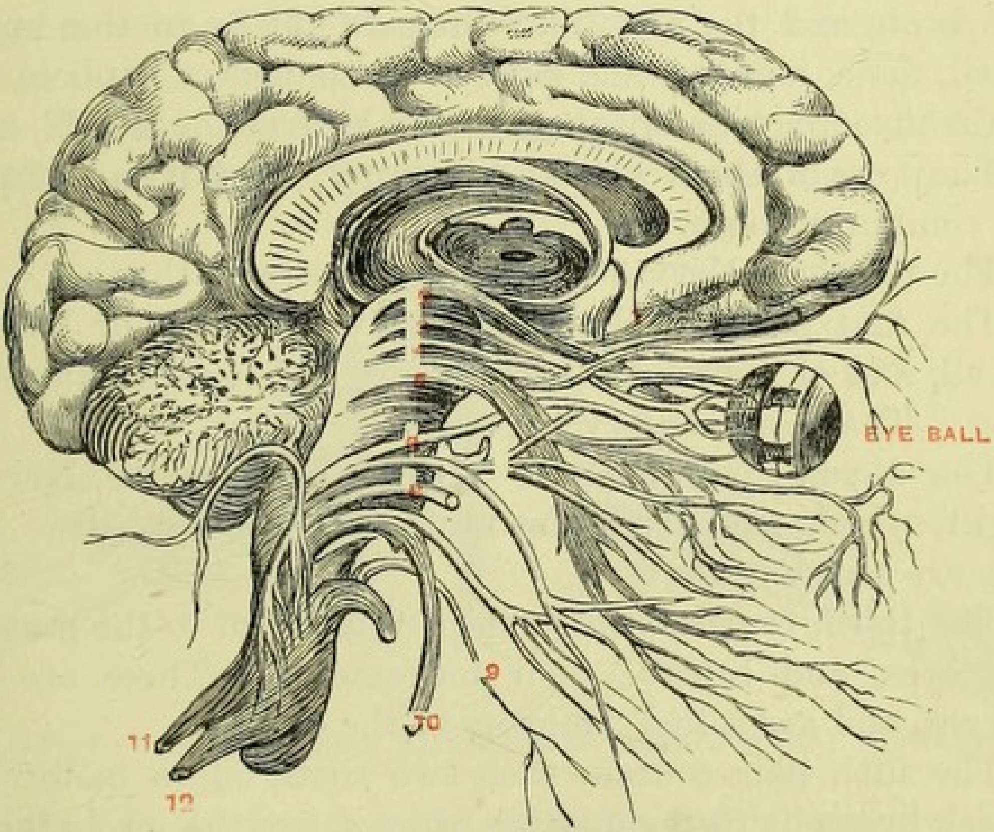


Fig. 6.—Brain and Roots of Cranial Nerves.

although the distinction is not so closely marked as in the spinal cord.

The Functions of the Medulla Oblongata are somewhat like those of the spinal cord, except that they are more closely connected with the vital functions. The *seat of sensation* is believed to be lodged in the upper part of the Medulla Oblongata, while the lower part exercises control over the action of the lungs and the heart. If the upper portion of the Medulla be injured the person loses all *sensation* or *feeling*. He lives and breathes, but feels no pain. Moreover, the connection between the cerebrum and the body is broken, and the man loses all power of Will and voluntary movement.

If, however, the lower portion of the Medulla be injured, the heart and lungs at once cease their work—in other words, circulation and respiration are stopped, and death is the immediate result.

The Cranial or Cerebral Nerves (Nerves of the Brain) consist of twelve pairs of nerves, which proceed from the brain and the medulla oblongata chiefly to the organs of smell, taste, hearing, and sight. These nerves pass out of the brain through nine openings in the base of the skull.

They are of three kinds: **sensory, motor,** and **mixed,** *i.e.* combining both.

The Cerebral Nerves are arranged in pairs thus:—

The first pair are the **Olfactory Nerves** or Nerves of Smell, and of course are spread over the inner surface of the nose. These are sensory nerves.

The second pair are the **Optic Nerves** or Nerves of Sight, which pass from the brain into the eyeballs. These, too, are sensory nerves.

The third, fourth, and sixth pairs proceed to the muscles of the eyes, and control their movements. These are motor nerves, and are called "movers of the eye."

The fifth pair contain each two roots, one a motor nerve, which proceeds to the muscles which move the jaws; the other a sensory nerve, which spreads itself over the front surface of the tongue, and is a nerve of taste.

The seventh pair proceed to the face, where they spread themselves over the facial muscles, and control their movements. These are motor nerves.

The eighth pair are the **Auditory Nerves** or Nerves of Hearing. These of course are spread out over the organs of hearing, and are sensory nerves.

The ninth pair are partly sensory and partly motor. Each nerve contains two roots, one a nerve of taste, which spreads itself over the back part of the tongue; the other a motor nerve, which controls the movements of the muscles engaged in the act of swallowing.

The tenth and eleventh pair are the only cerebral nerves which pass into the trunk.

The tenth is sometimes called the **Wandering Nerve**, and passes to the larynx, the lungs, the heart, the stomach, and the liver. It is partly motor and partly sensory.

The eleventh pair are strictly motor nerves, supplying the muscles of the neck and back.

The twelfth pair are also motor nerves, and are spread out over the muscles of the tongue to control their delicate movements in the act of speech.

The Spinal Cord is the continuation of the medulla oblongata through the vertebral canal. It extends from the base

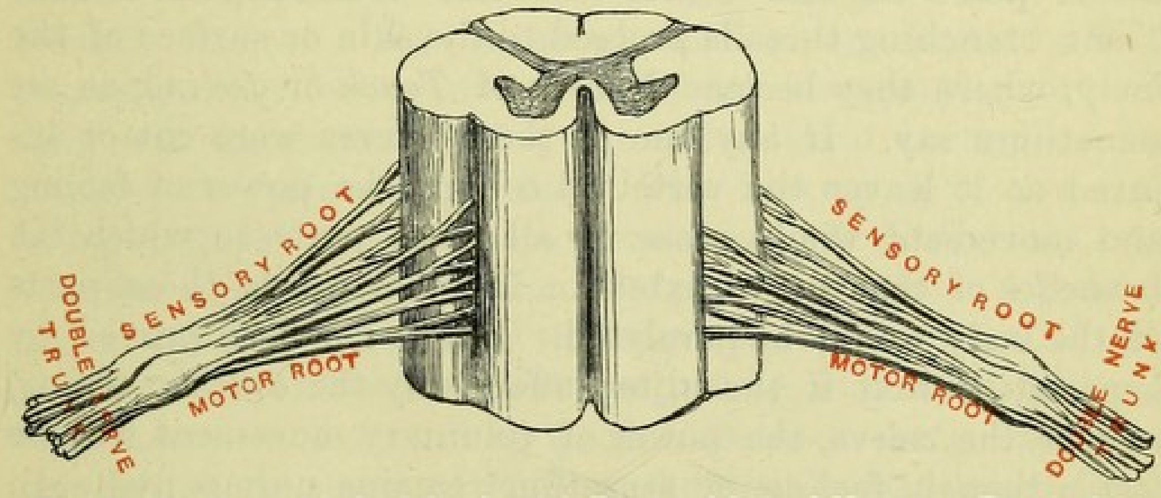


Fig. 7.—Section of Spinal Cord, with Roots of Spinal Nerves. Front view.

of the skull to the first lumbar vertebra, and is thus about 16 or 18 inches in length. It is about the thickness of one's little finger. The opening in the base of the skull through which the Spinal Cord passes is called **Foramen Magnum.** The three membranes (dura mater, arachnoid, and pia mater) envelop the Spinal Cord as well as the brain. Indeed these membranes are simply continuations of those lining the cavity of the skull.

The Spinal Cord, like the brain, consists of the two kinds of nerve matter—white and gray—but their position is reversed, the gray being in the interior and the white outside.

The gray matter of the interior sends off thirty-one pairs of nerves, called Spinal Nerves, which pass out on each side of the vertebral canal by means of small openings between the vertebræ. Each Spinal Nerve contains two roots—one proceeding from the front portion of the Cord, and the other from the hinder portion. These two roots unite and run side by side, forming one silvery thread as they pass between the vertebræ. After leaving the spinal canal each of these nerves branches or splits up again and again into finer and finer threads. These branches of the Spinal Nerves are distributed through the muscles, and terminate on the surface of the body. **Those roots which come from the front part of the Spinal Cord are Motor Nerves.** Their branches spread themselves through the muscles of the body and control their movements. **Those which proceed from the back part of the Cord are the Sensory Nerves.** Their branching threads proceed to the skin or surface of the body, where they become Nerves of *Touch* or *feeling*, as we sometimes say. If any one of these nerves were cut or injured as it leaves the vertebral column the power of feeling and movement would cease in all those parts to which the branches of that nerve extend. In other words, those parts of the body would be paralysed. But it has been proved by experiment that if the injury affect only the *anterior* (front) *root* of the nerve, the power of voluntary movement will be lost although feeling or sensation remains unimpaired. In the case of injury to the *posterior* (hinder) *root*, the reverse happens. Sensation is destroyed, but the muscles still obey the Will. This proves that the front roots of these spinal nerves are *motor;* the hinder roots *sensory.*

Functions of the Spinal Cord.

1. The Spinal Cord receives impressions from various parts of the body by means of its sensory nerves, and conveys them to the brain, where they excite sensation or consciousness.

2. It transmits by means of its motor nerves the commands of the brain to the voluntary muscles, and so causes movement.

3. It acts as a kind of independent centre, receiving impres-

sions from certain parts of the body by means of its sensory nerves, and on its own authority sending back instructions to the muscles by means of its motor nerves, without consulting the brain. **This constitutes what is known as Reflex Action.** In other words, the impulse which is sent up to the Spinal Cord by certain sensory nerves is *reflected* or sent back at once as a motor impulse to the muscles. Because it is *reflected* in this way we speak of it as a *Reflex Action.* Accidents have sometimes happened by which persons have crushed the spinal cord, and thus broken the connection between the brain and the whole of the body below the injured part. You know that under such circumstances all the lower part of the body becomes paralysed. Messages can no longer pass up to the brain to excite the sensation of feeling, and none can come from the brain to produce voluntary movement. That part of the body, therefore, neither feels nor moves. In such a case, although the legs are paralysed and possess neither feeling nor power of voluntary movement, yet they will immediately kick out if irritation be applied by tickling the soles of the feet. The kicking is in this case brought about by the independent action of the Spinal Cord, without any consciousness on the part of the man. Indeed, unless he saw the person tickling his feet he would know nothing of it, for he is incapable of feeling, so that his Will and Consciousness have nothing to do with the kicking. In other words, it is the result of **Reflex Action** in the Spinal Cord. This Reflex Action is perhaps the most important function of the Spinal Cord.

The brain itself, however, gives rise to certain reflex actions quite as distinct as those of the Spinal Cord, the actions taking place independently of the Will and often without the consciousness of the individual. A sudden flash of light may cause the eyes to blink, and we have a reflex action taking place, in which the optic nerves are the sensory and the facial nerves the motor conductors.

The instinctive shrinking from a threatened blow is also the result of a reflex action, and so is the sudden start of the whole body at some loud noise. In all these instances, and in many more besides, the result is brought about without the consciousness of the individual. In the same class of reflex actions we may place sneezing, coughing, and the continual wave-like roll of the stomach and intestines during digestion.

The Spinal Nerves, as we have seen, spring from the *gray nerve matter* in the interior of the cord. The messages, which pass along these nerves to and from the brain, are transmitted through this *gray matter* and not through the white on the outer part of the cord. Indeed, as in the case of the brain, all the active powers are confined to the *gray matter*. The only difference is that this *gray matter* is found on the external parts of the brain, while it forms the internal portion of the cord. The nerves themselves have nothing to do with *sensation* or *will*. They merely carry the messages to and fro; they cannot feel a sensation, they cannot issue a command. Hence we find none of the gray matter in them. They consist entirely of the white.

If both roots of a nerve were permanently injured all those parts of the body to which they sent branches would become paralysed, and would possess neither sensibility to pain nor power of voluntary movement. Indeed those parts might be even cut or burned without causing any pain. The case is practically the same as cutting a telegraph wire, and thus stopping the passage of the electric current.

To a certain degree this is the case when we say a leg or a foot "goes to sleep." The fact is, some of the nerves have been subjected to too much pressure, and their nervous action temporarily stopped. When the pressure is removed and the nerves regain their continuity the muscles of the limb also gradually regain their power of movement.

THE SYMPATHETIC SYSTEM.

The head-centre of the Sympathetic System consists of a chain of ganglia or knots of nerve matter lying along each side of the vertebral column. It is sometimes called the Sympathetic Cord; and the ganglia are connected with each other and with the hinder (sensory) roots of the spinal nerves by a net-work of gray nerve fibre.

From these ganglia nerves proceed to all the internal viscera, forming a complete system by themselves, and acting almost independently of the Cerebro-spinal System. A close net-work of the sympathetic nerves is spread round the muscles of the heart, the lungs, the stomach, and the intestines, as well as round the walls of the minute arteries and capillaries.

The Sympathetic System thus exercises an influence over the greater part of the internal machinery, and to a certain extent controls the functions of digestion, nutrition, circulation, and respiration.

Some of the sympathetic nerves are spread over the coats of the stomach and intestines, and are engaged in regulating the movements of those organs during the process of digestion. Others spread themselves over the walls of the *arteries*, and exercise a peculiar influence on the circulation. The arteries, as you know, have muscular walls of involuntary muscular fibre. In other words, the muscular rings which surround these vessels are not under the control of the *will*. We could not make up our minds to regulate the flow of blood through the arteries, and then proceed to carry out our wish. These vessels, however, *are controlled*, and by the Sympathetic Nerves, which perform their duties by a sort of Reflex Action similar to that which the Spinal Cord performs with the voluntary muscles. Under the influence of these nerves the muscles of the arteries are caused to contract, and thus the vessels themselves are made smaller and the flow of the blood through them is retarded.

Blushing is explained in this way. Certain emotions first spring up in the mind; then their influence is extended to the sympathetic system; and finally the nerve filaments of this system, which surround the walls of the blood-vessels, lose for the time their control over them, and a greater quantity of blood is allowed to pass, thus causing the familiar blush. The same thing happens in the act of turning pale, except that the result of the emotion in this case is to cause the nerves to exercise a more powerful control over the vessels, thereby closing them, and thus shutting off the flow of the blood.

SENSATION.

When discussing the Brain and its work, we learned that one of the chief duties of that organ is to appreciate sensation. We also learned that the chief seat of this power of sensation is probably in the *Medulla Oblongata.*

All nerves, as you know, belong to one or other of two classes—Motor Nerves, which control the action of the muscles of the body; or Sensory Nerves, which carry a variety of impressions from all parts of the body to the brain.

When by means of some sensory nerve the brain receives a certain impression, we become conscious of a feeling or *sensation.*

Sensations may be either common or special. With the former we need not trouble ourselves here. They are very numerous, and may be conveyed by many different nerves. The special sensations, on the contrary, such as sight, smell, taste, hearing, touch, are all the work of separate and distinct nerves.

The exact manner in which we become conscious of the vast multitude of common sensations felt by all is, and will no doubt ever remain, one of the mysteries connected with the human organism. Nevertheless our whole being is in such strict harmony with the bodily sensations that the sum of human happiness or misery to a great extent depends upon them. Some sensations, such as those of faintness, restlessness, despondency, cheerfulness, seem to spring up within ourselves in some mysterious way without any outward or apparent cause. The great majority of sensations, however, are produced by some stimulus or outward agency.

Sensations may be either pleasurable or painful. Indeed the same agent may cause pleasant and painful sensations according to its degree of intensity. We all know the pleasant sensation of spreading out the hands to the blazing fire on a cold night. Hold the hands too close to the fire, however, and the sensation of pleasure is changed to one of pain, and the hand is burned.

It is important to remember that the brain is the seat of sensation. In other words, **although we may feel a certain pain in the hand, the foot, or any particular part of the body, yet the sensation takes place, not in those parts, but in the brain.** In the same way the sensation of sight does not take place in the eye, but in the brain itself; that of smell, not in the nose, but in the brain; and so on.

From this it is evident that all sensations are produced by *three* distinct organisms:—

1. An organ specially adapted to receive the stimulus from the outer physical agent.

2. A sensory nerve to convey the impression from that organ to the brain.

3. The brain itself to convert the impression into an actual sensation.

Take, for instance, the sense of hearing. The waves of sound passing through the air form the external physical agent, and the ear is the organ specially adapted to receive impressions from it. The auditory nerve forms the connection between this organ and the brain, where the sensation actually takes place.

The same with the sensation of sight, and indeed with all sensations.

Any injury to either of these three—the organ of sense, the sensory nerve, or the brain itself—at once impairs or destroys sensation.

THE SENSES.

We are sometimes said to possess five senses, viz.: the senses of touch, taste, smell, hearing, and sight.

This is not quite correct, however. There is another very important sense termed the **Muscular Sense,** which enables us to judge the weight of different bodies according to the muscular effort required to lift or hold them. This sense becomes so highly developed with use, that shopkeepers and others who sell various articles by weight will often tell you the weight of a body by simply balancing it in their hands.

TOUCH.

The sense of touch is the most widely extended of all the senses, and perhaps the simplest. It has its seat in the skin all over the body and in the walls of the mouth and nasal passages. All parts of the body, however, do not possess this sense in an equal degree. We may ascertain the sensitiveness of the skin in different parts by applying the two blunted points of a pair of compasses simultaneously. It is very clear that where the sense of touch is least delicate we must separate the legs of the compasses farthest in order to feel the prick from both points. On the other hand, the more delicate the sense of touch the closer may the points be brought together. If in this way we gently prick the tip of the tongue we shall feel both points of the compasses distinctly when they are only one-twentyfourth of an inch apart. The tips of the fingers give a double sensation when the points are one-twelfth of an inch apart; the edge of the lips at one-sixth of an inch. On the cheek the points may be one inch apart, and in the middle of the back three inches, and yet produce only one sensation. The sense of touch is thus most delicate on the tip of the tongue, the tips of the fingers, and the edge of the lips, and least delicate in the middle of the back.

The sense of touch conveys to us, besides the feeling of contact, an idea of the relative temperature of bodies.

By the term *relative* temperature we mean the temperature of one body compared with another. Thus suppose we plunge one hand into a basin of hot water and the other into cold, and immediately afterwards both of them into tepid or slightly warm water. The hand which was first placed in the hot water feels the tepid water cold by comparison, and the other, which was taken out of cold water, finds the same tepid water warm also by comparison. In the same way, on a very cold day, suppose two persons met in the entrance hall of a house, one coming from the street, the other from the warm fireside of an adjoining room. The one who had left the biting cold winds would find the temperature of the air of the hall warm by comparison, but the same air would be cold to him who had left the warm room.

All parts of the skin and mucous membranes are not equally sensitive to differences of temperature. The tongue, the lips, and the palmar surfaces of the fingers, although most delicate in appreciating the ordinary sense of contact, are not so sensitive to heat as other parts.

The parts most sensitive to heat are the cheeks, the eyelids, and the elbows. You have all seen your mother hold the flat-iron to her cheek, to find whether it is hot enough or too hot for her linen. In giving a hot bath it is usual to test the heat of the water by holding the elbow in it.

The mucous membranes of the gullet and stomach are more sensitive to heat than those of the mouth. This should show the folly of swallowing our food too hot; for even though it may not feel hot in the mouth, yet it cannot pass into those more delicate organs without causing injury.

You no doubt remember that the skin consists essentially of an inner layer of fibrous tissue, closely intersected with minute blood-vessels and the terminating fibres of the nerves; and that above this layer is a thin horny membrane containing neither nerves nor blood-vessels, but serving to protect the more delicate layer beneath.

The deep inner layer is the **dermis**; the outer insensitive layer the **epidermis.**

The Dermis, however, is not a mere flat layer. Its surface is raised up into myriads of tiny hillocks, set close side by side, and forming row upon row of ridges, separated by intervening furrows or grooves. These ridges and furrows may be seen on the fingers and the palm of the hand.

The tiny elevations are termed the **papillæ.** In the centre of each papilla is the final termination of a sensory nerve, and a tiny artery and vein finer than the finest hair. Where the sense of touch is most delicate the papilla is found to contain a small oval body called the **tactile corpuscle.**

Professor Huxley considers that this Tactile Corpuscle is a swelling or enlargement of the **Neurilemma**—the delicate sheath which envelopes the nerve. It is said that there are more than 2400 papillæ to the square inch on the finger tips.

The Epidermis or outer integument overlies the dermis and dips down between the papillæ so as to fill up the furrows between the ridges. In this way the points of the papillæ seem to stand out so as to be near the surface of the skin.

One of the principal objects of the epidermis is to lessen or modify the sensitiveness of the true skin. If the epidermis be removed, as it is when some part of the skin is blistered, the slightest touch on the delicate under layer causes smarting pain. From this it is evident that if the true skin were not protected by the epidermis, every time we handled anything we should experience an exquisite feeling of pain, and not simply the delicate sense of touch.

The epidermis is in fact the medium between the nerve-fibres of the dermis on the one hand and the physical agent on the other.

It is important to remember that the epidermis varies in thickness in different parts of the skin. It is thus particularly thin at the tips of the fingers and on the surface of the lips, where feeling or touch is very acute. On the other hand, it is very thick on the palm of the hand, which is employed in grasping, and requires a stout protecting covering. It is still more gross on the sole of the foot, which has to sustain the weight of the body.

The sense of touch seems to become more delicately acute in blind persons than in others, and is an evidence of the merciful dispensations of God. You have of course all seen a blind man sitting by the road-side reading. He accomplishes his task by feeling the letters which are printed in a raised form on the leaves of his book. By means of their delicate sense of touch, blind people are taught a large variety of occupations, including mat-making, basket-making, knitting, sewing, &c.

You all know the story of the little blind girl who lost the use of her hands by a long illness, and while grieving that now her Bible would be a closed book to her, raised it to her lips to kiss it, and to her inexpressible joy found that she could read the letters with her lips.

TASTE.

The sense of taste is lodged in the tongue, especially in the hinder part, and in the back of the palate. The tongue is, however, the principal organ of taste. It is entirely made up of muscular substance, which enables it to perform all the movements required in the work of mastication.

Like the other parts of the body the tongue has two coverings—a deep sensitive layer and an upper or surface layer. The deep layer is raised up like the dermis of the skin into tiny hillocks or papillæ. The papillæ of the tongue, however, are larger than those of the skin even in its most sensitive parts. These papillæ are not all of the same shape or size. Those on the front of the tongue are long, pointed, and extremely small. They are known as the *Filiform Papillæ*, and are very numerous.

In addition to these there is a great number of larger papillæ, in shape something like a mushroom, and hence called *Fungiform Papillæ.* If you drop a little vinegar on your own tongue, and then look at it in the looking-glass, you will be able to see these *Fungiform Papillæ* swell out under the action of the acid.

Near the root of the tongue there are a few very large *papillæ* of a different kind from either of the former. They are arranged in the form of the letter V with the point of the V towards the back. They are called *Circumvallate Papillæ*, from a Latin word which means "surrounded by a wall." These papillæ are of a very peculiar form, for, just as their name denotes, each one is surrounded by a little wall, and in the space or hollow between the papilla and its surrounding wall, a number of tiny, conical papillæ, known as the *Taste Cones,* are found. The exact work of these tiny papillæ is not understood with certainty.

Above the deep under layer of the skin of the tongue, is an outer layer—the **epithelium**, which becomes coated with a thick whitish slime when the stomach is out of order. We generally speak of the tongue at such a time as being furred.

The papillæ of the tongue are abundantly supplied with tiny nerve fibrils from two great nerve trunks leading from the brain, viz.: the fifth and the ninth pairs of cerebral nerves. These are the nerves of taste. The branches of the fifth pair of nerves are spread over the front and sides of the tongue only; those from the ninth pair over the hinder part of the tongue, and the adjacent part of the palate.

In addition, however, to these sensory nerves the tongue receives numerous branches from a delicate motor nerve, which spread through its muscular substance and control its movements. The nerves of taste receive their impressions of various flavours by a rather complicated arrangement. The substance placed in the mouth is first bathed in saliva, and partially dissolved, and it is only in a somewhat dissolved state that its particles can be brought into close contact with the surface of the tongue, and so with the end of the nerves of taste. The tongue itself assists in bringing the food into contact with the nerves by pressing it against the hollow roof of the mouth, and then the sense of taste is produced in its full force.

Of course in this as in the other senses the nerves receive the impression, and convey it to the brain, where it is perceived, and gives rise to the sensation of taste.

It is a peculiar fact that these impressions are assisted very materially by the sense of smell. You may easily prove this for yourselves by closing the nostrils tightly, so as to breathe through the mouth only, and then placing in the mouth something possessing a strong flavour. You will find it almost impossible to taste it while the nostrils are closed; but as soon as the nasal passages are opened again its flavour will be at once recognized. It is even said that an onion might be easily taken for an apple if both eyes and nostrils were kept closed.

You have perhaps seen your mother pinch your little brother's nose, when she had to force medicine down his throat. This was to prevent him from tasting it.

This sense is of great value to all animals in directing them in choosing the kind of food suitable to their necessities. Most animals, thanks to this sense, at once reject substances which would be hurtful to them; while, at the same time, animals adapted for one kind of food will reject all others for it.

As a rule those substances whose flavour is pleasing to us are good and wholesome articles of food; but neither the rule nor the opposite of it is without exception.

SMELL.

Odours.—Certain bodies have the property of constantly giving off to the atmosphere extremely minute particles of their substance. These tiny particles, although much too small to be perceived by either the organs of touch or taste, are readily appreciated by the organ of smell, and produce what we call an *odour*.

As a rule gaseous bodies give off the most powerful odours, because their particles are more readily separated. Many liquids, however, and solid bodies possess this property to a greater or less extent.

You may perhaps form some idea of the extreme minuteness of the particles given off by odoriferous bodies from the fact that although such bodies are constantly losing some of their substance, they do not seem to lose any weight.

The most remarkable instance of this is musk. It has been ascertained that one grain of musk may be exposed in a small saucer to the air of a well-ventilated room for a great many years without showing any appreciable difference in weight, although during the whole period the air of the room has been laden with the odour.

The air conveys various odours to a great distance. Sailors tell us that they can smell the delicious odours of the Spice Islands for miles; and we know that a dog will scent his master's approach when he is a great distance off.

We cannot perceive an odour unless the minute particles floating in the air come into actual contact with the nerve of smell. The sense of smell thus bears some similarity to those of touch and taste.

The Organ of Smell.—The sense of smell is lodged in the delicate membrane which lines the nasal cavities. Over the surface of this membrane the minute fibrils of the olfactory or first pair of nerves are distributed. These nerves enter the nasal cavities from the brain through a multitude of tiny holes in a flat portion of the **ethmoid bone**, which forms the floor of the cranium.

Man, in common with all air-breathing animals, has two nasal cavities. The cavities communicate with the outer air by two nostrils opening in the front of the face, while two other passages—the **posterior nares**—open into the pharynx behind. An upright bony partition (the Vomer Bone) separates the two cavities, and to increase the length of the air-passages two light spongy bones, one on each side, form narrow winding channels. The mucous membrane, with the branches of the olfactory nerve, lines the dividing wall as well as the inner surfaces of these winding passages in the spongy bones. Below all these bones are the Lower Twisted Bones, which may be roughly said to divide the Olfactory Chamber above from the ordinary air-passages. These passages, like the Olfactory Chambers, are lined with mucous membrane, but they do not receive any fibrils from the olfactory nerve. They are covered with a delicate fringe like the pile of velvet, which is constantly waving to and fro. You of course remember the "**cilia**" in the air-passages of the lungs. These mucous membranes are kept moist by a fluid which they secrete, and the waving fringe seems to be intended to prevent too great an accumulation of this fluid in the nasal passages.

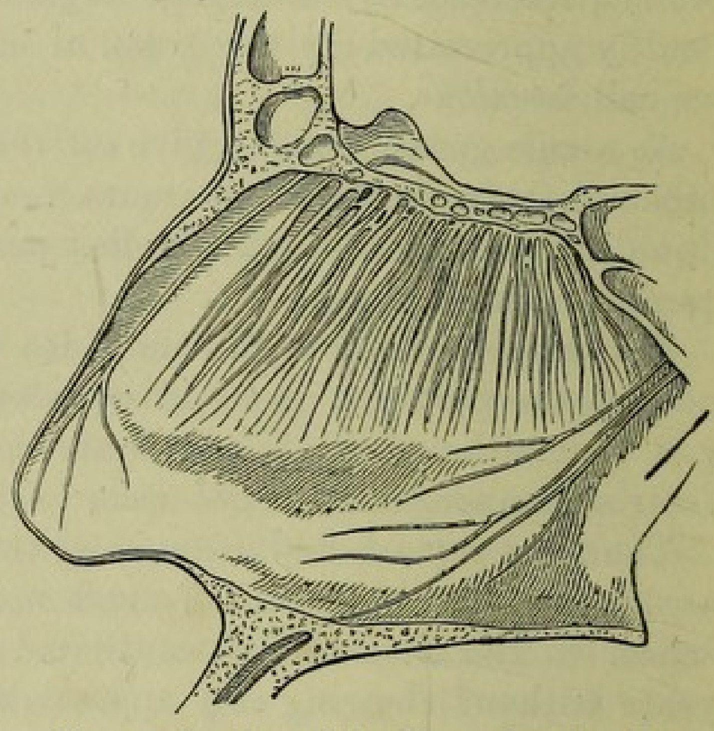


Fig. 8.—Section of the Nose, showing the branches of the Olfactory Nerve.

During an ordinary inspiration the air simply flows along the lower nasal passages into the pharynx, scarcely entering the olfactory chamber at all. This is why, when we wish to perceive a faint odour, we sniff up the air sharply. By doing so we cause a rush of air to the higher olfactory chamber, where some of the floating particles of odorous matter come into contact with the nerves of smell.

One of the most essential conditions of the sense of smell is that the nasal passages be kept well bathed in the fluid secreted by the lining membrane.

At the commencement of a cold in the head this membrane becomes dry and swollen, and the sense of smell is greatly diminished.

There is great diversity in the development of the sense of smell in different individuals. It is generally most acute in savage races. Many animals are more highly endowed with this sense than man; and it has been thought on good authority that the delicacy of smell in these animals depends largely upon the length of the nasal cavities. Deer, wild horses, and antelopes probably surpass all other animals in this respect.

HEARING.

Noises and Sounds.—All sounds are divided into *two* classes—musical sounds and noises, although in many cases it is extremely difficult to distinguish between the two. Both are produced by the vibration of some body in the air. The body communicates these vibrations to the surrounding air, which carries forward a series of waves in all directions.

You will understand these air-waves better if you throw a stone into a pool of water, and watch the result. You will see a series of tiny circular ripples gradually spread themselves over the surface of the water from the spot where the stone fell. This exactly represents the waves of sound caused by the vibration of bodies in the air. These air-waves travel with wonderful rapidity. The usual velocity of sound is 1118 feet a second. Sound, however, travels more swiftly in warm air than in cold, and its speed also depends upon the direction of the wind.

No sound could be produced without air, and where the atmosphere is very rare and thin the sounds that are produced are weak and thin also. Thus if all the air be exhausted from the glass receiver of an air-pump, and a bell be set in motion inside, you may see the tongue strike the bell and yet you will hear no sound. As soon as the air is allowed to re-enter the receiver, however, you will hear the bell distinctly. Persons up in a balloon, or on the side of a high mountain, where the atmosphere is rarer than below, may shout at the top of their voices, and yet it will sound to them little more than a whisper.

The organ of hearing is lodged in the thick inner bones forming the base of the skull.

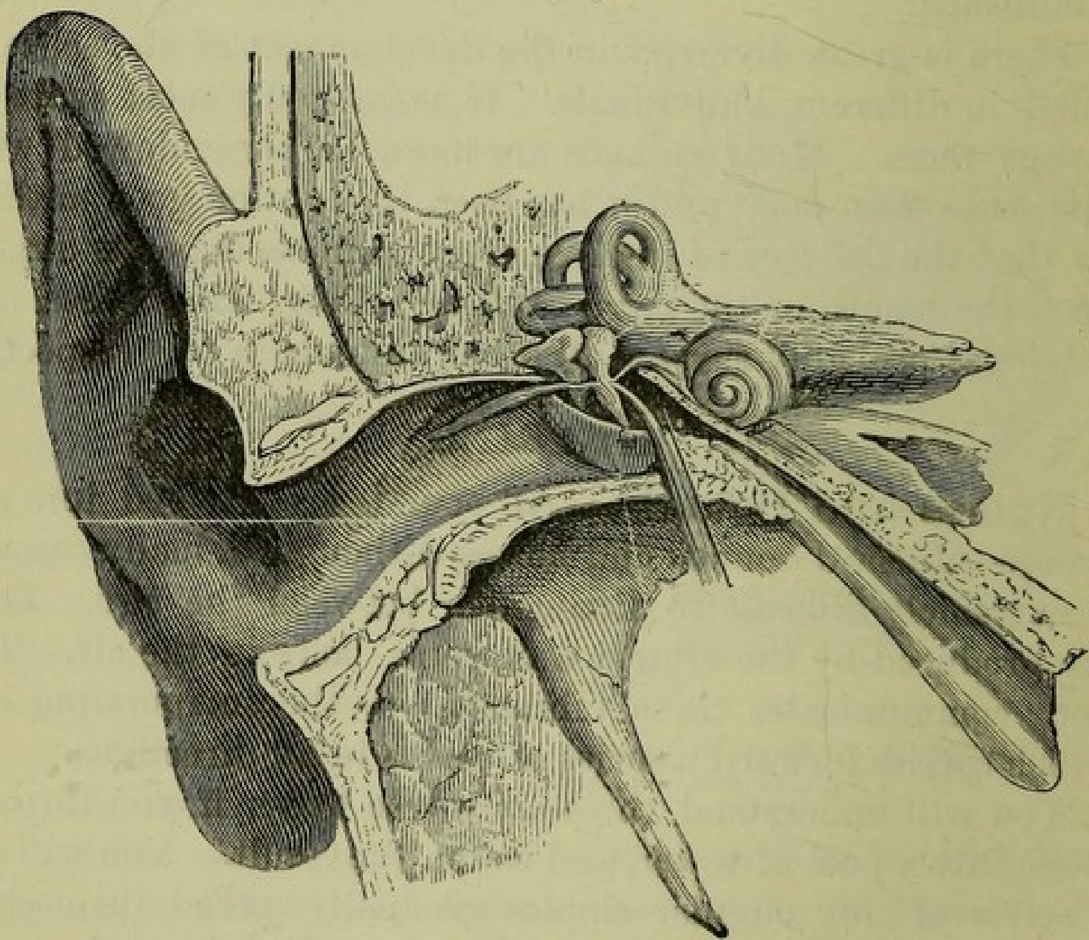


Fig. 9.—Section showing the different parts of the Ear.

The ear is divided into three parts—the Outer, the Middle, and the Inner Ear.

The Outer Ear consists of a broad plate of cartilage shaped somewhat like a shell, and commonly called *the ear*, and leading from it a tube about an inch long, called the **auditory canal.**

A delicate skin is tightly stretched over the outer shell-like plate and the auditory canal. The object of the curious modellings of the outer ear are not thoroughly understood.

It is supposed that the hollows and ridges direct the course of the waves of sound towards the entrance of the auditory canal.

The outer ear is very largely developed in animals of a timorous nature, so as to enable them to catch the faintest sounds. Among such animals we may mention the hare, the deer, and the bat, &c.

The first part of the auditory canal is formed of cartilage; but the inner part has bony walls. This inner portion of the tube is in fact hollowed out in the thick part of the temporal bone. The canal bends slightly forward from the outer ear, and its inner walls are covered with fine hairs, which prevent anything from entering the passage. Wax-glands also are studded over the surface of the canal, and these glands secrete the ear-wax for moistening its walls. The inner end of the passage is completely closed by a membrane stretched somewhat tightly across it. This membrane is known as the **Membrane of the Drum of the Ear.** It resembles the parchment stretched across the end of a drum. It is thin and elastic, but may be easily broken by a blow or by pushing anything into the ear. If once broken this delicate membrane cannot be repaired, and deafness ensues.

The Middle Ear is a small cavity hollowed out in the temporal bone, between the **membrane of the drum** and the **inner ear.** This cavity is the **Drum of the Ear.** (See Fig. 10.)

On the bony side of the chamber, opposite the membrane of the drum, are two tiny windows, one of an oval shape, the other round. Each of these little windows is closed by a delicate membrane.

The most curious feature of the drum is the string of tiny bones which stretch across it. The first of these—the **malleus** or **hammer-bone**—is attached by its long handle to the middle of the membrane of the drum.

The rounded head of this hammer-bone fits into another little bone, called the **anvil-bone** from its resemblance to a blacksmith's anvil.

At the end of the anvil-bone is a curious bone, shaped something like a horseman's stirrup, and hence called the **stirrup-**

bone. The part resembling the foot-plate of the stirrup is oval in shape, and exactly fits into the little oval window in the opposite wall of the chamber. It is firmly fastened by a small muscle to the membrane which stretches across the window.

In the floor of the chamber of the drum is the opening of a passage called the **Eustachian tube.** This tube is about an inch and a half long, and leads into the pharynx. By this

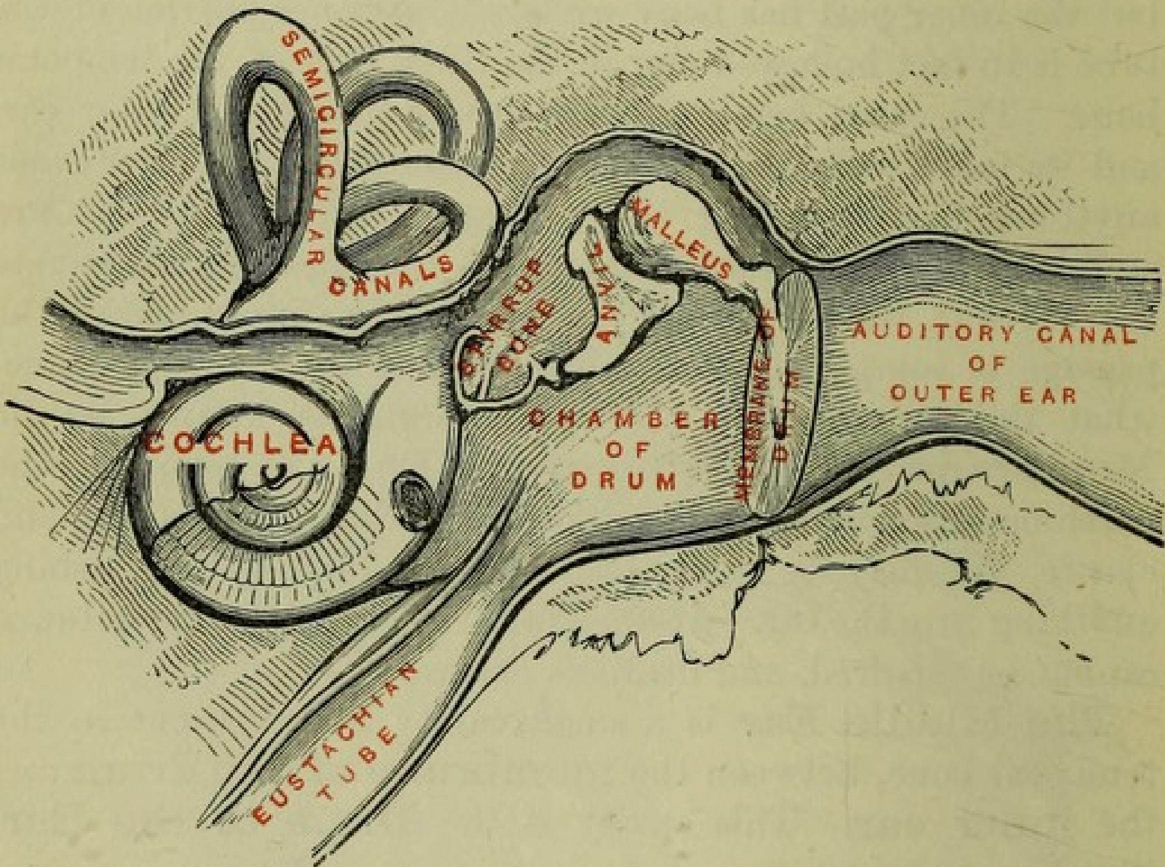


Fig. 10.—Showing the internal mechanism of the Ear—greatly enlarged.

arrangement the air inclosed in the drum of the ear is kept at the same pressure as the outer air.

Let us now see how this marvellous mechanism of the ear is affected by the external agent of sound—the air-waves. As these air-waves strike upon the stretched membrane of the drum, they cause it to vibrate in harmony with their own vibrations. At every vibration of the membrane the head of the malleus is made to strike upon the anvil-bone. You remember that the long handle of the malleus bone is firmly fastened to the middle of the membrane on the inner side. The blow of the malleus drives the anvil-bone forward, and as the stirrup-bone is at the end of the anvil-bone this goes forward as well. The result is that the oval foot-plate of the stirrup-bone is pushed in and drawn out of the oval window on the inner wall of the chamber at every movement of the membrane of the drum.

The Inner Ear is that portion of the organ of hearing which perceives the impression of sound, and carries that impression directly to the brain, where it gives rise to the sensation of hearing. It forms one of the most delicate and complex pieces of mechanism in the whole human system.

The inner ear consists of *three* distinct portions — **the vestibule, the semicircular canals**, and **the cochlea or snail's shell.** All these are variously-shaped chambers hollowed out in the solid bone. (See Fig. 10.)

The Vestibule is a chamber of a somewhat oval shape occupying the middle portion of the inner ear. It is on the inner side of the **tympanum** or **drum**, and immediately opposite the membrane of the drum. In the bony wall which separates it from the drum are the two little windows mentioned above—the oval window and the round window.

From one side of this vestibule or central hall the three semicircular canals pass off, and from the other side the cochlea or snail's shell.

The three **Semicircular Canals** are simply bony tubes which pass out from the vestibule, and after bending round something like a hoop return again to the vestibule. Two of these semicircular canals are vertical, the third is horizontal. At one end of each canal is a swelling or enlargement of the tube. This swelling is called the **ampulla.**

The Cochlea or snail's shell is another chamber hollowed out in the solid bone. In shape it is almost identical with the interior of a snail's shell. There is a central pillar, and a long spiral canal winds two and a half times round it. You will understand this better by taking an ordinary snail's shell and chipping away all the outer covering. When that is done you will see the central pillar with its spiral tube leading round it. This will give you a tolerably clear notion of the cochlea.

The long spiral tube of the cochlea, however, is divided into two passages by a thin long partition which runs through the entire length. The two passages communicate with each other at the top of the spiral, but have no connection elsewhere.

At the lower end of the spiral one of these passages opens directly into the vestibule, the other leads to the chamber of the drum, and is separated from it by the little round window in the bony wall which we described above.

You now see that the various chambers and passages of the Inner Ear communicate by two small openings with the chamber of the drum. The oval window is in the wall which separates the drum from the vestibule, and has the plate of the stirrup-bone closing it. The round window separates one of the passages of the cochlea from the drum. Both these windows are closed by membranes.

It is important also to remember that there is a continuous connection between all the passages of the Inner Ear. Thus from the vestibule the way is quite open along the three semicircular canals on the one side, and the spiral tube of the cochlea on the other. The whole system of passages is known as the **Labyrinth.**

These tubes and chambers of the Inner Ear inclose and protect a delicate membranous bag of exactly the same shape as themselves. This bag, which is about half the size of the bony passages in which it is placed, is called the **Membranous Labyrinth.** Between the bony walls of the passages and the membranous bag inside is a clear thin fluid called the **perilymph.**

The membranous bag itself contains a similar fluid called the **endolymph,** and in the fluid some tiny particles like sand. These particles are called **otoconia.** Every movement of the fluid itself throws these minute grains of sand from side to side.

The **Auditory Nerve** or Nerve of *Hearing* passes from the brain through a passage in the solid bone of the skull, to the inner ear. Its fibrils spread themselves at last over the inner walls of the membranous labyrinth in two branches—one going to the vestibule and the ampullæ at the ends of the semicircular canals, the other branch leading to the cochlea.

On the central wall of the cochlea, or rather on the membrane belonging to it, rest an immense number of these minute fibrils side by side. They are known as the **fibres of Corti**, and the microscope shows us more than three thousand of them.

Each fibre is composed of two branches joined at an angle. They have somewhat the appearance of the key-board of a musical instrument.

It is supposed, by the most distinguished writers on physiology, that the cochlea, by means of these fibres of Corti, is the musical portion of the organ of hearing. In other words, the function of the cochlea is to receive and appreciate musical sounds.

The Mechanism of Hearing.—We have already seen how waves of sound are carried by the air till they strike upon the membrane of the drum; and that this membrane, being thus set vibrating, communicates the motion to the little bones of the middle ear—the hammer-bone, the anvil-bone, and the stirrup-bone. You of course remember that the foot-plate of the stirrup-bone fits into the little oval window in the opposite wall, and that behind that window is the vestibule of the inner ear.

You know too that this chamber, as well as the passages leading from it, contains a watery fluid, the perilymph.

Every time the stirrup-bone is pushed in and drawn out of the oval window this watery fluid the perilymph is set in motion, more or less violently according to the intensity of the sound. The membranous labyrinth, however, occupies the central portion of the vestibule and the passages leading from it. When, therefore, the perilymph is shaken it communicates the motion to the endolymph contained in the inner membranous bag.

The remainder of this marvellous and complex mechanism is performed by the endolymph and the tiny grains of sand (otoconia) dashing against the sides of the membranous bag and so striking the ends of the auditory nerves. These nerves flash the impression they have received to the Brain, **and it is in the Brain itself that the sensation of hearing takes place.**

It is almost an undisputed fact that the vestibule, or rather the fibrils of the nerve distributed over its membranous walls, tell us whether sounds are loud or soft, but they do not take account of the pitch of musical tones.

SIGHT.

Light is the external agent which makes us acquainted, by means of the sensation of sight, with the position, size, form, and colour of surrounding bodies. Before we can understand the action of the eye it is essential that we should know something of the laws of the transmission of *light.*

Light travels at the rate of 191,500 miles in a second. Its rays always proceed in straight lines when passing through the same medium (*e.g.* air, water, or glass); and also when passing *perpendicularly* from one medium into another, either from air into water, or from air into glass. When, however, rays of light pass *obliquely* from one medium into another their course is bent out of the straight line, and we say that the rays are *refracted.* Glass refracts light more strongly than water does.

Let us take an illustration of this. Suppose A B C D represent a small box or tank, with a circular hole in one side at E. If now you hold a lighted candle a short distance from the hole you will see on the floor of the box, at M, a small circle of light, formed by the rays from the candle shining in a straight line through the circular hole at E. Suppose we place a bright shilling on the little circle at M, and then fill the vessel with water up to about P P. The shilling remains where we placed it, but the circle of light is not shining

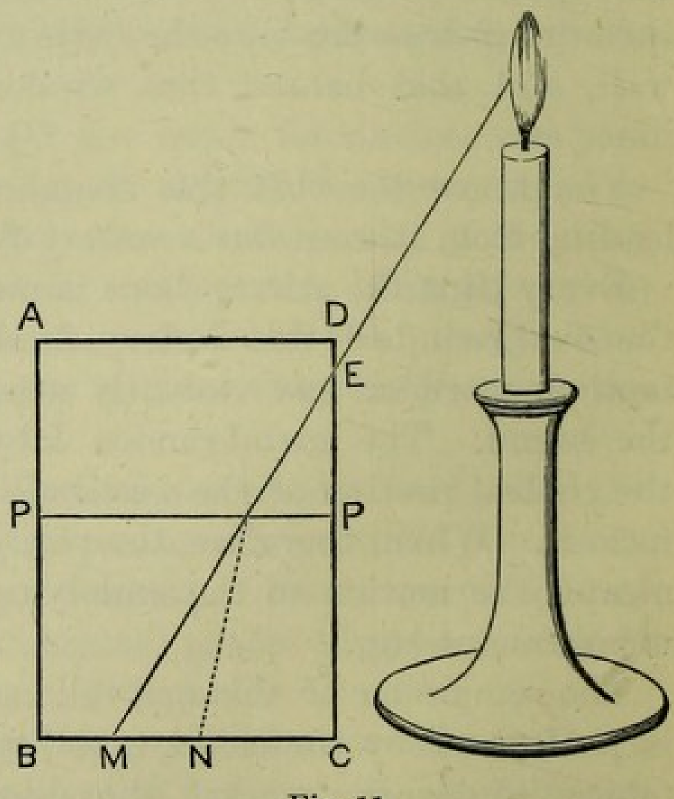


Fig. 11.

on it now. It has taken another direction, and you can see it at N. In other words, the light has had to travel through the water, which is a denser medium than air, and its rays have been bent out of the straight line, or as we said *refracted.* Again, suppose we empty the vessel, remove the candle, and place the shilling on the spot M as before. If we look through the little hole at E, we shall see the shilling, because rays proceed from it in a straight line to the eye. Fill up with water again as far as P P, and then look through the hole at E. You will find that you cannot see the shilling until you move it to N; because the rays proceeding from it are refracted or bent out of the straight line when passing from the water into the air.

Lens.—You have all seen a common magnifying glass, and you know that its opposite sides are not parallel, but are bulged out so as to make the glass thicker in the centre than at the edges. Such a glass is called a *Lens.* All lenses, how-

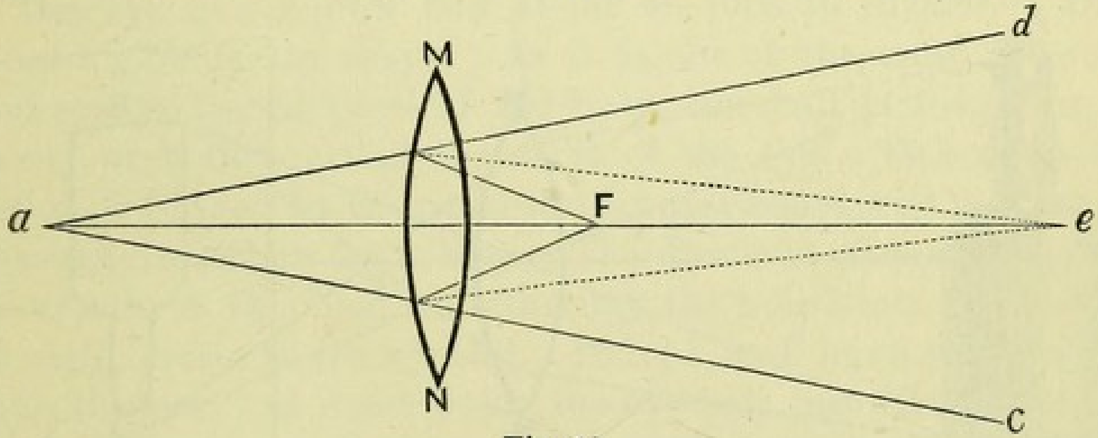


Fig. 12.

ever, are not like this one. Some instead of being thicker in the centre are thinner. If the lens is thickest in the centre we call it a **Convex lens**; if hollowed out at the centre and thickest at the edges it is a **Concave lens.** An ordinary spectacle glass is a lens. Those used by elderly persons are more or less bulged out or **convex.** There are others, however, used by short-sighted persons, and these are hollowed out in the middle or **concave.**

If from a certain point several rays of light proceed through the air and fall upon a *convex* lens (such as an ordinary magnifying-glass) only one ray will fall perpendicularly upon the lens, and consequently pass straight through. All the other rays fall more or less obliquely on the lens, and are refracted or bent out of their course and made to cross each other. The point at which they all cross is called the **focus.**

Thus, looking now to Fig. 12, suppose *a* to be a bright light and *a d*, *a e*, *a c* three rays proceeding from it to the lens M N. The centre ray *a e* passes perpendicularly through the lens to the point *e*. The rays *a d* and *a c*, however, strike the lens obliquely, and are bent out of their course towards the centre ray. All these rays eventually cross at the point F, which is thus the **focus.**

The flatter the lens the greater will be the distance of the focus from it, and, on the contrary, the more curved the lens the nearer will the focus be to it.

Let us take another example.

A B is any object, say a bottle; M N a convex lens. As the bottle is placed rays proceed from every part of it to the lens.

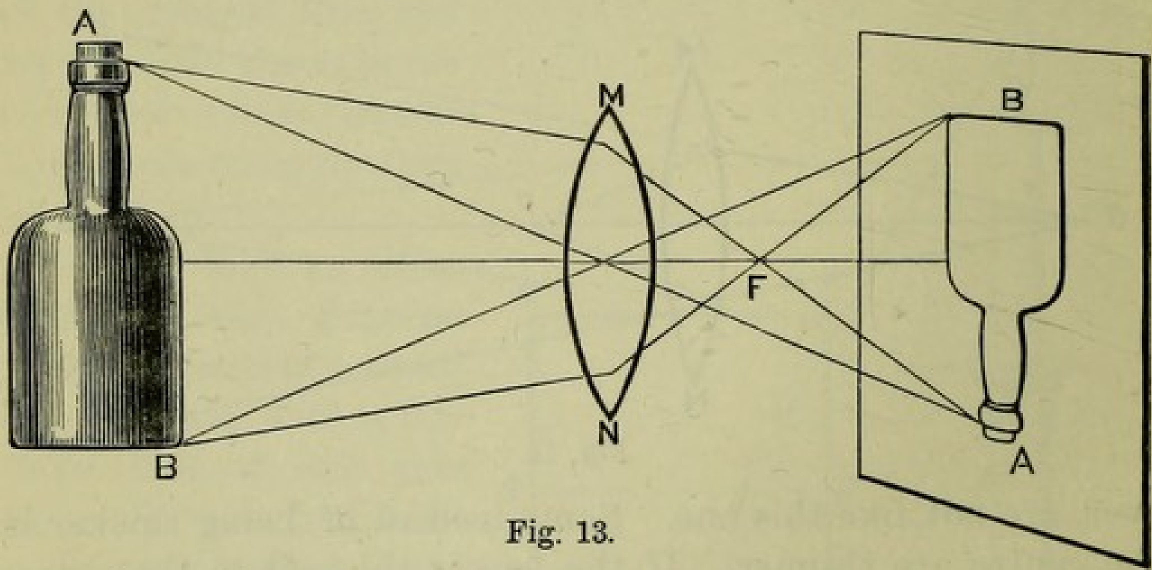


Fig. 13.

We will simply follow the two rays proceeding from the extremities. As in the former example these rays are made to converge by the lens, and are brought to a focus at the point F. Passing through F, however, they now continue their course, and you notice that the ray which issued from A is now below the centre line, while the one which came from B is above. The same thing happens to every other ray which proceeds from the bottle. If now a screen be placed at a suitable distance from the focus we shall get an image of the bottle on the screen, **but the image will be inverted.** This is exactly what is done by a magic lantern.

The Water Camera.—On these principles a curious contrivance called a Water Camera may be formed. It consists of a box, in one side of which a round watch-glass is fitted. The box is filled with water, and a convex lens is adjusted behind the watch-glass. If now a lighted candle be placed in front of the box the lens may be so placed that a distinct inverted image of the candle shall appear on the opposite wall of the box. The lens and the water combined refract the rays proceeding from the candle, bring them to a focus, and so form the picture.

As we proceed we shall see that the eye is constructed on very similar principles. Indeed the eyeball is virtually a water camera.

THE EYE.

The eye is a hollow ball about an inch in diameter, and almost globular in shape. As it is one of the most delicate and easily-injured parts of the body, this ball is lodged in a cavity or hollow called the orbit of the eye. This orbit or socket is formed by the nasal and frontal bones, and is pierced through its centre by a hole. The Brain is of course on the other side of this hole, and through the hole itself the Nerve of sight passes to the eyeball. Indeed, as I have once before said, the nerve of sight holds the eye-ball just like the stalk holds the apple on the tree. The walls of this hollow ball are composed of *three* coats or layers—the Sclerotic, the Choroid, and the Retina.

The Sclerotic Coat.—This is the thick, white, opaque membrane which forms the outer covering of the eyeball. It is generally spoken of as the *white of the eye.* It is one of the toughest and strongest membranes in the body, and is intended to protect the delicate structures inside.

The Cornea.—The sclerotic gives place in the front of the eye to a transparent, horny, circular plate, just as in a watch the silver or gold case gives place to a glass plate over the dial. This transparent plate is called the Cornea. It is more rounded than the rest of the ball. It forms a kind of window for the eye, and corresponds to the watch-glass in the water camera.

The Choroid Coat.—This second coat is immediately under the sclerotic. It is much more delicate in structure, and is closely intersected with nerves and blood-vessels. It is lined with a thick black coating, designed to absorb the surplus rays of light, which would otherwise cause a confused or blurred vision. Too much light is as bad as too little, as, I daresay, you have often discovered for yourselves. Did you ever gaze at the sun, and then try and look at something else immediately afterwards? If so, you know you could not see distinctly the object at which you were looking. The sight was blurred and indistinct, owing to the great amount of light that had found its way into the eyes, and could not be readily absorbed. Black has this power of absorbing rays of light better than any other colour, while bright colours reflect or throw back the light. Hence in ordinary vision, if the light be too strong, some of the rays which enter the eyeball are absorbed by the black colouring matter in the Choroid coat.

There are a certain class of persons called Albinos. They receive their name from the fact that there is none of this black colouring matter in the second coating of their eyes. They never see clearly or distinctly in the day-time because the light is too bright. The Choroid coat in the eyes of such people consists wholly of a close network of blood-vessels, and it shows, not black as yours does, but bright pink. That is to say, the little round spot in the centre of the eye (about which I shall have something to say presently) is black in most people, but in an Albino it is pink. Like the outer coat, the Choroid is modified in the front of the eye, where it forms the Iris.

The Iris (the coloured portion of the eye) is a circular curtain with a hole through its centre. This curtain is attached all round its circumference or outer edge to the rim of the sclerotic coat, just where the sclerotic ends and the cornea begins. Between the Iris and the Cornea is a space called the **Anterior** (or front) **Chamber of the Eye.** The central aperture in the Iris is called the **Pupil.**

The Iris consists of muscular fibres, some of which radiate from the pupil to the outer edge of the curtain, others form concentric circles round the pupil. If the radiating fibres contract it is clear that they must draw the curtain back towards the outer edge, and this makes the pupil larger. When, however, the muscular rings round the pupil contract,

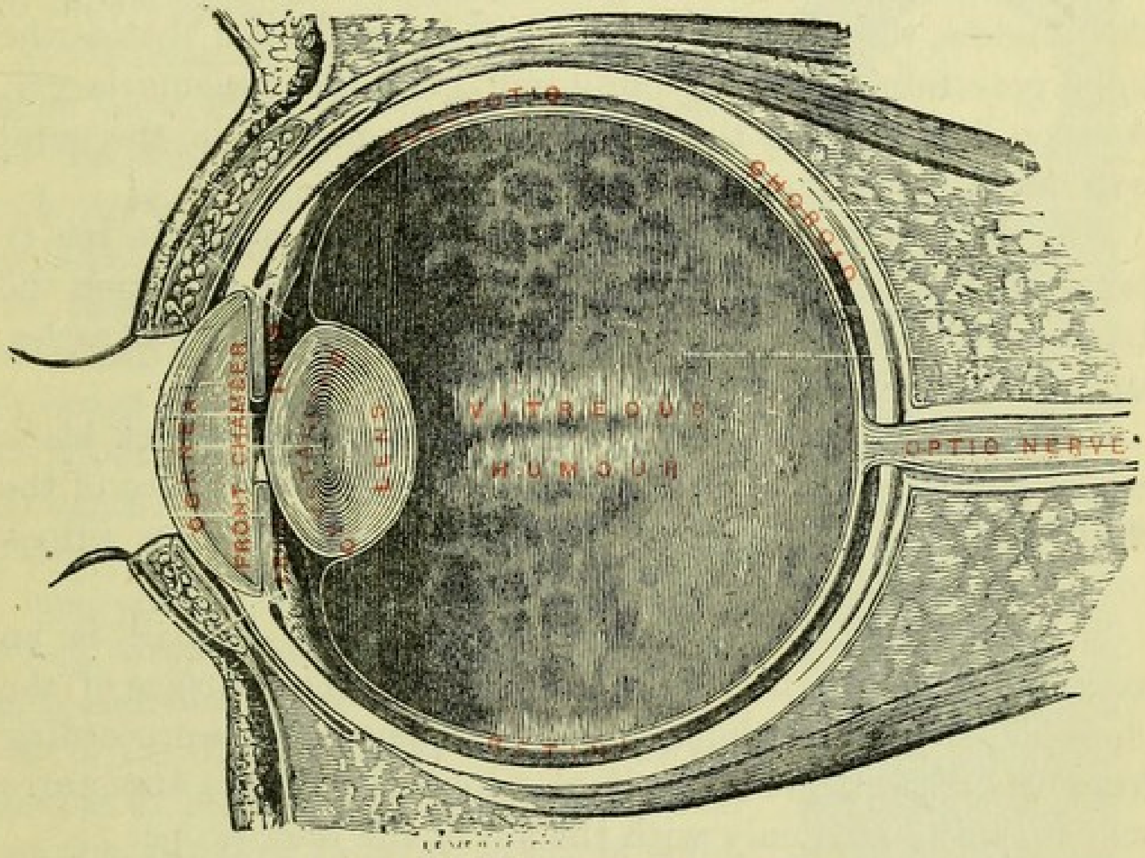


Fig. 14. – Vertical section of the Eye.

it is equally clear that the curtain will be drawn in towards the centre, and thus the pupil is diminished in size. A bright light affects the *circular muscles* of the Iris, causing them to contract, and thus partly close the pupil; but if the bright light be removed these muscles lose their stimulus, and the pupil resumes its former size. A dull, dim light, on the contrary, is the signal for the other set of *radiating muscles* to contract. This they do, and so draw back the curtain from the pupil.

The reason of this is clear. When the light is very strong and brilliant the Iris spreads its curtain farther over the pupil in order to shut out some of the rays; but when the light is faint the curtain is drawn back from the pupil in order to admit as many rays of light as possible. You know that on a very bright day you pull down the blind to shut out some of the dazzling light from the room; while on a dull day you draw blinds and curtains back from the window in order to get as much light as you can. It is just so with the eye.

Suppose you stand at a window, and watch your face in a looking-glass, while some one gradually closes the shutters. You will notice that at first, when the full light comes in at the window, the pupil of the eye will be small, and that as the light gets fainter so the pupil will gradually become larger. As soon, however, as the shutters are opened again the pupil will diminish in size.

You notice too that your will has no power over the Iris to prevent these movements, because the muscles of which the Iris is composed belong to the class of Involuntary Muscles, and act independently of the will.

The black appearance of the pupil is due to the thick black coating which we spoke of as lining the interior surface of the choroid. It is like looking through a small window into a room whose walls are hung with black paper.

The Retina or innermost layer of the eyeball is an extremely delicate film which covers the inner surface of the choroid. It consists almost entirely of nerve fibres proceeding from the optic nerve; but it also contains curious structures which can be seen only with the aid of the microscope.

The Optic Nerve enters the back of the eyeball not exactly opposite the pupil, but at a point nearer to the nose. From this point the nerve fibres may be seen spreading themselves over the inner surface of the ball. The point itself is called **the Blind Spot,** because whenever the image of an object falls upon that spot it is not perceived.

In the centre of the back of the eyeball, *i.e.* immediately opposite the pupil, is another round spot called **the Yellow Spot.** This is the point of most distinct vision.

You may look now at Fig. 15. Turn your book round so as to have both the white spots facing you. If you now close the left eye, and keep the right steadily fixed on A, while you slowly move the book towards you, you will presently find that B has disappeared altogether. As you continue to move the book nearer to the eye, you will catch sight of B again, however.

Now, during this experiment your eye was fixed on A, and it therefore follows that the image of A remained fixed on that part of the retina opposite the Pupil—or in other words, on the yellow spot.

When you first saw both A and B, the image of B fell between the yellow spot and the blind spot; but as you moved the book towards you the image of B moved too, until at last it covered the blind spot, and then you lost sight of it. As you continued to move the book towards you the image of B gradually moved away from the blind spot and it became visible to you again.

This little experiment proves that there is one point (the entrance of the optic nerve), where the retina is insensible to light, and thus quite blind.

It is the Retina which renders the eye sensible to light, so that we may consider it as the actual or essential organ of sight.

The Crystalline Lens.—Immediately behind the Iris is a clear transparent jelly-like body, the **Crystalline Lens.** It is convex or *rounded* both back and front, and is about one-third of an inch in diameter. It is perhaps the most beautiful part of the eye. It is held in its place by a number of bands or ligaments.

The Crystalline Lens separates the front chamber of the eye from the back chamber.

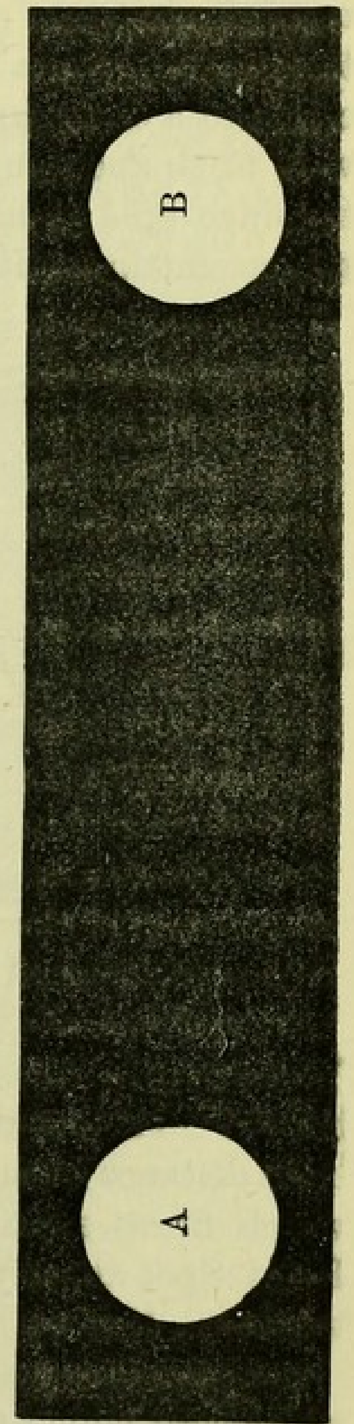


Fig. 15.

The front chamber, *i.e.* the space between the Crystalline Lens and the Cornea, is filled with a clear watery fluid called the **Aqueous Humour.**

The back chamber also contains a transparent, jelly-like fluid called the **Vitreous Humour.**

You will best follow this description of the eyeball by examining for yourselves a bullock's eye, which you may get from the butcher. Take a knife and cut the eye in two, so as to divide it into a front and a back half. You will require care and a sharp knife, for the Sclerotic Coat on the outside is very thick and tough, and cuts like leather. The best way is to pinch up a small piece with some nippers, and then commence cutting with a sharp pair of scissors. As you cut through the eye, the jelly-like Vitreous Humour in the back chamber will flow out, and you may examine it and see that it is perfectly clear and transparent.

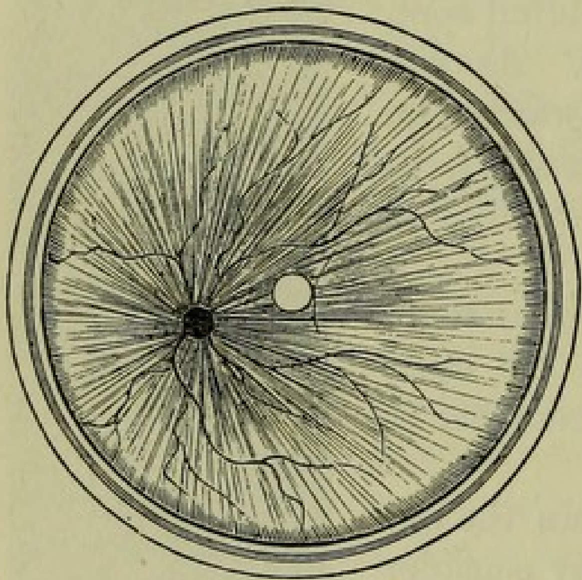


Fig. 16.—Back half of Eye-ball.

If you now examine the back half of the ball you will see the Retina lining the whole of its inner wall and having the appearance of an extremely delicate membrane with a smooth even surface. It is of an opal-white colour and may be easily torn. You will see too in the centre a little yellowish, circular hollow. This is the Yellow Spot spoken of above, and at a little distance from it on the inner side you will see a spot from which fibres seem to radiate in all directions. This is the Blind Spot already mentioned, and the fibres are the fibres of the Optic Nerve. See Fig. 16.

Immediately behind this Blind Spot you will see a thick white cord which passes out from the ball, and resembles the stalk which holds an apple or a plum to the tree. This thick white cord is the Optic Nerve, and proceeds to the Brain.

If the Retina be examined with the aid of a powerful microscope it will be found to consist of five distinct layers. The most important is the innermost layer, which is composed of rods or cylinders joined together like the stakes of a palisading, and forming with their extremities a kind of mosaic. See Fig. 17. There are none of these rods in the Blind Spot.

Immediately under the Retina you will see the black layer of the Choroid Coat, and on removing this you will at last reach the thick tough outer Sclerotic Coat.

On turning now to the front half of the eyeball, you will examine the Crystalline Lens. Unless the eye be quite fresh it will be difficult to take the Crystalline Lens out without tearing away the Iris with it, because the Iris hangs close in front of the lens. If you now hold the Crystalline Lens up to the light you will be struck with its clear, transparent, glassy appearance, while at the same time you will find that it is very elastic and gristly. It is enveloped in an exceedingly fine transparent membrane called the **capsule** of the Lens.

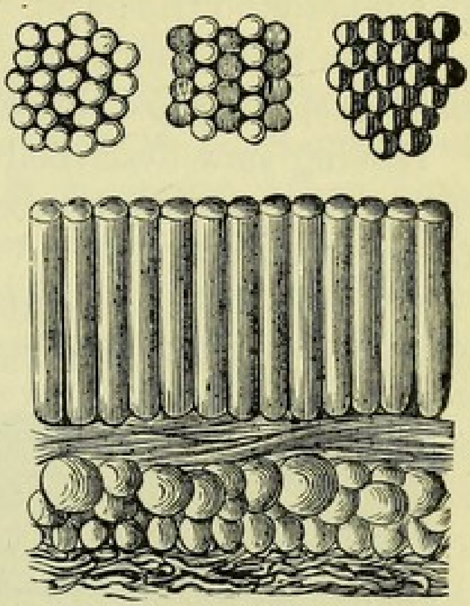


Fig. 17.—Highly magnified section of the Retina, showing the Rods and Cones.

Leaving the Crystalline Lens you may now examine the Iris, which will have somewhat the appearance presented in Fig. 18. The central aperture is the Pupil, and this is surrounded by the curtain of the Iris. Outside this are seen the Suspensory Ligaments which held the Crystalline

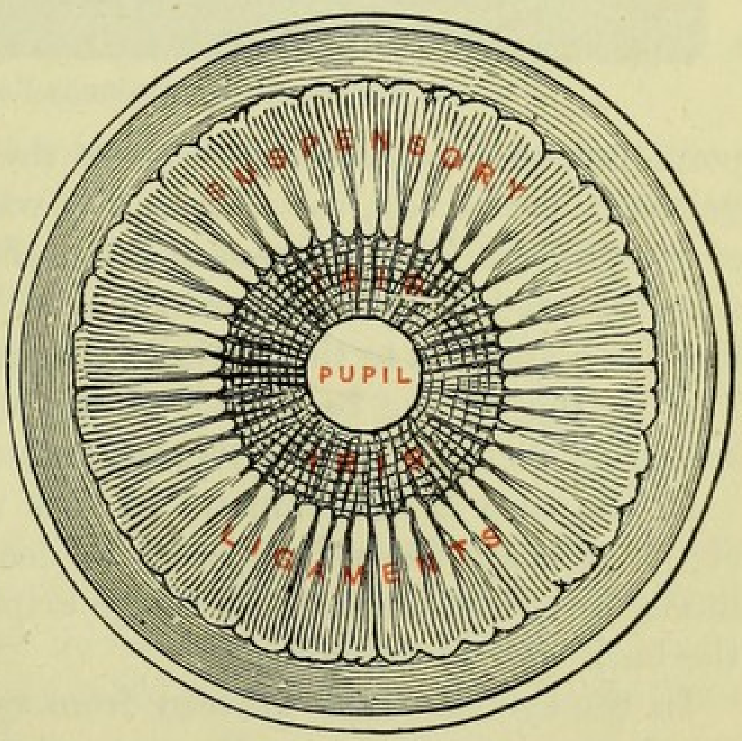


Fig. 18.—Front section of Eye-ball viewed from behind, and showing Suspensory Ligaments, Iris, and Pupil.

Lens in its place. In the Iris you see the two sets of muscular fibres, the first radiating from the centre the others arranged in rings round the pupil.—Nothing remains now but to remove all these parts, and examine the Cornea, which you will find to be a clear, transparent, horny plate like a watch-glass.

Having now described the structure of the essential parts of the eye, we shall proceed to examine how each part performs its function.

We have already mentioned that the eyeball is constructed on the principles of a water camera. You can now no doubt

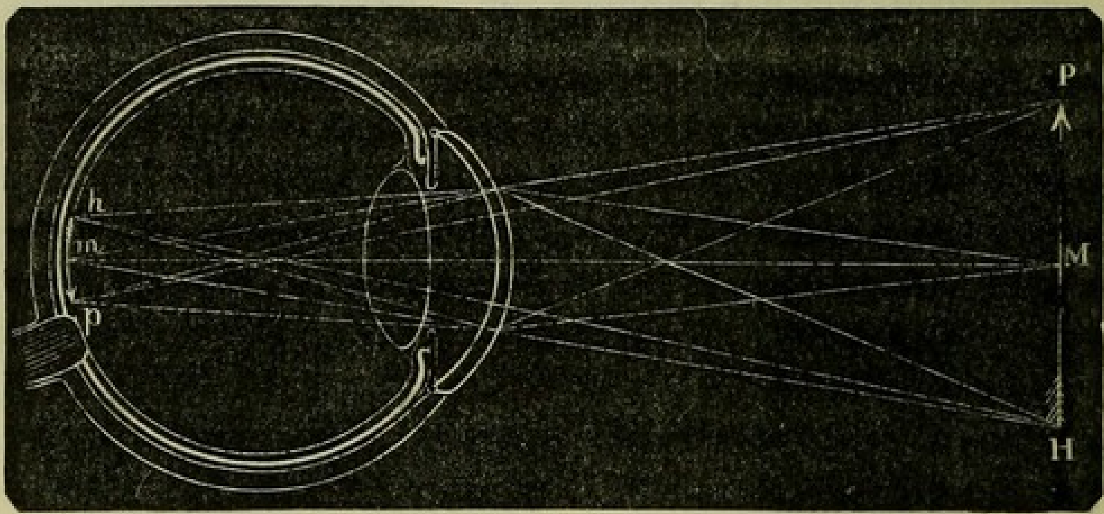


Fig. 19.—Course of the Luminous Rays in the Eye.

point out the resemblance between the different parts. The Sclerotic is the box, the Cornea the watch-glass in the front of the camera. The Aqueous and Vitreous Humours of the eye take the place of the water which fills the box. The Crystalline Lens answers to the glass lens placed behind watch-glass. The Retina on the back wall of the eyeball answers to the screen on the back wall of the camera.

In the case of the camera we saw rays proceed from an object through the watch-glass, the lens, and the water, and finally by refraction form an image or picture of the object on the back wall of the box.

In the eye also rays proceed from various objects through the Cornea, the Aqueous Humour, the Crystalline Lens, and the Vitreous Humour; and after suffering refraction by all these, form a picture of the object on the Retina, which lines the back wall of the eyeball. See Fig. 19. The impression is then conveyed to the Optic Nerve by the Retina, and carried to the Brain, where it gives rise to the sensation of sight.

In the water camera it is impossible to form images of objects at different distances without each time changing the lens.

The Crystalline Lens of the eye, on the other hand, has the power of adjusting itself so as to be able to form images of objects at ever-varying distances. It is, as you know, very elastic, and is held in its place by the suspensory ligaments.

When we wish to look at any object a long distance off, these ligaments are drawn very tight by some muscles, to which they are attached, and the crystalline lens is thus flattened. If we next turn our attention to objects close at hand, the ligaments are allowed to relax, and the crystalline lens returns to its former rounded or convex shape.

We have now studied the most essential parts of the eye. There are, however, surrounding the ball, several important structures, which serve either to move, protect, or clean it. These are the muscles of the eye, the cushions of fat in which the eyeball is lodged, the tear glands and ducts, the eyelids, and the eyebrows.

The Muscles of the Eye.—The various movements and rollings of the eyes are effected by six muscles:—

1. The **Superior Rectus**	muscle	moves the	eyeball upwards.
2. The **Inferior Rectus**	,,	,,	downwards.
3. The **Internal Rectus**	,,	,,	inwards.
4. The **External Rectus**	,,	,,	outwards.
5. The **Superior Oblique**	,,	,,	downwards & outwards.
6. The **Inferior Oblique**	,,	,,	upwards and outwards.

These muscles spring from the back part of the bony orbits in which the eyes are placed, and are attached to the front part of the eyeball by means of tendons. In other words, their *origin* is in the bony orbit, and their *insertion* in the front wall of the eyeball.

The cushions of fat which line the bony orbits serve to protect the eyeball from shocks, to keep it warm, and to give it freedom of movement without friction.

The Tear Glands and Ducts.—At the outer corner of each eye is a small yellowish-red gland about the size and shape of an almond. These glands pour a watery secretion—the Lachrymal Fluid—over the eyeball, to moisten its surface and make its movements easy. The **Lachrymal Fluid,** after thus moistening the eyeball, is collected up and carried off by a number of very fine tubes which open on the inner surface of the eyelids. These tiny tubes unite at last and form the **Lachrymal Ducts,** which lead from the inner corners of the eyes into the nasal passages. Thus the lachrymal fluid is poured out by the glands at the outer corners of the eyes, and after flowing between the eyeballs and the eyelids is collected up and carried off at the inner corners.

The Eyelids are thin, flexible covers or shutters for protecting the front of the eyeballs. They are formed of thin plates of cartilage covered with skin. They are lined on the inner side with a very delicate mucous membrane called the **Conjunctiva,** which also envelops the front part of the eyeball. On the inner side also are a number of tiny glands which pour out an oily fluid to moisten the surfaces. The edges of the eyelids are provided with a fringe of fine hairs—**the eyelashes**—which help to shade the eye and to guard it from dust.

The Eyebrows form a protecting and shading ridge over the eyes, while the thick fringe of hairs with which they are studded prevents the perspiration from rolling into the eyes as it trickles down the forehead.

QUESTIONS FOR EXAMINATION.

1. What do you understand by the Nervous System? Explain why this is the most highly important part of the Human Organism.

2. Explain the term Cerebro-Spinal Axis.

3. What is the Sympathetic System?

4. Show roughly what part the nervous system takes in the following actions:—

(*a*) The act of snatching the hand from a hot iron.

(*b*) The act of turning round when some one calls you.

(*c*) The act of laughing at some funny sight.

5. What is Nerve Tissue?

6. What are the Nerves? Explain *Sensory* and *Motor* Nerves. What parts of the body have no nerves?

7. Give a short description of the Brain.

8. What is the usual size of the Human Brain? Compare this with the brain of some other animals.

9. Describe fully the Cerebrum or Brain proper.

10. What are the functions of the Cerebrum? How can it be proved that the Cerebrum is the seat of the intellect?

11. Describe the three coverings of the Brain.

12. Where is the Cerebellum? Describe its structure, and say what you can of its functions.

13. Describe the Medulla Oblongata.

14. Say what you can of its functions.

15. What do you understand by the Cranial Nerves? How are they arranged?

16. Name the twelve pair of Cranial Nerves.

17. Describe briefly the Spinal Cord.

18. How is this delicate organism lodged and protected? How is it connected with the Brain?

19. What are the functions of the Spinal Cord?

20. Explain fully what you understand by Reflex Action.

21. Suppose a man met with a serious accident and severed the Spinal Cord, what would be the result? and what would happen if you tickled the soles of his feet?

22. Describe certain Reflex Actions which are continually taking place in the body.

23. How has it been proved that the hinder roots of the spinal nerve-trunks are sensory nerves, and the front root a motor nerve?

24. Describe fully the Sympathetic Nerve System.

25. What are the functions of the Sympathetic Nerves?

26. Explain "blushing," and "turning pale."

27. What do you understand by the term "sensation?" Where do all sensations take place?

28. "Three distinct organisms are necessary to produce a sensation."—Explain this and give examples.

29. What do you understand by the Muscular Sense?

30. Give a short description of the skin as an organ of touch.

31. Some parts of the body are more sensitive to touch than others. Which are they? How would you prove this?

32. What do you mean by "relative temperature." Which parts of the body are most sensitive to heat?

33. What is the great use of the epidermis? How is this proved?

34. Show how the sense of touch is sometimes made to do duty for another sense.

35. Describe the tongue as the principal organ of taste.

36. What nerves are engaged in the sensation of taste?

37. The sense of taste is greatly assisted by that of smell. Prove this.

38. Explain fully what takes place in the act of tasting.

39. What constitutes an "odour" or "smell?"

40. How do we become cognizant of an odour?

41. Describe the cavities of the nose.

42. How is it that in quiet gentle breathing we may sometimes not detect an odour, while by a short sharp sniff we at once notice it?

43. What nerves are concerned in the sense of smell?

44. Explain why it is we are unable to smell when we have a cold in the head.

45. Explain roughly the way in which sound travels through the air.

46. How could you prove that air is necessary for sound?

47. What do you mean by the Auditory Canal?

48. What separates this canal from the Middle Ear? Describe this membrane.

49. Describe the "Drum of the Ear."

50. Describe the three movable bones in the "Drum."

51. Explain how the air in the cavity of the Drum is kept at the same pressure as the outer air.

52. Describe the mechanism which sets in motion the foot-plate of the stirrup-bone in the little oval window in the inner wall of the Drum.

53. Describe the Inner Ear.

54. What are the Semicircular Canals?

55. Describe the Cochlea.

56. How are these two placed with regard to the Vestibule?

57. Describe the Vestibule, and say how it is connected with the chamber of the Drum.

58. How is the Cochlea connected with the same chamber?

59. What do you understand by the terms "Labyrinth" and "Membranous Labyrinth?"

60. Explain "Endolymph," "Perilymph," "Otoconia."

61. Say what nerves are concerned in the sense of Hearing.

62. What are the fibres of Corti? What is their function?

63. What is supposed to be the function of the Vestibule?

64. Explain fully what takes place between the act of striking a bell and hearing its sound.

65. What do you understand by refraction of light?

66. Describe an illustration of the way in which light is refracted in passing from air into water, and again in passing from water into air.

67. What is a lens? What are the two simplest lenses called? Describe them.

68. Explain the term "focus."

69. Show how you may form on a screen a picture of some object by means of a convex lens.

70. How would you describe a Water Camera?

71. The eye is a hollow ball with three coats or layers. Describe each.

72. What is the purpose of each?

73. Describe the Iris. What causes the Pupil of the eye to have a black appearance?

74. Why should the Iris be enabled to contract and expand?

75. Describe the Retina.

76. What are the "Blind Spot" and the "Yellow Spot?"

77. Say what you can of the Crystalline Lens. How is it enabled to adapt itself for seeing objects at different distances?

78. Describe the "humours" of the eye.

79. Show that the eyeball is essentially a water camera. Show its superiority over the ordinary camera.

80. What nerves are engaged in the sense of vision?

81. Describe how the eyeball is lodged, protected, and warmed.

82. Name the muscles which move the eyeball.

83. Say what you know of the Tear Glands and Ducts. What becomes of the fluid?

84. Describe the eyelids and eyebrows, and say what are their uses.

HUMAN PHYSIOLOGY.

BOOK IV.

CHEMICAL PRELIMINARIES.[1]

We have already been made acquainted with the element carbon. We have handled it in its black solid form as charcoal; and we know that it forms the basis of the whole vegetable world, that it is, in fact, an essential constituent of all organic matter. We know too that our various vegetable foods are valuable mainly because of the carbon which they contain; that this carbon is a combustible substance; and that in the body the oxidation (or combustion) of the carbon helps to produce the necessary animal heat and energy. That will be sufficient for our purpose at present. We will now turn our attention to a little closer examination of the other three elementary bodies—oxygen, hydrogen, and nitrogen.

OXYGEN.

You can tell me that oxygen forms an important element in the air around us—that the air, in fact, consists of 21 parts of *oxygen* mixed with 79 parts of *nitrogen.* But this is not all. One-half of the mass of this solid earth is *oxygen;* eight-ninths of all the water is *oxygen;* it forms an important constituent of all soils, rocks and sand, and of all vegetable and animal substance; and two-thirds the weight of our own bodies is the same element oxygen. It is thus the most important and wide-spread of all the elementary bodies.

Its Preparation:

1. **From Red Oxide of Mercury.**—Oxygen may be prepared very easily in small quantities from this red powder. Put a little of the powder into a small test-tube of hard glass

[1] See also pp. 54–57.

(Fig. 1), fit it with a cork and a piece of bent glass tubing, and heat it over the flame of the spirit-lamp or the Bunsen burner. In a very short time the powder will change colour, and tiny globules of a silvery white substance will be deposited on the upper and cooler part of the tube, while from the other end of the bent tube which dips down into the

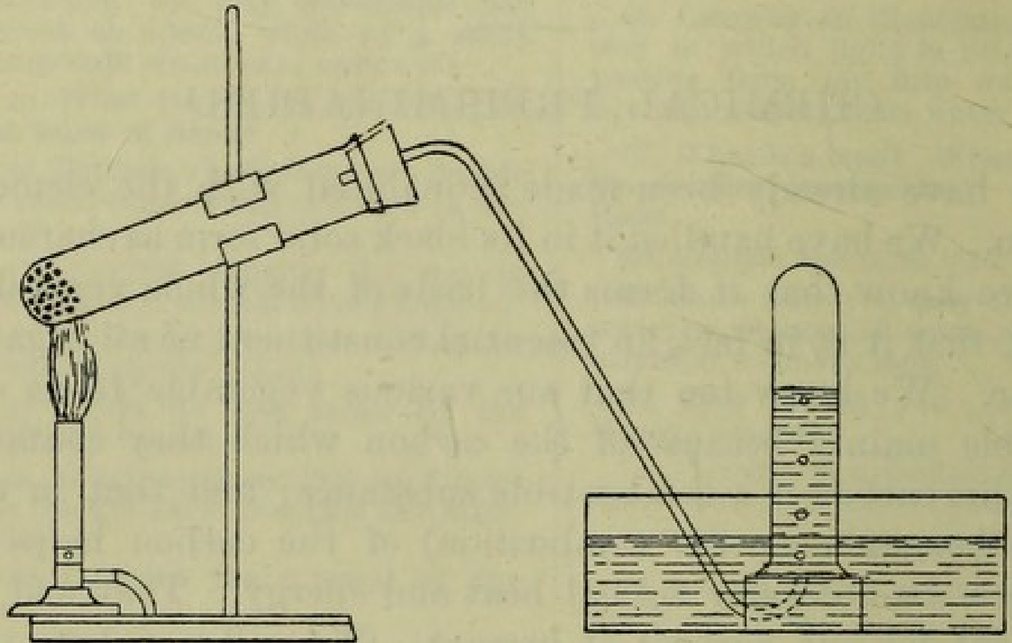


Fig. 1.—Apparatus for preparing and collecting Oxygen from Red Oxide of Mercury by means of a test-tube and a spirit-lamp.

water, little bubbles of gas will be seen to come off. These may be collected in a glass-jar filled with water and inverted over the trough. The gas is the element *oxygen;* and the silvery-looking liquid left behind in the test-tube is the metal mercury. The red powder was made up of these two substances, and these two substances only.

2. **From Chlorate of Potassium.**—The above method is never employed when oxygen is required in anything like large quantities, the oxide of mercury being too expensive. It is prepared from the white crystals of potassium chlorate. The crystals are first ground into a powder, and then mixed with enough black oxide of manganese to make the mixture black. The powder is then heated and the gas collected as before, except that in this case a flask is used instead of the test-tube (Fig 2).

Its Properties:

1. Lower into one of the jars of the new gas a piece of

taper, with the wick not flaming but red hot. It immediately bursts into flame and burns with a brilliant glow. It will continue to burn till extinguished by the carbonic acid gas produced by the combination of the carbon of the taper with the oxygen. This is the only proof we have that the jar contained oxygen, for as it was a transparent and colourless gas we could not see it.

If we notice the inside of the glass jar presently, we shall find it covered with tiny dew-drops. These drops are drops of actual water which has been formed by the burning of the taper in the oxygen, and is now condensed all round the sides of the glass. This being so, you can tell me at once that the taper itself contains *hydrogen*, because *water is always formed when hydrogen burns in oxygen.*

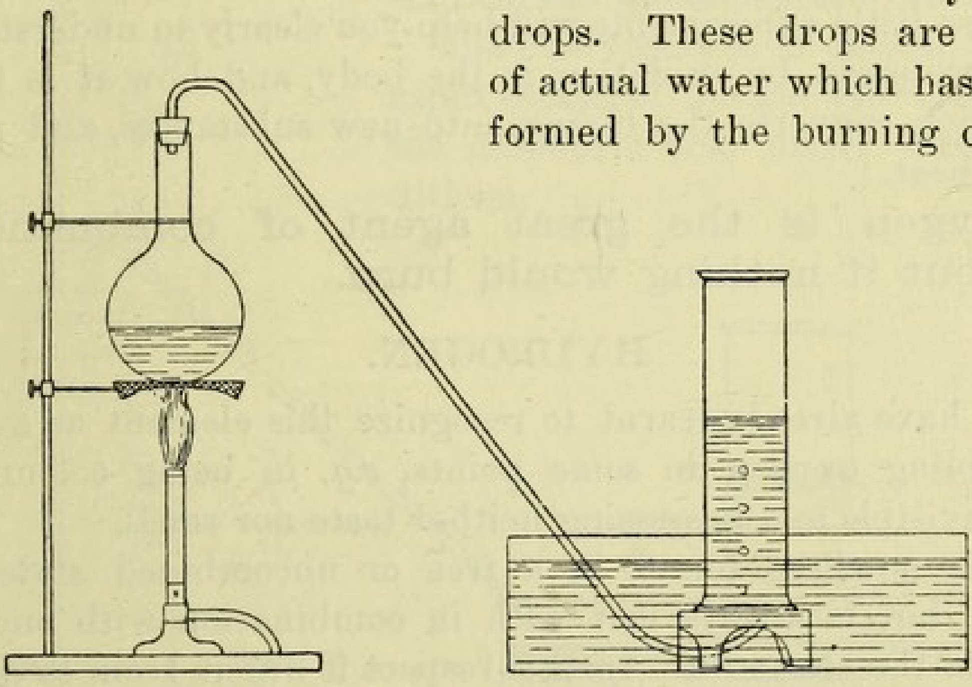


Fig. 2.—Apparatus for preparing and collecting Oxygen, in larger quantities, from Potassium Chlorate, as it is generally done in the laboratory.

If now we take the jar, and pour into it a little of this clear lime-water, we shall soon find that there is something else in the jar besides the watery deposit on the side. Shake the jar, and the clear lime-water quickly becomes clouded and milky-looking. This would never have happened if the glass had been empty (I mean if it had contained only air). The change that has taken place is a proof, as we shall learn later on, that the jar contained *carbonic acid gas.* So then the burning of the taper in oxygen has produced water and carbonic acid, and we know that the taper must have contained the two bodies hydrogen and carbon.

2. Similar experiments might be repeated in the other jars of oxygen with a red-hot splinter of wood, a piece of red-hot charcoal, a piece of heated sulphur, or a piece of phosphorus. Each of these substances burns fiercely in the oxygen. We can feel on the sides of the jar the intense heat that is generated. In each case, too, new and different compound substances are produced as the results of the burning.

These little experiments will help you clearly to understand what we mean by oxidation in the body, and how it is that oxidation converts the tissues into new substances, and produces heat.

Oxygen is the great agent of combustion; without it nothing would burn.

HYDROGEN.

We have already learnt to recognize this element as a gas resembling oxygen in some points, *e.g.* in being colourless and invisible and possessing neither taste nor smell.

It is nowhere found in a free or uncombined state in nature, but is always met with in combination with one or other of the elements. In this respect it differs from oxygen, which in the air is simply mixed with nitrogen, as we might mix any other two substances together.

We know, for instance, that when hydrogen is burned in oxygen, a totally new substance—water—is formed, which is not merely a mixture of the two gases, but the resulting compound product of the burning. The two gases if shaken up together in a bottle would not form a liquid water, but would still remain in the gaseous form—a mixture of oxygen and hydrogen.

Hydrogen is an important constituent of water in every form wherever it exists, and is also found in all vegetable and animal matter, and in many soils and minerals.

Its Preparation.—Put some zinc clippings into a flask or a bottle with a wide mouth (a small pickle bottle will do) (Fig. 3). Fit the mouth tightly with a good sound cork, having first bored two holes through the cork. Through one hole pass a funnel tube, allowing it to reach nearly down to the bottom of the bottle, and into the other fit a piece of bent glass tubing, this one simply passing through the cork.

It is in the highest degree essential that the flask and tubing should be perfectly air-tight. When all is ready pour down the funnel enough water to cover the zinc clippings, and then add sulphuric acid till the whole begins to effervesce.

The effervescence is caused by the rapid escape of the gas *hydrogen* from the sulphuric acid under these conditions.

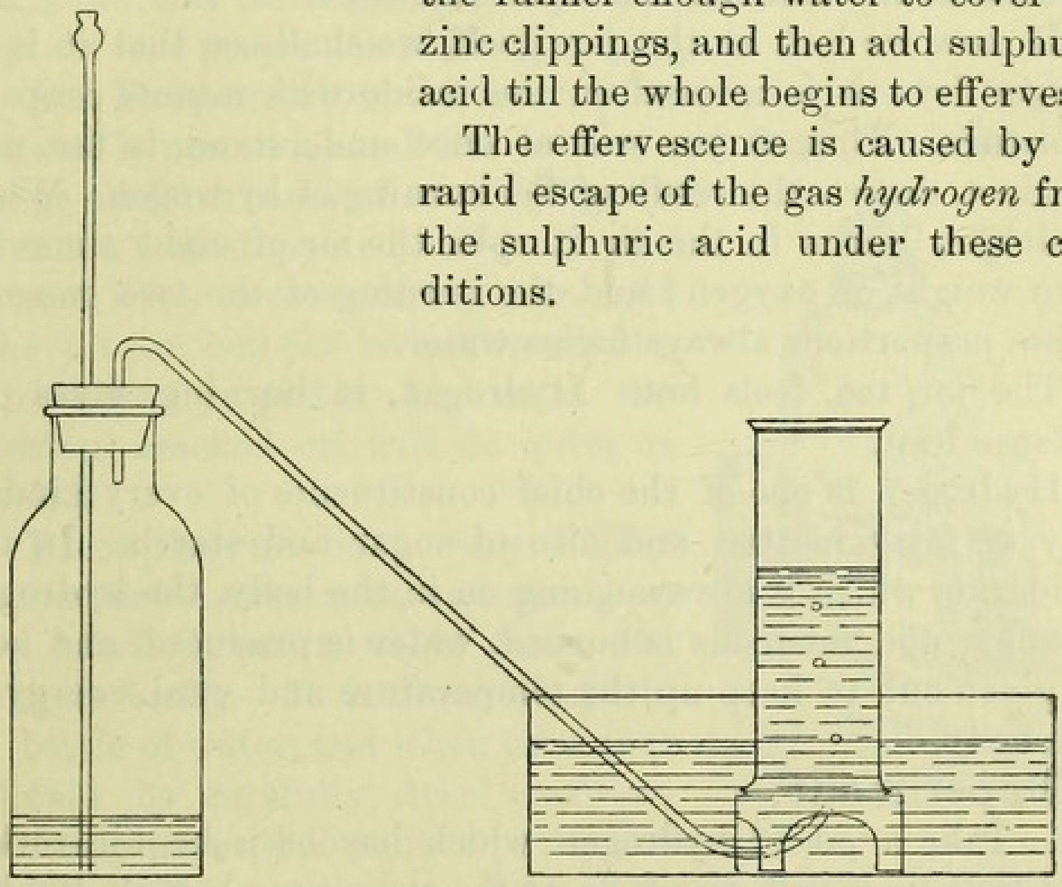


Fig. 3.—Apparatus for preparing and collecting Hydrogen.

The gas may be collected over the trough, as we collected oxygen, by displacing water from inverted glass-jars; or it may be collected at once by merely holding an inverted jar over the delivery-tube.

The only thing that is necessary is to guard against any air mingling with the gas, and to keep the whole apparatus at some distance from a flame.

Its Properties:

Experiment.—Take a jar of the gas prepared in the way just indicated, and, still keeping its mouth downwards, plunge into it a lighted taper. The flame of the taper is immediately extinguished, but we see that the gas in the jar has itself taken fire with a little pop, and is burning with a pale blue flame.

Now let us see what this teaches us:

1. **Hydrogen will not support combustion**, for immediately the taper was thrust into it the flame went out.

2. **Hydrogen is highly inflammable**, for it took fire as soon as the flame of the taper touched it.

If now we look at the jar itself, we shall see that it is no longer dry; it is covered on the inside with minute drops of moisture. This, as you will at once understand, is the new product, *water*—the result of the burning of hydrogen. When hydrogen burns in the air it robs the air of eight times its own weight of oxygen; and the burning of the two gases in these proportions always forms water.

The jar, too, feels hot. Hydrogen, in burning, gives out intense heat.

Hydrogen is one of the chief constituents of every kind of oily or fatty matter, and also of sugar and starch. In the oxidation which is always going on in the body, the hydrogen in sugar and fat foods is burned, water is produced, and heat is given out to keep up the temperature and vital energy of the body.

Experiment:

1. Take a jar of hydrogen which has been kept inverted and turn its mouth upwards, at the same time bring a lighted taper near it. The gas immediately takes fire, but instead of burning quietly in the mouth of the bottle, it rises in a long flame towards the ceiling.

2. Take a jar of hydrogen in one hand, and one filled with air in the other. Invert the latter, and gently slant the former, so as to bring the two mouths together. In a very short time the whole of the hydrogen will have passed upwards from the one jar into the other, displacing the air which it contained. We have, in fact, poured the hydrogen upwards.

These two experiments teach us that *hydrogen is an extremely light substance, much lighter than air.*

In reality it is the lightest body known, and is fourteen and a half times lighter than air.

NITROGEN.

Air, as we have seen, is simply a mixture of *oxygen* and *nitrogen;* and you can, of course, tell me that nitrogen resembles oxygen in appearance, being a transparent, colourless gas, having neither taste nor smell. It will be well, therefore, to make this our starting-point for further inquiries into the nature and properties of the gas *nitrogen.*

Its Preparation.—Place a *piece of phosphorus* about the size of a pea on a small tin saucer, and float the saucer in a large shallow basin of water (Fig. 4). Stand a well-stoppered bell-jar in the water, so as to cover the saucer. (If the proper bell-jar be not available, an ordinary pickle-jar with the bottom cracked off will do quite as well.)

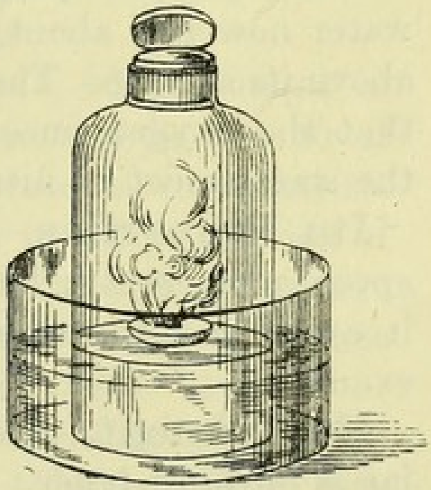


Fig. 4.—Experiment for removing the Oxygen contained in a jar of ordinary atmospheric air.

Phosphorus is a very highly inflammable substance, and must not be handled, as it would burn the fingers badly. It is always kept in a bottle of water, and when taken out should be carefully dried between blotting-paper, before it is put into the saucer.

The bell-jar or bottle, of course, contains air, and we may notice that the water inside is just as high as the water in the basin.

Now we will remove the stopper, touch the floating piece of phosphorus with a red-hot wire, and then close the bell-jar again. The phosphorus immediately bursts into a dazzling white flame, and fills the jar with dense white fumes.

What is it that makes the phosphorus burn? The oxygen in the air. It will continue to burn till every trace of oxygen is removed from the air in the jar. We must now wait while the jar cools, and we shall see the white fumes gradually disappear.

But we see something more than this. We see that the jar, which was at first full of air, now contains a considerable quantity of water. The water in the jar stands much higher than the water in the basin. The water has rushed into the jar from the basin. But why did it not rush in before the burning took place? Because the jar was already full of air, and the water and air could not both occupy the space in the jar. The burning has removed all the oxygen from the air, and made room for the water.

Now, as the air originally consisted of a mixture of the two gases nitrogen and oxygen, it is clear that what is left is the gas nitrogen.

If our jar were properly graduated we should find that the water now fills about one-fifth of the jar, leaving four-fifths above its surface. The water fills exactly the amount of space that the oxygen once occupied; hence the four-fifths above the water must be nitrogen.

Its Properties.—The jar, as we now see it, is to all appearance empty; but if we test it, we shall soon find that it contains a gas which differs from both of those we have examined.

Experiment.—Remove the stopper, and plunge into the jar a burning taper. The taper at once goes out, just as it would in hydrogen; but the gas itself does not take fire, as hydrogen would.

This shows us that nitrogen *does not support combustion* in other bodies, and *is not itself combustible.*

It is important to form a clear conception of this burning or combustion. We already know that life itself is entirely dependent upon the constant oxidation or combustion which is going on in our bodies. This oxidation within the body, and the burning of a taper or a match, are essentially the same thing, and can only go on with the aid of oxygen. Hence oxygen in supporting combustion in the body is actually supporting life; and this the other elements hydrogen and nitrogen cannot do, because, as we see, they extinguish flame.

The part which nitrogen has to play in the air is simply to dilute the oxygen. In an atmosphere of oxygen alone, the burning would go on too rapidly. The nitrogen being in itself negative in its properties, serves to weaken its effect much as water would act if mixed with vinegar or brandy. If the atmosphere consisted of nitrogen alone there could be no burning of any kind, and of course with no burning, no life.

Its Distribution in Nature.—Besides forming four-fifths of the entire bulk of the air, nitrogen is found in all animal and vegetable substances, and in many minerals and soils. In the tissues of the body itself it is the most important element of all; it is the basis of all animal matter.

Now let us summarize what we have learned about these three gases, oxygen, hydrogen, and nitrogen.

1. **Oxygen** is the agent of all burning.

2. **Hydrogen** is very inflammable, and, when burned in oxygen, forms water. Hydrogen, in burning, robs the air of eight times its weight of oxygen. Pure water always consists of these two gases hydrogen and oxygen in the proportion of 1 to 8 by weight; and of nothing else. Water is not a mere mixture of these two gases; but it is an entirely new substance formed by the burning of hydrogen and oxygen.

3. **Nitrogen** neither burns nor assists burning. It is mixed with oxygen in the proportion of 4 to 1 by bulk (*i.e.* four gallons of nitrogen to every gallon of oxygen) to form atmospheric air. The mixing of the gases dilutes or weakens the powerful burning properties of the oxygen.

CARBONIC ACID.

We have seen the piece of charcoal (carbon) burn in the jar of oxygen, and you can already tell me that the product of that burning was a new substance (carbonic acid gas). Carbon also burns (or combines with oxygen) in our bodies, but not at a red heat as we saw it in the jar. The burning that goes on in our bodies is a slow combustion at the ordinary temperature of the body. It is important, however, to remember that the burning, in either case, means simply the combination of the two elements carbon and oxygen, and that the product is always carbonic acid.

Its Preparation.—You remember, no doubt, what takes place when we breathe into lime-water. We used this experiment as a test to prove that carbonic acid is given off by the lungs. The carbonic acid combines with the lime which is dissolved in the water, and forms with it another substance—carbonate of lime (common chalk). This chalk is insoluble, and hence may be seen in the water, first clouding it, and afterwards forming a sediment at the bottom.

Chalk, wherever it is found, consists of these two substances—carbonic acid and lime. It is as easy to separate a piece of chalk into its constituent substances—carbonic acid and lime—as it was to make chalk by breathing into a solution of lime.

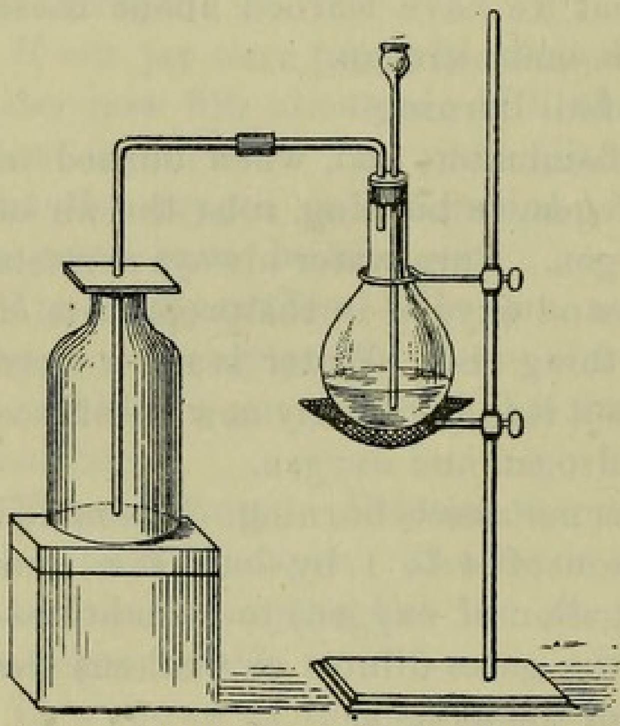


Fig. 5.—Apparatus for the preparation and collecting of Carbonic Acid Gas from chalk or limestone and hydrochloric acid.

Put a few pieces of chalk (marble or limestone will do as well; they are essentially the same substances) into the bottle which was used for the preparation of hydrogen (Fig. 5). Cover them with water, and then add hydrochloric acid (common muriatic acid or spirits of salt) till it begins to effervesce. The effervescence is caused by the rapid passing off of the carbonic acid from the chalk. The reason why the carbonic acid gas is separated, is that the hydrochloric acid has a very strong affinity for the lime. It combines with the lime to form a new substance, *chloride of lime;* and the carbonic acid not being required, is set free.

As carbonic acid is much heavier than air, it may be collected by the downward displacement of the air; *i.e.* by simply letting the delivery-tube dip into the jar. The heavy gas will sink to the bottom of the jar, and gradually fill it, driving the air upwards to make room for itself.

Several jars may be filled with this gas in a very short time.

Its Properties:

Experiment.—1. We will first make sure that we really have carbonic acid in the jars, and not some other gas.

We will use our lime-water test again. The lime-water is perfectly clear and transparent now; it looks like pure water. The lime is there, but we cannot see it, because it is dissolved. Now we will pour the lime-water into the jar of gas, and shake it up well. It at once begins to assume the white milky appearance, and this can happen only in the presence of carbonic acid. The carbonic acid has combined again with the dissolved lime to form insoluble chalk, carbonate of lime.

If now we examine the gas in one of the other jars, we shall find by ordinary observation that it is invisible and colourless, and that it has a slight acid taste and smell.

Experiment.—2. Tilt the jar containing the gas, as though in the act of pouring water from it, and hold another jar below. The gas is so heavy that it will pour from the upper into the lower vessel just like water. If a lighted taper be held between the two jars so that the stream of the gas passes over it, the flame will be at once extinguished, but the gas itself will not take fire.

We learn from this (1) *that carbonic acid is a heavy gas* (it is half as heavy again as ordinary air), (2) *that it extinguishes flame*, and (3) *that it is uninflammable.*

In the two last properties it appears to resemble nitrogen, which, we have seen, also extinguishes flames, without itself taking fire. The resemblance, however, is apparent and not real. We know that by mixing four volumes of nitrogen with one of oxygen, we shall make a gas resembling air, in which burning will readily go on and animals can live and breathe, and that the burning of the flame and the breathing of the animal will not cease until all the oxygen is consumed. That is to say, the burning and the breathing cease only from want of oxygen, and not because the nitrogen itself destroys them.

If, however, we made a similar mixture of four volumes of carbonic acid and one of oxygen, it would immediately extinguish a flame, and breathing would be impossible in it.

Carbonic acid acts as a direct poison in both cases, although there is abundance of oxygen present.

Many fatal accidents have taken place through the practice of burning charcoal in close rooms. The air of the room of course contains plenty of oxygen, but the burning of the charcoal has likewise loaded it with *carbonic acid,* and death has been due to suffocation—the direct poisoning effects of that gas—and not to any want of oxygen.

Ordinary atmospheric air always contains a small quantity of carbonic acid—usually about 4 parts in 10,000. The burning of coal, wood, and gas, (of carbon in fact in any form,) the breathing of animals, and the decaying or fermenting of all organic matter give off carbonic acid into the air.

This gas is also given off in great volumes by volcanoes, and is present in our coal-mines under the dreaded name of choke-damp. The object of ventilation is to prevent the accumulation of carbonic acid in our rooms, schools, workshops, mines, &c., by keeping up a constant current of air, so that the injurious gas may be driven off as quickly as it is formed.

Just one other thought about carbonic acid, and this is a very important one to us in our study of physiology.

This gas is very soluble in water. Water will dissolve, suck up, or absorb its own volume of carbonic acid. That is, a pint of water will hold in solution exactly a pint of this gas.

This explains how it is that the body gets rid of its carbonic acid so easily. The carbonic acid as it is formed is readily sucked up or dissolved in the stream of the blood, and carried away to the excretory organs, to be expelled from the body.

AMMONIA.

You have all no doubt paid the penalty of meddling with your mother's smelling-bottle. You know that the substance it contains gives off a very powerful odour which makes you sneeze, and brings tears to your eyes. The odour belongs to a gas called *ammonia,* which escapes rapidly from the bottle when the removal of the stopper admits the air.

We want now to learn something about this gas—*ammonia.*

Its Preparation.—It may be easily prepared by powdering equal weights of *sal-ammoniac* and *quicklime*, mixing them in a flask, and gently heating with the spirit-lamp (Fig. 6). The gas *ammonia* is rapidly set free, and may be collected in an inverted jar by displacing the air. It is only about half as heavy as air, and therefore at once rises to the highest part of

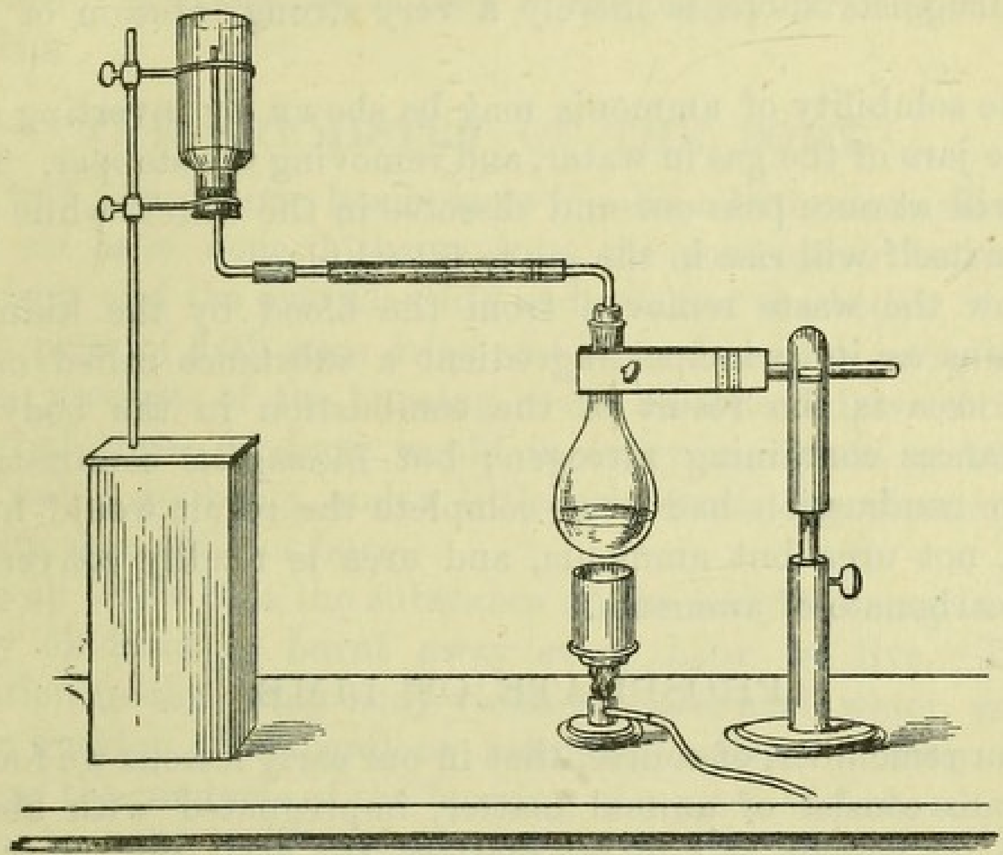


Fig. 6.—Apparatus for preparing and collecting Ammonia Gas from Ammonium Chloride and Quicklime. The collecting bottle is empty and inverted to receive the gas from the delivery-tube.

the bottle, gradually fills it, and drives the air down before it until it flows out at the neck.

This will explain (as far as we require to know) what takes place. The *sal-ammoniac* is a salt consisting of *nitrogen*, *hydrogen*, and *chlorine*. Chlorine has a very strong affinity for lime, and at once combines with it to form another substance, *chloride of lime*, setting the remainder of the combination (nitrogen and hydrogen) free. The **solid salt** thus gives off under the action of heat a combination of the two *gases* **nitrogen** and **hydrogen**, and this combination is the new substance *ammonia*.

Ammonia exists in all decaying animal matter, and all animal excretions. The ancients gave it the name of **spirits** of hartshorn, because they prepared it by a distilling process from deer's horns.

The property of ammonia which concerns us most is its remarkable solubility in water. Water will dissolve nearly 1000 times its own bulk of this gas. The liquid ammonia sold in the druggists' shops is merely a very strong solution of the gas.

The solubility of ammonia may be shown by inverting one of the jars of the gas in water, and removing the stopper. The gas will at once pass out and dissolve in the water, while the water itself will rise in the jar to fill its place.

Now the waste removed from the blood by the kidneys contains as its principal ingredient a substance called *urea.* This urea is the result of the combustion in the body of substances containing nitrogen; but *incomplete* combustion. If the combustion had been complete the result would have been, not urea but ammonia, and urea is readily converted into carbonate of ammonia.

PHOSPHATE OF LIME.

You remember, of course, that in our early lessons we found bone to consist of animal matter, impregnated with about twice its weight of mineral matters, the most important of these mineral matters being phosphate of lime and carbonate of lime. We have lately learned something of the latter of these; it will now be our business to turn our attention briefly to the other substance—*phosphate of lime.*

Phosphate of lime is a combination of the two substances, *phosphorus* and *lime.* You are quite familiar with both these substances. *Lime* is the grayish-white mineral substance used in the preparation of mortar, and *phosphorus* is the peculiar inflammable substance which has to be kept in water to prevent it taking fire. Most soils are more or less rich in phosphate of lime, and this is taken up and assimilated by plants, especially by those whose seeds are used as food. Wheat grains, for example, are very rich in phosphate of lime.

Animals in their turn all live upon vegetable food, either directly or indirectly, for even the flesh-eaters feed upon the bodies of animals, which took their own sustenance and built up their substance from plants. In the animal (man included) these phosphates are used in the formation of brain and bone. The greater part of the ash left after burning a bone consists of phosphate of lime. Phosphorus itself is prepared from this bone-ash. It exists also in milk in the proportion of about 2½ per cent.

THE CHEMISTRY OF THE BODY.[1]

It will now be our business to inquire a little more closely than we have done hitherto into the connection between chemistry and the everyday life and work of the body.

If a piece of flesh were dried and burned in such a way that all the products of the burning could be collected, we should find that these products would in every case yield carbonic acid, water, ammonia, and a little ash, consisting of mineral matters that will not burn.

We all know that the substance of the body is being incessantly oxidized or burnt away every hour we live. This oxidation in the living body yields carbonic acid, water, urea, and a residue of mineral or inorganic matter—exactly the same as the products of the burning of a piece of flesh outside the body, with this exception, that in the body *urea, not ammonia*, is produced. But I have already explained that this is because the burning in the body is not absolutely complete.

Indeed it matters not in what way the body is oxidized, the result is the same. The products of the oxidation are always carbonic acid, water, urea or ammonia, and a residue of mineral matter—*and nothing else.*

The oxidation of the living body produces these; the gradual oxidation or mouldering away of the dead body in the grave, and the rapid burning of cremation also produce them—*and nothing else.*

You, of course, can prove to me that the body gives off carbonic acid and water—the former chiefly by the lungs, and the latter by both lungs, skin, and kidneys.

The urea passes off, as we shall learn by and by, in the

[1] See also pp. 57–59.

urine, which is excreted by the kidneys. Hence you see the first three of these products are easily traceable. Not so the residue of mineral matters. These consist of phosphorus, sulphur, lime, and other elements, which the oxidation has converted into salts—phosphates and sulphates, &c. Salts are soluble in water, and hence these substances at once enter the blood in a state of solution, and are carried away in its stream.

Slight traces of them pass off with the perspiration through the pores of the skin. You may taste the saltness of the perspiration. The greater part, however, leave the system in the urine. Carbonic acid is produced, as we have seen, by the oxidation of carbon; water by the oxidation of hydrogen; ammonia is a compound of the two gases—nitrogen and hydrogen; and urea of carbon, hydrogen, oxygen, and nitrogen.

Hence it is quite clear that, if oxidation of the substance of the body always yields these products, that substance must contain carbon, hydrogen, nitrogen, and oxygen.

As a fact the body is made up of the elements nitrogen, hydrogen, carbon, and oxygen, together with such mineral matters as common salt (chloride of sodium), phosphorus, sulphur, lime, magnesia, iron, &c.

We may for the present disregard the mineral constituents, and confine our attention to the four principal elements.

It must not be supposed that these elements exist in the body in the simple or uncombined state. They form various combinations, but the combinations can take place only through the agency of living structures. Hence the compounds formed by these elements are said to be **organic** substances.

Let me explain. Man and all animals, as we said before, depend, either directly or indirectly, upon plants for their sustenance. Plants live upon the inorganic matter of the soil and air, but they are able from the elements (nitrogen, hydrogen, carbon, and oxygen) derived from these, to build up their own organic structures. Animals (man included) use these organic constituents of the plant as food, and with them build up the still more highly organized structures of their own bodies. But they could not build up their structures from the elements themselves, as plants do. That part of the business is essentially the work of the vegetable world.

The organic matters found in the body are of three kinds:—Proteids, Carbo-hydrates, and Fats.

1. **Proteids.**—We have already become acquainted with these substances in the form of the *fibrin* and *albumin* of muscle, the *ossein* of bone, which on boiling becomes *gelatin*, and the *chondrin* of gristle. Proteids are the chief constituent of muscle, bone, nerve, and blood; and are also found in almost all the fluids of the body.

Proteids consist of all four elements, nitrogen, hydrogen, carbon, and oxygen, usually in combination with a certain amount of sulphur.

The vegetable world supplies proteid food-matters in the form of gluten and legumin; and milk and eggs respectively yield casein and albumin. These directly or indirectly build up the proteid structures of the body; all other substances are useless for this purpose. You all know that as proteids are the only organic structures that contain nitrogen, they are usually termed *nitrogenous substances*.

2. **Carbo-hydrates.**—Under this name we include starch, sugar, and gums. They exist only in small quantities in the body. A sort of animal starch known as *Glycogen* is manufactured in the liver; and sugar is found in various forms in blood and muscle. Carbo-hydrates consist of carbon, hydrogen, and oxygen only. These substances abound in the vegetable world. We have already dealt with them.

3. **Fats.**—In the substance of the body there are three kinds of fat—*stearin*, a substance resembling tallow; *olein*, an oily fluid like olive-oil; and *palmitin*.

Fats, like the carbo-hydrates, consist of carbon, hydrogen, and oxygen. The reason why the same elements make such totally different compounds is that they are combined in different proportions, and in different ways.

In the carbo-hydrates the hydrogen and oxygen always occur in exactly the proportion necessary to form water; but the fats contain a larger amount of hydrogen.

You know that both the carbo-hydrates and the fats are usually known as carbonaceous substances, carbon being the chief constituent.

These carbonaceous substances are quite useless in the work of building up the tissues, because they contain no nitrogen. They are all highly combustible substances, as we may see by putting a piece of fat on the fire. In the body they serve the purpose of fuel, the burning of which tends to maintain the natural heat and provide the necessary vital force of the body.

MUSCULAR TISSUE—ITS PROPERTIES AND MODE OF ACTION.[1]

We are already familiar with the fact that bodily movement of every kind is brought about by muscular activity. Such movements as affect the limbs and the body as a whole, are performed by muscles which we can see and handle. They form the round, shapely covering of flesh for the bony framework. The whole of the internal organs—those of digestion, secretion, circulation, respiration—perform their functions by muscular activity of another kind, and by muscles which we cannot see. Moreover, we know that we have it in our own power to decide whether we will move our head, our hand, or our foot. The muscles whose duty it is to move them are under the direct control of the Will, and cannot move without orders. We call them *Voluntary Muscles.* But the Will has no power of control over the muscles of the stomach, the heart, the lungs, the kidneys, the bladder, or any of the internal organs. Their work goes on quite independently of the Will. We call these *Involuntary Muscles.*

If the white skin were stripped off from any part of our body or limbs the red flesh beneath would be exposed. This red flesh is muscle. It is sometimes called *Red Muscle.*

The muscles of the internal organs are not red, but white. In fact they are sometimes called white muscle, to distinguish them from the red or voluntary muscles.

The Voluntary Muscles.—A piece of the red flesh from our own body, or from the body of any animal, although

[1] See also pp. 32–37.

apparently a solid mass, would be found to consist of separate bundles or masses of flesh, varying in size and length, and divided off from each other by walls of a loose cellular substance, connective tissue (Fig. 7). Their arrangement is such as to allow every separate bundle the power of independent movement. Each bundle of flesh is a muscle. It is joined to the part of the bony framework to which it belongs, not directly, but by *tendons*. Every muscle has its own set of blood-vessels, arteries, capillaries, and veins, and its own lymphatics, and nerves. It is the blood in these vessels that gives the muscle its red appearance. The vessels and nerves, on their way to other parts of the body, do not pass through the muscles themselves, but through the connective tissue between them. Each muscle is enveloped in its own sheath of connective tissue, known as the *fascia*.

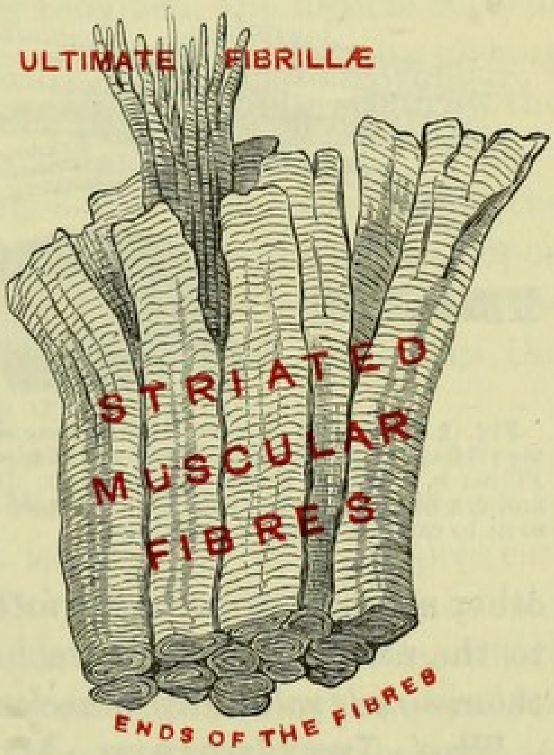


Fig. 7.—Portion of a Voluntary Muscle—showing its plan of structure.

Under the Microscope.—If a piece of one of these voluntary muscles be examined with the aid of the microscope, it is found to consist of bundles of separate fibres, arranged side by side. Each separate fibre is enveloped in a sheath of transparent, elastic membrane, known as the *Sarcolemma* (Fig. 8). The bundle of fibres is known as a *Fasciculus*. If one of these fibres be still further examined under a very powerful microscope, it will be seen to consist of, and can be actually split up into a great number of little fibres—*fibrillæ*

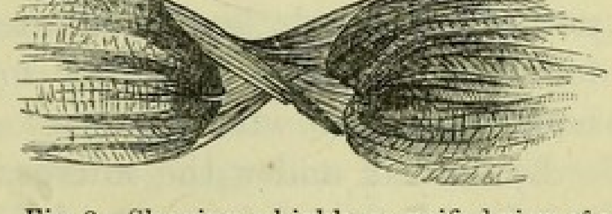


Fig. 8.—Showing a highly magnified view of a fibre of Striped Muscular Tissue, with its inclosing sheath of *Sarcolemma*. In this case the fibre has been torn, and the torn ends separated, but the delicate and elastic sheath still stretches between them.

(Fig. 9). The fibres, too, are seen to be marked cross-wise with dark stripes, and can be separated at each stripe into *discs.*

So then, the *fibrillæ* are bound together in a bundle to form a *fibre,* which is enveloped in its own covering sheath, the *Sarcolemma.* The *fibres* are, in turn, bound together to form bundles, called *Fasciculi,* and they, too, are inclosed in a covering sheath of the same connective tissue.

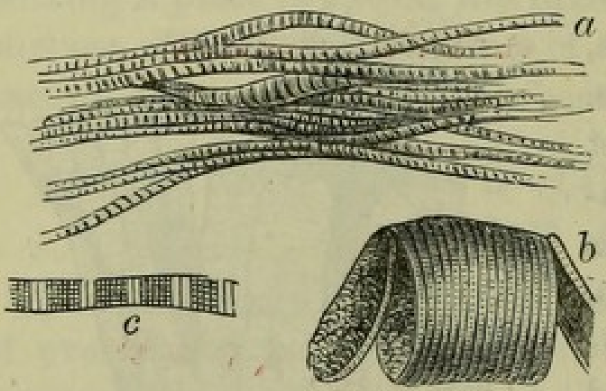


Fig. 9.—Showing a very highly magnified view of A, the Separated *Fibrillæ* of Muscular Fibre; B, a Whole Fibre splitting into discs; and C, a Single Fibrilla very highly magnified, so as to exhibit its cross markings.

The muscle itself is made up of a number of these *fasciculi,* bound together with an outer covering, the *Fascia.*

The cross markings on the fibres of these muscles give them another name of *striped* or *striated* muscles, in addition to the names by which we have already described them—*red, voluntary* muscles.

The Involuntary Muscles.—The white, involuntary or organic muscles surround hollow fleshy tubes, or cavities, and are never attached to bony levers. We might compare them to an india-rubber ring on a roll of paper. Hence they have no need of tough, leather-like tendons, such as are found in the solid *voluntary* muscles. They are never furnished with tendons.

Fig. 10.—A very highly magnified view of a single spindle-shaped cell of Involuntary Muscular Tissue.

Examined under the microscope these muscles are found to consist, not of fibres, but of long, spindle-shaped cells, bound together in such a way as to form bands or ribbons (Fig. 10). They have no sarcolemma; and there are no stripes or cross-markings similar to those of the voluntary muscles. This last fact adds two other names to those we have already given these muscles. We call them *non-striated* (*i.e.* unstriped) and *smooth* muscle.

How Muscles Act.—Muscles perform their work by their own inherent power of contracting. They possess a kind of *irritability*, which under certain conditions causes them to draw themselves together. When the muscle contracts in this way, it not only shortens itself, but at the same time it swells up or thickens, and hardens in the middle. When the cause of contraction is removed, the muscle returns to its former state. This we may note for ourselves by placing one hand on the biceps of the opposite arm while we draw the arm up.

Why the Muscles Act.—We have seen that the muscles act only when some influence is brought to bear upon them. That is to say, there must be something to cause the muscle to act. We call this something which influences the muscle, its *stimulus*. Let us see what this is.

The voluntary muscles are, as we have already seen, all under the direct control of the Will. When we determine to perform a certain movement, it is our Will that compels certain muscles to set to work. The brain is the centre of the Will, and you know that the delicate nerve fibrils, which spread themselves through the muscles, are in communication with the brain. The command then sent down to the muscles from the brain by means of the nerves, becomes the *stimulus*, which sets them in action.

Over the involuntary muscles the Will has no influence at all, and yet these muscles perform their functions. Many of them work incessantly, day and night, sleeping and waking. There must be a stimulus to make them work; and that stimulus reaches them by nerve-fibres, but does not originate in the Will. Thus, the food awaiting digestion in the stomach becomes the *stimulus*, which sets the muscles of the stomach into those wave-like contractions, and enables the organ to churn up whatever it contains. The heart is kept rhythmically beating by the regular discharge of stimuli from nerve-centres which are beyond the control of the Will.

Many actions similar to these are always going on in our bodies without any reference to the Will. The muscles carry on their work under the impulse of their own particular stimuli, and *without our being even aware* of what is going on. When a muscle works it becomes hotter, and the greater the muscular effort, the greater the heat. If the blood were drawn from a vein belonging to that muscle, it would be found to contain a large quantity of carbonic acid, evidently showing that some change had taken place in the composition of the muscle. Some of its substance must have been used up, and burnt with the aid of the oxygen, during the contraction.

After long-continued exertion muscles become tired or exhausted with their contractions. This feeling of fatigue may arise from one or all of the following causes:—

1. The destruction or using up of a large amount of muscular tissue.

2. The accumulation of waste matters in the muscle, produced too quickly for immediate removal.

3. Exhaustion of the nerve power which controls and directs the work.

We know that the feeling of fatigue passes away with rest, and the muscle recovers all its old power; and while we are resting, the blood is pouring in fresh supplies of oxygen and building material.

If such a muscle were deprived of fresh supplies of oxygen and food material, *i.e.* if the blood supply were cut off, it would quickly lose its power of contracting. It would, in fact, become dead. We speak of this as *local death.* The part so affected might be separated from the body without injury to its well-being as a whole, of course provided that it was not in itself a vital part.

The difference between *Local* and *General Death* is this:—*Local Death* is the death of some non-vital part of the body, through interference with its proper nutrition; *General Death* is the death of the body as a whole, as a result of interference with some one or more vital organs.

Thus, for instance, the death of the body as a whole must result the moment the heart ceases to perform its work of blood-pumping. The lungs, in like manner, cannot fail in their work of supplying a sufficient quantity of oxygen to the blood, without seriously interfering with the general nutrition of the body, and death follows. Any sudden interference with the work of breathing causes immediate death. Lastly, a blow on the head may, by injuring the brain, cause it to relax its controlling influence over these two vital organs, the heart and lungs; they cease their work at once; death is the result.

SECRETION.[1]

We have seen that many of the functions of the body, especially those connected with the work of digestion, could not be carried on without the help of certain juices or fluids prepared in the body itself. We have already had occasion to mention some of these fluids, and we know that each has its own distinct characteristics, and differs from all others.

We must now inquire a little further into their nature and properties, and the manner in which they are prepared. In the first place it must be distinctly understood that the blood itself, in every case, supplies the materials from which these various fluids are elaborated; and one fluid differs from another only because different materials have been extracted from the blood for their preparation.

The work of elaborating these fluids is carried on by special organs called **glands.** The process is called **Secretion,** and the organs that do the work are known as **Secretory Glands,** from a Latin word *secerno* = I separate. Each gland *separates* or *sets apart* certain materials from the blood, to be manufactured into a certain fluid *required in the further work of the body.* It is this which distinguishes *secretion* from *excretion.*

The excretory organs, such as the skin and the kidneys, also separate substances from the blood; but only such substances as would be injurious, and *must be cast out of the system* as quickly as possible. Hence the name **Excretion**—*ex* meaning *out of.*

Whatever be the purpose of separating these matters from the blood, whether it be *as a secretion for future use,* or *as an excretion to be cast out,* the process is always the same. It is all done by the activity of living cells.

[1] See also page 46.

The glands themselves may be very simple in structure, or very intricate; but the essential part of their arrangement is always a delicate membrane, having on one side closely-packed cells, on the other the flowing stream of the blood in the hair-like capillary vessels.

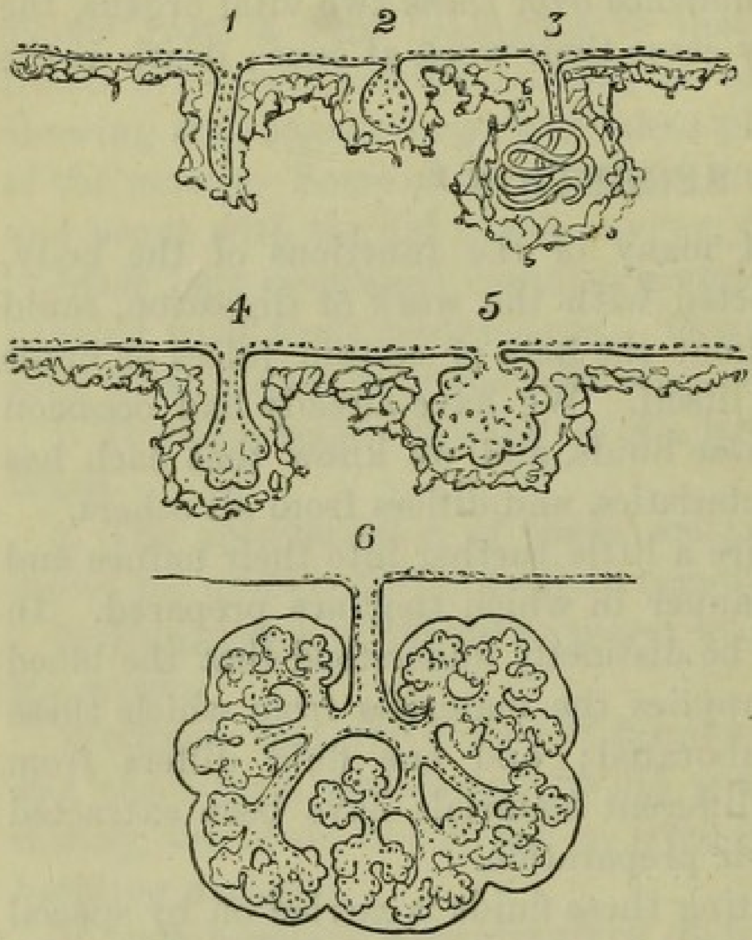


Fig. 11.—Diagrammatic View of the Structure of varieties of Secreting Glands.

No. 1 represents a simple tubular gland; No. 2 shows a modification of this, in which the tube itself becomes a closed hollow sac, with the mouth almost shut; No. 3 represents the coiled tube of the sweat gland; Nos. 4 and 5 show others in which the wall is formed into hollow recesses, to form what is called a sacculated gland; No. 6 represents a racemose gland.

The plan in each is similar. The continuous line represents the membranous wall itself; the dots represent the cells that line the membrane on one side; the broken and irregular markings show the position of the blood-vessels on the opposite side (not shown in 6).

The cells select from the blood only those matters which they themselves require for the elaboration of their own special secretion. That is to say, the Salivary Glands, for instance, never make a mistake, and take up from the blood materials that the liver requires for making bile; nor does the liver attempt to make its bile from materials specially fitted for the elaboration of saliva or gastric juice. All these materials wash the thin membranous walls of the various glands as the blood courses along, but each gland selects only its own.

Each cell having extracted from the blood the necessary materials, becomes a tiny workshop, in which they are worked up or elaborated into the required form. In other words, the fluids do not exude from the blood fully formed, but are prepared in the little cells (Fig. 11).

The simplest form of glands are the **Peptic Glands** of the stomach, which consist of a short, simple tube, dipping down into the substance of the mucous membrane, and opening on the surface. The walls of the tube are lined with cells, and hair-like blood-vessels supply the constant streams of blood whence the cells draw the materials for elaborating the gastric juice.

The **Intestinal Glands**, known as *Lieberkühn's Glands*, from the anatomist who discovered them, are very similar to these. They, too, consist of a simple tube.

In the **Sweat Glands** of the skin we find a more elaborate arrangement. The tube is of considerable length, and coiled up into a ball for the sake of economizing the space.

In the **Hair Glands** (known also as the Sebaceous Glands, from the oily, fatty secretion they prepare for lubricating the hair and skin) the arrangement is again different. Each little gland forms a sort of pouch, with hollow recesses all lined with minute cells.

In the **Salivary** and **Buccal Glands** the arrangement is still more intricate. Instead of single tubes we find a cluster of little sacs or pouches, attached to a central tube or channel, much in the same way as bunches of grapes are attached to the twigs which hold them. Indeed, because of their resemblance to a bunch of grapes they are sometimes described as "**racemose**," from the Latin *racemus* = a bunch or cluster of grapes.

THE LIVER.[1]

Now that we understand something about the nature and work of glands in general, it will be well to turn our attention to the largest gland in the body, the **Liver**, and see how it bears out in its own structure and functions the characteristics that we have already met with in others.

You can tell me that the liver is a large reddish-brown organ, weighing about 4 lbs., and measuring 12 inches in length and 6 or 7 inches inches across; and that it lies immediately under the diaphragm in the upper part of the right side of the abdomen, part of it extending also across the middle line of the body towards the left side.

[1] See also pages 44 and 66.

It has a smooth, convex, upper surface, which fits into the concavity formed by the diaphragm. Its hinder portion is thick, but in front it tapers off to a thin edge (Fig. 12).

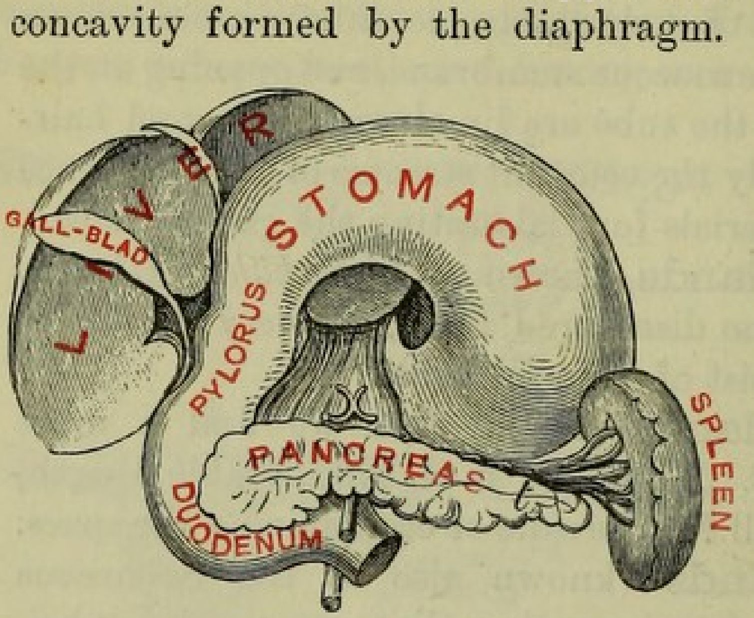


Fig. 12.—Showing the relative positions of the Stomach, Liver, and Gall-bladder, the Pancreas and Spleen.
The stomach is here represented so as to show its *under* surface and the under surface of the liver. The normal position of both will be seen in fig. 29, page 42.

In the sitting or standing position, the thin front edge of the liver reaches just below the bony ridge formed by the edge of the ribs; but when the person is lying down, the dome-shaped diaphragm rises slightly, and the liver passes up, so as to be completely covered by the ribs. It is enveloped and held in its place by a coat of the peritoneum. One of the evils of tight-lacing in women is that, by contracting the ribs, it forces the liver downwards beyond their edges, so that in a short time it becomes permanently displaced, and the other organs in the abdomen and pelvis are crowded together, and become in consequence displaced too.

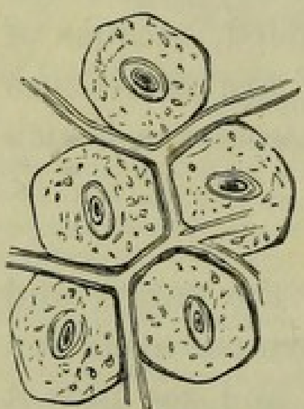


Fig. 13.—Showing Liver Cells, with ducts or channels between them for the secretion of bile, as they appear under the microscope.

You know that, as a secretory gland, the liver is concerned in elaborating bile for the digestion of the fatty matters of the food. In order to understand the secretory functions of the liver, it is necessary to know something of the minute structure of its substance.

If a small piece of liver is examined with the aid of a microscope it is found to be made up of masses of many-sided cells, each cell measuring about $\frac{1}{1000}$ of an inch in diameter (Fig. 13).

Each separate mass or group of cells is called a **Lobule.**

The lobules can be easily seen and separated, if a piece of liver be torn across. The torn edges will be seen to have a coarse granular appearance, showing where the lobules have been pulled asunder. Close examination of one of these lobules proves it to be an irregular, spherical mass, with the cells arranged in it in rows, radiating from the centre to the circumference. Minute hair-like channels separate the cells one from another, themselves uniting into one main duct leading from the lobule.

You already know that the liver makes its bile out of materials drawn from the blood which is brought to it by the Portal Vein. This blood has been collected up from the stomach and intestines by innumerable streams, all of which finally lead into the main trunk, the Portal Vein, and comes to the liver by this great vessel, laden and enriched with nourishing materials obtained from the newly-digested food.

The Portal Vein enters the liver through an opening called the **porta** or gateway, and it is this fact that gives the vessel its name, *porta* being the Latin word for a *gate.*

On entering the substance of the liver, this great vein at once acts as though it were an artery, for it begins to break up and ramify in all directions, sending off smaller and still smaller branches, which at length spread themselves over the surface of the lobules. The final capillary ramifications from these surrounding vessels pass inwards among the cells to the very centre of the lobules, so that this venous blood is distributed through the whole cellular substance. This is the first[1] instance we have met with of a vein assuming the property of an artery in breaking up into smaller and smaller vessels, which reach at last the capillary form.

Now I think I can make it clear that we have in the liver, on an enormous scale, exactly the same conditions as we met with in the smaller and simpler glands.

We find in each lobule multitudes of thin-walled cells, washed on one side by constantly flowing streams of blood, and having on the other ducts or channels communicating

[1] The efferent vessels of the glomeruli of the kidney do the same.

one with another, and eventually uniting into a main channel leading outwards.

It is easy to see what takes place under these conditions. The cells rob the blood of certain materials which it contains; work up these materials into a new fluid, the bile; and then pour out this newly-manufactured article into the little channels which surround them, and whose business it is to carry it off. These little channels are hence known as the **Bile-ducts.**

The Bile-ducts from all the lobules gradually unite and form at last one principal channel, which carries the fluid away from the liver. This is known as the **Hepatic Duct,** from a Greek word *hepas* meaning the *liver*. We shall have to refer to this later on.

The bile thus prepared is a reddish-yellow, slimy-looking fluid, having an extremely bitter, nauseous taste, and a peculiar smell. It will froth up if shaken, and possesses alkaline properties.

You know that soda is an alkali; and we have already had occasion to notice how it acts upon fatty, oily matters. Potash and ammonia are two other common alkalies, and would act in a similar way.

It is the alkaline properties of bile that make it so valuable in the work of digestion. By its aid the fatty matters of the food are rendered capable of being absorbed.

Some idea may be formed of the value of this fluid from the fact that the liver daily secretes almost its own weight of it.

Now let us return to the Hepatic Duct. This, as you remember, is the channel by which the bile leaves the liver. It passes out on the under side of the organ. The liver itself rests upon the right or Pyloric end of the stomach, and the small intestines. The first part of the small intestines is known as the Duodenum, which bends round into a sort of horse-shoe form. Near the middle of the bend the duodenum is pierced obliquely, so as to form an opening or gateway for the admission of a tube about the diameter of a goose-quill. This tube is the end of the Hepatic Duct, and is here known as the

Common Bile Duct. We shall see the reason for the name presently.

This tube has to pass through all the coats of the intestine, and these act as a kind of valve, so as to regulate the flow of bile into the intestine as it is required.

While the partially digested food (chyme) is being sent out of the stomach into the intestine, the walls of the duodenum become very much distended, and this has the effect of widening the opening through which the bile must pass. Thus it happens that at the very time when the fluid is required there is special facility provided for its passage.

When the digestive process is over (for of course this work is periodical and not incessant), and chyme is no longer passing from the stomach to the intestines, the duodenum is empty and its walls collapse. This is sufficient to close the aperture and make the sides of the duct fall together, so that the passage for the bile, which is not now required, remains closed.

The liver, however, does not work at intervals, but incessantly, for the blood is incessantly coursing through it. It is constantly at work preparing bile, and sending it onwards towards the intestine.

We have seen that that which is prepared between meals cannot be made use of because it cannot enter the intestine. What then becomes of it? Let us see.

Communicating with the Hepatic Duct is a smaller tube known as the **Cystic Duct.** This leads back to the undersurface of the liver, where it expands into a sort of bag, about the size of one's thumb. It is capable of holding about two ounces of fluid, and is known as the Gall-bladder. When the valve leading to the intestine is closed between meals, and bile is no longer wanted there, the excess passes upwards by the Cystic Duct and is stored in the gall-bladder till it is required.

Now you can see the reason for the name *Common Bile Duct.* This is the name given to the tube only after the junction of the two—the Hepatic and the Cystic Ducts. This tube becomes the **common** channel for the bile that flows down the **Hepatic Duct** from the liver, freshly manufactured, and that which has been stored up in the gall-bladder, and now comes down the Cystic Duct.

Ox-gall is used to take grease-stains out of carpets, cloth, and other textile fabrics.

You may easily procure it from the butcher's, and examine it for yourselves. If you put the thick greenish fluid into a bottle with some fatty, oily matters and a little warm water and shake it for a few minutes, you will soon see why it takes out grease-stains, and why it is of such importance in the work of digestion. In a very short time the floating particles of fat and the globules of oil will entirely disappear, because the alkaline bile fluid has emulsified them.

We have not done with the liver itself yet. We have seen the great *Portal Vein* entering it through the *porta*, and bringing the raw material, so to speak, to the factory where it is to be manufactured into a new and important fluid—*bile*. But we must not forget that the liver itself, being a great organ intrusted with most important work, requires constant nourishment. Like all other parts of the body it uses up its own substance in carrying out the work which is assigned to it. That substance must be constantly renewed.

Now the blood which comes to it by the Portal Vein, being venous blood, is not fit for the work of nourishing the organ. That work can be done only by arterial blood.

The liver is supplied with arterial blood for the nourishment of its own tissues by a great branch direct from the Aorta, known as the *Hepatic Artery*. This great artery on entering the substance of the liver breaks up into smaller and smaller vessels, which eventually reach the capillary form, and spread themselves round and amongst the lobules. The blood which they bring after performing its office is collected up, laden as it is with impurities, by minute veinlets, which unite again and again until they at last form one great trunk, the Hepatic Vein. This carries the blood away from the liver, and finally discharges it into the *Inferior Vena Cava*.

But we have seen that besides these arterial capillaries there is another set of venous capillaries, the ultimate branches of the Portal Vein, and that these in like manner are spread round and amongst the lobules. What becomes of the blood which they bring after it has been robbed of its bile-making materials? This, too, is collected up by the little veinlets that surround the lobules, and finds its way with the rest into the Hepatic Vein.

That is to say, blood is brought to the liver and distributed through its substance by two distinct channels—the Portal Vein and the Hepatic Artery, but it all leaves the liver by one channel—the Hepatic Vein.

We have hitherto thought of the liver only as an organ of secretion, whose business it is to elaborate bile for further use in the work of digestion. But this is only one of its functions. We must now examine the organ from another stand-point.

Once again it is the blood that supplies the material from which the bile is prepared. This bile is eventually made to serve a useful purpose as a digestive fluid; but the first and great object is to separate and remove the materials of which it is made from out of the blood, because they are a source of harm. The liver, then, purifies the blood by separating from it hurtful matters for the purpose of casting them out of the body. Hence it is an Excretory Organ, as well as an Organ of Secretion.

It is absolutely necessary to remove these matters from the blood before they work mischief; but it is one of nature's surprises that these very ingredients are elaborated, *in the cells of the organ itself*, into a new fluid which has special functions to discharge in the further work of the body, before it is cast out. Bile is found to consist of 86 per cent of water, with about 14 per cent of solid matter. The solid matter may be separated by chemical processes into bile-salts, fats, colouring matter, chloride of sodium, phosphates, traces of iron, and a peculiar crystallized substance called chloresterine.

Now of all these ingredients the bile-salts are the only ones that are of use in the work of digestion, for they act upon fats by dissolving them and forming them into an emulsion. They form the main portion of the solid matters, and as they are never found cast out with the fæces, they appear to be absorbed with the dissolved fats into the stream of the blood again.

Thus it becomes clear that of all the matters separated from the blood by the liver, the bile-salts are the real secretion, and that the greater part of the rest is mere excretory matter, destined only to be expelled from the system. Just a few words now upon another and very important function of the liver.

If immediately after an animal has been killed, the liver be removed and thrown into boiling water, it is found that the water in a short time assumes a cloudy milky appearance. Something has been given out to the water from the substance of the liver. It is possible by proper methods to extract this substance from the water which contains it, and it is then found to be a substance resembling starch. It is known as **Glycogen**, and also as **Animal Starch.**

Its chief property is its strong tendency to change into sugar in the presence of any animal ferment. A little saliva added to the milky-looking water containing this substance will at once convert the insoluble starch into soluble sugar, and the water will become clear again as the sugar passes into solution. The sugar formed from *glycogen* is known as **Glucose** or **Liver Sugar.**

If the liver be removed from the body of a recently killed animal, and water be injected into the Portal Vein until it flows out and is collected at the Hepatic Vein, *glucose* or *liver sugar* will be found in the water.

There is neither glycogen nor glucose in the blood which is brought to the liver by the Portal Vein.

Hence it appears that the liver forms glycogen out of the blood which is brought to it, and stores it up in its cells. The cells further extract, *also from the blood*, some fluid similar to saliva which acts as a ferment, and converts the *insoluble glycogen* into *soluble glucose.* This manufactured glucose passes in a state of solution into the stream of the blood. It is always found in the blood of the Hepatic Vein and the Vena Cava.

EXCRETION.[1]

We have lately been engaged in investigating the nature and work of certain organs—glands—whose duty it is to

[1] See also pp. 39 and 45.

separate from the blood materials for the elaboration of special fluids required in the further work of the body. We call them Secretory Glands, and the work in which they are engaged is known as Secretion.

We now turn our attention to a function somewhat similar to this, in that the object of it is to separate certain matters from the blood, but this time it is only for the purpose of throwing them off from the system before they work mischief. The name for this work is Excretion; and the organs that do the work are known as Excretory Organs.

The lungs perform a most important work of excretion in removing from the blood those elements of the tissues which oxidation has converted into *carbonic acid.* But the lungs are not merely organs of excretion, they are a source of gain to the blood, and hence to the tissues. Their air-cells give up to the blood, in the capillary vessels round them, as an exchange for its carbonic acid, new supplies of life-giving oxygen from the surrounding air.

Then again, we have studied the skin as another cleansing organ. You know that it is engaged, by means of its Sweat Glands, in removing from the blood those materials, in particular, of the worn-out tissues which have been converted into *water* by oxidation. This water, known as Sweat or Perspiration, is cast out from the mouths of the Sweat Glands, on the surface of the skin. *The skin is an organ of excretion.* The watery sweat is removed from the blood only because it would be injurious if allowed to remain. Much of this water passes off from the skin as vapour, and we speak of it as **insensible perspiration.** The average daily quantity that escapes from the skin in this way is about 2 lbs. Active exercise, or increase of temperature, will always be accompanied by increased activity in the Sweat Glands, and the perspiration then becomes **sensible**, *i.e.* it is formed in such large quantities that we become conscious that it is oozing out of the pores, and collecting in drops on the surface of the skin.

The sweat or perspiration is a clear colourless liquid, consisting almost entirely of water. It holds, however, in solution small quantities of inorganic salts, and some traces of urea, and it also carries off with it some carbonic acid, though probably not $\frac{1}{50}$ of the quantity given off by the lungs.

The Sweat Glands, themselves, present exactly the same ultimate structure, as we have already found in the Secretory Glands.

The walls of the coiled tube consist of a delicate membrane lined with cells. The hair-like blood-vessels spread themselves in a dense network round and among the coils, and so there are constant streams of blood washing the thin membranous walls. The work of separating the watery waste from the blood is carried on by the little cells through the fine membrane.

It is important to remember that in addition to its excretory functions the skin has the power of absorption through its pores. We know that fluids and ointments rubbed into the skin quickly disappear. Why do they disappear? They are absorbed through the pores. Sailors, who have been cast away, have alleviated their thirst by keeping their clothes constantly soaked with the salt water, so that it might be sucked up by the pores. In the ordinary way the skin, by means of its pores, takes in or absorbs oxygen from the surrounding air, although in much smaller quantity than the lungs.

But our present business is with the excretory functions rather than with those of absorption.

Carbonic acid and water, as we have seen, are not the only substances produced by the oxidation of the tissues. The decomposition of the nitrogenous proteid matters of the body yields the equally important waste-matter **urea**; and this must be rapidly excreted or thrown off from the system, or death will be the result.

The kidneys are intrusted with the special work of removing and expelling the waste nitrogenous products. They separate these materials in the form of a liquid, the **urine**, water being again the predominant excretion, and holding the solid matters in solution. Just as in their ultimate structure all these excretory organs resemble each other, so do they resemble one another in the substances excreted. Water, carbonic acid, and urea are given off by both skin and kidneys (though the quantity of urea given off by the skin is very small), and the lungs give off carbonic acid gas, water, and traces of ammonia. The three organs differ chiefly in the relative quantities of each which they expel.

Water, in all of them, forms the main constituent by weight; the lungs give off most gaseous matter; and most of the solid matter passes off through the kidneys.

The skin occupies a sort of middle position between the lungs and the kidneys. Like the lungs it sends out carbonic acid and water, and absorbs oxygen; but, like the kidneys, it also excretes urea, and certain saline matters in solution.

The skin is so closely connected with the kidneys in its functions, that the work of the two organs seems to be, to a certain extent, interchangeable. Thus, in hot weather when the sweat glands of the skin are thrown into more active exertion, the excretion by the skin increases and that of the kidneys diminishes. In cold weather, on the other hand, the reverse of this takes place. The skin works less, and consequently more responsibility is thrown upon the kidneys.

THE KIDNEYS.[1]

These two important organs are situated in the abdomen, one on each side of the vertebral column. They are placed between the upper lumber vertebræ and the top of the haunch bone. They lie close against the back wall of the chamber, and are embedded in fat. In front of them lies the convoluted tube of the intestinal canal. The liver is situated above the right kidney, and the spleen above the left.

In shape, colour, and general appearance the human kidney is exactly the same as that of a sheep or a pig. It is about 4 inches long, 2 inches across, and 1 inch thick; and weighs about 5½ ounces. The hollow or concave side of the kidney is turned inwards, and the convex side outwards to the right and left (Fig. 14).

The middle of the concave side of each kidney (known as the **Hilus**) forms the entrance into the organ. Through this

[1] See also pp. 45 and 46.

passes into the substance of each a branch artery (the **Renal Artery**) from the main arterial trunk—the Aorta, which extends downwards through the abdomen in front of the vertebral column. Passing outwards from each through the same channel is another large blood-vessel, which, on being traced, will be found to be in connection with the Inferior Vena Cava. This is the **Renal Vein**. The blood brought to the kidney by the Renal Artery is collected up again and carried away into the circulation by the Renal Vein.

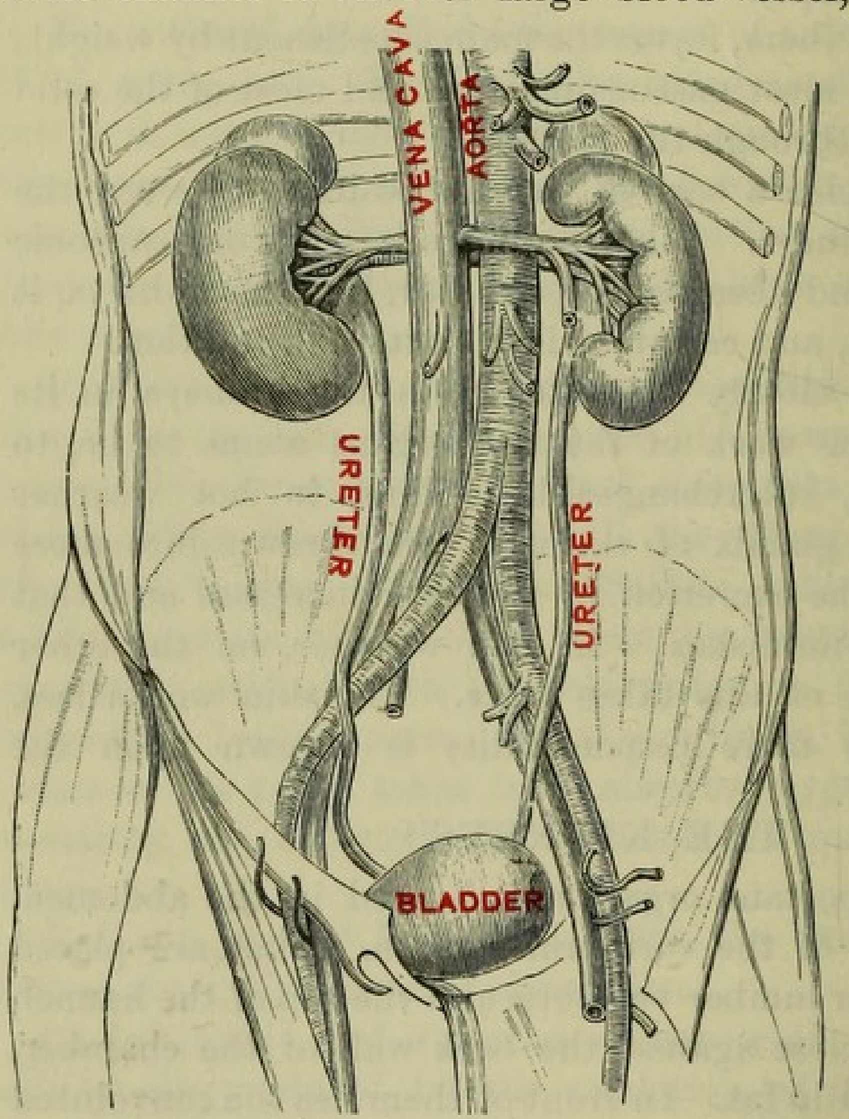


Fig. 14.—Showing the Kidneys and the vessels in connection with them.

In addition to these blood-vessels, a long tube, the **Ureter**, passes out through the Hilus of each kidney, and proceeds downwards to the **Bladder**,[1] which is situated in the basin of the Pelvis. These tubes convey the urine from the kidneys to the bladder.

The bladder is merely a receptacle or reservoir to receive the urine from the ureters until a certain quantity has accumulated, and gives rise to the uneasy sensations which demand its discharge. It is an oval or pear-shaped bag, and lies in front of the termination of the large intestine. When full the

[1] See also p. 46.

bag presses against the pubic bones in front, and it is this pressure which gives rise to the painful sensation, and causes the voluntary effort by which the contents of the bladder are discharged.

The bladder itself has three distinct coats, a tough fibrous outer layer, a middle one of unstripped muscular fibre, and a smooth lining of mucous membrane.

The ureters open into the bladder side by side, and on the hinder and lower part of the bag. They are from 16 to 18 inches in length, and about the diameter externally of a goose-quill, although the bore or channel itself is very small.

The urine is conveyed from the kidneys to the bladder by the same peristaltic or wave-like motion of the walls of the ureters, as we have already become familiar with in the gullet and the intestine; and it passes along drop by drop, as it filters from the kidneys, and not in gushes or streams, and so accumulates gradually in the bladder.

The ureters enter the walls of the bladder obliquely, so that while the fluid passes easily from them into the bladder, the return passage from the bladder into the ureters is effectually blocked.

In the lower, small end, or neck of the bladder (the stalk end of the pear) is an aperture leading into the canal (the **Urethra**), by which the receptacle itself is brought into communication with the outside of the body.

Round the neck of the bladder, where it joins the urethra, is a strong muscular ring termed the Sphincter Muscle of the bladder. This muscle is usually in a state of contraction, and so the outlet from the bladder is kept effectually closed. Immediately, however, the walls of the bladder contract for the purpose of expelling the urine, the Sphincter Muscle relaxes, and thus the channel is open and free for the discharge of the fluid.

We must now examine more particularly the kidneys themselves, and find out the mode by which they excrete the urine from the blood.

If a kidney be cut open lengthwise the section will show something of the appearance represented in Fig. 15. The upper end of the ureter will be seen to widen out into a basin-like hollow, which is known as the **Pelvis** of the kidney; and all round the walls of this hollow basin will be seen projecting a number of conical masses of the fleshy substance of the kidneys. There are about twelve of them in all. These are known as the **Pyramids of Malpighi,** from the name of the anatomist who first discovered them, and learnt their functions. The summits of these cones are crowded with multitudes of minute openings or pores, and these pores are actually the mouths of exceedingly fine tubes (*tubuli uriniferi* = urine-carrying tubes). There are such multitudes of these tubes that the whole of the fleshy substance of the kidney is chiefly made up of them.

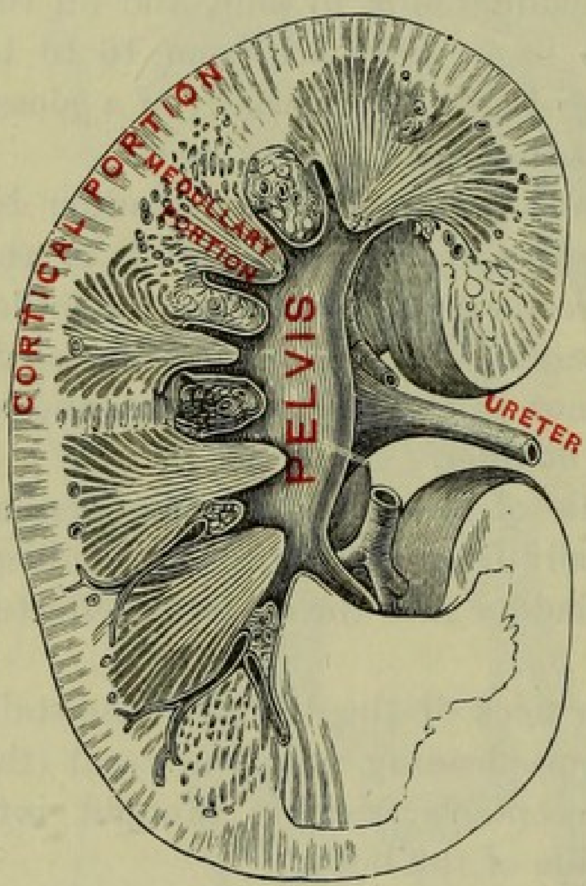


Fig. 15.—Showing the Section of a Kidney cut through in the direction of its length.

From their openings on the apex of each pyramid, these tubes at first pass through the substance of the kidney in straight parallel bundles; but as they near the outer convex surface, they wind about, and twist, and interlace in a remarkable manner, ending at last in a blind dilated pouch or capsule. The change from the straight parallel tubes to the twisted interlacing ones can be readily seen with the naked eye in the section of the divided kidney. These tubules are about $\frac{1}{600}$ of an inch in diameter, *i.e.* it would take 600 of them set side by side to measure an inch across.

The central parts, from the pyramids outwards, with their straight parallel tubes, are usually know as the **Medullary** portion of the kidney; the external part round this is called the **Cortical** part, from the Latin *cortex*, which means *the* *bark.* It is the outer coat of the kidney, just as bark is the outer coat of the tree.

The dilated pouches or capsules which form the ends of the tubes give the cortical part a granular appearance, and a darker aspect than the rest of the section. These pouches are known as the **Malpighian Capsules** (Fig. 16). It is in them that the real work of separating the urine from the blood commences.

Into each capsule passes a small blood-vessel—one of the final branches of the Renal Artery, which we have already mentioned. In the capsule it immediately breaks up into a bunch of looped capillary vessels, which nearly fill the entire cavity, and form a sort of ball, known as the **Glomerulus.**[1]

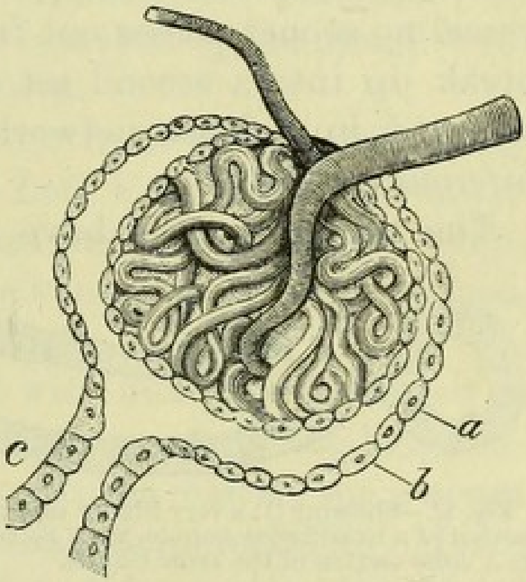


Fig. 16.—Very highly magnified view of a Section of a Malpighian Capsule, showing the cell-lined wall of the dilated capsule *a*, *b*, *c*, and its tubule; and the blood-vessels of the capsule itself. The larger tube is the incoming vessel; the smaller is the outgoing one.

The capillary vessels of the glomerulus eventually reunite and form a single vessel, the outlet from the capsule. It is a very curious fact that this outgoing vessel is smaller than the artery that enters the capsule. That is to say, the wide supply artery is constantly bringing an abundant flow of blood to the glomerulus; but the narrowness of the outlet forms an obstacle to its equally rapid escape.

The result of this is clear. The blood accumulates in the capillaries, and presses with unusual force on their thin delicate walls, and the pressure causes a kind of filtration of the watery fluid parts of the blood to take place. The liquid oozes through, and passes into the capsule.

It is important to remember that the capsules are merely the blind, dilated, pouch-like ends of the uriniferous tubules; and that these tubules eventually open on the surface of the

[1] The capsule with its glomerulus is known as a Malpighian Body.

Pelvis in the middle of the kidney. Hence the fluid as it filters through into the capsule passes down the tubule, and ultimately finds its way into the basin-like Pelvis, and so into the Ureter.

Now, let us return once more to the little blood-vessel that leaves the capsule, and carries away the blood which it has collected up from the capillaries of the glomerulus. This vessel no sooner passes out from the capsule, than it begins to break up into a second set of capillaries, and these are distributed in a dense network all over the walls of the *uriniferous tubules.*

The tubules, as we have already noticed, wind and twist about in many convolutions, probably for no other purpose than to increase the length of the tubes. Their walls consist of an extremely delicate membrane, lined with large working-cells, and all round them are the still thinner-walled capillary vessels, through which the blood is coursing (Fig. 17). We have here simply a repetition of what we have so frequently met with in all the secretory glands. The blood, which has already given up in the capsules the watery fluid part of its waste, now loses, by the activity of the cells of the tubules, its other waste-matter, and the cells work them up and pass them on into the tubule. Here they enter the watery stream which has already filtered through, and the whole flows onward to the Pelvis, as urine. The capillaries from the walls of the tubules afterwards unite into larger and larger vessels, and eventually form a large vein, the *Renal Vein,* which passes outwards from the kidney by the Hilus to join the Inferior Vena Cava. It is by this channel that all the blood finally leaves the kidney to pass into the course of the circulation through the system. We see from what has been said, that the work of excreting urine from the blood is a twofold process:—(1) The fluid portion of the urine is separated from

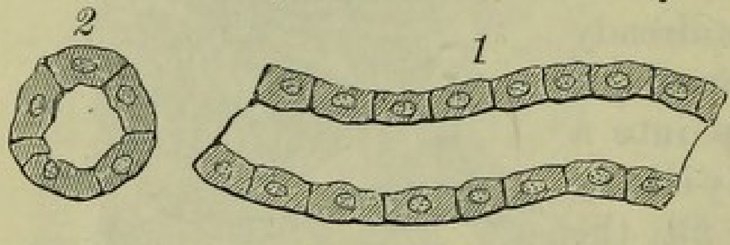


Fig. 17.—Showing (1) a very highly magnified view of a section of a uriniferous tubule, with its cell-lined walls. (2) A cross section of the same tubule.

the blood by a filtering process through the thin walls of the capillaries in the Malpighian Bodies; (2) The more solid constituents are secreted and worked up like all other secretions, by cell action, and this cell action goes on, not in the capsules, but throughout the entire length of the winding tubules.

Now let us compare the blood which enters the kidney by the Renal Artery with that which leaves it by the Renal Vein on its way to the Inferior Vena Cava.

The Renal Artery springs direct from the Aorta shortly after that great vessel leaves the Left Ventricle of the heart. The blood in the Left Ventricle has just come from the lungs. It was brought to the heart by the venæ cavæ as venous blood, and sent to the lungs to be purified.

This venous blood was charged with nitrogenous as well as carbonaceous waste, but the cleansing power of the lungs extends only to the removal of carbonaceous matter, the amount of nitrogenous matter removed being inappreciable. Hence the blood sent out by the Aorta, and from it to the Renal Artery, although cleansed from carbonic acid, is still charged with urea and uric acid.

These nitrogenous matters are removed as we have seen, in the kidneys, and thus it happens that the blood which leaves these organs by the Renal Vein is the purest blood in the body.

The nature and composition of urine may be seen from the following table from Vogel:—

1000 parts (pints, gallons, &c.) of **Urine** contains				
958	„	(„	„)	of **Water** and
42	„	(„	„)	of **Solid Matters.**

The quantity and composition of the urine excreted daily are not always the same. They vary in different periods of the day. They vary with the temperature and moisture of the atmosphere. (In cold damp weather, when perspiration by the skin is to a great extent checked, the kidneys expel most urine.) They vary with the full or empty condition of the stomach, and also with the nature of the food.

These 42 parts of solid matters are made up as follows:—

Urea, ...	23·3	parts.
Uric Acid, ...	0·5	„
Chloride of Sodium (Common Salt),	11·0	„
Phosphoric Acid, ...	2·3	„
Sulphuric Acid, ...	1·3	„
Earthy Phosphates, ...	0·8	„
Ammonia, ...	0·4	„
Free Acid, ...	2·0	„
Total, ...	42·0	„ (nearly).

The chief of all these solid constituents is the substance Urea.[1] It is, as we have already said, an organic substance, and contains all four elements, nitrogen, hydrogen, carbon, and oxygen, half its entire weight consisting of nitrogen. This substance, urea, is the product of the ultimate decomposition of all the nitrogenous or proteid matters which enter the body, just as carbonic acid is the product of the carbonaceous matters, starch, sugar, gum, and fats.

Uric Acid contains the same elements, but in a less advanced stage of decomposition than in urea. In healthy human urine the quantity of uric acid as shown in the table is very small. But in certain fevers and other diseases, when the kidneys do not perform their proper functions in fully developing the *urea*, the quantity of uric acid becomes abnormally large. It then frequently forms deposits round the joints, and gives rise to rheumatism and gout; or it may be deposited in the kidneys or bladder, and produce a dangerous disease known as "stone."

One property of uric acid is its greater solubility in hot water than in cold. This explains why, when it is present, it may be seen as the urine cools in the form of a brick-red sediment.

ALIMENTATION.[2]

Our earlier study of work, waste, and repair in the body may now be supplemented with the following tables as given

[1] See also p. 57. [2] See also pp. 57–62.

by Professor Huxley. He assumes the average weight of a man to be 154 lbs., made up of:—

Muscles and their appurtenances,	...	68 lbs.
Bony Skeleton,	...	24 „
Skin,	...	$10\frac{1}{2}$ „
Fat,	...	28 „
Brain,	...	3 „
Organs and Vessels in Thorax,	...	$2\frac{1}{2}$ „
Organs and Vessels in Abdomen,	...	11 „
Total,	...	147 „

The above computation leaves a deficit of 7 lbs., which would be made up by the blood that would drain away from the body. This does not mean to state that the total quantity of blood in the body is 7 lbs., for a considerable quantity would always remain in the vessels, and that would be included in the weight of the various tissues mentioned above.

The total quantity of blood in the body is usually given as about $\frac{1}{13}$ of its entire weight. For such a body as we have taken, therefore, this would mean about 12 lbs.

This total of 154 lbs. consists of only 66 lbs. of solid matter; the remaining 88 lbs. being water.

The solids, as we have already seen, consist of Proteids, Fats, Carbo-hydrates (or Amyloids) and minerals. They are made up of about fourteen different elements; chief among them being nitrogen, hydrogen, carbon, oxygen, sulphur, phosphorus, chlorine, potassium, sodium, calcium, and iron.

Taking first the work and waste in such a body during 24 hours, it is found that the losses would be by—

	Water.	Solid Matters.	
Lungs, ...	5,000 grains.	12,000 grains.	
Kidneys, ...	23,000 „	1,000 „	
Skin, ...	10,000 „	700 „	
Fæces, ...	2,000 „	800 „	
	40,000 grs. (about 6 lbs.)	14,500 grs. (about 2 lbs.)	= Total, 54,500 grs.

The 14,500 grains (or 2 lbs.) of solids contain in addition to other matters 300 grains of nitrogen, and 4000 grains of carbon given off by—

	Nitrogen.		Carbon.
Lungs, ..	—	...	3300 grains.
Kidneys, ...	250 grains.	...	140 „
Skin, ...	10 „	...	100 „
Fæces, ...	40 „	...	460 „
Totals,...	300 „	...	4000 „

Evidently, therefore, if such a body is neither to lose nor gain in weight, it must be supplied with a daily quantity of *nitrogen* 300 grains, and *carbon* 4000 grains. These quantities of the two essential elements would be found in combination with other matters in—

Proteids, ...	2,000 grains.
Fats,...	1,200 „
Carbo-hydrates (Amyloids), ...	4,400 „
Minerals, ...	400 „
Water, ...	36,500 „
Total, ...	44,500 „

This leaves a deficit of 10,000 grains short of the daily waste (54,500 grains), which would be supplied by the amount of oxygen taken in from the atmosphere.

The 44,500 grains of solid and liquid matters might be supplied by—

Lean Meat, ...	5,000 grains.
Bread, ...	6,000 „
Milk, ...	7,000 „
Potatoes, ...	3,000 „
Butter, ...	600 „
Water, ...	22,900 „
Total, ...	44,500 „

Professor Huxley further calculates that in such a person the heart would beat 75 times a minute, and that the amount of blood propelled at each stroke of the pump would be from 5 to 6 cubic inches.

The flow of the blood in the great arteries would be about 12 inches per second, and in the capillaries from 1 inch to $1\frac{1}{2}$ inches per minute. The time taken in making the complete circuit would be about 30 seconds.

Respiration would proceed at the rate of 15 times a minute, and during the day about 350 cubic feet of air would pass through the lungs. Such air would lose from 4 to 6 per cent of its oxygen, and gain from 4 to 5 per cent of carbonic acid.

The total amount of oxygen consumed would be, as we stated above, 10,000 grains.

The total amount of carbonic acid exhaled would be about 12,000 grains, and this quantity would contain the 3300 grains of carbon given in the above table. The daily respiration would vitiate 1750 cubic feet of pure air by adding to it 1 per cent of carbonic acid; and therefore, in order that the surrounding air might not become overloaded with carbonic acid, such a man ought to have at least 800 cubic feet of space, and that should be well ventilated.

APPENDIX.

EXTRACT FROM THE DIRECTORY OF THE SCIENCE AND ART DEPARTMENT.

SYLLABUS OF REQUIREMENTS IN ANIMAL PHYSIOLOGY.

FIRST STAGE OR ELEMENTARY COURSE.

Questions will be confined to the under-mentioned points in the elements of anatomy and physiology.

With the exception of the characters of the corpuscles of the blood, no information upon points of structure needing the use of the compound microscope is required for this stage. The information demanded under "Chemical Preliminaries" must be precise, but no further chemical knowledge will be required.

No candidate will be allowed to pass who makes gross errors in the answers to questions relating to the matters enumerated under the headings A., B., C., and D *a.* to D *i.*, inclusively.

A. Anatomical Preliminaries.

The general build of the body.

The form, the position, and the uses of the following parts of the skeleton :—skull, vertebræ, ribs, sternum; scapula, clavicle, humerus, radius, ulna, carpus, metacarpus, phalanges (of the hand); pelvis, femur, tibia, fibula, tarsus, metatarsus, phalanges (of the foot).

The more obvious distinctive characters of integument, mucous membrane, connective tissue, tendon, ligament, cartilage, bone, muscle, and nerve.

The position in the body, and the general form and size, of the following internal organs :—The brain and spinal cord; the pharynx, gullet, stomach, and intestines; the salivary glands, the liver and the pancreas; the posterior nares, the larynx, trachea, and lungs; the kidneys and the bladder; the heart and the great vessels; the spleen; the diaphragm.

B. Chemical Preliminaries.

The characters of the elementary bodies, carbon, oxygen, hydrogen, and nitrogen. The composition of air, water, carbonic acid, ammonia, carbonate of lime, and phosphate of lime.

The chemical elements of which proteid substances, fat, starch, sugar, urea and uric acid are composed.

The results of the combustion of carbon and of hydrogen.

The ultimate chemical products of the decay and putrefaction of the dead body.

C. General View of the Animal Body in Action.

The evidence that the body constantly wastes during life; the nature of the waste products, and of the compensation for waste; the essential characters of food stuffs.

The part played by oxygen in the economy.

The nature and uses of secretory glands.

The physiological properties of muscular tissue.

The modes in which muscles give rise to movements.

The physiological properties of nervous tissue.

The number, position, and uses of the sensory organs.

The general functions of the brain and of the spinal cord.

The maintenance of the erect posture.

Local and general death.

D. Special Physiology.

a. The Circulatory System.—The arrangement of the chambers of the heart and the form and position of its valves. The general differences between arteries, veins, and capillaries. The course of the circulation of the blood; and the reasons why the blood moves in only one direction. The meaning of the beat of the heart, of the pulse in the arteries, and of the jet-like flow of blood from a cut artery. The evidence of the circulation obtainable in the living body.

b. The Blood.—The phenomena presented by blood drawn from the body. The form, size, and structure of the corpuscles of the blood. The general composition of the blood.

c. The Respiratory System.—The obvious differences between arterial blood and venous blood.

How venous blood can be converted into arterial blood out of the body. Where and how venous blood is converted into arterial blood in the body.

In what respects the air which leaves the lungs differs from that which enters them.

The arrangement of the ribs, sternum, and intercostal muscles; the manner in which the walls and the floor of the chest change their position during the respiratory movements. Why air enters the chest during inspiration; why it leaves the chest during expiration. The course of the air, when breathing takes place through the nose. Where and how arterial blood is converted into venous blood in the body.

The conditions which give rise to asphyxia.

d. THE URINARY SYSTEM.—The composition of the urine, so far as its chief constituents are concerned. The structure of the kidney, so far as it is visible to the naked eye. The manner in which the ureters open into the bladder.

e. THE SKIN.—The essential composition of the sweat.

The obvious differences between the dermis and the epidermis.

f. THE LIVER.—The manner in which the blood enters and leaves the liver.

The obvious characters and properties of the bile. The use of the gall bladder.

g. ANIMAL HEAT.—The sources of the heat of the body. The manner in which heat is distributed through the body, and the temperature of the body regulated.

h. THE ALIMENTARY SYSTEM.—The quantity of dry solid and gaseous aliments required daily by an adult man. The classification of food stuffs. The economy of a mixed diet. What becomes of proteid, fatty, amyloid, and mineral food stuffs respectively.

The obvious characters and functions of the salivary, gastric, and pancreatic secretions.

The manner in which nutritive matters are absorbed, and innutritious matters excreted, from the alimentary canal.

i. THE MUSCULAR SYSTEM AND ANIMAL MECHANICS.—The different kinds of levers, with examples of them in the body.

The nature of joints, with examples of ball and socket, hinge and pivot joints.

The structure of muscle, of tendon, and of bone, so far as it can be made out by the naked eye or a simple lens. The mode of attachment of muscles.

k. THE SENSES.—The conditions of sensation. The different kinds of sensation.

The means of measuring the acuteness of the sense of touch in different parts of the body.

The general structure of the organ of smell, and the manner in which its function is performed.

The eyelids, and the manner in which they are moved. The lachrymal apparatus. How tears are formed, and what becomes of them. The form of the eyeball. Such characters of the cornea, the sclerotic, the choroid, the iris, the aqueous and vitreous humours, the crystalline lens, and the retina, as are discernible by ordinary dissection. The comparison of the eye with a camera obscura; the uses of the cornea and crystalline lens. The working of the iris.

The manner in which the movements of the eyeball are effected.

The blind spot. The duration of luminous impressions. Complementary colours.

l. THE NERVOUS SYSTEM.—The structure of the spinal cord, so far as it is visible to the naked eye. The arrangement and the functions of the roots of the spinal nerves. The evidence that the spinal cord is capable of effecting reflex action. The influence of the medulla oblongata upon the respiratory movements.

The evidence that the higher faculties of the mind have their seat in the brain.

The olfactory and the optic nerves; their connection with the brain; and the distribution of their fibres in the nose and eye.

EXAMINATION PAPERS.

GENERAL INSTRUCTIONS.

If the rules are not attended to, the paper will be cancelled.

You may take the Elementary, or the Advanced, or the Honours paper, but you must confine yourself to one of them.

Put the number of the question before your answer.

The value attached to each question is shown in brackets after the question, but a full and correct answer to an easy question will in all cases secure a larger number of marks than an incomplete or inexact answer to a more difficult one.

Your name is not given to the Examiners, and you are forbidden to write to them about your answers.

You are to confine your answers *strictly* to the questions proposed.

The examination in this subject lasts for *three* hours.

FIRST STAGE OR ELEMENTARY EXAMINATION.

1881.

1. Describe the form and appearance of the diaphragm in a dead animal. What regions of the body, and what chief organs does it separate? What structures pass through it? What part does it play in the act of breathing? (16)

2. To what bone is the humerus fitted at the shoulder, and how is the connection effected? To what bone is the femur fitted at the hip, and in what respects does the hip joint differ from the shoulder joint? Why can the arm be swung round so much more freely than the leg? (16)

3. How would you deal with a sheep's heart in order to obtain a clear view of the semilunar valves? What are they like? What happens to them when the vessels contain blood and the heart is in action? (16)

4. What are the appearances presented by the corpuscles of the blood when seen under a microscope? Describe the structure of the colourless and that of the red corpuscles. Mention an important use of the red corpuscles. What are the chief components of the *serum* of the blood? (16)

5. What are the most important proteid food-stuffs? Why can a man live on proteid substances alone, but not on starch alone, or on sugar alone? (9)

6. How does the flow of blood in the arteries differ from the flow of blood in the veins, and what are the causes of this difference? (9)

7. What changes do fats undergo in the alimentary canal? How do they pass from the alimentary canal into the blood? (9)

8. A boy seeing an apple on a tree stretches out his hand to pluck it. What is the general nature and the order of the changes which take place in the nervous and the muscular systems of the boy under these circumstances? (9)

9. What is the retina and where is it situated? What portion of the retina is most sensitive, and what portion is quite unaffected by light? (9)

10. With what bones are the ribs connected, and what is the nature of the connection? How are the ribs moved, and how are the form and the capacity of the chest altered by their movements? (9)

11. When a long bone, such as the femur, is taken from the body, how do its ends and its interior (shown when it is sawn lengthways) differ from those of the same bone after maceration, as in an ordinary skeleton? (9)

12. What is the general structure of the liver? Whence does it receive its blood, and whither does its blood go? (9)

1882.

1. What is the oesophagus or gullet? Where does it begin, where does it end, through what part of the body does it pass, and what structures lie behind and in front of it? What is it made of and what is its use? (16)

2. How can you prove that the air which you breathe out differs from the air which you breathe in? State exactly what the differences are and what gives rise to them. (16)

3. Describe as exactly as you can how the blood moves in your own arm. How do you *know* that it does move as you say it does? (16)

4. What is the shape of the lower jaw-bone? How is it fastened to the skull? How is it moved when you open and shut your mouth? (16)

5. How does the small intestine join on to the large one? Where would you place your hand if you wanted to press upon their junctions in your own body? What is the condition of the contents of the small intestine when they are just ready to pass into the large intestine? (9)

6. What do the kidneys look like? Where are they placed? What is their use? (9)

7. What does a nerve look like in a dead body? What is it made up of? If by accident you were to cut one of the chief nerves of your own arm (such as the ulnar) right through, what would happen? (9)

8. Of what chemical elements is sugar composed? How does it differ from fat? How do they both differ from lean of meat? (9)

9. What is the pupil? What makes it grow small in a bright light and large in a dim light or in darkness? What is the use of this change in size? (9)

10. What does venous blood look like, and what does arterial blood look like, and in what other respects besides colour do they differ from each other? If you cut into a large blood clot which is bright red on the outside, you will find it dark within, how is this? (9)

11. What are the chief differences in appearance, structure, and properties between a muscle and its tendon? (9)

12. If you tie a string moderately tightly round your finger the end of the finger will become swollen and dark; but if you were to tie the string from the first *very* tightly, the end of the finger would be pale and cold. Explain how this is. (9)

1883.

1. How many ribs have you? Where are they placed? How do they move? What moves them? What purpose is served by their moving? How do the lower ribs differ from the upper ones? (16)

2. When you cut open a large vein and see the valves, what do they look like? Describe a simple method of proving on your own body how the valves of the veins act. What is the use of the valves, and what would happen if the valves of the veins of the leg were absent or did not act? (16)

3. What do you understand by the abdominal cavity? How are its walls formed? What part of the alimentary canal is placed in it and what is not? What is the general disposition of that part of the alimentary canal which lies in the abdominal cavity? (16)

4. Of what chemical elements is the fat of meat composed? Of what chemical elements is the lean of meat composed? Why is it possible to live on the lean of meat alone, but not on the fat alone? And why is it best to eat both lean and fat? (16)

5. When a man gets a large piece of meat in his windpipe, he is choked, and when he goes into foul air, such as "choke-damp," or is shut up in a confined space, he is also choked or suffocated. What is the immediate cause of the choking or suffocation which takes place in both these cases? (9)

6. What is the pulmonary artery? Where does it start from and where does it lead to? Describe carefully the appearance of certain

structures which may be seen in it just as it springs from the heart. (9)

7. Of what two parts is the skin composed, and how do they differ from each other? What are the most important uses of the skin, and what are the structures in the skin which correspond to these uses? (9)

8. Several large arteries are spread over the stomach and intestines, and break up into capillaries in the walls of those organs. By what course does the blood get back from those capillaries to the right side of the heart? (9)

9. When any one cries where do the tears come from? Are tears produced when one does not cry, and if so why are they not seen? (9)

10. What is gastric juice? Where and how is it formed? Of what use is it in digestion? (9)

11. The blood flows through a muscle along blood-vessels, arteries, capillaries, and veins, all closed tubes, and yet the blood nourishes the muscular fibres which are outside these blood-vessels. How does the nourishment then get from the blood-vessels to the muscular fibres? (9)

12. You can move your fingers and you can feel with your fingers. Instances of injury or disease have been met with in which the power of movement in the arm has been lost and yet feeling has remained, and others in which feeling has been lost and yet the power of movement has been retained. State what parts must have been affected by the injury or disease in these cases. (9)

1884.

1. What is a capillary? About how wide is a capillary? In what parts of the body are capillaries found? What changes does the blood undergo in the capillaries of the lungs? What changes does the blood undergo in the capillaries of a muscle? (16)

2. How is the skull fastened on the spinal column? How are the movements of turning and nodding the head brought about? Why does a man nod when he goes to sleep sitting up? (16)

3. Where is the mitral or bicuspid valve placed? Where are the aortic semilunar valves placed? How does the mitral valve differ from the aortic semilunar valves in structure and action? (16)

4. What food-stuffs are present in each of the following articles of food:—a slice of bread and butter, a basin of porridge, a mutton chop, a boiled potato, a glass of milk, a boiled cabbage? One kind of food-stuff differs in a most important particular from all others. What is that kind of food-stuff, and what is that important particular? (16)

5. What is the sternum, and what is it made of? How are the bony ribs connected with it? In what way does it move during breathing? (9)

6. What is it gives to blood its redness? Suppose you were able to remove from blood all the red corpuscles, without otherwise

changing it, what kind of fluid would be left behind? *i.e.* What would the fluid look like and what would be its chief properties? (9)

7. What is the large intestine? Where is it placed? Where does it begin and where does it end? What changes does the food undergo in it? (9)

8. What does fresh bile look like? Where does it come from and where does it go to? What are its uses? (9)

9. What is the crystalline lens? Where is it placed? Sometimes the crystalline lens has to be removed; what difference does its removal make to the power of seeing? (9)

10. Explain what is meant by the roots of spinal nerves. How may it be proved that the two roots of a spinal nerve have different functions? (9)

11. Describe the various movements which make up the act of walking. Explain why the top of a man's head moves up and down as he walks. (9)

12. Very often when your leg is kept for a long time in one position it "goes to sleep." What is the position which we thus call "going to sleep," and how is it brought about? (9)

1885.

1. What is the shape of the human thorax or chest? What structures form its walls? Name all the important organs which are contained in it, and state the position of each. (16)

2. In what important respects does the blood in the pulmonary veins differ from the blood in the pulmonary artery? Describe the structures in which the bronchial tubes end, and explain how these structures are adapted for bringing about the above differences. (16)

3. Describe what is seen when the right auricle of the heart is laid bare in a sheep's or bullock's heart, and give an account of the walls of the auricle, and of the position and characters of the several openings leading into and out of the auricle. Why does the blood not flow back into the veins when the auricle contracts? (16)

4. Describe carefully the form and position of the stomach. Of what structures are the walls of the stomach composed? What parts of an ordinary meal are digested in the stomach, and what parts are digested elsewhere? (16)

5. Of what parts is a tooth composed? How do these parts differ from each other? How is a tooth fastened into the jaw? (9)

6. What is the position of the kidneys, and what is their general structure? What changes take place in the body when the kidneys are so injured or diseased that they are no longer able to secrete urine? (9)

7. In what parts of the body are no blood-vessels found? How are these parts nourished? (9)

8. What is the medulla oblongata? Where is it placed? Why does an animal generally die when the medulla oblongata is seriously injured? (9)

9. In what parts of the body is connective tissue found? What does it look like when examined by the naked eye, and what does the microscope show it to be composed of? (9)

10. What, in speaking of the eye, is meant by the "blind spot"? How may its existence be shown? What conclusions may be drawn from its presence? (9)

11. What is the thoracic duct? Where does it end? What does it contain after an ordinary meal? What does it contain when no food has been taken for some time? (9)

12. Sometimes persons are killed by sleeping in a close room in which a charcoal stove is burning. What is it in such a case which kills them? (9)

1886.

1. About how much air do we take into the chest at a breath? What makes it go in? What makes it come out? What is the effect on the lungs of trying to take a deep breath, if, while trying to take it we keep the nose and mouth tightly closed? (16)

2. What is the composition of fat, and how does it differ from that of sugar? What is meant by the digestion of fat? Where and how does it take place? (16)

3. Of what parts is the wrist-joint made up? How do the movements of the hand which you can make at the wrist-joint differ from those of the foot which you can make at the ankle-joint, and why? (16)

4. How, in a living body, does the blood flow from a cut artery; and how from a cut vein? Why is the flow different in the two cases? How can you best stop the bleeding from a cut artery, and how from a cut vein? (16)

5. What is a muscular fibre? About how big is a muscular fibre of one of your own muscles? Explain how muscular fibres are built up into an ordinary muscle. (9)

6. How does the arrangement of the blood-vessels and the circulation of the blood in the liver differ from the arrangement of the blood-vessels and the circulation of the blood in a muscle? What purpose is served by the peculiar blood supply of the liver? (9)

7. Where is the spinal cord placed? Where and how does it end above and below? What can you learn concerning its structure without using a microscope? (9)

8. How does the upper part of the cavity of the nose into which the nostril leads differ from the lower part? What different functions are performed by the two parts? (9)

9. Of what two distinct parts is the skin made up? How do they differ from each other in structure, and what are the chief uses of each part? (9)

10. What is saliva? Where and how is it formed? What are its uses? (9)

11. Explain how it comes about that your body has about the

same temperature on the hottest day in summer and the coldest day in winter. What is that temperature? (9)

12. When a body has been buried for some time nothing is left but the bones. Why have all the other parts disappeared, and what has become of them? (9)

1887.

1. Where is the tricuspid valve placed? What is its form and structure? Describe how it appears when seen in a sheep's heart. Explain how it works in carrying on the circulation of the blood. (16)

2. Where is the diaphragm placed? What important organs touch it on the one side, and what on the other? What structures pass through it, and through what part of it do they pass? What are the two kinds of tissue of which it is mainly made up, and how does each of these act in carrying on the work of breathing? (16)

3. Where does the small intestine lie? Where and how does it begin, and where and how does it end? What is the general structure of its walls? What changes does food undergo in the small intestine? (16)

4. What parts go to form the elbow-joints, and how are they arranged to form that joint? How is it that we are able to move the forearm on the arm in one way only, and that to a certain extent only? (16)

5. What is the colour of venous blood when it flows from a vein, as for instance when a man is bled in the arm? What is the colour due to? If venous blood were spread out in a thin sheet over a large surface, would it change colour? If so, why? (9)

6. What is the nature of the several food-stuffs present in milk? Why is milk so largely used, and so desirable an article of food? (9)

7. Describe what may be seen by the naked eye, or with the help of a simple lens, when a long bone in a dried skeleton, the femur or humerus for instance, is sawn through lengthwise. How would a bone, taken from a recently dead body, and similarly sawn through, differ in appearance from the above? (9)

8. How do the "red" and "white corpuscles" of the blood differ from each other? About how big is a red corpuscle and a white corpuscle in human blood? What is the name and nature of the fluid in which the blood corpuscles swim in a living blood-vessel? (9)

9. What is the medulla oblongata, and where is it placed? What is its form and general appearance? What are its more important functions? (9)

10. When is the pupil of the eye large, and when is it small? How does it become large, and how does it become small? What purposes are served by these changes in its size? (9)

11. What is the general composition of urine? What substances which are present in urine and so leave the body by the kidney,

also leave the body by the skin or by the lungs? What substances present in urine do not leave the body in appreciable quantity by the skin or lungs? (9)

12. When a man faints he generally falls down. Why does he fall down? (9)

1888.

1. What structures form the roof, the front wall, and the back wall of the cavity of the abdomen? Mention the most important organs which lie in the cavity of the abdomen, and describe as accurately as you can the general form and position of each of these important organs. (16)

2. State the exact place in the aorta and in the pulmonary artery where valves are found. Describe the form of these valves, and their nature (as far as can be ascertained without a microscope). Explain exactly what happens to them during and after a contraction of the ventricles. (16)

3. How does the blood in the pulmonary veins differ from the blood in the pulmonary artery? How is that difference brought about? Under certain circumstances the blood in these vessels may be almost exactly alike: What are these circumstances? (16)

4. Give an account of any one of the ribs, say the fifth or sixth, describing its form, and stating how it is connected to other parts of the body. In what ways can it be moved by muscles, and what muscles can move it? (16)

5. What is meant by a food-stuff? What are the three chief classes of food-stuffs, and how do they differ from each other? Give examples. (9)

6. How are spinal nerves joined on to the spinal cord? What is the evidence that the two roots have different uses? (9)

7. What is the portal vein? Where does it begin? Where does it end? Is the blood flowing in the portal vein always of the same quality, or does it vary? If so, when and how? (9)

8. What is cartilage, and how does it differ from bone? State as fully as you can, all the places in a grown-up body in which cartilage is found. (9)

9. What does a nerve look like when seen with the naked eye? What is shown by the microscope to be its structure? What is going on in the nerves of the arm when we move the arm? (9)

10. What is meant by the clotting of blood, and what changes take place in blood when it clots? What other fluids in the body, besides blood, clot like blood? (9)

11. With what part of the nose do we smell? What is the nerve by which we smell? From what part of the brain does it start, and how does it reach the nose? Why does closing the nostrils do away with certain so-called tastes? (9)

12. What is perspiration, and how is it produced? What is meant by "sensible" and "insensible" perspiration? (9)

1889.

1. What is the composition of ordinary atmospheric air? State exactly how expired air differs from inspired air, and explain how these differences can be proved. Explain the bad effects of breathing over again air which has been already used for breathing. (15)

2. State the form, position in the body, and general structure of the stomach. What are the chief changes which an ordinary meal undergoes in the stomach, and in what condition does the food, which is not absorbed by the stomach, pass through the pylorus into the duodenum? (15)

3. What is a capillary? About how big is a capillary? How does a capillary differ from an artery and from a vein? What changes take place in the blood as it passes through a capillary in such a tissue as muscle. In what parts of the body are no capillaries to be found? (15)

4. Describe the form and general structure of the left ventricle of the heart. Describe the valves as they may be seen when the cavity is laid open. Explain how the ventricle empties itself at each beat of the heart. (15)

5. Give an account of the position and general structure of the liver. Where does most of the blood, supplying the liver, come from? Does that blood which thus reaches the liver while digestion is going on, differ from the blood which reaches the liver when no food has been taken for some time? If so, how? (10)

6. Explain how it is that the body has always nearly the same temperature, whatever be the temperature of the surrounding air. (10)

7. What is "serum" of blood? What are the most important bodies present in it? How does serum differ from plasma? (10)

8. What is the pupil? By what means does it grow larger, and by what means does it grow smaller? Why does it generally become small in the light, and large in the dark? (10)

9. What is meant by proteid food? Give examples. Why cannot we live without proteid food? Why is it desirable to have other food besides proteids? (10)

10. What is the form, general structure, and position of the spleen? Where does the blood coming from the spleen go to? (10)

11. Describe the structure of a muscle as far as can be made out without a microscope. What is meant by the contraction of a muscle? What change of form takes place in a muscle when it contracts? (10)

12. What are the lacteals? How does the chyle which they contain after a meal get into the blood? (10)

1890.

1. What structures form the walls of the thorax or chest? How is the thorax made air-tight? What important viscera are contained in it, and what positions do they occupy in it? Explain how changes in the diaphragm alter the size of the thorax. (15)

2. If a heart, a sheep's heart for instance removed from the body, were put before you, how could you tell which was the top, which the bottom, which the front, and which the back? What are the chief differences between the left ventricle and the right ventricle, and what purposes are served by these differences? (15)

3. What is the spinal cord? Where is it placed? Explain how the spinal cord is protected from injury by the structure and arrangements of the walls of the cavity in which it lies. (15)

4. Of what chemical elements are fat and starch composed? How do fat and starch differ from each other? What changes does starch and what changes does fat undergo in the alimentary canal? Where and how are those changes brought about? (15)

5. What is the most important substance and, next to the water, the most abundant substance present in urine? Of what chemical elements is this substance composed, and how does it come about that the kidneys are always to a greater or less extent engaged in secreting this substance? (10)

6. What do the red and white corpuscles of the blood look like when a drop of blood is examined under a high power of the microscope, and how do they differ from each other? State an important use of the red corpuscles. (10)

7. How in a *dead* body can you tell an artery from a vein? What are the chief differences between them, and why are they thus different? (10)

8. What are the two chief parts of the skin, and how do they differ from each other? How does the skin of the lip differ from the skin of the heel, and why? (10)

9. What differences can be observed, without the aid of any microscope, between (*a*) a bone just fresh from the body, (*b*) one which had been dried and kept for some time, and (*c*) one which had been steeped in acid for some time? (10)

10. What is meant, in speaking of vision, by "the blind spot," and how can its presence be demonstrated? What conclusions concerning the nature of sight can be drawn from the existence of the blind spot? (10)

11. What parts go to form the hip-joint? What movements of the hip-joint can be carried out? How are they limited, and why? (10)

12. Describe the course taken by the air in breathing until it reaches the glottis or pharynx, and explain why it is better to breathe through the nose than through the mouth. (10)

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