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PHYSIOLOGY
FOR BEGINNERS

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1870
The following is a list of the names of the persons who have been elected to the office of Justice of the Peace for the year 1870.

NAME	RESIDENCE
John A. Smith	St. Louis, Mo.
James B. Jones	St. Louis, Mo.
William C. Brown	St. Louis, Mo.
Charles D. White	St. Louis, Mo.
Edward F. Green	St. Louis, Mo.
George H. Black	St. Louis, Mo.
Frederick I. Gray	St. Louis, Mo.
Henry J. Hall	St. Louis, Mo.
Isaac K. King	St. Louis, Mo.
John L. Lee	St. Louis, Mo.
Samuel M. Miller	St. Louis, Mo.
Thomas N. Moore	St. Louis, Mo.
William O. Parker	St. Louis, Mo.
James P. Quinn	St. Louis, Mo.
Robert R. Reed	St. Louis, Mo.
David S. Russell	St. Louis, Mo.
John T. Scott	St. Louis, Mo.
Charles U. Stone	St. Louis, Mo.
Edward V. Taylor	St. Louis, Mo.
George W. Walker	St. Louis, Mo.
Frederick X. Wilson	St. Louis, Mo.
Henry Y. Young	St. Louis, Mo.

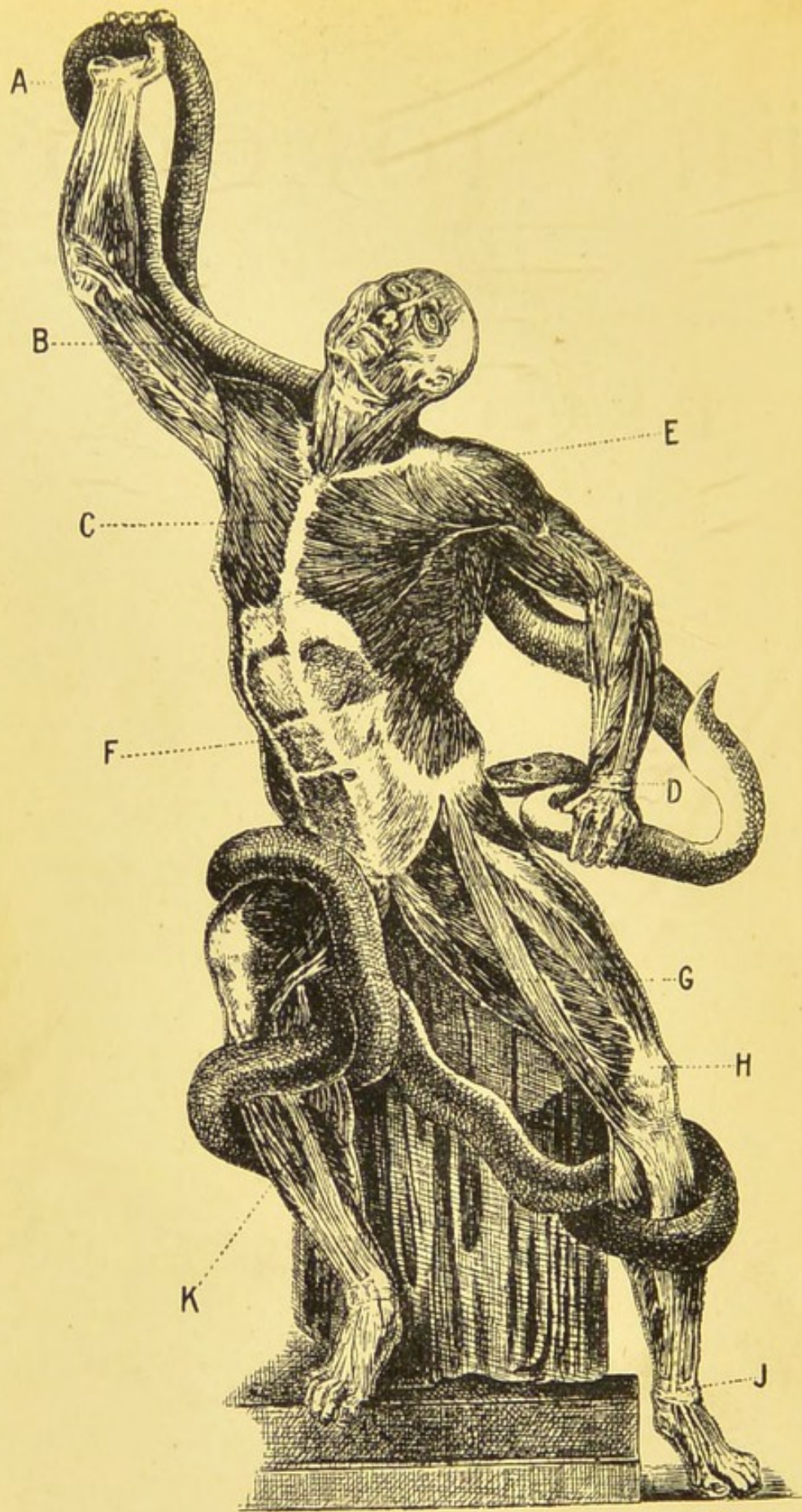


Figure taken from the Laocöon Group. The skeletal muscles are shown in action. A, D. Fibrous bands which confine the tendons of the flexor and extensor muscles of the fingers. B. Biceps. C. Pectoral. E. Deltoid. F. Fibrous sheet enclosing muscles of abdominal wall. G. Sartorius or tailors' muscle. H. Tendon of extensors of leg attached to the tibia and enclosing the patella. J. Fibrous bands enclosing muscles which flex the feet. K. The calf-muscles.

PHYSIOLOGY

FOR

BEGINNERS

BY

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'PHYSIOLOGY AND PATHOLOGY OF THE CEREBRAL CIRCULATION,' ETC.

ILLUSTRATED

London

EDWARD ARNOLD

1902

PHYSIOLOGY

RECORDS

ERROR

On page 68, line 7, *for* 'mucia' *read* 'mucin.'

SCHOOL OF MEDICINE,
UNIVERSITY OF LEEDS.

602415

PREFACE

THE author has set himself the difficult task of putting in simple language the essential facts concerning the structure and functions of the human body. These facts cannot be properly learnt without the aid of practical demonstration. This book is designed to assist students who are attending lectures and classes where such demonstrations are given. The practical exercises required for the elementary study of Physiology are described in the author's *Manual of Physiology*.

PHYSIOLOGY

REVIEW

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PHYSIOLOGY FOR BEGINNERS

CHAPTER I

PHYSIOLOGY: WHAT IT MEANS—PROTOPLASM

WHY do you become hungry every few hours and eat food and drink water? What is food, and why are some things good to eat and others poisonous? What happens to the food which you swallow? Why does a man become thin and weak if starved or not properly fed? How is it that your body is always warm, not only in summer time but on the coldest winter days? Why do you feel hot when you run, why do you pant for breath, and why does perspiration then make your skin quite wet? Why does your chest rise and fall about sixteen times a minute, and why and how do you draw air into your body and then puff it out with the help of these movements? Why do you feel choked if you squeeze the front of your neck, and why does a man soon become choked if shut up in an air-tight box? What is the blood which flows from you wherever you cut yourself? What is the heart doing which you feel beating against the front of your chest on the left side about seventy times a minute? What is the pulse which you can feel throbbing in your wrist? How do the eyes see, the ears hear, the tongue taste, the nose smell, and the skin feel? Lastly, how is it that you can move the parts of your body, and walk and run, and train your hands to skilled uses?

These are the kind of questions which the study of Physiology will help you to answer.

Before, however, you can understand anything of the functions of the body you must learn something about its structure. The science of Anatomy deals with the **structure** of the different parts of the body, while the science of Physiology treats of their **functions** or actions and uses.

When a butcher kills a sheep and cuts it up, he finds he has to sell the skin, the suet or fat, the bones, and marrow in the bones, the flesh, the blood, the heart, the lights or lungs, the liver, two kidneys, the milt or spleen, the sweetbread or pancreas, the tripe or bowels, the head with the brain inside it. The same structures go to make up the body of a man.

Tissues and organs. The body is made up of **tissues**, such as muscle or flesh, bone, connective tissue, nervous tissue, and glandular tissue. Some tissues, such as bone and connective tissue, hold together and support the others and form the framework of the body: the rest of the tissues go to form the **organs**, such as the heart, lungs, brain, liver, kidneys, &c. Each organ has a special **function** to carry out.

Protoplasm. The simplest living animals we know of, such as those which are seen when a drop of water from a ditch is examined under the microscope, are made up of a tiny lump of jelly-like transparent material called **protoplasm**. The protoplasm contains minute particles of food, and in one part of it there may be seen a spot called the **nucleus**. The lump of protoplasm with its nucleus makes up what is called a living **cell**. The cell which forms one of these little animals is so small that it can only be seen when magnified four or five hundred times by the microscope. Such an enlargement would make a pin's head appear to be the size of a cart wheel.

The amoeba. One of the simplest and commonest of the **one-celled** animals which live in ditch water is called the **amoeba**. The life of the amoeba can be easily observed under the microscope. It continually moves as the protoplasm, now on this side and now on that, pushes out little projections. The protoplasm creeps round any tiny particle of vegetable matter which may float within reach. The **food** is thus taken into the amoeba at any part of its

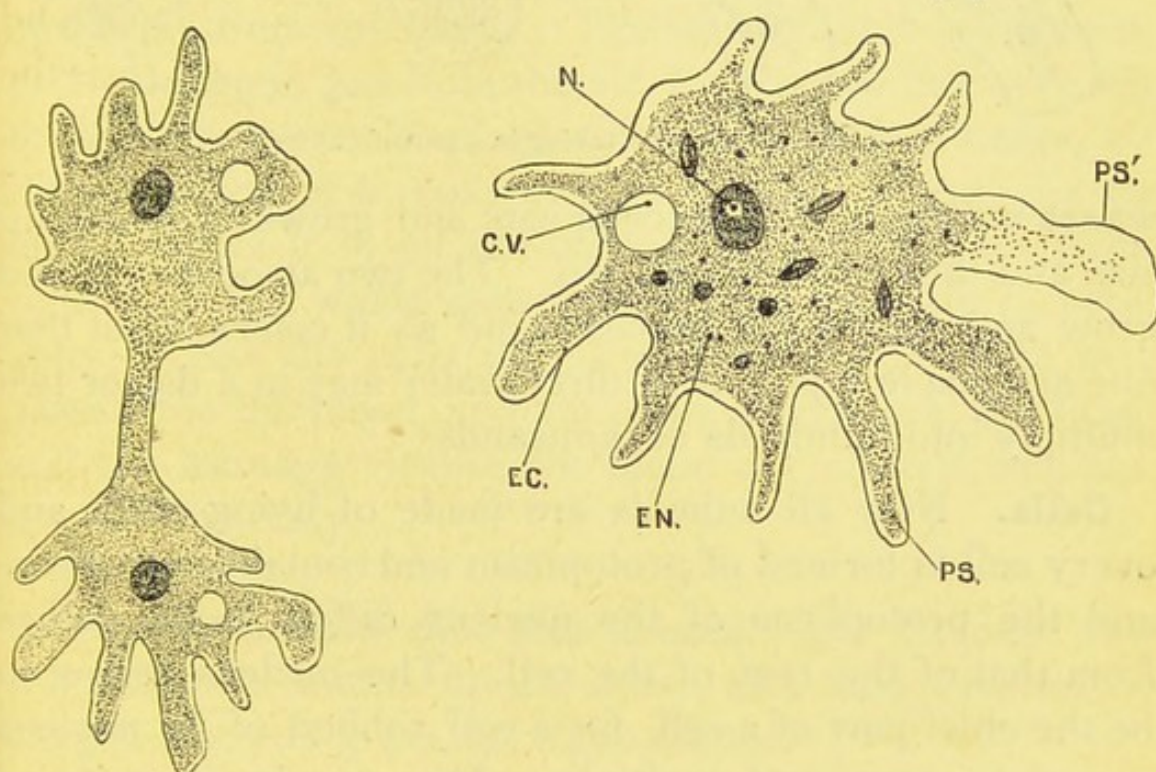


FIG. 1. Amoebae as seen under the microscope. The one on the left is dividing into two. N. Nucleus. C.V. Contractile vacuole. EN. Protoplasm with food particles in it. EC. and PS. Protoplasm flowing out into projections or pseudopodia.

body, for it has no mouth. The food soon disappears, as it is first dissolved or **digested** and then made into part of the protoplasm of the amoeba. From indigestible or poisonous substances the protoplasm shrinks away. In one part of the amoeba there may be seen a clear round spot filled with water. This spot slowly grows larger, then suddenly shrinks up and disappears, to gradually reappear once more and go through the same performance. What does this mean? Well, the amoeba draws water into itself, and from the water it takes **oxygen gas** and the

traces of **mineral salts** which are always found dissolved in water. These are food substances which are just as necessary to its life as vegetable matter. When the amoeba squirts the water out of itself it sends out with it

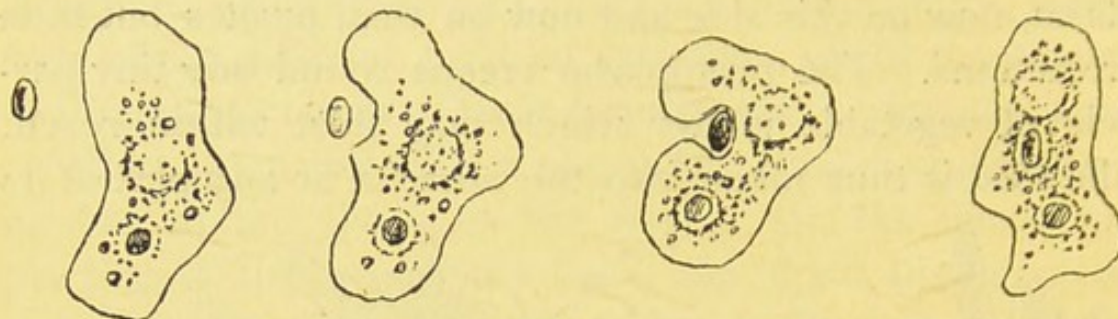


FIG. 2. An amoeba taking in a particle of food.

waste matter. The amoeba eats and grows to a certain size and then divides into two. The two amoebae eat and grow and repeat the process, and so it comes about that one amoeba in a puddle of dirty water may in a day or two multiply into hundreds of thousands.

Cells. Now all animals are made of living **cells**, and every cell is formed of protoplasm and contains a nucleus, and the protoplasm of the nucleus differs in its nature from that of the rest of the cell. The nucleus seems to be the chief part of a cell, for a cell robbed of its nucleus ceases to grow and multiply. The amoeba is made of one cell, which moves and feels, eats and drinks, breathes in oxygen gas, and excretes waste substances. Man, on the other hand, is composed of **countless myriads of cells**, and these cells are grouped into tissues and organs, and in each tissue or organ the cells have a special structure and their protoplasm a special nature, which makes them fit to carry out not all but one of the functions of a living animal. The labour is divided among many, and so a higher life is attained. Thus certain groups of cells form the tissue called **bone**, the function of which is to **support** the body. Other cells grow into **muscles** which **move** the body. Other cells form the **nervous system** and **organs of sense**,

organs with which we **feel** and **direct the movements** of the body. Still other cells form the **alimentary canal**, the structure into which we take our food and drink. Other cells arrange themselves into a **circulatory system** of tubes full of **blood**, and the food which is digested and taken in by the cells of the alimentary canal is carried by the blood to all parts of the body. Thus the cells which carry out other functions than eating and digesting obtain their food and drink from the blood. The cells of the body must all receive **oxygen gas** from the air, for this too is a necessity of life. Certain cells are therefore arranged as **lungs**, and their function is to pass oxygen into the blood, and the blood carries it to all the other cells. Lastly, the living cells all give off **waste substances**, and these must be taken away or else the cells will die. The waste of the cells passes into the blood, and the cells which form the **lungs** and the **kidneys** cleanse the blood of the waste, and pass it out of the body.

Why an animal eats and drinks. Let us next consider why an animal drinks water, eats food, breathes in oxygen gas, and gives out waste matter.

If you cover a small lighted lamp with a large glass bottle, the lamp will soon go out. This is because the burning oil uses up the oxygen gas in the air within the bottle. The bottle becomes misty inside because the oil in the process of burning turns partly into water. If you passed the air in the bottle through some lime-water, you would see the lime-water turn milky. This is because the burning oil turns partly into carbonic acid gas. Carbonic acid gas combines with the lime and produces the white substance which is carbonate of lime. You see, then, that oil in the process of burning uses up oxygen, and turns into water and carbonic acid. When coal is burnt the results are the same, only some ashes are left over as well. If you

put the lamp under the boiler of a toy steam engine, the heat of the lamp would boil the water inside the boiler and turn it into steam, and the steam trying to escape would push the piston and make the wheels of the engine move. If all the oil in the lamp or all the water in the boiler became used up, the engine would stop working.

Now your own body is warm because it is **burning**, but it is not hot in the same degree as is the lamp, for it burns more gently and slowly. If you put a piece of flesh in an iron pot, and put the pot on a fire, the flesh would first char and then burn away and turn into water and carbonic acid, and, like coal, leave some mineral ash behind. The burning flesh would give off in addition some ammonia gas.

The living body as it slowly burns also gives off carbonic acid into the air. This is breathed out by the lungs. If you breathe out or expire into a bottle containing lime-water the latter will become milky, showing the presence of carbonic acid. The body also gives out water. If you breathe on a looking-glass it becomes misty owing to the water vapour given out by your breath. Water also continually evaporates from your skin, for this is always slightly moist, and sometimes becomes quite wet when you are hot and perspire. Water also leaves your body in the form of urine, and in this water there is found to be dissolved mineral salts and a substance called **urea**. When urine becomes stale and decomposed the urea turns into ammonia. You see then that the living body gives off the same things as a piece of burning flesh, and with the addition of urea the same things as burning oil, namely, **water, urea, carbonic acid, and mineral ash**. In order that the body may burn it must have oxygen, and life goes out if oxygen be not supplied. Thus a man when shut up in an air-tight box becomes choked just like the lamp. Of course the body, like the oil in a lamp, would soon burn away if it were not fed. We therefore

eat food to keep up the fire of life. The burning oil can boil water into steam, and make an engine move. In our body the burning of the food brings about the movement of our muscles, and enables the other organs to carry out all the functions of life. If we cannot eat we starve, become thin, burn away, become weak, too weak to move, finally too weak to feel or think, and so, like the lamp without oil, we flicker out and die.

If you sat all day on a weighing-machine you would find your weight to grow less between meals, because your body slowly burns away into water, carbonic acid, and urea. At each meal you would make up your weight again, and if you did this exactly you would find at the end of the day that you weighed the same as at the beginning. Suppose, however, you eat more than enough food to balance the loss, then you would put on flesh and fat and grow in weight; suppose, however, you eat too little food, then you would lose flesh and fat, grow thin, and weigh less.

CHAPTER II

THE CHEMICAL COMPOSITION OF THE BODY

WHEN the body of an animal is burnt, completely burnt, it turns into water vapour or steam, carbonic acid gas, ammonia vapour, and the ashes or mineral salts are left. These are all **compound** substances, for, by heat and other means, they can be split into still simpler substances. Water, when decomposed, turns into two gases, hydrogen and oxygen. Carbonic acid gas turns into carbon and oxygen (charcoal is an impure form of carbon). Ammonia turns into two gases, nitrogen and hydrogen. The mineral salts when decomposed yield sulphur, phosphorus, chlorine, sodium, potassium, calcium, magnesium, and iron. All these substances are called **elements**, for they cannot be decomposed by any means in our power. The whole world is made up of elements and compounds of elements. There are altogether about seventy elements known, but only these elements can be obtained from the body, namely, oxygen, hydrogen, nitrogen, carbon, sulphur, phosphorus, chlorine, sodium, potassium, calcium, magnesium, and iron¹. The elements are **compounded** in the body **into the following** substances: **proteid, fat, carbohydrate, water, and mineral salts**. The same substances form our food.

¹ You must read about elements and compounds, salts and acids, &c., in a primer of chemistry, as we cannot stop to discuss them here.

We do not know the chemical nature of living protoplasm, for so soon as we try to examine it we kill it. The protoplasm then changes into the dead substance called proteid. Fat and carbohydrate are food-stuffs stored up by the cells of the body. **Two-thirds of the weight of the body is formed of water.**

Proteid. Egg-white and flesh are examples of proteid. If you heat raw egg-white it will set, as in a hard-boiled egg, into a white, opaque, solid substance. Nitric acid added to egg-white turns it into a solid substance. On boiling proteid with nitric acid it becomes yellow, and, on then adding ammonia, orange. This is a **test** which shows the presence of proteid.

When decomposed, proteids yield the elements carbon, hydrogen, oxygen, nitrogen, a little sulphur, and, in some cases, phosphorus and iron. The exact chemical nature of proteid is not yet discovered, for it is a very complex compound, and the chemist has not yet found how to make it out of the elements.

Plants have the power to build up proteid from simple chemical substances; their roots take up ammoniacal and other mineral salts and water from the earth, while their leaves absorb carbonic acid gas and oxygen from the air. With the help of the light and warmth of the sun plants build up out of these substances proteid, fat, and carbohydrate. Animals eat plants or other animals, and so obtain the proteid, fat, and carbohydrate which is required to build up their bodies. When animals or plants die, moulds and bacteria grow in them and decompose proteid, fat, and carbohydrate into water, carbonic acid gas, ammonia, and mineral salts, which again become the food of plants. Bacteria are the smallest of living things. They appear under the highest power of the microscope as minute rods or specks.

The spores or seeds of moulds and bacteria blow about in the dust and get into everything, and we have therefore to take great care that they do not spoil our food. Some kinds of bacteria if they gain an entry into our bodies

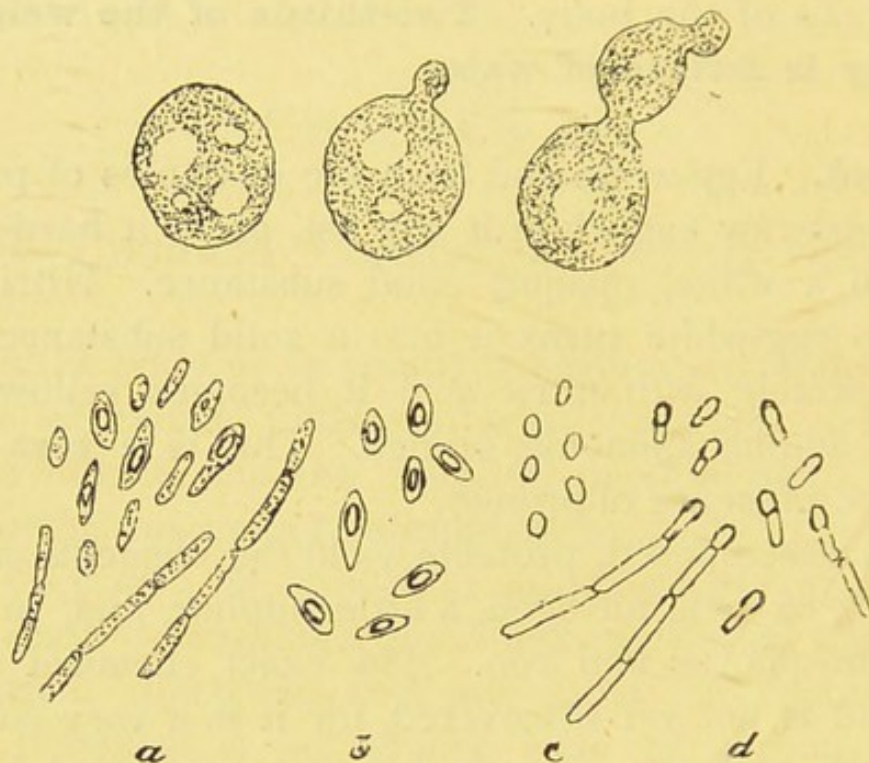


FIG. 3. Yeast cells (above) and bacteria (below) as seen under the high power of the microscope.

grow and infect us with disease. Boiling is the simplest and best way to free food and water from bacteria.

Fat is the chief food-store of the body. You know how lean a man becomes when he is starved or too ill to eat. When fat is decomposed it yields carbon, hydrogen, and oxygen, but far more hydrogen than oxygen.

Oil, butter, and suet are different kinds of fat.

Carbohydrate is the name given to such substances as sugar and starch. Starch is one of the chief foods. Potatoes, carrots, rice, flour, and bread all contain large quantities of starch. The total quantity of carbohydrate in the body is very small. There is a little grape-sugar in the blood and muscles, and the cells of the liver store up animal starch or **glycogen**. Carbohydrate is the chief

source of muscular power and bodily heat. Proteid, on the other hand, is used to build up the tissues. The carbohydrate which we eat becomes oxidized (burnt) in the muscles, and turned into carbonic acid and water. If we take in more than is required to keep up our muscular power and bodily heat, it is turned into fat, and so stored up in the body.

When starch is treated with a solution of iodine it turns blue. This is the test used to detect the presence of starch.

Mineral salts. The mineral salts are chiefly found in the bones. Two-thirds of the weight of a bone is made of mineral matter, and one-third of proteid. The chief mineral substances in bone are salts of lime. The proteid in bone turns into **gelatin** when it is boiled.

The following figures give approximately the amounts of the chief ingredients which can be obtained from the body of a man weighing 150 lb. :—

92 lb.	of water
21 „	of fat
18 „ „	dry proteid
9 „ „ „	gelatine
3 oz.	„ „ sugar and glycogen
8 $\frac{1}{4}$ lb.	„ „ phosphate of lime
1 „ „ „	carbonate of lime
6 oz.	„ „ phosphate of magnesia
2-3 „ „ „	chloride of sodium and chloride of potassium

and as much iron as there is in four tacks.

CHAPTER III

THE GENERAL STRUCTURE OF MAN—THE SKELETON

THE **skeleton** is the bony framework which supports the body. In Fig. 4 you see the skeleton as it appears after all the soft parts of the body have been taken away, and the bones have been fastened together with wire. The bones are really fastened together by **ligaments**. Ligaments are formed of a white fibrous material called **connective tissue**. The ligaments are very strong and bind the bones together. The places where the bones are joined together by ligaments are called **joints**.

Owing to the joints the bones can be moved one upon another, as in bending or straightening the arms or legs, nodding the head, and bending or straightening the back.

Fig. 5 displays the body as it appears after the skin has been taken away, and the chest and **abdomen** (belly) opened. You see the soft parts of the body which clothe the bones. Notice, firstly, the muscles (flesh). These are fixed to the bones, and, by shortening at the command of the brain, move the bones, and so bring about all the movements which a man is able to carry out. Secondly, observe the **viscera** which fill the two large spaces or cavities of the body. The upper cavity is the chest or **thorax**, and the lower the **abdomen**. In the thorax lie the **heart** in the middle and the two **lungs**, one on either side of the heart. In the upper part of the abdomen and on the right side you see the **liver**. The **stomach** lies on the left side, while the coiling **intestine** is below the liver and stomach. The food passes from the mouth down a tube called the gullet or **oesophagus** into the stomach.

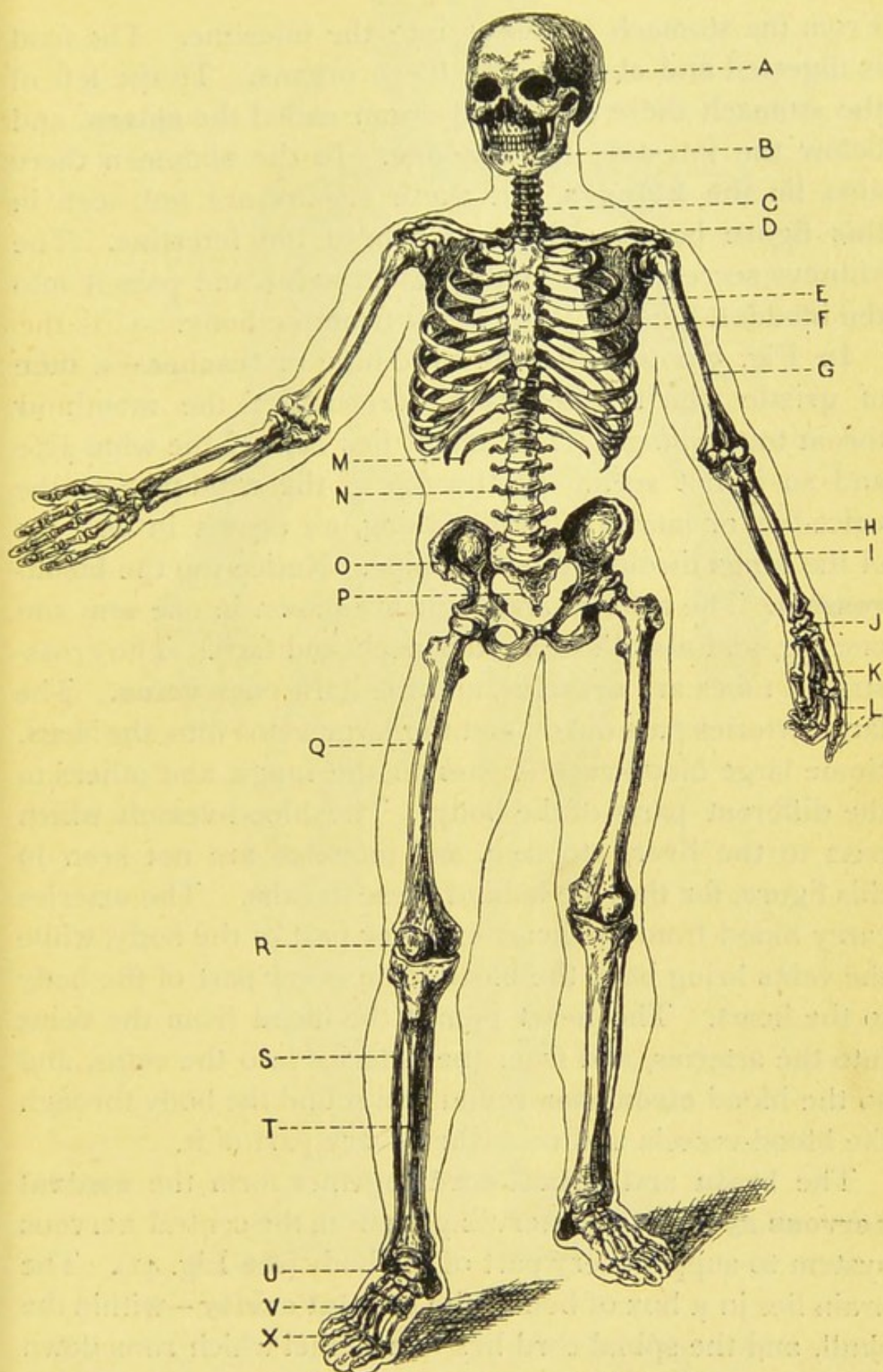


FIG. 4. The skeleton. A. Skull. B. Lower jaw. C. Cervical vertebrae. D. Clavicle. E. Scapula. F. Sternum. G. Humerus. H. Ulna. I. Radius. J. Wrist or carpal bones. K. Metacarpal bones. L. Finger-bones. M. Floating ribs. N. Lumbar vertebrae. O. Hip-bone. P. Sacrum. Q. Femur. R. Patella. S. Fibula. T. Tibia. U. Tarsal or feet-bones. V. Metatarsal bones. X. Toe-bones.

From the stomach it passes into the intestine. The food is digested and absorbed in these organs. To the left of the stomach there is a small organ called the **spleen**, and below the intestine the **bladder**. In the abdomen there also lie the **kidneys**, but these organs are not seen in this figure because they lie behind the intestine. The kidneys secrete waste matter called **urine** and pass it into the bladder, whence it is voided from the body.

In Fig. 5 notice also the wind-pipe or **trachea**—a tube of gristle which leads from the back of the mouth or throat to the lungs. The gullet lies behind the wind-pipe and so is not seen. At the top of the wind-pipe is the voice-box or larynx. In breathing, air passes in and out of the lungs through the wind-pipe. Notice too the **blood-vessels**. The arteries and veins are shown in one arm and one leg, and also those in the neck and face. The cross-striped tubes are **arteries**, and the dark ones **veins**. The large arteries pass out of, and the large veins into, the heart. Some large blood-vessels pass to the lungs, and others to the different parts of the body. The blood-vessels which pass to the liver, stomach, and intestine are not seen in this figure, for they lie behind these organs. The arteries carry blood from the heart to every part of the body, while the veins bring back the blood from every part of the body to the heart. The heart pumps the blood from the veins into the arteries, and from the arteries into the veins, and so the blood **circulates** round and round the body through the blood-vessels and nourishes every part of it.

The **brain** and **spinal cord** together form the **central nervous system**, and nerves pass from the central nervous system to supply every part of the body (see Fig. 41). The brain lies in a box of bone—the **cranial cavity**—within the skull, and the spinal cord lies in a tunnel which runs down the spine, called the **spinal canal**. The **special sense organs**—eye, ear, nose, tongue, and skin—send, by means

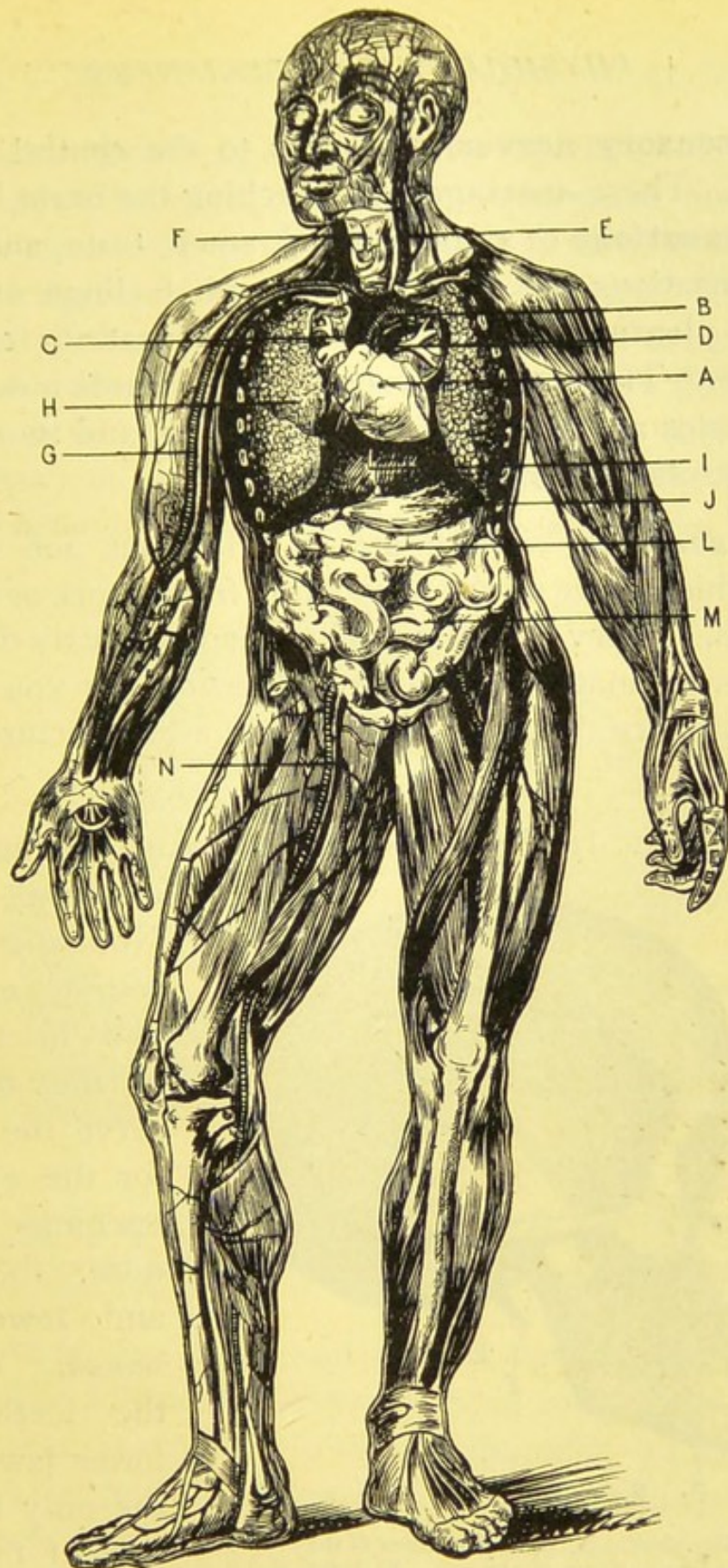


FIG. 5. The skin and the front wall of the chest and abdomen are removed to show the muscles, viscera, and some of the blood-vessels. A. Heart. B. Aorta. C. Vena cava superior. D. Pulmonary artery. The white tubes which the lines C D cross are the pulmonary veins. E. Carotid artery and jugular vein. F. Larynx. G. Brachial artery and vein. H. Lung. I. Liver. J. Stomach. L. Large intestine. M. Small intestine. N. Femoral artery and vein. A coloured map of this figure is published by G. Gill, Warwick Lane.

of the **sensory nerves**, messages to the central nervous system. These messages, on reaching the brain, produce in us **sensations** of sight, hearing, smell, taste, and touch. The sensations are accompanied with feelings of like or dislike, pleasure or pain, &c. The sensations excite us to move. The central nervous system sends messages to the muscles and viscera by **motor nerves**, and thus excites and controls the **actions** of the body.

The skeleton. There are in all about 206 separate bones which make up the supporting frame-work or skeleton of a man. Every bone has a name, and is exactly described in books on anatomy, but there is no need for you to learn anything more than the general form and structure of the skeleton.

The skull. In Fig. 4 you see the skull resting on the vertebral column.

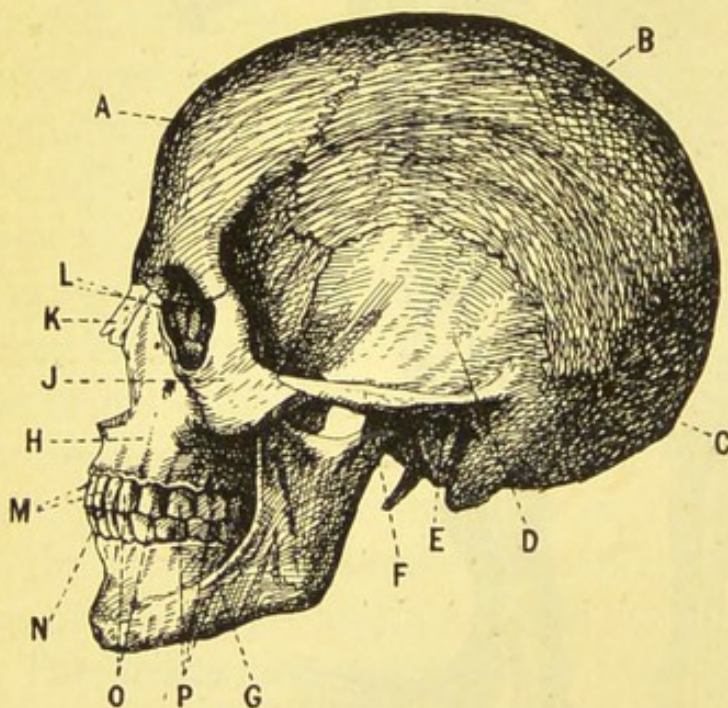


FIG. 6. The skull. A, B, C, D. Bones of the cranium. E. Hole leading to drum of the ear. F. Joint of lower jaw-bone G. H. Upper jaw-bone. J. Cheek-bone. K. Nose bone. L. Socket of eye. M. Incisor teeth. N. Canine. O. Bicuspids. P. Molars.

Notice the smooth, round **cranium**, and in the face of the skull observe the sockets for the eyes, the openings of the nose, the **upper** and **lower jaw-bones**, carrying the teeth. The lower jaw-bone is the only movable part of the skull. It is jointed to the skull just in

front of the ear. There is a hole in each side of the skull leading to the **drum of the ear**. The bones of

the cranium enclose a large cavity which contains the brain. There is a large round hole (**foramen magnum**) in the bottom of the skull. This hole leads into the tube (**vertebral canal**) which passes down the spine. Through it the stem of the brain passes. The stem of the brain is continuous with the spinal cord which runs down the vertebral canal. On each side of this hole there is a smooth knob of bone. These knobs fit into two smooth surfaces on the top of the spine. The head is thus jointed

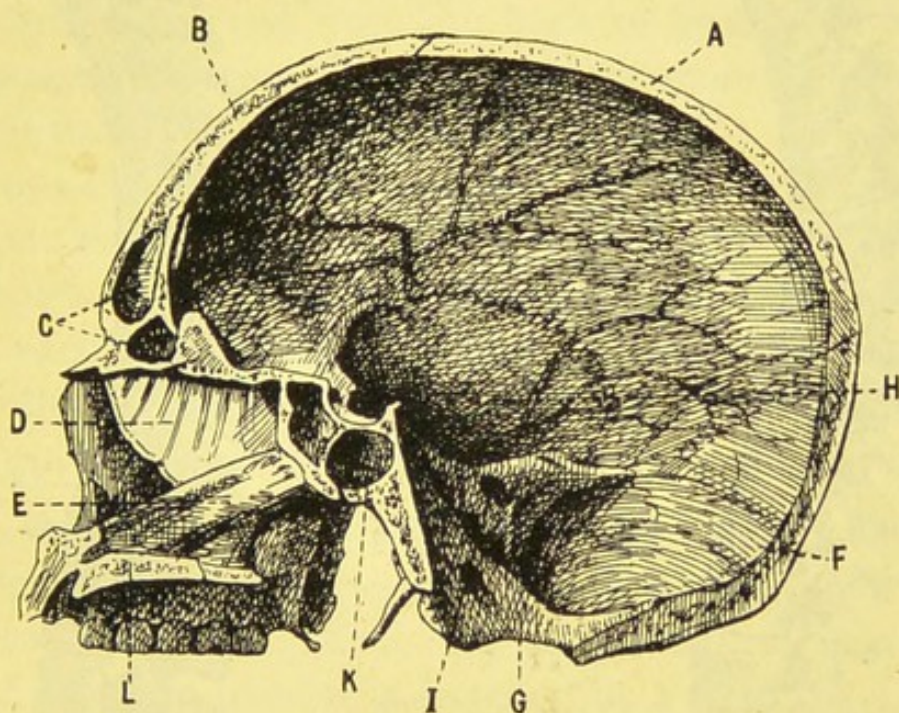


FIG. 7. The inside view of one-half of the skull. A, B, F. Bones of the cranium. H. Cranial cavity. D, E. Bones which form the partition of the nose. L. Hard palate. G. Foramen magnum. C, K. Air cavities in bones. I. Hole through which nerve of hearing passes from brain to ear.

to the spine so that it can nod up and down, or from side to side. The joint also allows the head to be turned half round, so that we can look over our shoulder. There are other small openings in the base of the skull through which blood-vessels and nerves pass to and from the brain.

The spine is made up of thirty-three vertebrae. There are seven vertebrae in the neck. The next twelve vertebrae are jointed to the ribs and form the back of the thorax. The next five vertebrae are at the back of the abdomen.

Below these there are five which are joined together to form one curved, broad, solid bone, the **sacrum**. The

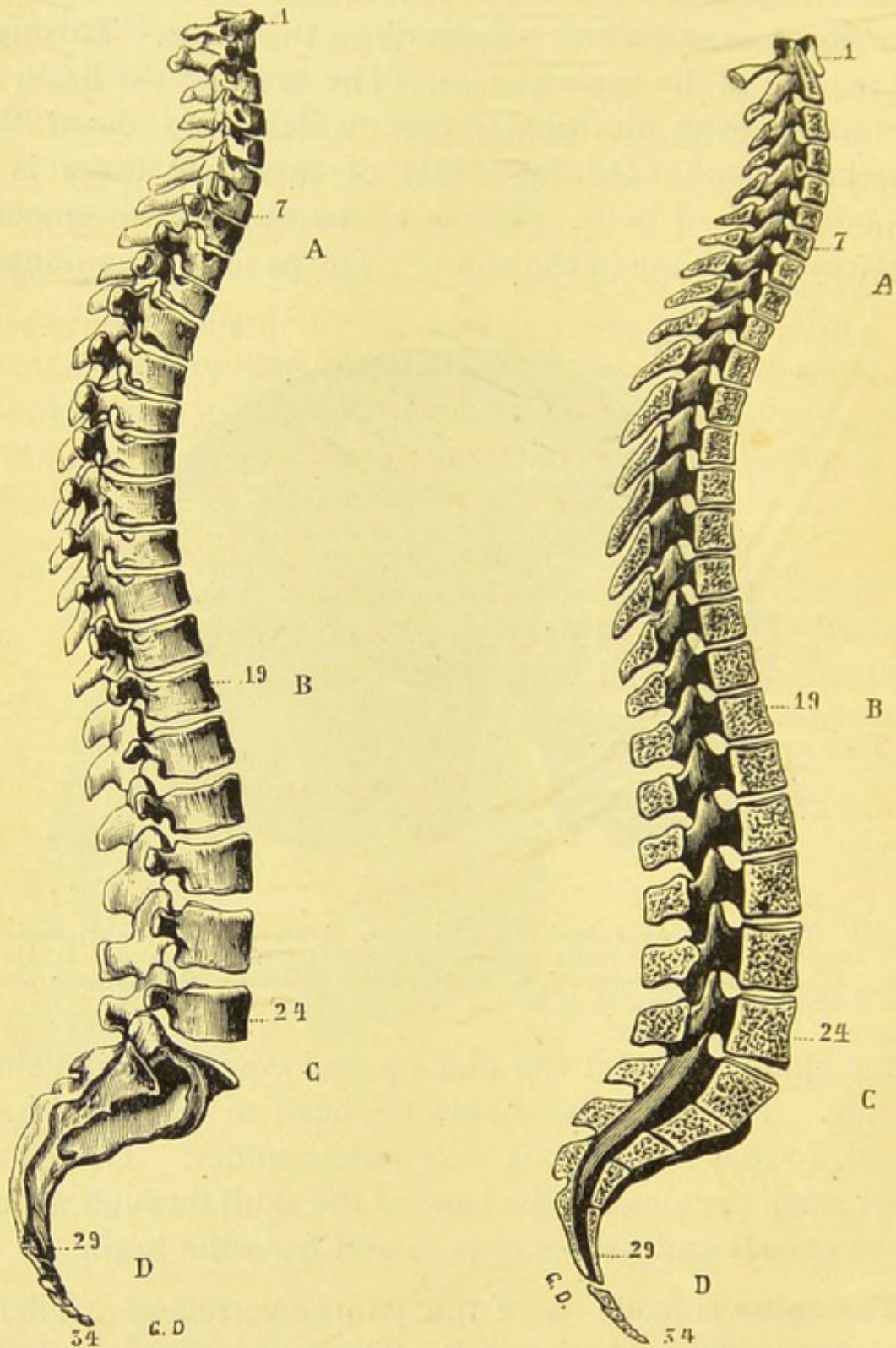


FIG. 8. The spine or vertebral column. On the left one-half is removed to show the vertebral canal. 1-7. Neck or cervical vertebrae. 7-19. Thoracic vertebrae. 19-24. Loin or lumbar vertebrae. 24-29. Sacrum. 29-34. Tail-bone.

sacrum is on either side tightly joined by ligaments to the hip-bones, and forms the back of the **pelvis**. Lastly, there are four little vertebrae which form the tail-bone. Each vertebra consists of a rounded mass of bone, the **body**, and an irregular **arch** of bone which springs from the back of the body. The arches, when the several vertebrae are fitted together, make the canal down which the spinal cord runs. The vertebrae are joined both by their bodies and by bony projections which stick out from the arches. A projection which sticks out from the back of each arch is called the **spinous process**. You can feel the spines of the vertebrae on running the finger down the back. Strong bands of fibrous tissue bind the bony projections of the vertebrae together, while elastic pieces of gristle or cartilage join the bodies of the vertebrae together. The elastic nature of the cartilage prevents the spine from being jarred, and allows the vertebrae to move a little so that the spine can be bent and straightened by the muscles of the back.

The thorax. Next notice the twelve ribs on each side, and the slender, flat bone, the **sternum**, which lies in front of the chest. Each rib is jointed to a vertebra behind, while in front it is fastened by a piece of cartilage to the sternum. Observe the shape of the ribs, and how they slope downwards. The last two ribs do not reach the sternum.

Shoulder-girdle. Joined to the top of the sternum is the **collar-bone**. The collar-bone curves outwards to join a broad flat bone, the **scapula**, which lies on the back of the chest. The scapula does not join the ribs or spine but is hung in its place by muscles. The scapula and collar-bone together form the **shoulder-girdle**, to which the arm is jointed.

The arm. In the upper arm there is a long strong bone, the **humerus**. The rounded top of this bone is

jointed to a smooth surface on the scapula. The joint is something like a cup and ball. This shoulder-joint allows the arm to move forwards and backwards, inwards and outwards, and round in a circle. At its lower end the humerus broadens to form the elbow-joint with the two bones of the fore-arm. One of these bones is called the **radius** and the other the **ulna**. The **elbow-joint** is formed like a hinge, and allows the arm to be bent or straightened there. At the wrist-joint the radius is jointed to several small bones. In the palm of the hand there are five slender bones, one for each finger and one for the thumb. In each finger there are three finger-bones, but only two in the thumb. There are joints between the bones at the wrist, allowing the hand to be bent or straightened or moved from side to side. The joints between the finger-bones allow the fingers to be bent or straightened.

The radius is also so jointed at the elbow and wrist that it can roll round the ulna, and thus bring the palm or back of the hand in turn uppermost.

The pelvic-girdle. The **hip-bones** are two broad bones of a peculiar shape. In front these bones are joined together by a narrow bridge, while the sacrum fits in between them. The hip-bones and the sacrum form the **pelvic-girdle**, to which the lower limbs are attached. The pelvic-girdle, unlike the shoulder-girdle, is firmly fixed to the spine. In consequence of this, the leg at the hip-joint cannot be moved so freely as the arm at the shoulder-joint. The legs support the pelvic-girdle, this supports the spine, and the spine supports the head. The pelvic-girdle also supports the weight of the organs in the abdomen.

The leg. The long **thigh-bone** or **femur** on each side is jointed by its round head to a socket in the hip-bone. The joint is like a cup and ball, and allows the leg to be

bent or straightened, to move from side to side, or to swing round in a circle. The lower end of the thigh-bone broadens out and is jointed at the knee to the shin-bone or **tibia**. The knee-joint is formed like a hinge. Attached to the outside of the tibia there is a slender bone called the **fibula**. The lower ends of the tibia and fibula form a hinge-joint with the bones of the feet. In the feet there are the **heel-bone** and several other small bones, and, lastly, three bones in each toe, and two in the big toe. The toe-bones are like those in the fingers. The bones of the feet are arranged so as to form the arch of the instep, and the cartilage which lies between the ends of the bones gives spring to the arch, and this allows us to walk without jar or jolt. If a man becomes flat-footed from the arch of the foot giving way, he must wear a steel spring in his boot or else suffer much discomfort. It is evident at a glance that the bones in the arm and leg are arranged on much the same plan. The joints in the arm, however, allow of freer movement, while the bones in the leg are fastened together in such a way as to support the weight of the body.

CHAPTER IV

JOINTS. SUPPORTING TISSUES

THE joints are enclosed in a loose bag of fibrous membrane, the inside of which is kept moistened by a little fluid, and the ends of the bones are smooth and covered with gristle or cartilage. In order that a hinge may work well the parts must fit together perfectly, and be smooth and well oiled. So it is with our joints. When old people get rheumatic and their joints stiff, the surfaces of the bone have become roughened, and the joints no longer work smoothly.

The ends of the bones are strapped together at the joints by stout bands of white glistening fibrous tissue. These ligaments prevent the bones being pushed out of their place or **dislocated**. We find different kinds of joints in the body, namely, **gliding**, **hinge**, **ball and socket**, and **pivot** joints. These are all **perfect** joints. There are also **imperfect** joints, such as those between the vertebrae and between the hip-bones, which allow only a very little movement.

Hinge joints. This kind of joint allows the parts to open and shut like the lid of a box. The elbow-joint is a good example; you can only bend or straighten it. The wrist, knee, and ankle are also hinge joints, but these joints also allow slight movement from side to side. The lower jaw is fixed to the skull by a hinge joint, which also allows a certain amount of gliding movement, so

that the jaw can not only be open and shut, but also moved sideways or forwards and backwards, as in chewing.

Gliding joints exist between the small bones of the wrist and feet. The ends of these bones have smooth flat surfaces, but only a small amount of movement is allowed by the strong ligaments which surround the joints.

Ball and socket joints exist at the hip and shoulder. In this kind of joint the round head of one bone fits into the cup-shaped surface of another. Such a joint allows movements in all directions, (1) forwards and backwards, (2) inwards and outwards, (3) round and round in a circle, and (4) rotation, as in twisting round the leg.

Pivot joints, like the swivel of a dog-chain, only allow rotation. The head is pivoted to the top of the spine so that it can be turned round; the radius is also pivoted to the ulna so that the hand can be turned with the palm upwards or downwards.

Examples of joints. The **shoulder-joint** (cup and ball). The smooth round head of the humerus fits into a shallow cup-like cavity in the scapula. The bony cup is deepened by a ring of cartilage. The joint is enclosed by a fibrous bag which is fixed to the margin of the cup above, and below to the neck of the humerus. Strap-like ligaments fasten the humerus securely to the scapula, and the muscles passing over the shoulder-joint help to keep the bone in its place. By means of these muscles the arm can be raised, lowered, swung forwards and backwards, rotated, and swung round in a circle. When the arm is raised into line with the shoulder, the humerus comes against the overhanging projection formed by the union of the collar-bone to the scapula. If the arm be raised still further the scapula moves also.

The elbow-joint (hinge). At the lower end the humerus broadens and ends in a smooth rounded surface, which is divided into two parts by a ridge. The upper end of the ulna forms the point of the elbow, and has a deep notch

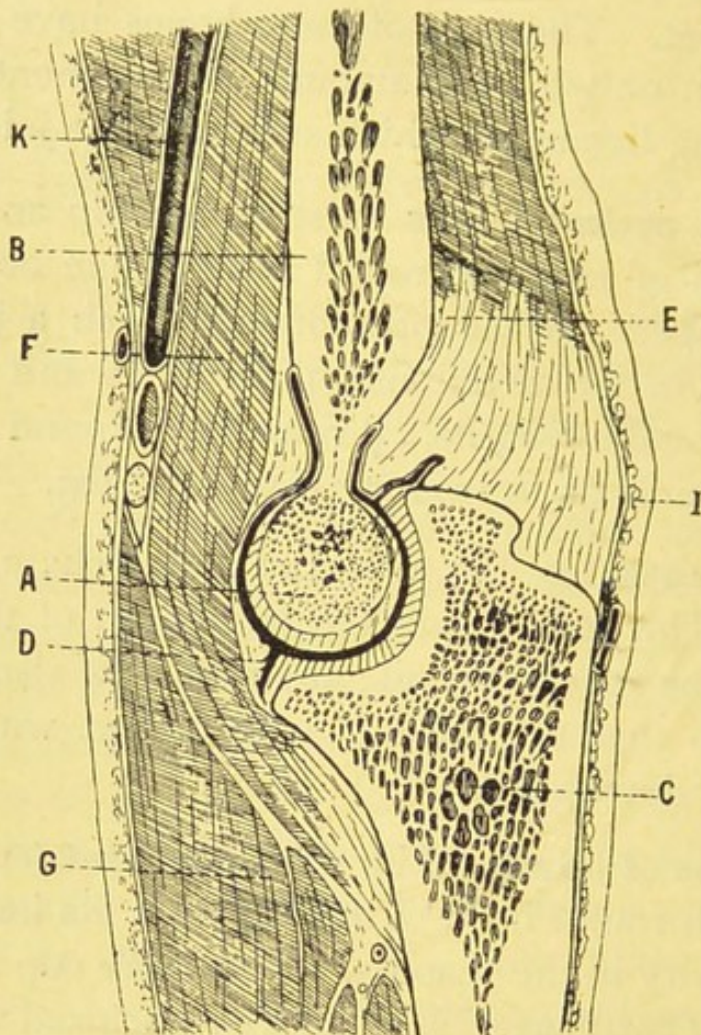


FIG. 9. Elbow-joint sawn in half. The rounded end A of the humerus B fits into the notch D at the top of the ulna C. F, E, G. Muscles. I. Skin. K. Blood-vessel.

in it. Into this notch the inner part of the smooth rounded surface of the humerus exactly fits.

The top of the radius is small and round, and has a shallow cup-like surface, into which fits the outer part of the smooth rounded surface of the humerus. Ligaments and muscles keep the joint in its place.

The hip-joint (cup and ball). The round head of the femur fits into the deep cup-like cavity of the hip-bone.

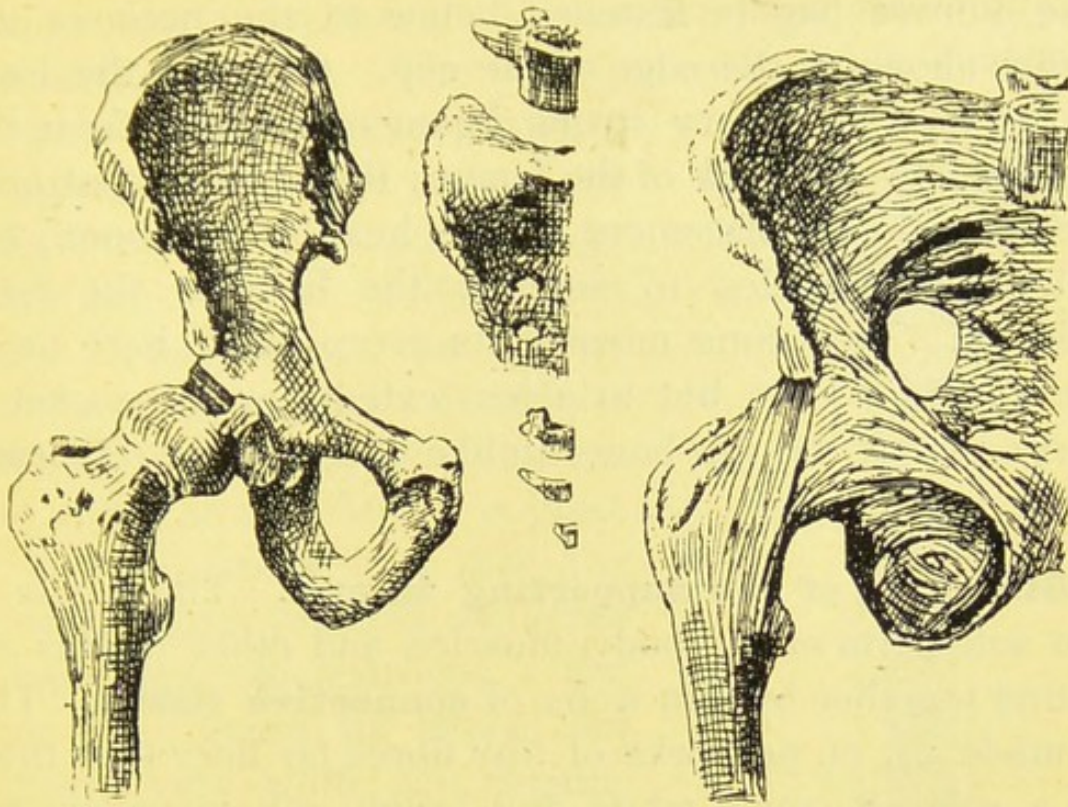


FIG. 10. Upper end of femur, hip-bone, and half the sacrum. On the right side these bones are shown strapped together by ligaments.

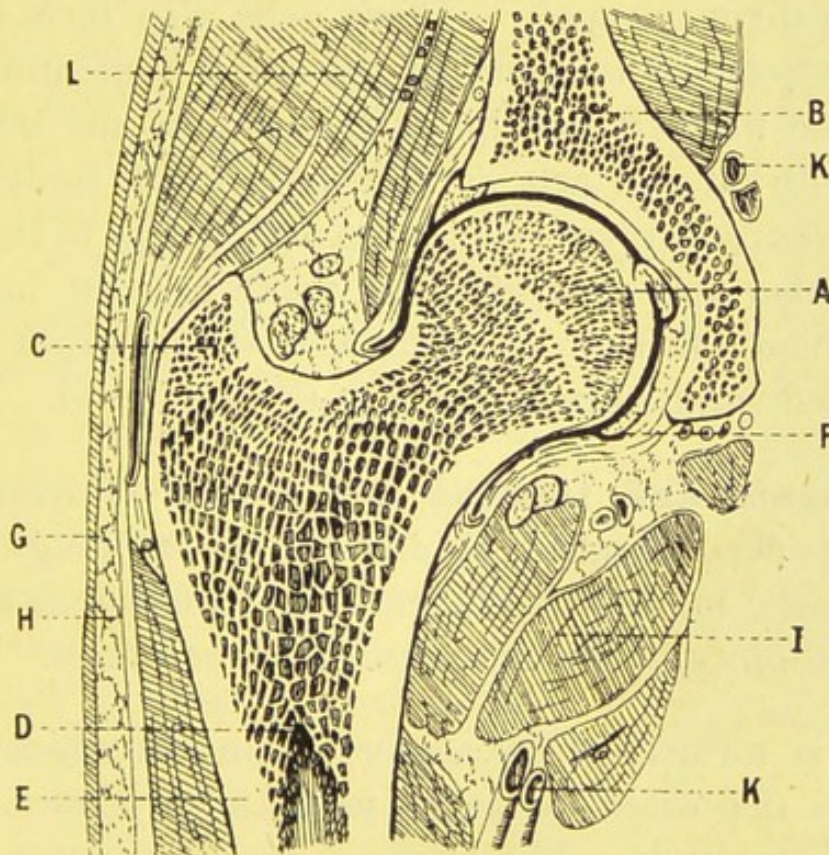


FIG. 11. Hip-joint sawn in half. The round end of the femur A is shown fitting into the cup-like hollow in the hip-bone B. L, I, Muscles. G, Skin. K, Blood-vessels.

The fibrous bag is fastened below to the neck of the femur, above to the edge of the cup. Crossing the front of the joint is a very strong ligament running from the hip-bone to the neck of the femur; the ligament not only prevents the displacement of the head of the bone, but helps the muscles to support the body in the erect position. The same movements are possible here as in the shoulder-joint, but to a less extent, for the socket is deeper, and the hip-bone, unlike the scapula, is firmly fixed to the spine.

Structure of the supporting tissues. The whole of the soft parts of the body, muscles, and other organs are bound together by thin webs of **connective tissue**. This is made up of networks of tiny fibres far finer than those of a cobweb, some white and tough, others yellow and elastic. In the meshes of the network there lie **connective-tissue cells**, whose business it is to make the fibres and keep them in repair. These cells also form fat when the food brought to them by the blood is plentiful. The connective tissue which binds the skin to the muscles is loaded with fat and acts as a cushion to the body, fills up inequalities, and gives roundness and beauty to the figure. The fat also acts as a garment, protecting the body from loss of heat; further, it forms a most important store of food which can be drawn upon at times of need.

Ligaments and tendons are formed of white fibres densely packed together so as to form very tough, strong, and inelastic bands. Ligaments bind the bones together, while tendons connect the muscles to the bones.

Bone is formed of connective tissue, in which mineral matter is deposited so as to make a very hard, strong, and rigid structure. The shafts of the long bones, to make them light and yet strong, are hollow and full of marrow.

Blood-vessels run through holes in the shaft and supply the marrow with blood. The outer part of a bone is made of very hard **compact bone**, the inner of **spongy bone**. The ends of the long bones are filled with spongy bone and have no hollow within them. The bars of the spongy bone are arranged in a definite manner so as to support pressure and resist strain. When a piece of bone is burnt in a fire the mineral matter remains, while the animal matter is destroyed. The bone still keeps its shape, but appears very white and brittle. A bone kept in acid for some weeks loses all the mineral matter, but retains the animal matter. It still keeps its shape, but becomes soft and flexible. Two-thirds of the weight of the bone is mineral matter and one-third animal matter. A thin slice of compact bone appears under the microscope to be made of layers arranged in rings round tiny little tubes (Haversian canals). In the layers of bone there appear little branching spaces which contain bone-cells. The branches of the cell-spaces communicate with each other, and with the Haversian canals. The Haversian canals contain marrow and blood-vessels. By means of the cell-

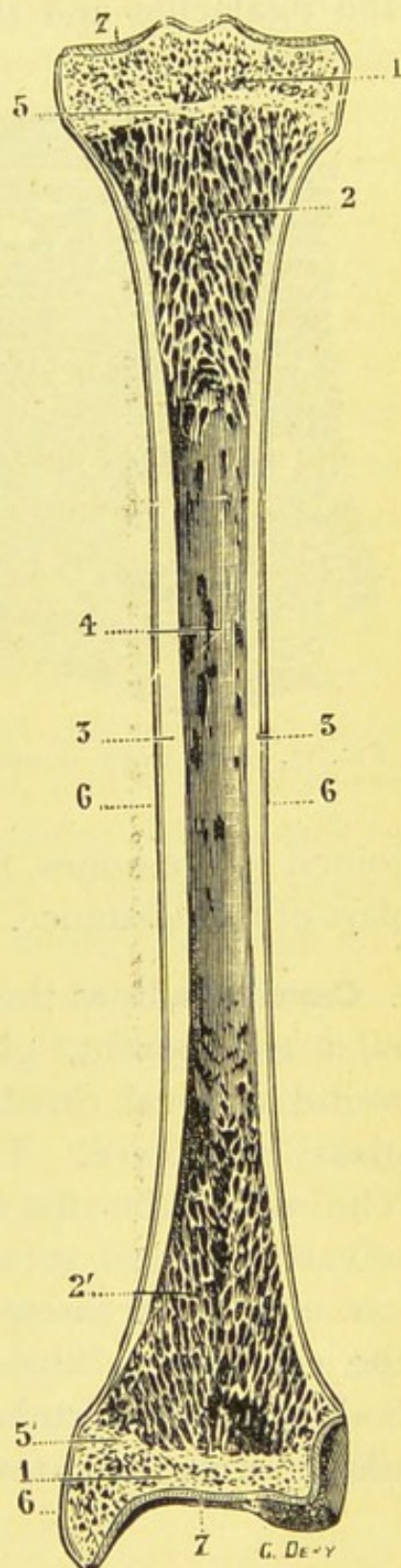


FIG. 12. Tibia sawn in half. 2. Spongy bone. 3. Compact bone. 4. Marrow cavity. 7. Cartilage covering articular ends.

spaces and Haversian canals every part of the bone receives nourishment from the blood. The fibres of the ligaments and the tendons of the muscles are firmly

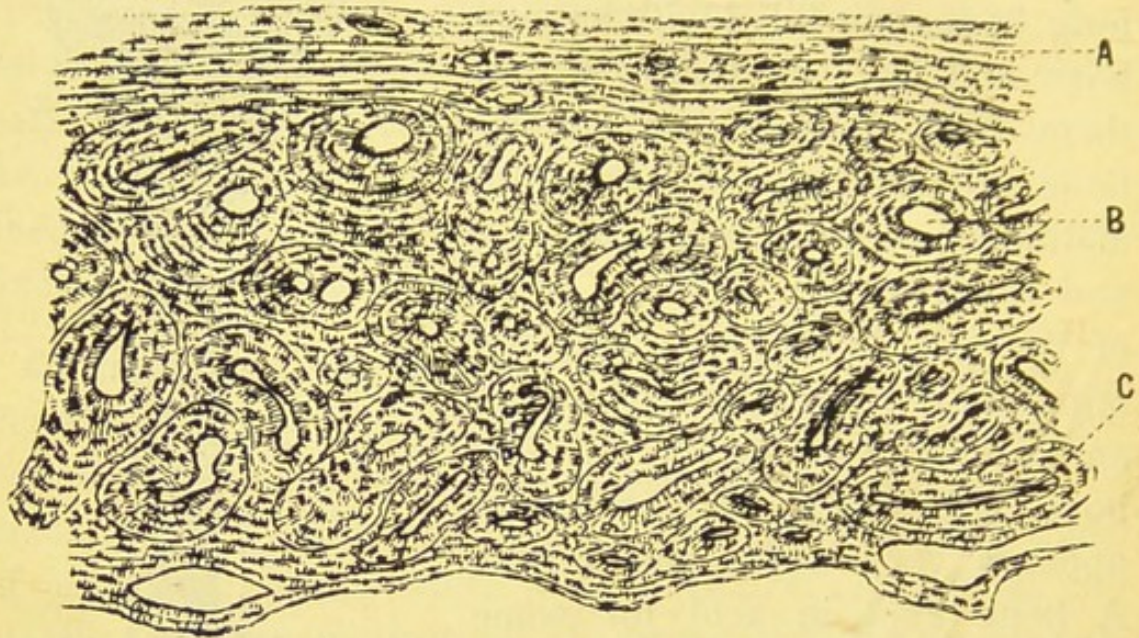


FIG. 13. Microscopic section of compact bone. B. Haversian canal. C. Bone-cell spaces.

joined to the bones, for they run into the bone and become part of its substance.

Cartilage lines the ends of the bones in the joints. It is a transparent, glassy, elastic substance. Groups of round or oval cartilage-cells lie here and there in the glassy substance. There are no blood-vessels in cartilage. The ends of the ribs where they join the sternum are made of cartilage, and so also is the substance of the external ear and the framework of the larynx. In some places the cartilage is fibrous; white fibrous cartilage joins the bodies of the vertebrae together, and yellow elastic cartilage forms the external ear.

CHAPTER V

HOW WE MOVE

How we move. The muscles are the organs which move the body. The ends of muscles are attached to bones by tendons or strong fibrous bands, the middle part is formed of flesh. Each muscle arises from one bone, passes over a joint, and is **inserted** into another bone. A muscle when excited (by a message sent down its nerve from the brain) shortens in length and thickens. It pulls upon the bones to which it is attached, and if one of these be fixed the other moves. The movement takes place in the joint over which the muscle passes. Think of a swing-door; a spring passes from the lintel across the hinge and is fixed to the door. When you let the door go the spring shortens, and the door moving on its hinge shuts to. Similarly the biceps muscle is fastened at one end to the shoulder-bone, at the other end to the radius below the elbow-joint. When the biceps contracts the belly of the muscle swells, while the fore-arm moving on the hinge joint at the elbow closes up against the upper arm. By catching hold of a post with your hand you can fix the fore-arm; on then contracting the biceps, the shoulder is pulled down. The muscles can thus move either of the bones to which they are attached.

The bones considered as levers. When a burglar takes a crowbar, and placing it in the crack of a door uses it to force the door open, he uses it as a **lever**. The

crowbar is pressed against the lintel of the door, and this forms the turning-point or **fulcrum** of the lever. The short arm of the lever moves in the crack; the long arm is wielded by the burglar. A lever can be employed either to increase the power or to enlarge the range of movement. In the case of the burglar's crowbar the end of the long arm is moved through a wide space, while the short arm in the crack of the door moves through a very little space. The power is here increased at the expense of the range of movement.

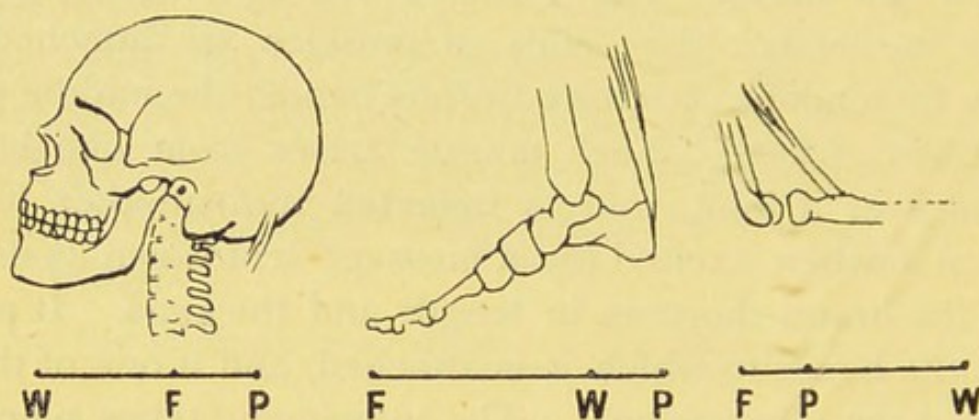


FIG. 14. Examples of levers.

Head pulled back.

Standing on tip-toe.

Bending up fore-arm.

P. Power. F. Fulcrum. W. Weight.

Insert one end of a stick in the keyhole of a door, hang a weight on the other end, and support the stick by means of the hand between the fulcrum (the keyhole) and the weight. If the hand (the power) be moved nearer the keyhole (the fulcrum), the weight to be lifted becomes greater, but you will notice, on raising the lever, that the weight moves through a much wider space than your hand. In this case range of movement is increased at the expense of power. In the body the power is usually applied to the bones in such a way as to increase the rapidity and range of movement. In order that the muscles may be packed within the skin into a compact form they are inserted into the bones close to the joints or fulcra. The biceps muscle, for example, is inserted into the radius just below the

elbow-joint. The power is applied there, the fulcrum is the elbow-joint, the weight is that of the hand and fore-arm. The hand and fore-arm form the long arm of the lever, and the part of the radius between the attachment of the biceps and the elbow-joint forms the short arm. When the biceps contracts it shortens by only a little, but the hand by the principle of the lever moves through a wide space. Since rapidity and range of movement are thus obtained at the expense of power the muscle must be a powerful one. Stand on tip-toe, and feel how the calf-muscles contract, and the tendon at the back of the heel becomes taut. The power is applied at the back of the heel ; the fulcrum is at the toes ; the weight of the body falls on the feet at the ankle-joint. Power is here gained at the expense of range of movement, for the power is applied at the longer arm, and the weight at the shorter arm of the lever.

Standing. The body is supported by the muscles, and these are controlled by the brain through the nerves. If the brain, owing to a shock or blow on the head, suddenly ceases to control the muscles, the man faints and falls in a heap.

In standing upright the head is balanced on the top of the spine by the neck-muscles. The spine supports the head and is kept straight by the back-muscles. The pelvis and legs support the spine. The body is balanced on the top of the thigh-bones by the muscles which pass from the trunk to the thigh-bones. The great muscles in front of the thighs pass to the leg-bones and prevent the knees from bending. At the ankle-joints the body is kept from falling forwards by the action of the calf-muscles. Lastly, the weight of the body is borne by the spring of the arch of the feet. The ligaments at the joints keep the bones in their places so well that only slight muscular effort is required to keep the body upright.

Walking. In walking one leg, say the right, is slightly bent at the knee and planted down in front of the other. The weight of the body is then thrown on to this leg, while the left leg, raised on to the toes by the action of the calf-muscles, forms a straight stiff rod. The left leg next pushes off from the ground and throws the body forwards. Thereupon the right leg straightens up, while the left leg, slightly bent at the knee, swings forward like a pendulum and comes down in front of the right. It is now the turn of the right leg to push off, and of the left leg to bear the weight of the body.

Structure of muscle. A muscle is made up of bundles of **muscle-fibres** bound together by connective tissue. The fibres may be an inch long, but so minute is their width that they can only be seen under the microscope.

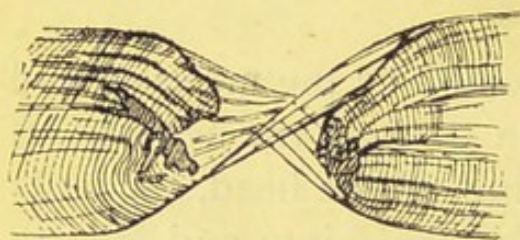


FIG. 15. A piece of a striated muscle-fibre. The protoplasm has broken apart in the middle, and the thin transparent membrane, which encloses it, is seen there.

Each fibre consists of a peculiar kind of protoplasm cross-marked by alternate dark and light lines. Hence the muscle is termed **striated**. The protoplasm of the fibre is enclosed by a thin transparent membrane. Each

muscle is supplied with a nerve, and every fibre receives a branch of the nerve. The nerve acting something like a telegraph wire sets the muscle in motion at the order of the brain. The organs of sense send messages along their **sensory nerves** to the brain; the brain receives the messages, and commands, through the motor nerves, the muscles to move. The muscles can be **excited** to contract by an electric shock or by pricking or striking them a sharp blow. Strike the tendon just above the front of the knee when sitting with one leg crossed over the other; the

thigh muscles will contract and the leg will jerk up. A muscle will also contract if the nerve going to it is excited. If a frog be killed (by putting it under a tumbler with some chloroform), and the white nerve, which runs among the muscles at the back of the thigh, be pinched, the muscles of the leg contract. Both nerve and muscle are **irritable**, but only the muscle contracts. The nerve when excited **conducts** a message or **impulse** to the muscle and thus causes it to contract.

The living muscle consists of protoplasm. From dead muscle we can obtain water, proteid, and a little mineral salt. There is nearly four times as much water as proteid.

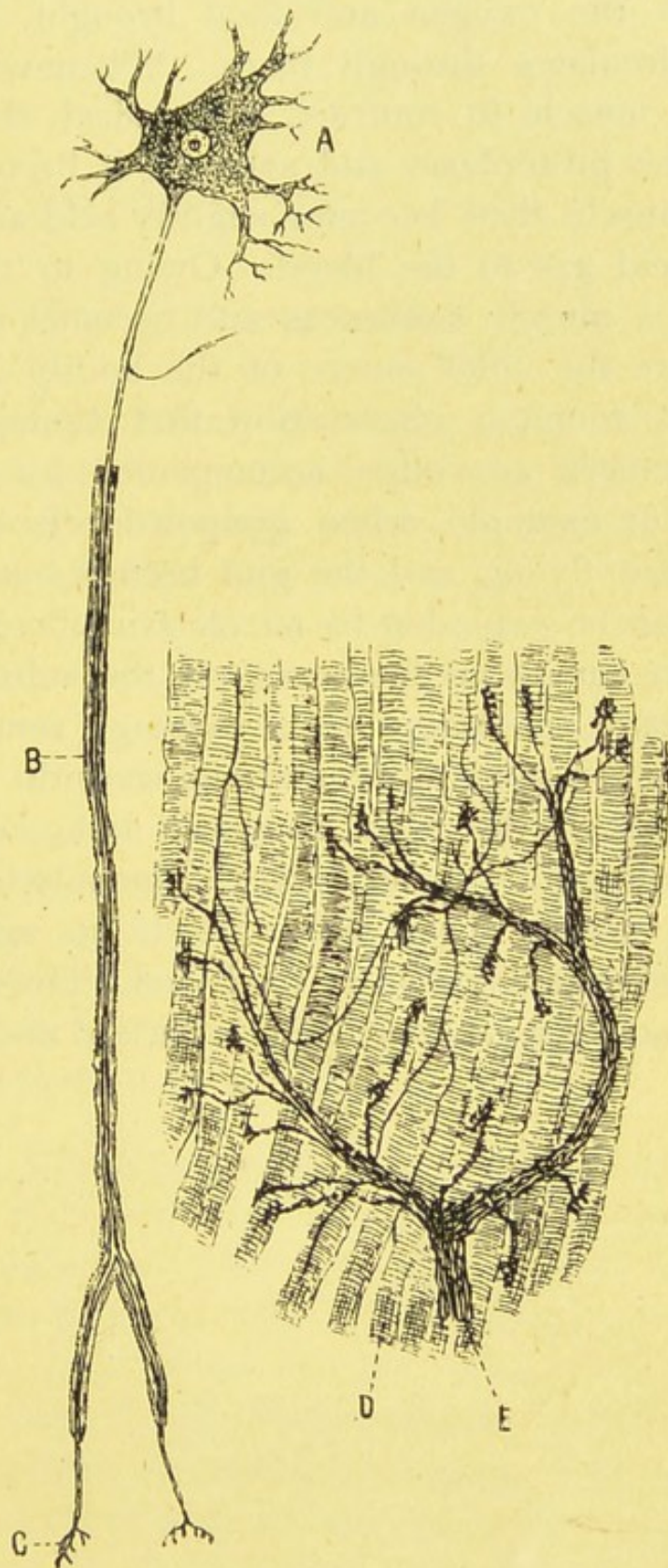


FIG. 16. A. Nerve-cell from spinal cord. B, C. Nerve-fibre. D. Muscle-fibres. E. Nerve-fibre branching and ending in the muscle-fibres

The muscles continually build up their protoplasm out of the oxygen and food brought by the blood which circulates through them. Whenever the nerve excites a muscle to contract, a chemical change takes place in the protoplasm and some of it becomes **oxidized**. The muscle then becomes slightly acid and gives off carbonic acid gas to the blood. Owing to this chemical change the muscle **contracts** and becomes **warm**. The muscles are the chief source of the bodily heat. It is a matter of common observation that chemical changes in substances are often accompanied by movement and heat. For example, when gunpowder is exploded the shot is sent flying, and the gun becomes hot. The gunpowder can be exploded by an electric current sent along a wire. In somewhat the same way the substance of a muscle is made to change by a message sent down a nerve, and there results movement and warmth. But it is not known what is the exact chemical nature of the change in the living muscle and nerve. The muscle-substance as fast as it breaks down builds itself up again out of the food material supplied by the blood. The waste material, which is chiefly carbonic acid, is carried away by the blood.

CHAPTER VI

THE BLOOD

IN whatever part of your body you make a cut there comes forth blood, for in every part of the body there is a network of blood-vessels through which the blood is circulating. The blood brings food and oxygen to all parts of the body and takes away the waste matter. You can see the blood circulating in the transparent web of a frog's foot or a tadpole's tail examined under the microscope. To see the circulation, obtain a tadpole in the spring, gently wrap round it a piece of wet blotting-paper, and leaving the tail exposed lay it on a slip of glass. Then place it under the microscope and focus it until you can see the network of tiny blood-vessels, called capillaries, and the wonderful flow of blood passing through them. In every part of your body there is a similar network.

Blood corpuscles. The blood contains myriads of little round bodies called blood-cells or **corpuscles**. These corpuscles are so small that there are five million in a drop smaller than the head of a pin. They are coloured bodies and give the red colour to the blood. The colouring matter is a proteid called **haemoglobin**, and the haemoglobin has the **power** of **taking in oxygen**. When the blood-corpuscles circulate through the lungs they load themselves with oxygen which they obtain out of the air in the lungs. When the corpuscles circulate through the capillaries in the tissues and organs they then yield up the oxygen there. The red corpuscles thus act as oxygen-

carriers to all the tissues and organs. When the haemoglobin takes up oxygen it becomes scarlet in colour, but when it yields up the oxygen to the tissues it turns dark-bluish-red. Such is the difference in colour between arterial and venous blood. The proteid haemoglobin, when decomposed, is peculiar in yielding a small quantity of iron as well as the elements carbon, oxygen, nitrogen, hydrogen, and sulphur. The iron helps to carry the oxygen.

The red corpuscles of the blood are flat, round, and bi-concave in shape, that is, thinner in the middle than the

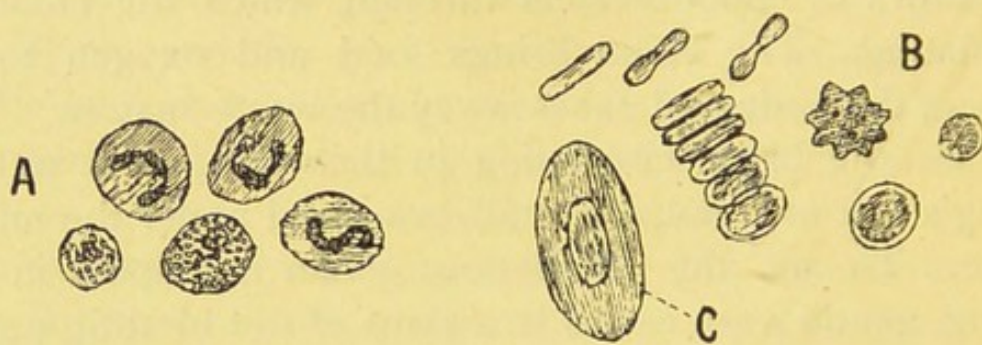


FIG. 17. A. White corpuscles. B. Red corpuscles of man, some are seen on the flat, others edgewise. C. Nucleated red corpuscle of frog.

edges. There is no nucleus within them. It would take more than 3,000 red corpuscles placed side by side to make a line one inch long. They are constantly being destroyed in the body and replaced by new corpuscles which grow in the red marrow of the bones. The haemoglobin of the worn-out corpuscles is turned into the colouring matter of the bile and the urine. The red corpuscles float in a fluid called **plasma**. There are also some **white corpuscles** in the plasma, but there is not more than about one white cell to every five hundred red. The blood, then, is made up of red and white corpuscles and plasma. A white corpuscle consists of a minute lump of protoplasm. There is a nucleus within it. The white corpuscles have the power of altering their shape and can creep out of the capillaries into the tissues.

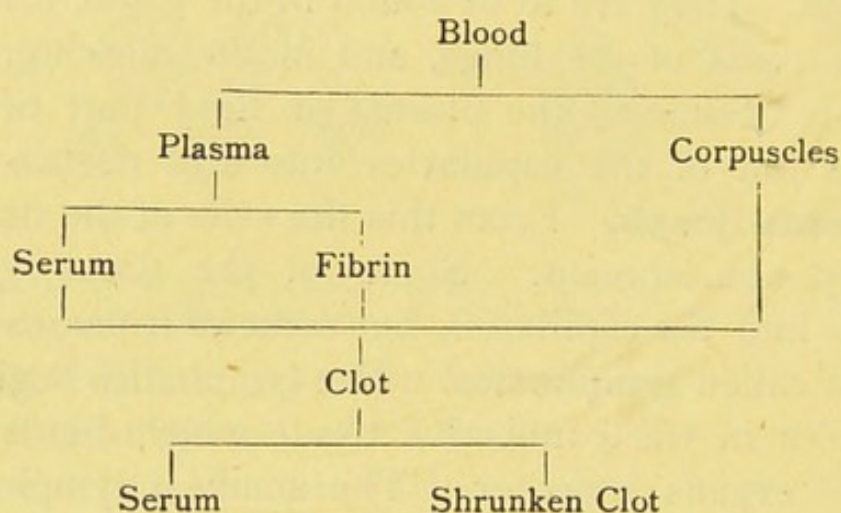
They act as the dust-men of the body. If any bacteria or particles of dirt get into the body through a wound or sore they are eaten up by the white corpuscles and carried away to the **lymphatic glands**, there to be destroyed or stored up out of harm's way. The lymphatic glands in the neck swell when the throat is sore because the white corpuscles carry thither the germs of the disease in the throat. White corpuscles are often destroyed in battling with dirt, but as they grow and multiply in the lymphatic glands, spleen, and marrow, the supply never fails.

The lymphatic glands and lymphatics. The lymphatic glands are little round or oval bodies about the size of a hazel-nut. They are to be found in the groin, armpit, neck, at the roots of the lungs, and in the mesentery of the intestine. Some of the plasma or fluid part of the blood soaks out of the capillaries into the tissues and becomes **tissue-lymph**. From this the cells of the tissues obtain their nourishment. Some of the tissue-lymph passes back into the capillaries, but some of it passes into little vessels called **lymphatics**. The lymphatics begin in minute spaces in the connective tissue which binds the cells of the organs together. The smallest lymphatics join together to form larger ones, and these pass to the lymphatic glands. After passing through the lymphatic glands the lymphatics join together, and finally convey the lymph into the veins at the root of the neck.

The clotting of blood. The blood **clots** when it is shed. The clotting of the blood in a wound prevents loss of blood. A cut should not therefore be washed, for this keeps up the bleeding. Moreover, as bacteria are the cause of inflammation, and even the purest water contains bacteria, it is unwise to apply water to a wound, unless the water be first boiled to kill the bacteria. A wound

should be at once covered with clean dry linen or cotton wool, and left alone to heal.

When blood is drawn into a basin it sets in a few minutes into a firm jelly. After a few hours the clot will be found shrunken and surrounded by a fluid which oozes out of it. The fluid is called **serum**. Serum contains less proteid than plasma, but is otherwise the same. Some of the proteid in the plasma changes, when the blood clots, into a network of fine fibres called **fibrin**. The network of fibrin binds the corpuscles and serum together and thus forms the clot. The serum oozes out as the fibrin shrinks, and thus becomes separated from the corpuscles. The following table shows the sequence of changes which takes place when blood clots :—



If freshly-drawn blood is whipped with a bundle of twigs, the fibrin as fast as it clots is caught on the twigs, and the blood after removal of the fibrin remains fluid. The fibrin caught by the twigs when well washed appears as a white stringy substance. The formation of the fibrin seems to be brought about by the blood-corpuscles, for some of these die and turn into fibrin-forming substances so soon as the blood is shed.

So long as the blood is circulating in the living healthy blood-vessels it does not clot, but clots may form in diseased vessels. A clot in the vessels of the brain is

sometimes the cause of paralysis and death in old people. Blood may be kept from clotting by mixing it with salt, or by cooling it to the freezing-point. The corpuscles then sink to the bottom, and the plasma, a straw-coloured liquid, rises to the top.

The plasma. Plasma when heated sets just like the white of a hard-boiled egg, for it contains about ten per cent. of proteid. In addition to proteid there are dissolved in the plasma traces of mineral salts, including sodium chloride or common salt and other salts, such as phosphates and chlorides of calcium and potassium. Also there are minute quantities of urea and sugar in the plasma. The proteids, salts, the sugar and oxygen are food materials carried to the tissues by the blood, while the urea and carbonic acid are waste materials carried from the tissues to the organs of excretion. The carbonic acid given off by the tissues combines with the salts in the plasma, and is thus carried to the lungs. Some of the carbonic acid is however carried by the red corpuscles.

CHAPTER VII

THE CIRCULATION OF THE BLOOD

THE body of a man may be likened to a sponge full of liquid. The framework of the sponge represents the tissues of the body, while the network of spaces in the sponge represents the lymphatics and blood-vessels. You must remember that in the body the tissues are not all alike, but vary in the different organs, and the whole is supported by a bony skeleton. A sponge placed in a sponge bag will neither drip nor dry up. Similarly, the skin confines all the parts of the body in their place, and stops the fluids of the body drying up or settling down into the lower parts of the body.

In the sponge the liquid is at rest, but in the body there is a pump—the heart—which keeps the fluid steadily moving round the blood-vessels.

On its way through the lungs the blood takes up oxygen and gives off carbonic acid; in the intestines it takes up food; in the liver and other glands the blood is altered and prepared; in the kidneys it gives up the waste substance, urea; to all the organs and tissues it carries oxygen and food, from all it carries away the waste substances, carbonic acid, and urea: lastly, the circulating blood distributes the heat produced by the muscles and glands to all parts of the body.

How you can tell that the blood circulates. Firstly,

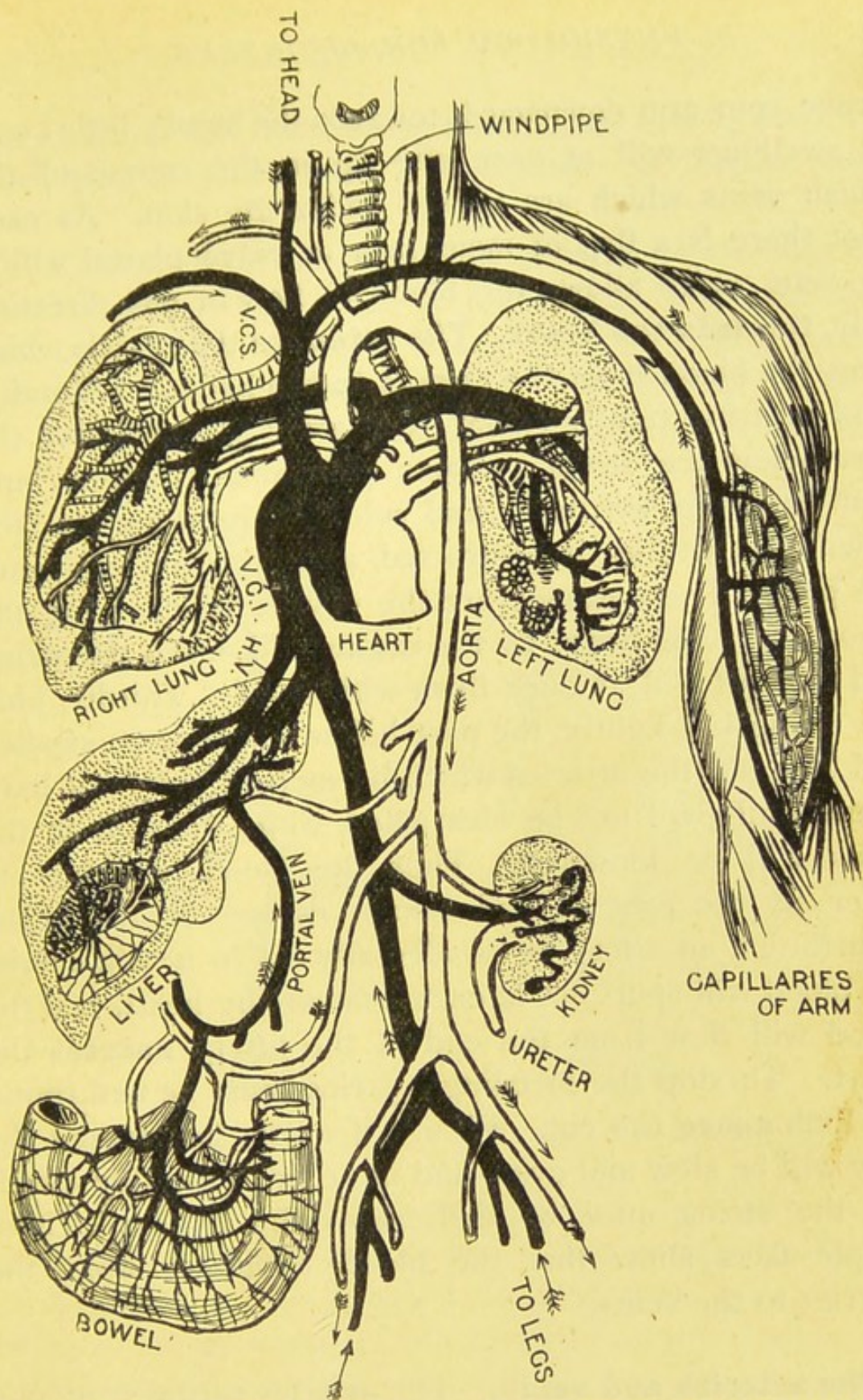


FIG. 18. Diagram of the circulation. The venous blood *black* in the vena cava superior and inferior and their branches, in the portal vein, and in the pulmonary artery. Arterial blood *white* in the aorta and its branches. In the left lung some air sacs are shown and the blood changing from *venous to arterial*. In the capillaries of the arm-muscles, bowel, and kidney the blood is shown changing from *arterial to venous*. In the kidney two tubules are shown. The kidney tubules purify the blood from urea, and pass the urine into the ureter. In the bowel three villi are indicated. These absorb the food. The food passes by the portal vein to the liver. A lobule of the liver is shown. The liver-cells prepare the portal blood. The blood passes from the liver into the vena cava inferior. The renal tubules, the air sacs, the liver lobule, and the villi are *really* of microscopic size. A coloured map of this figure is published by G. Gill and Sons, Warwick Lane.

stroke your arm downwards towards the hand ; little knots or swellings will at once rise up in the course of the bluish veins which are visible under the skin. At each knot there is a flap of membrane or **valve** placed within the vein, which allows the blood to flow in one direction only, **towards the heart**. The **veins** are the vessels which carry the blood **from the organs to the heart**. Secondly, bind a string tightly round your arm ; you will find the part below the string remains pale and bloodless, and soon begins to feel numb and cold. This is because the flow in the arteries is obstructed, and no blood can enter the part. The **arteries** are the vessels which bring the blood **from the heart to the organs**. Loosen the string and the part will at once flush with blood. Thirdly, bind the string but lightly, the part below will become swollen and blue, for the arteries which lie more deeply and have firmer walls will not be obstructed, while the flow in the veins will be hindered. Thus the blood continues to enter by the arteries and cannot escape by the veins. Fourthly, if an artery be accidentally cut in a man's wrist the blood will spurt out at each beat of the heart, and the blood will flow from the end of the artery **nearest** the heart. To stop the bleeding a string must be tied round the limb **above** the cut. Fifthly, if a vein be severed the flow will be slow and even, and in order to stop the bleeding the string must be tied **below** the wound. These simple facts show that the blood circulates from the arteries to the veins.

The arteries and veins. The arteries spring from one main artery, the **aorta**, which comes out of the left side of the heart, while all the veins join two main veins (the superior and inferior vena cava) which enter the right side of the heart. The aorta branches out into arteries which run to every part of the body **except the lungs**, and from

every part of the body **except the lungs** there pass veins which run to join either the superior or inferior vena cava.

The veins from the head and arms pass to join the superior cava, while those from the legs and abdomen enter the inferior vena cava. The arteries end in a network of wonderfully small vessels, far smaller than a hair. These vessels are called **capillaries**, and the net-

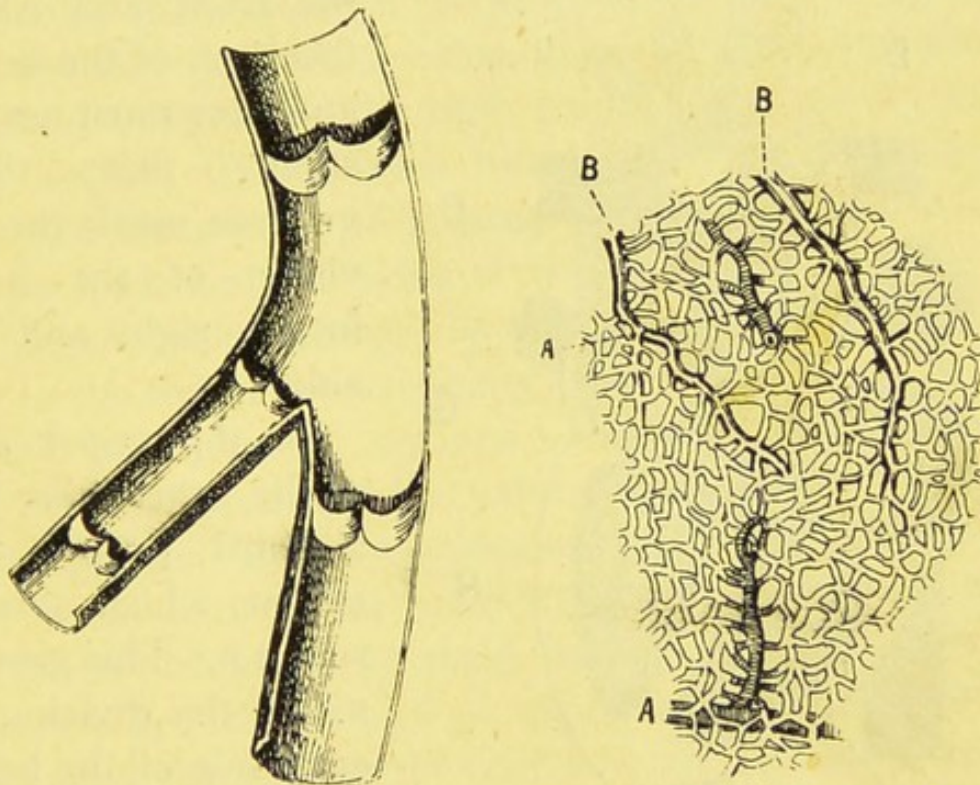


FIG. 19. Vein cut open to show the valves.

Diagram of a network of capillaries.

work is so close that no matter where you prick your finger with a needle you cannot help wounding a capillary, and by so doing you cause a drop of blood to ooze out. Owing to the closeness of the capillary network every cell in the body can obtain its nourishment from the blood.

To the lungs there runs an artery from the heart called the **pulmonary artery**, and from the lungs the blood is brought back to the heart by **four pulmonary veins**.

The heart. To understand the working of the heart you must buy a sheep's heart from the butcher, and dissect

it. The heart is shaped like a cone. The **apex** or point of the cone is the lower end, while the broad part or **base** is the uppermost part of the heart. Running obliquely down the front surface of the heart, **from left to right**, is a shallow groove filled with fat. The back surface of the heart is not so rounded as the front, and up the **middle** of it there runs a shallow groove. By means of these grooves

you can tell which is the front and which the back of the heart, and you must understand that these grooves mark the division of the heart into a right and left side.

In the upper part of the heart there lies a third groove full of fat which circles round it. This groove marks the division of each side of the heart into an upper and a lower chamber. There are therefore four chambers in the heart, two on the right side and two on the left.

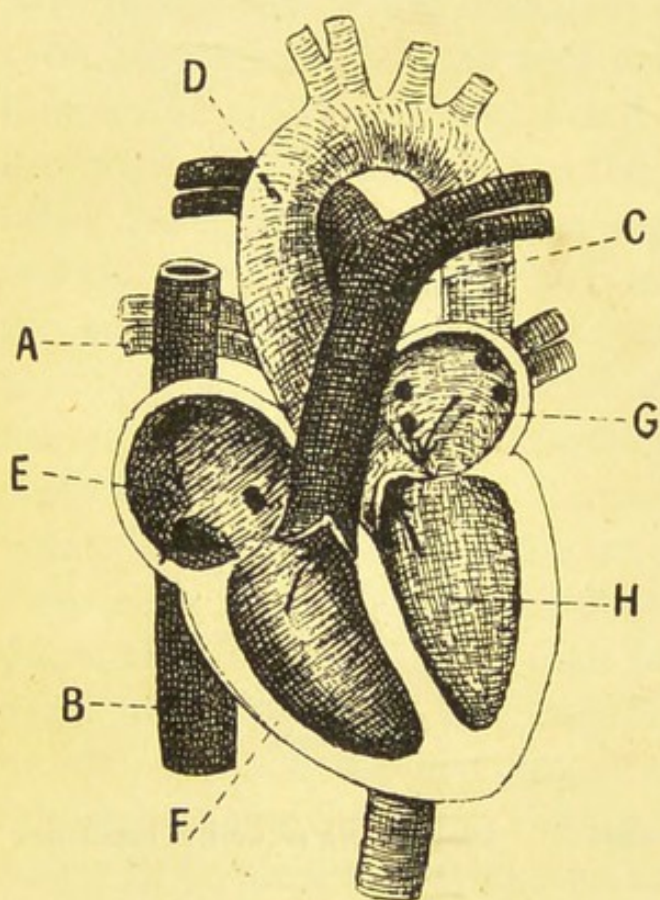


FIG. 20. Diagram of the heart. A. Vena cava superior. B. Vena cava inferior. C. Pulmonary artery. D. Aorta. E. Right auricle. F. Right ventricle. G. Left auricle. H. Left ventricle.

The upper chambers are called the right and left **auricles**, the lower chambers are called the right and left **ventricles**. Inside the heart there is a wall which completely separates the right side from the left side. Each auricle is not completely divided from the corresponding ventricle, for the partition between the auricles and ventricles is on each

side pierced by a large hole—one hole opening from the right auricle into the right ventricle, the other from the left auricle into the left ventricle. Some thin flaps of membrane hang from the margins of each hole. When these flaps are raised they meet together and so complete the partition. The flaps are valves set to regulate the flow of blood between the auricles and ventricles. While the left ventricle is a thick and the right a thin walled muscular chamber, both the auricles are thin-walled. The left ventricle is thick because it has to pump the blood all over the body, while the right has to pump it only through the lungs. The auricles have only to pump the blood into the ventricles. The greater part of the auricles lies at the back and the sides of the broad part of the heart, and is concealed in front by the large arteries which come out at the top of the ventricles.

You will have to cut open the heart before you can see the partitions and the valves, but before doing so you must first look at the blood-vessels which enter and leave the broad part of the heart. In front and from the top of the ventricles there come out two large whitish tubes. These tubes, if you pull on them, are elastic. The front one rises from the right ventricle, and is the **pulmonary artery**. The other coming out from the left ventricle is the **aorta**, the great artery which supplies with blood all the body except the lungs. Into the right auricle there open two large veins, the superior vena cava bringing the blood from above, and the inferior vena cava bringing it from below. The veins have thinner walls than the arteries, and are not elastic in the same way. Into the left auricle there open two (four in man) pulmonary veins.

Now cut through the pulmonary artery just above where it comes out from the right ventricle and look inside it. You will see three little flaps of membrane, each forming a little pocket, like a watch-pocket. These are the **semi-**

lunar valves of the pulmonary artery. Pour some water into the pockets and you will at once see that the valves close together and prevent the water running into the ventricle. Push a penholder between the valves down into the heart and you will feel it in the right ventricle. Next cut open the right auricle and look down into the right ventricle; you will see three little flaps of membrane hanging round the margin of the opening between the right auricle and right ventricle. To these flaps are attached some little strings or tendons which come from fleshy projections in the wall of the right ventricle. If you pour some water into the ventricle you will see the flaps rise up and close the opening in a wonderfully perfect way. The little strings or tendons prevent the valve from being turned inside out, just as an umbrella is kept from such mishap by its wires. These three flaps form the **tri-cuspid valve**, and it is this valve that allows the blood to flow from the right auricle into the right ventricle, but will not allow the blood to flow back from the right ventricle into the right auricle. Now cut through the root of the aorta just above the top of the left ventricle. On looking within you will see three little pocket-shaped valves just like those in the pulmonary artery. Pour water upon these, and they will close and prevent the entry of water into the left ventricle. They are called the **aortic semi-lunar valves**. Next open the left auricle and you will see the opening which leads from this auricle into the left ventricle. There are two little flaps of membrane hanging from the margins of this opening, and they are attached by little strings to fleshy projections in the wall of the left ventricle. Pour water into the left ventricle and these valves will float up until they close the opening. The flaps are called the **bi-cuspid** or mitral valve. The mitral valve allows the blood to flow from the left auricle into the left ventricle, but will not permit it to return from the left ventricle into the left

auricle. Having now opened the heart you will see the fleshy partition which completely divides the right from the left side.

The way the living heart acts. The blood flows into the right auricle from the superior and inferior vena cava. When the right auricle is full it contracts and drives the blood into the right ventricle. Then the right ventricle contracts, and the tri-cuspid valve closes so that no blood can get back into the right auricle. The pulmonary semi-lunar valves are forced open, and the blood is driven out

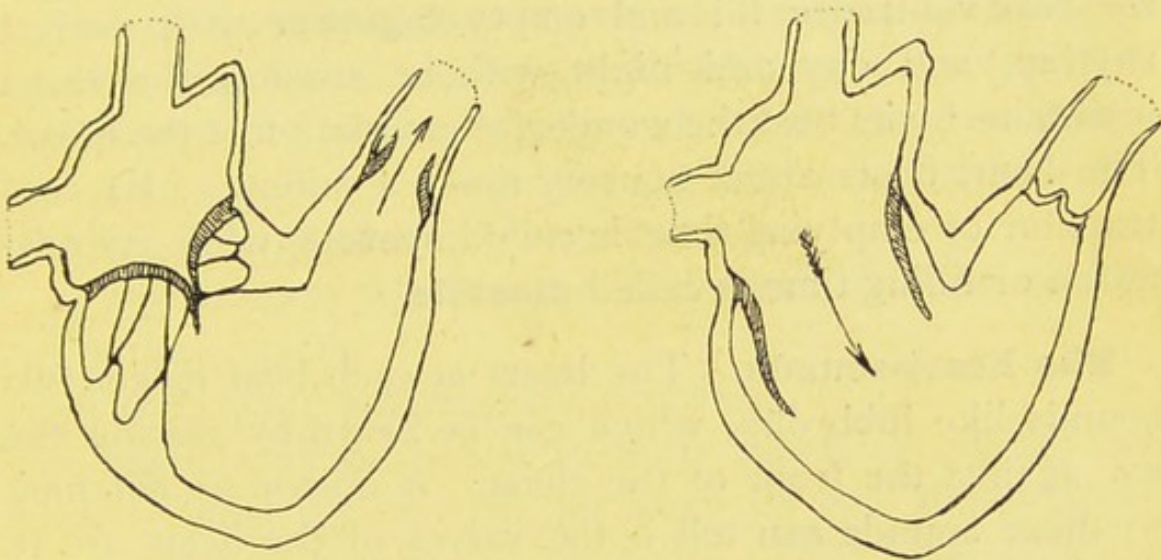


FIG. 21. Diagram of the right auricle and ventricle. In the figure on the right the tri-cuspid valve is open, the pulmonic semi-lunar valves shut as in diastole. In the left figure the tri-cuspid valve is shut, and the pulmonic valve open as in systole.

of the right ventricle into the pulmonary artery. When the right ventricle has emptied itself of blood it ceases to contract, and opens out again; but the blood cannot return into it from the pulmonary artery, for the semi-lunar valves shut to. So soon, however, as the right ventricle dilates the tri-cuspid valve opens, and the right auricle, which has become again filled with blood from the veins, can once more drive blood into the right ventricle.

While all this is going on, on the right side of the heart, the blood flows from the pulmonary veins into the left auricle. As soon as it is full the left auricle drives the

blood into the left ventricle. The left ventricle then contracts, and the mitral valve closes and prevents the blood passing back into the left auricle, while the ventricle drives it through the aortic semi-lunar valves into the aorta. So soon as the left ventricle has emptied itself it dilates, and the blood cannot pass back into it from the aorta, because the semi-lunar valves shut to. So soon, however, as the left ventricle dilates the mitral valve opens, and the left auricle, which has again become filled with blood from the pulmonary veins, once more fills the left ventricle. The two auricles fill and empty **together**, and the two ventricles fill and empty **together** with perfect rhythm, and day and night without ceasing the heart maintains by its beat the wonderful circulation of the blood. The heart beats about seventy times a minute. Its contraction or emptying-time is called **systole**, while its dilatation or filling-time is called **diastole**.

The heart-sounds. The heart at each beat makes two sounds like lūbb dŭp, which can be heard by placing the ear against the front of the chest. A doctor by listening to these sounds can tell if the valves of the heart are in good working-order, for the **first sound** lūbb is partly caused by the vibration of the contracting heart-muscle and partly by that of the auricular-ventricular valves when these are closed and made tense during systole; while the **second sound** dŭp is caused by the vibration of the semi-lunar valves when these are closed at the beginning of diastole, that is, at the end of systole.

The blood-flow in the vessels. While the large arteries are very elastic tubes and the small arteries muscular tubes, the capillaries are formed of very thin flat cells, which allow the oxygen and food material in the blood to soak through to the tissues. If an artery be cut the blood spurts out with each beat of the heart. From

a capillary or vein, on the other hand, the blood flows smoothly and steadily. You can feel the beat of the heart or **pulse** in the artery which lies on the thumb side of the wrist. By feeling the pulse a doctor can tell whether the heart is working well and at the proper rate. The blood in flowing through the branching arteries rubs against the walls of these tubes, and so is hindered in its flow by **friction**. During the beat of the heart the blood cannot escape through the arteries as quickly as it is driven into them. The large elastic arteries are therefore stretched by the force of the heart, and during the resting period of the heart **the stretched arteries continue to squeeze the blood** which is within them on through the capillaries. Thus the jerky flow from the heart is turned into a steady flow through the capillaries. You will see that this is brought about by two things :

(i) the friction which stops the blood flowing quickly out of the arteries,

(ii) the elastic nature of the arteries.

The small arteries, owing to their muscular nature, can open or shut up, and so let more or less blood go to one or other organ of the body. The size of these arteries is regulated by nerves called **vaso-motor nerves**. When the face blushes the little arteries expand and allow more blood to come to this part. When food is being digested the arteries of the stomach, intestine, and pancreas expand. In cold weather the arteries of the skin contract, and so by keeping the blood away from the outer surface of the body lessen the loss of heat. In hot weather just the opposite happens. These examples show you how the blood can be made to flow to one or other part according to the needs of the body.

The flow of the blood in the veins is largely kept up by the movement of the muscles, and especially the muscles of respiration. For every movement squeezes

the blood past the valves in the veins on towards the heart. When the thoracic cavity is enlarged at each breath blood is sucked from the veins into the right side of the heart and lungs, while at the same time the descent of the diaphragm presses the organs of the abdomen and squeezes the blood from these, and especially from the liver, into the vena cava inferior and so into the heart. Active breathing is then of great importance to the circulation. This being the case you will see that it is impossible to have a vigorous circulation of the blood, and therefore a vigorous brain, if you neglect to take a proper amount of muscular exercise. So soon as you neglect to take exercise the blood, owing to its weight, stagnates in the veins of the abdomen and lower parts of the body.

CHAPTER VIII

RESPIRATION

EVERY cell of the body must have oxygen, and it is the duty of the blood to bring a plentiful supply. Every cell must likewise get rid of waste products such as carbonic acid and urea, and it is the duty of the blood to take these away. The blood in its turn takes up fresh supplies of oxygen in the lungs and gives out carbonic acid. The lungs are two large elastic bags placed in the thorax. The bags are full of spongy tissue. The holes called **air-sacs** in this spongy tissue are filled with air, while the meshes of the sponge are formed of elastic connective tissue and capillaries. The right ventricle drives the dark venous blood into the capillaries of the lungs. Between the blood in the capillaries and the air in the air-sacs there is only a very thin wet membrane formed of flat cells. Thus the blood can receive oxygen from the air and give up carbonic acid to it. So soon as the blood combines with the oxygen it becomes scarlet arterial blood. The left side of the heart drives the arterial blood to the organs, and there the blood gives up oxygen to the cells and receives carbonic acid from them. So soon as the blood gives up the oxygen it changes its colour and becomes dark venous blood. So you see the blood as it circulates changes from venous to arterial blood in the lungs, and from arterial to venous blood in the other organs of the body. The haemoglobin in the red corpuscles is the

oxygen-carrier. Haemoglobin plus oxygen is scarlet; haemoglobin minus oxygen is dark-purple in colour.

The exchange of gases between (A) blood and air, (B) blood and tissues. One of the properties of a gas is that it always escapes from a space in which it is pressed into a space where there is little or none of it. A gas is not influenced in this respect by the presence of other gases, that is so long as it does not chemically combine with them. When a soda-water bottle is opened carbonic acid bubbles off into the air. Soda-water is made by forcing carbonic acid gas into water. The water dissolves the gas. There is not more than a trace of carbonic acid gas in the air, while in the bottle the gas is under great pressure. The oxygen and nitrogen gases, of which air is composed, do not hinder the escape of the carbonic acid. As the atmosphere contains almost no carbonic acid, this gas escapes into it just as if it were an empty space. Now the tissues are always producing carbonic acid and pressing it into the blood, and when the blood comes round to the lungs some of this gas naturally escapes into the air. Carbonic acid gas is, however, not simply dissolved in the blood, for it chemically combines with the salts of the blood to form carbonates. Owing to this fact the blood can carry a great deal of carbonic acid, but at the same time the explanation of its escape into the air through the lungs is rendered more difficult. When the blood reaches the lungs the carbonates are decomposed, and probably the chemical union of oxygen with haemoglobin helps to bring about this decomposition. Haemoglobin is a substance which greedily combines with oxygen, but the tissues are greedier still and rob the haemoglobin of its supply. Thus it comes about that there is only a little oxygen left in the blood when it enters the veins. In the air within the lungs, on the other

hand, there is a great deal of oxygen, and the oxygen, like other gases, escapes into any space where there is little of it. Thus it passes from the lungs into the venous blood. The haemoglobin chemically combines with the oxygen as fast as it comes through, until it has taken up all it can hold.

The following table shows the amount of gas in the arterial and venous blood:—

	100 pints of venous blood yield to the air-pump	100 pints of arterial blood yield to the air-pump
Carbonic acid gas	46 pints	40 pints
Oxygen . . .	12 pints	20 pints
Nitrogen . . .	1-2 pints	1-2 pints.

A little of the nitrogen in the air becomes dissolved in the blood as it passes through the lungs, but this gas is of no use or importance to us.

In order that the exchange of gas between air and blood may continue, the air in the lungs must be frequently changed. The ventilation of the lungs is brought about by the movements of breathing or respiration.

The structure of the lungs. To the lungs there passes the wind-pipe or **trachea**. At its upper end the wind-pipe opens into the throat. It is a large tube made stiff by rings

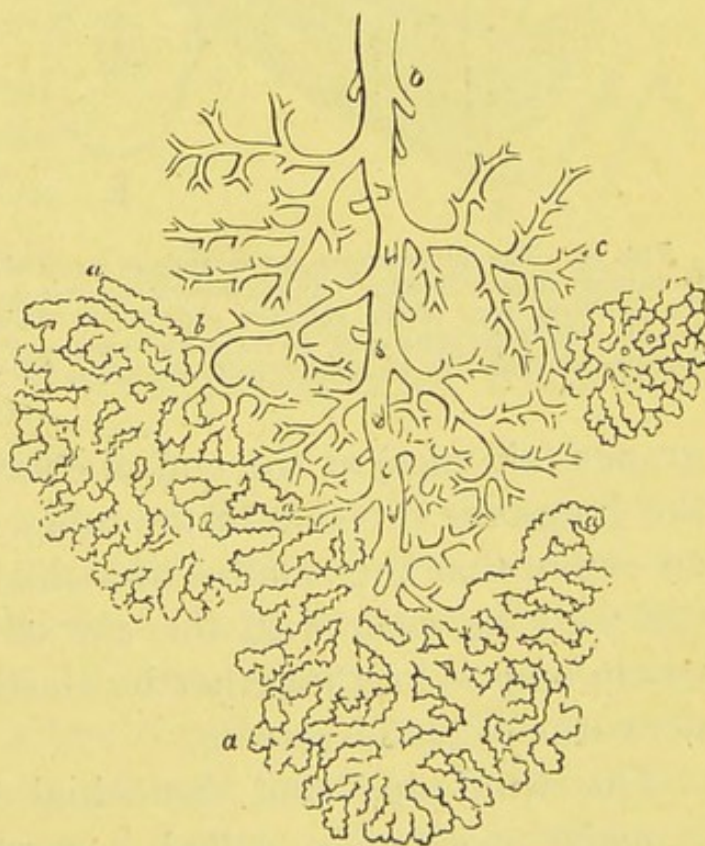


FIG. 22. Diagram of a bronchial tube branching into a number of air-sacs.

of cartilage set in its wall. At the top of the wind-pipe lies the voice-box or larynx. The wind-pipe runs down the neck, in front of the gullet, and passes into the thorax. There it divides into two branches, one for each lung. These branches divide again and again into smaller and smaller branches, and finally the smallest branches end in the little **air-sacs**.

The lung is thus made somewhat after the plan of a bunch of grapes: there is the main stalk (the wind-pipe), the big and little branches (the **bronchial tubes**), and the

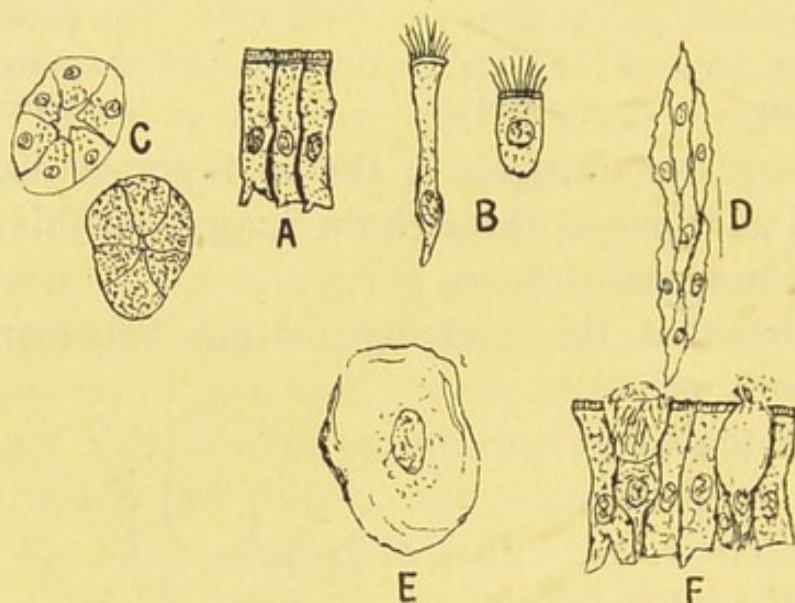


FIG. 23. The microscopic appearance of some of the cells of the body. A and B. Columnar cells with cilia. These line the air-tubes. C. Glandular cells such as form the secreting sacs of the salivary glands. D. Thin flat cells which line the blood-vessels. E. Flat cells such as form the outermost layer of the cells which line the mouth and skin. F. Columnar cells which line the alimentary canal.

grapes (air-sacs) at the end of every little branch. But in the lungs the division of the tubes is carried to so minute an extent that the smaller bronchial tubes and the air-sacs can only be seen with the aid of the microscope. The whole lung is knit together by elastic connective tissue and networks of blood-vessels.

The wind-pipe and bronchial tubes are lined with a moist membrane called a **mucous membrane**. The cells which line this membrane are provided with tiny

protoplasmic processes or **cilia**. The cilia continually lash to and fro, and drive the dust which is drawn in to the air-tubes up into the throat. The air-tubes are thus kept clean. The tubes are moistened with a fluid of the same nature as saliva. This is made by little **glands**, numbers of which lie in the walls of the air-tubes. Such a gland consists of a branching tube or **duct** lined with **secreting** cells. The gland-cells make the **secretion** out of the blood and send it through the ducts into the air-tubes.

The thoracic cavity.

The lungs and heart lie within the thoracic cavity. The thorax is formed of a bony cage, made by the ribs, spine, and sternum. Filling up the spaces between the ribs lie thin sheets of muscle, **the intercostal** muscles. On the outside of the thoracic wall is the skin, on the inside a thin glistening membrane, **the pleura**. The lungs are also covered

with pleura. The lungs are attached to the spine by connective tissue at the place where the vessels and wind-pipe enter, but otherwise hang freely in the thoracic cavity. The surfaces of the pleura are moistened with fluid, so as to allow the lungs to glide over the inner wall of the thorax without friction. In the illness called pleurisy the pleura becomes inflamed and rough, and prevents the lungs moving easily in the thorax.

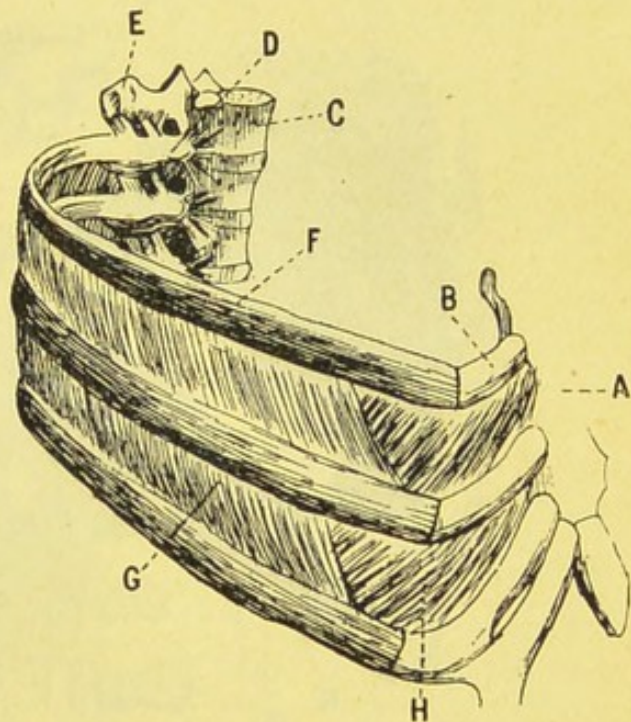


FIG. 24. Three ribs and the intercostal muscles between them. A. Sternum. B. Cartilage joining ribs to sternum. C, E. Vertebral column. D. Attachment of rib to vertebral column. F. Rib. G, H. Intercostal muscles.

The lungs are full of air and **exactly fit the thoracic cavity**.

The thoracic cavity is divided into a right and left chamber by the heart and the fibrous tissue which fastens the heart to the spine and breast-bone. Each chamber contains a lung. The floor of the thoracic cavity is formed by the dome-shaped muscular partition called the

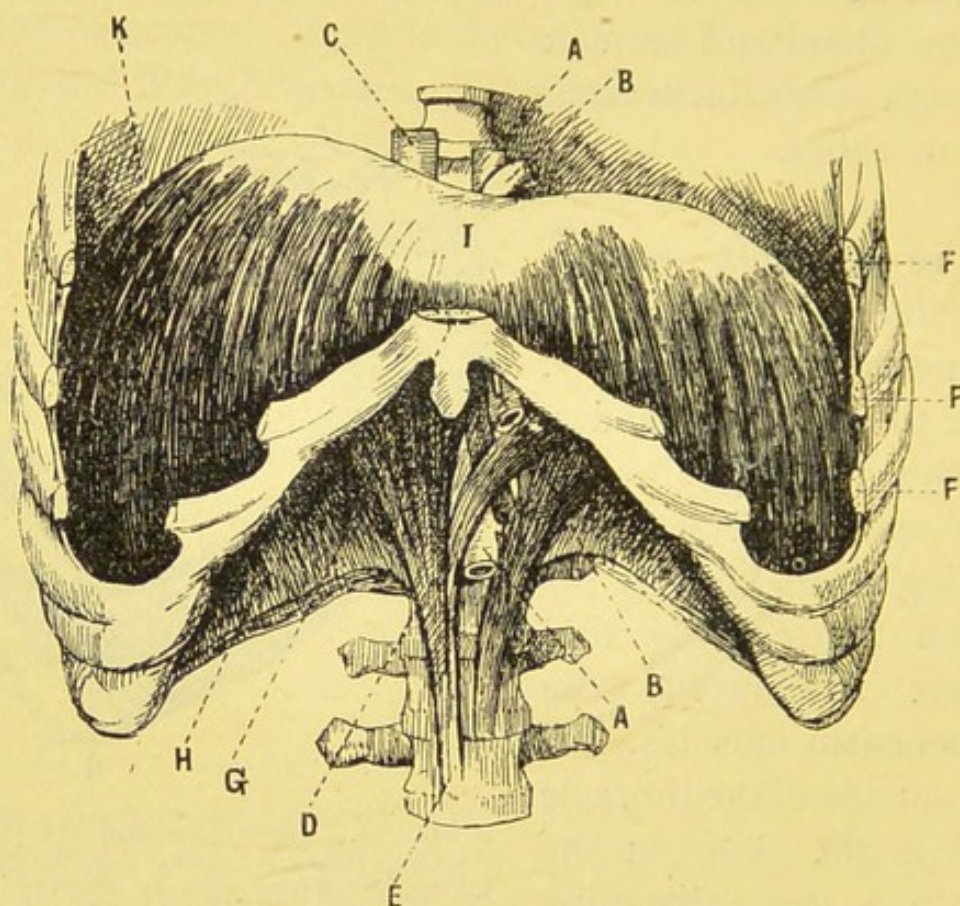


FIG. 25. The diaphragm as it appears after the front of the thorax and the thoracic and abdominal organs have been taken away. A. Aorta. B. Gullet and C. Vena cava inferior passing through diaphragm. E. Spine. F. Ribs. G. Lower end of sternum. I. Central tendon and K. muscular part of diaphragm.

diaphragm. To the outside of the bony cage of the thorax many muscles are attached. Some of these pass to the head and shoulders, while others pass to the hip-bones and form the muscular wall of the abdomen.

The act of breathing or respiration. Breathing consists of two movements, **inspiration** or the drawing in of air, and **expiration** or the giving out of air.

Draw in a deep breath in front of a mirror, and you will see your thorax rise and abdomen swell out. At each inspiration the intercostal muscles, helped by some of the neck-muscles, pull up the thorax. The ribs slant downwards. They are jointed to the spine behind and bound by cartilage to the breast-bone in front. When the slanting ribs are pulled up they naturally push the breast-bone forwards, and make the cavity of the thorax larger.

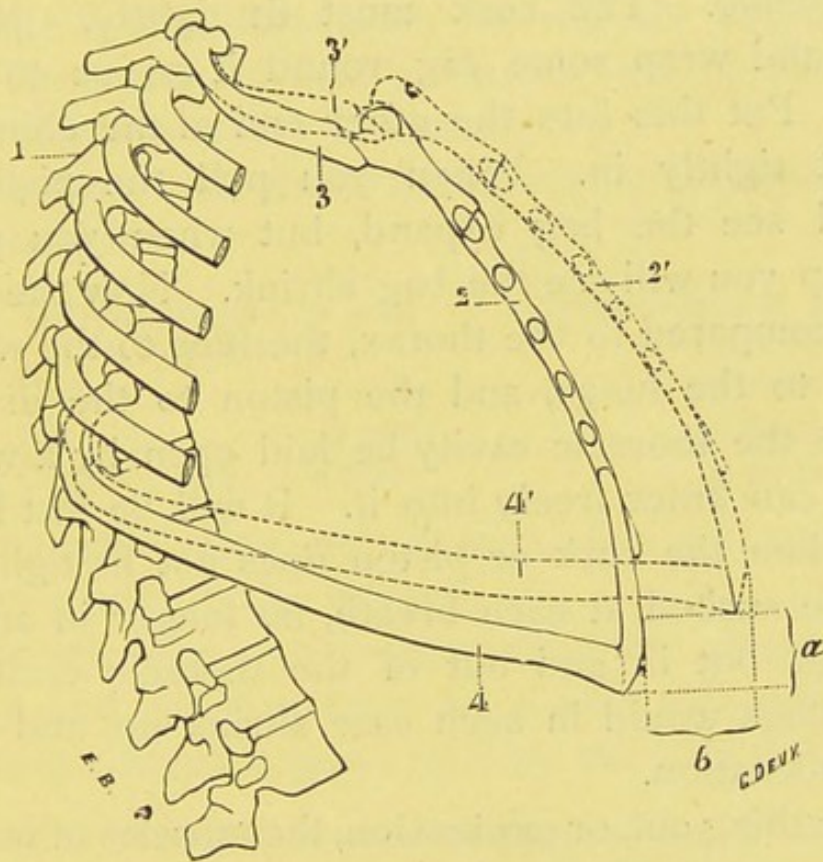


FIG. 26. Diagram showing how the sternum is pushed forward when the ribs are pulled upwards.

The muscle of the diaphragm also contracts at each inspiration. The contraction makes it flatter and less dome-shaped. The diaphragm thus enlarges the thoracic cavity and at the same time presses upon the organs in the abdomen. The descent of the diaphragm causes the abdomen to swell out.

When the thoracic cavity becomes enlarged in inspiration

no air can pass into it, for it is an air-tight chamber. On the other hand, air easily passes down the wind-pipe and expands the lungs. The pressure or weight of the air¹ blows out the elastic lungs when the thoracic cavity is made larger, just as it forces water into a toy syringe when the piston is pulled out.

Bore a hole in a large cork and pass a tube through the hole. On to one end of the tube tie a toy balloon. Put the cork into a lamp-chimney so that the balloon hangs inside. The cork must fit tightly. Next take a stick and wrap some rag round it so as to make a piston. Put this into the other end of the chimney. It must fit tightly in. When you pull the piston down you will see the bag expand, but when you push the piston up you will see the bag shrink. Now the chimney can be compared to the thorax, the tube to the wind-pipe, the bag to the lungs, and the piston to the diaphragm. Suppose the thoracic cavity be laid open by a wound so that air can enter freely into it. It will be just like your model when the cork or piston does not fit tightly. Air would be sucked at each breath, no longer in and out of the lungs, but in and out of the thoracic cavity. The elastic lungs would in such case shrink up, and the man die of suffocation.

In breathing out, or **expiration**, the muscles of inspiration cease to contract, the diaphragm relaxes and becomes dome-shaped, and the heavy thorax, owing to its weight, sinks down into its former position. Thus the thoracic cavity becomes smaller, and the elastic lungs shrink and drive out air.

There are always within the lungs about five pints of air, and at each respiration about half a pint is taken in and given out. Thus you see only a small part of the air in the lungs is changed at each breath.

¹ See Atmospheric pressure in Physics Primer.

The difference between inspired and expired air.

Expired air contains about five per cent. less oxygen and four per cent. more carbonic acid than atmospheric air.

If you blow through a straw into a bottle containing **lime-water** the latter will turn **milky**, owing to the carbonic acid in the expired air. The carbonic acid combines with the lime to form a white solid salt, carbonate of lime. If you allow the carbonate of lime to fall to the bottom of the bottle, and then, having poured off the water, add a little hydrochloric acid, you will see the salt effervesce. The carbonic acid is driven out by this strong acid and chloride of lime is formed.

The following table shows the difference between inspired and expired air:—

Composition of 100 pints of inspired air.		Composition of 100 pints of expired air.	
Oxygen . . .	21 pints		16 pints
Nitrogen . . .	79 pints		79 pints
Carbonic acid . .	a trace		4 pints.

The nitrogen does not change, but its presence is necessary to dilute the oxygen.

The breath of a man is warmed to the temperature of the body, and appears misty on a cold day owing to the water-vapour which it takes up from the air-tubes.

The effect of exercise on the respiration. When a man runs he breathes rapidly, and pants for breath. This is because the muscles are hard at work, giving out carbonic acid, and using up oxygen. The working muscles therefore need plenty of arterial blood. The rapid movements of respiration not only purify the venous blood but help to bring it back to the heart, and aid the heart in driving it through the lungs. When the lungs expand in inspiration not only more air but more blood is drawn into them. When the lungs shrink in expiration not only air but blood is driven out of them. The blood is driven into

the left side of the heart, for it cannot pass back into the right side of the heart owing to the semi-lunar valves in the pulmonary artery.

Suffocation. A man dies in two or three minutes if he cannot breathe. He first struggles violently for breath, then loses consciousness and becomes convulsed. The veins of his face become distended with venous blood, and his skin assumes a dusky blue colour. The convulsions soon cease, and after two or three gasps the man lies motionless and dying. The heart continues to beat for a few minutes, and recovery may even at this stage be brought about by artificial respiration. To carry out artificial respiration, the obstruction to breathing must first be removed, and then the lower part of the thorax must be rhythmically and forcibly squeezed, so as to imitate the movement of respiration. Fresh air is drawn into the lungs when the thorax is allowed to expand after each squeeze. By squeezing the thorax the heart is also stimulated to drive on the blood.

Suffocation, or **asphyxia**, is brought about by hanging, drowning, or any other cause, such as a bone in the throat, which obstructs the wind-pipe. A man is likewise asphyxiated, owing to lack of oxygen, by going down into a well full of foul air, by being shut up in an air-tight chamber, or in a place full of coal gas.

As a man uses up oxygen and gives out a poisonous gas—carbonic acid—it is clear then that to live healthily he must keep his room well ventilated, and be out in the fresh air as much as possible.

CHAPTER IX

THE WASTE OF THE BODY

Food. IF a man were to sit all day in a weighing machine, he would find that he lost weight between meals, and gained weight by eating and drinking. The loss of weight is due to the excretions which the man gives off. The day's loss would be about as follows:—

From the bowel	. 5 oz. faeces
„ „ skin	. 25 oz. sweat
„ „ kidneys	. 50 oz. urine
„ „ lungs	. 35 oz. carbonic acid gas, and water-vapour
Total	. 115 oz.

The total loss is, then, about 8 pounds, and of this water forms the greater part (about 6 pounds); the remainder consists of those waste materials which result from the breaking down of the active living protoplasm into simpler chemical substances.

In considering these waste materials we can set aside the faeces, for these consist almost wholly of the undigested food and water which have never entered into the substance of the body, but have simply passed through the alimentary canal.

The sweat contains $\frac{1}{4}$ oz. of salts and a trace of **urea**, the urine 1 oz. of salts and $1\frac{1}{4}$ oz. of **urea**. Urea is a substance of great importance, as it is the chief waste substance produced by the processes of decay and growth in the cells of the body. It can be separated from the urine by chemical means, and then appears as a white

crystalline powder. When urea is broken down by the chemist into its elements, it is found to yield carbon, hydrogen, oxygen, and nitrogen, but almost half its weight consists of **nitrogen**.

Urea is easily changed into ammonia by the action of bacteria, and is decomposed by fuming nitric acid into nitrogen, carbonic acid, and water. The chief waste substances of the body are, then, water—a compound of oxygen and hydrogen; carbon dioxide—a compound of carbon and oxygen; urea—a compound of carbon, oxygen, hydrogen, and nitrogen—and mineral salts. The salt is chiefly sodium chloride or common salt. There are also in the urine small quantities of phosphates and sulphates of lime, sodium and potassium.

To make up this loss food must be taken or else the man will waste away and die.

The food of man consists of proteids, fats, carbohydrates, water, mineral salts, and oxygen. The chief proteids we eat are vegetable proteids found in flour, oatmeal, peas, and beans, and animal proteid found in eggs, milk, and flesh. In the $1\frac{1}{4}$ oz. of urea which is daily lost there is contained a little more than $\frac{1}{2}$ oz. of **nitrogen**, while in the carbonic acid lost there is about **8 oz. of carbon**. There is, then, fifteen times as much carbon lost as nitrogen, and it is clear that the food must contain carbon and nitrogen in the same proportion. If too much of one be taken it will be turned into fat or wasted, and the digestive organs will be given extra work which is of no value to the body. If, on the other hand, too little be taken, the man must, to keep alive, consume part of his body-substance, and in consequence will lose fat or flesh and eventually die of starvation.

Foods. Now in lean meat the proportion of nitrogen to carbon is as 1 to $3\frac{1}{2}$. Thus to obtain the right amount of

carbon (15 to 1 of nitrogen) from a diet of meat a man would have to eat about four times as much nitrogen as he requires. Since fat, starch, or sugar contain plenty of carbon but no nitrogen, it is clear that by mixing these with meat the proper amount of nitrogen and carbon can be obtained. By taking $\frac{3}{4}$ pound of lean meat each day and 2 pounds of bread enough of both elements is secured, and on such, with plenty of water and a little common salt, a man can live.

Milk contains a great deal of water (almost 90 per cent.), and fat, sugar, and proteid in about equal quantities.

The infant, owing to its rapid growth, needs a greater proportion of proteid and water in its food to build up its tissues. Flour, oatmeal, and bread contain proteid and carbohydrate (starch), but almost no fat. The amount of proteid is not quite sufficient in these foods, but by adding milk to oatmeal man can obtain a sufficient and wholesome food—one on which the Scots have lived and thrived. Sago, tapioca, arrowroot, consist of starch and water. Peas and lentils are rich in starch and vegetable proteid, but the latter is not so digestible as animal proteid. When cooked these substances swell and form a very bulky food. Potatoes consist of starch and water and a very little proteid. Green vegetables contain mostly water, with a very little starch and proteid, and some useful salts. Dried fruits such as figs, dates, raisins, contain proteid and much carbohydrate. Nuts are rich in all the food materials, including fat. The following is a liberal diet for a hard-working man:—

Breakfast : Oatmeal, 3 oz. ; milk, $\frac{1}{4}$ pint ; bread, 6 oz. ; butter, $\frac{1}{2}$ oz.

Dinner : Meat, 6 oz. ; potatoes, 6 oz. ; bread, 4 oz. ; apples, 6 oz.

Supper : Bread, 8 oz. ; butter, $\frac{1}{2}$ oz. ; cheese, 2 oz.

No other kind of food but proteid will yield nitrogen in a form such as the body can use. Therefore we must have proteid, and to this we must add carbohydrate or fat,

and it is found to be best to take both, for while carbohydrate is the cheapest, fat is much more easily digested. Fat, when burnt in the body, produces the most heat. So we eat more fat in the winter.

Pepper, mustard, &c., excite the taste-nerves and in-

crease the flow of digestive juices. Tea, coffee, and alcohol are brain stimulants. They are often used to relieve feelings of weariness or misery. To stimulate the nervous system at a time when it should take rest is a dangerous habit, and the frightful injury to the tissues and loss of nerve power produced by such a habit and by drunkenness cannot be too forcibly taught to us all. Beef-tea and meat extracts and juices are pleasant to taste and stimulate digestion, but the advertisements concerning them are untrue, for they contain very little food. The uses of

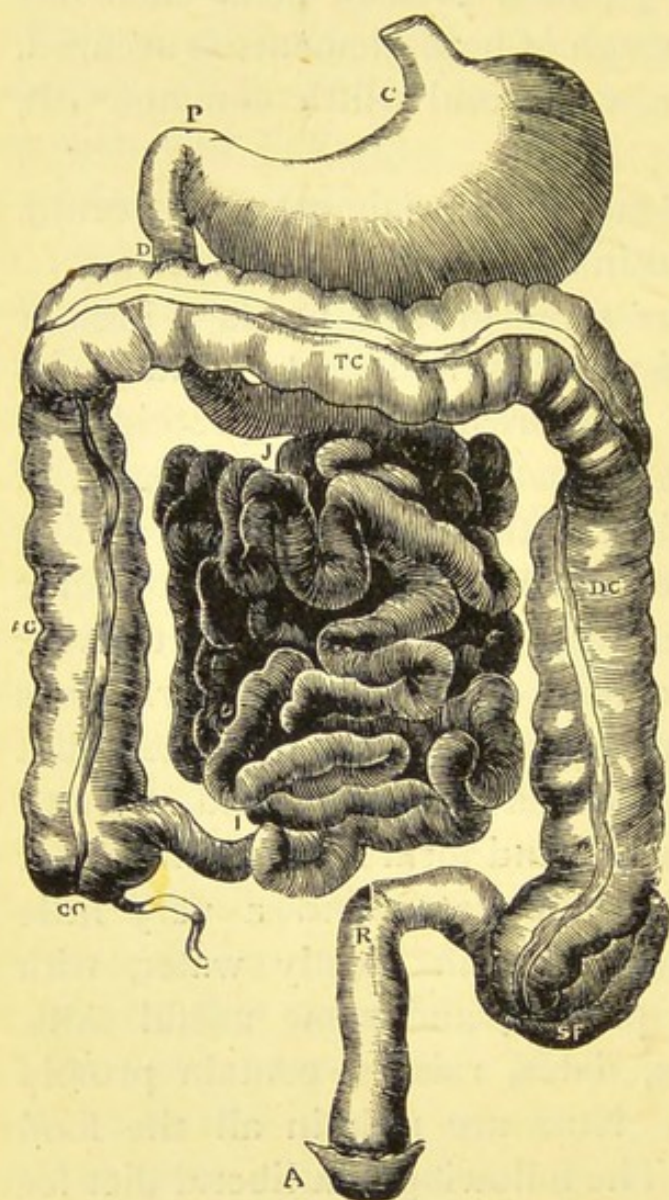


FIG. 27. Stomach and intestine removed from the abdomen. C, P. Stomach. D, J, I. Small intestine. CC to A. Large intestine.

cooking are to destroy bacteria and parasites in the food, to render the starch and proteid in vegetables more digestible, and to improve the taste of food.

The digestion of food. The food is digested in the

alimentary canal and from thence taken up, or **absorbed**, by the blood-vessels and lymphatics. The alimentary canal consists of:

(1) The mouth, where the food is chewed and mixed with saliva.

(2) The gullet, a soft muscular tube about ten inches long, which passes down into the thorax behind the trachea, pierces the diaphragm, and opens into the stomach. The gullet carries the food which we swallow from the mouth to the stomach.

(3) The stomach, a large bag wherein the food is stored and partly digested.

(4) The small intestine, where the food is completely digested and absorbed.

(5) The large intestine, where the waste materials in the food are separated, gathered together, and expelled as faeces.

The teeth. The teeth are fixed in their sockets in the jaw-bones, each tooth consisting of a **crown** and one or more **fangs**. In the centre of each tooth there is a hollow full of pulp, i.e. soft connective tissue, blood-vessels, and nerves. The substance of a tooth is something like bone,

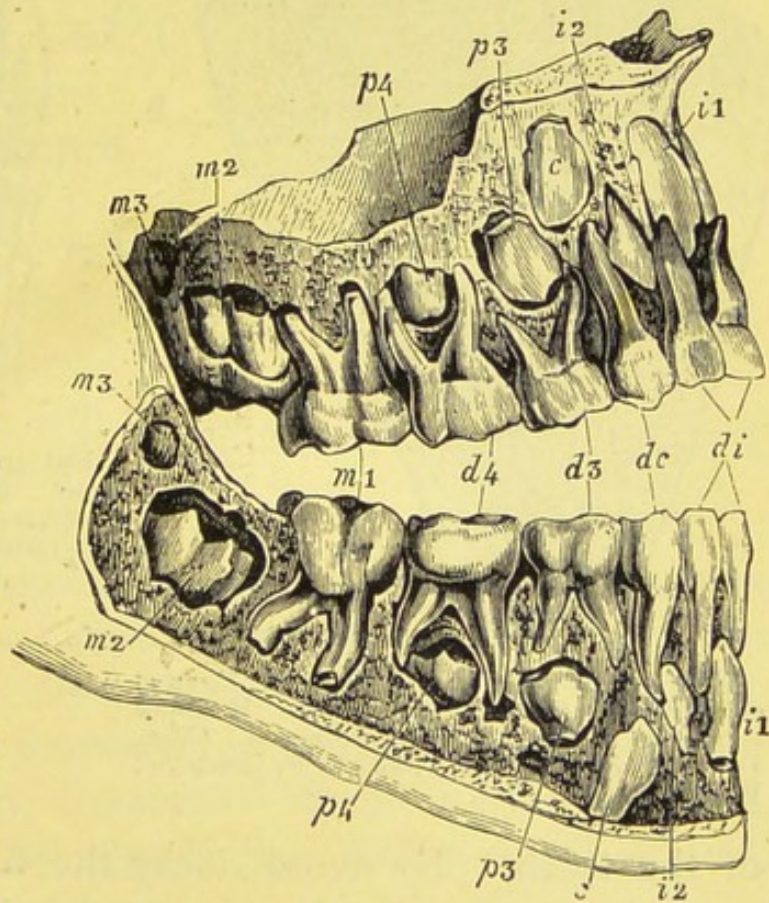


FIG. 28. Upper and lower jaw of child cut open to show the milk teeth and the growing permanent teeth. The milk teeth are: *di* 8 incisors, *dc* 4 canines *d3* and *d4* 8 premolars, *m1* 4 first molars.

and the crown is covered with a thin layer of **enamel**, a very hard substance almost entirely composed of mineral salts. The decay of the teeth is brought about by bacteria, which produce acid fermentation in the food-particles which lodge between the teeth. The acid dissolves the mineral matter

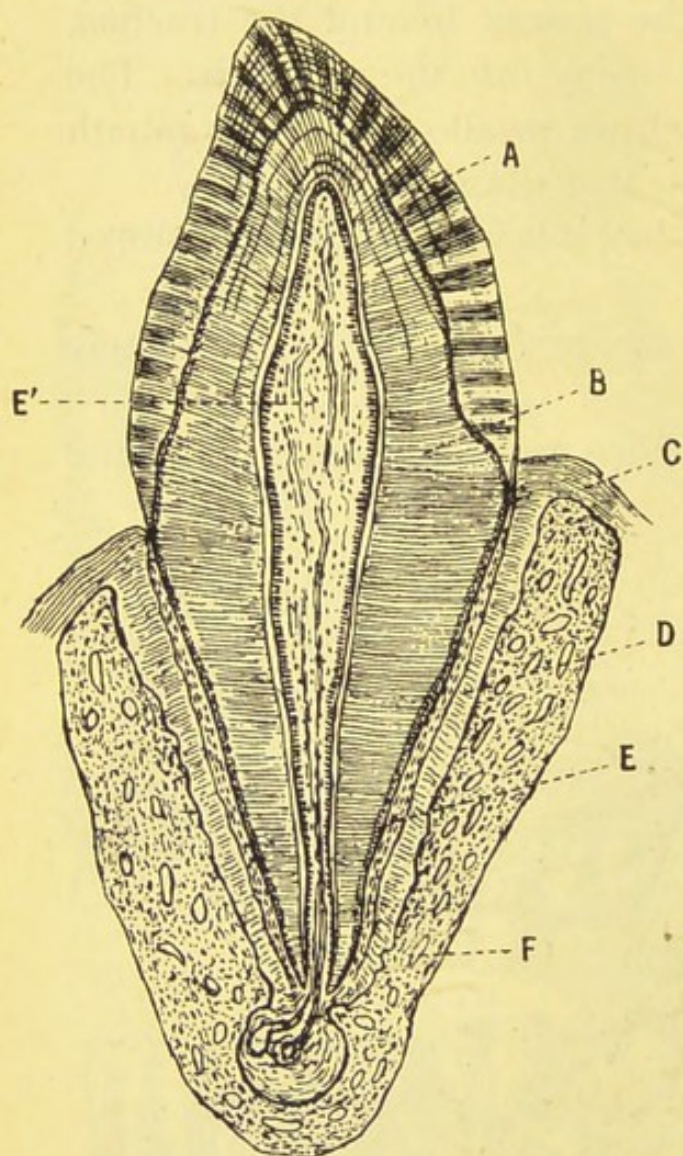


FIG. 29. Section of a tooth. A. Enamel covering the crown of the tooth. B. Bony substance of tooth called dentine. C. Gum. D, E. Tissue cementing tooth to F, jaw-bone. E'. Pulp.

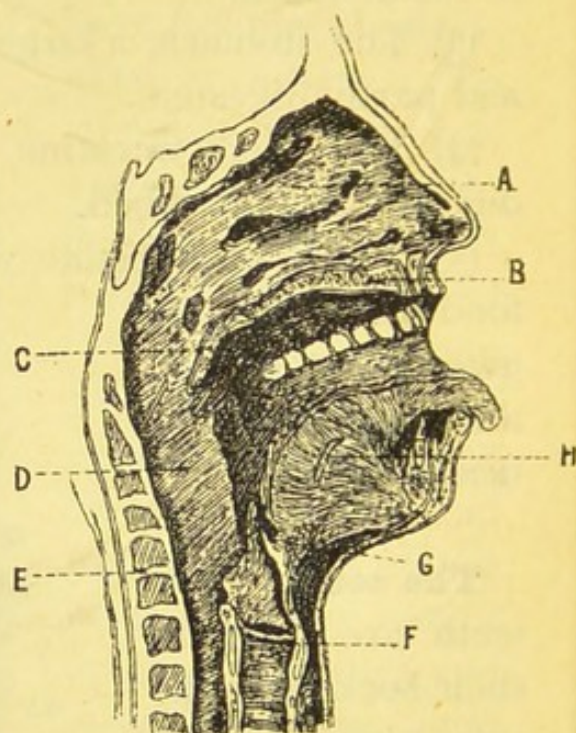


FIG. 30. The head divided in two. A. Nose. B. Hard palate. C. Soft palate. D. Pharynx. E. Spine. F. Larynx. G. Epiglottis. H. Tongue.

of the teeth. To avoid decay the teeth should be kept very clean. By chewing the food is broken up into small particles, so that the digestive juices may reach all parts of the same. Food should not be swallowed whole.

The tongue is a muscular organ with a rough surface. It mixes the food with saliva, pushes it between the teeth, tastes it, and finally gathers it up into a mass ready for swallowing, and pushes it into the gullet. The gullet is a muscular tube, and grasps the food delivered to it by the tongue and drives it down into the stomach.

The salivary glands. The saliva in the mouth is secreted by six salivary glands, three on each side of the mouth. There are two **parotid glands**—these lie one on each side, just in front of the ear and behind the angle of the jaw: two **submaxillary glands**—these lie one on each side under the lower jaw: the two **sublingual glands** lie under the tongue. From each gland a little tube, or **duct**, passes to open in the mouth. In each gland the duct branches into lesser ducts, and these into still smaller ones. The smallest ducts open into tubes

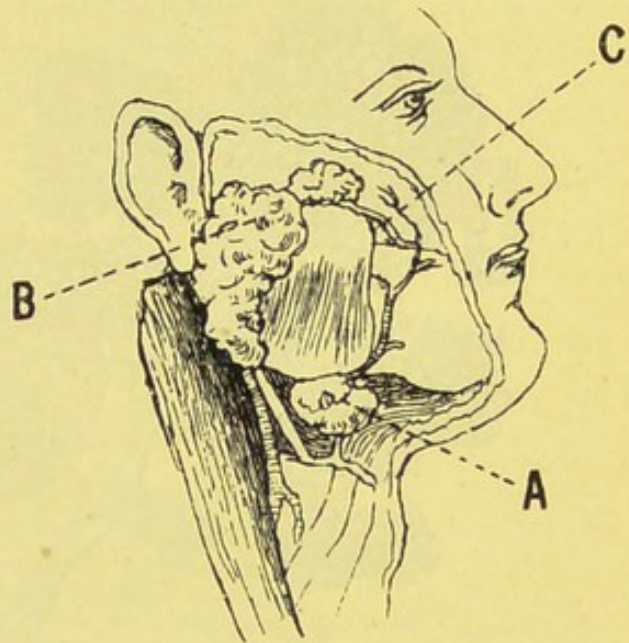


FIG. 31. Dissection of face showing the salivary glands. A. Submaxillary gland. B. Parotid gland. C. Duct of parotid gland.

or sacs lined with **secreting cells**, and the whole structure is something like a bunch of grapes. The stalk of the bunch is the main duct, the branches of the stalk the little ducts, and the grapes the secreting sacs. The whole is knit together by connective tissue into a complete roundish mass. The glands are richly supplied with nerves and blood-vessels.

From the blood the secreting cells draw certain substances and manufacture their secretion. Nerves excite

the glands to secrete when we taste, see, smell, or even think of food. At the same time the nerves dilate the blood-vessels in the glands, so that they may have plenty of blood at their disposal.

Saliva is a watery alkaline fluid, and contains a little mineral salt, a **ferment**, and a slimy proteid substance called **mucia**.

The ferment **ptyalin** has the power to change cooked starch into sugar.



FIG. 32. Diagram of a salivary gland.

The **digestive ferments**, such as ptyalin, exist in the digestive juices in so minute a quantity that they can only be detected by their action on food. They are able to change the nature of a large quantity of food without any loss of their power to do so. They are destroyed by boiling, act feebly in the cold, and rapidly at blood-heat. The chemical nature of a ferment is not known. If you boil a little starch in some water, cool it, and add a drop of iodine, it will turn dark blue. If, however, you hold the starch-solution in your mouth for a minute or two, it will

taste sweet and fail to give the iodine test, for it is changed by the ferment ptyalin into sugar.

The stomach is a muscular bag shaped somewhat like a pear and holding about four pints. The gullet opens into the broad part, while the narrow part opens into the intestine. Round the opening into the intestine there is a band of muscle which regulates the size of the opening and the passage of food.

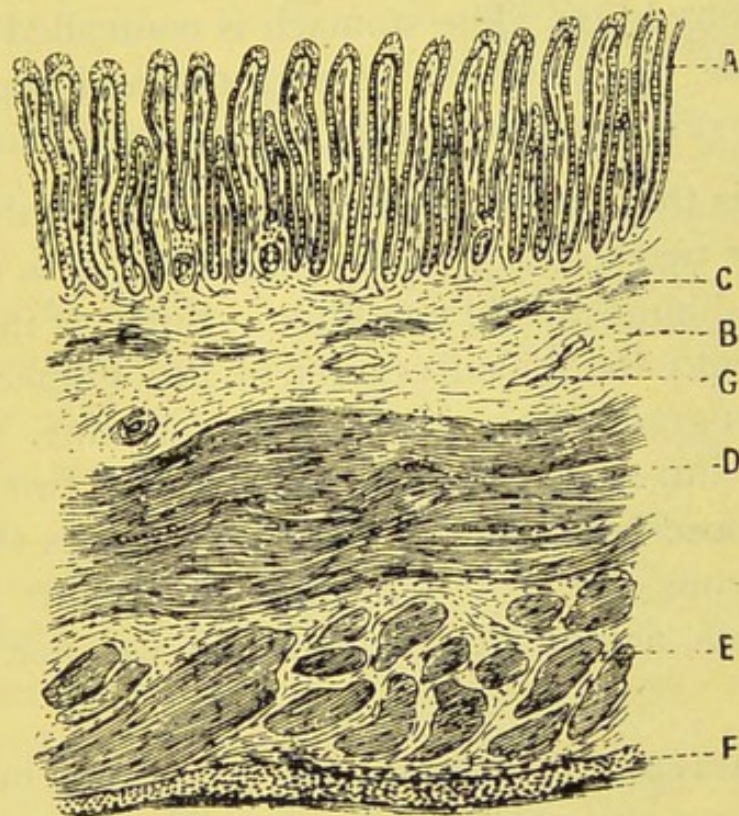


FIG. 33. Section through wall of stomach as seen under microscope. A. Glands of mucous membrane. B, C, G. Connective tissue containing blood-vessels. D, E. Muscle. F. Peritoneum.

The stomach and intestine are suspended to the wall of the abdomen by thin sheets of membrane called **mesentery**, in which the blood-vessels and nerves run to these organs. The inner wall of the abdomen and the organs within it are covered with a glistening membrane called **peritoneum**. Inflammation of this membrane is called **peritonitis**.

The walls of the stomach and intestine are formed of three coats: (1) the inner coat or mucous membrane, (2)

the middle coat or muscle, and (3) the outer coat or peritoneum. The mucous membrane of the stomach contains numberless little tube-like glands, which are lined with secreting cells. Their watery secretion contains a ferment **pepsin** and a little hydrochloric acid. The acid and the pepsin together digest proteid food and change it into a soluble form of proteid called **peptone**. The acid also kills the bacteria which are swallowed, and so protects us from the germs of disease. The **gastric juice** has no action on fat or carbohydrate. The stomach is controlled by nerves, which cause the juice to be secreted and the muscular wall of the stomach to contract and churn the food.

Chyme is the name given to the food in the stomach when, after two to three hours' digestion, it is reduced to a pulpy and almost fluid condition. Some of the chyme is absorbed into the blood-vessels of the stomach, but the greater part gradually passes into the intestine. In the first part of the intestine the chyme mixes with two fluids, **the bile** and **pancreatic juice**. The bile comes through the bile-duct from the liver, and the pancreatic juice from the pancreas, a long flat gland which lies just below the stomach.

The pancreas. The pancreas is a gland built on the same lines as the salivary glands. The pancreatic juice contains three ferments: (1) **trypsin** digests proteid into peptone, (2) **amyllopsin** changes starch into sugar, (3) **steapsin** splits fat into fatty acid and glycerine. The warm bile dissolves the fatty acid, while peptone, sugar, and glycerine dissolve in water, and thus by the action of the pancreatic juice all the food-stuffs are brought into a **soluble form**. After the chyme has been acted on by the bile and pancreatic juice it is called **chyle**.

The mesenteric vessels and portal vein. The small intestine is about twenty feet long, and lies in coils in the

abdomen suspended by the mesentery. In the folds of the mesentery there run the mesenteric arteries, which supply the wall of the intestine with capillaries.

The blood gathered from these capillaries passes into the mesenteric veins. The mesenteric veins join together

and form the **portal vein**. The portal vein enters the liver, breaks up into a network of capillaries, and supplies the liver-cells with blood. Finally the blood passes from the liver into the vena cava inferior. Thus all the dissolved proteid and sugar which are absorbed from the alimentary canal **by the blood-vessels** pass through the liver and are dealt with by the liver-cells before entering the general circulation.

The lacteals. In the mesentery there are also numerous lymphatics called lacteals.

The lacteals run in the walls of the intestine and absorb the fat and carry it into the thoracic duct. This conveys it to the large vein at the root of the neck, which brings the blood from the left arm and left side of the head to the vena cava superior.

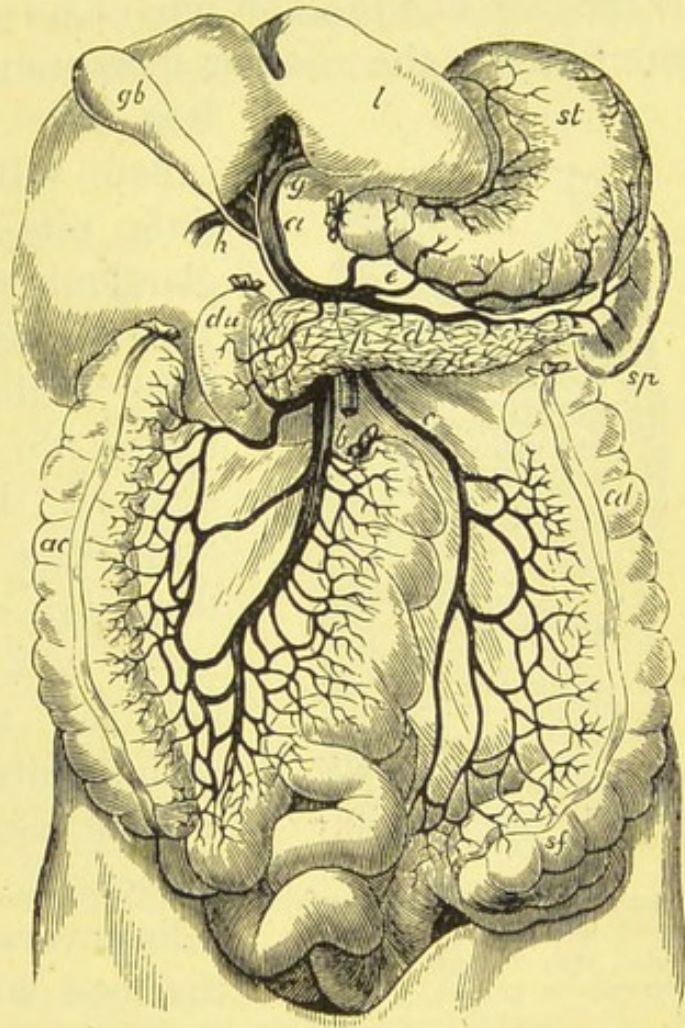


FIG. 34. Dissection showing the portal vein carrying the blood from the stomach and intestine to the liver. *l.* liver. *gb.* gall-bladder. *st.* stomach. *p.* pancreas. *sp.* spleen. The stomach is cut away from the small intestine (*du*) so as to show the portal vein and bile-duct. *ac, cd.* large intestine.

The fat does not pass through the liver on its way to the general circulation.

The structure of the small intestine. The mucous membrane of the small intestine is thrown into transverse folds called **valvulae conniventes**, and on close inspection it appears like the soft pile of velvet. This is so owing to the fact that the mucous membrane rises up into number-

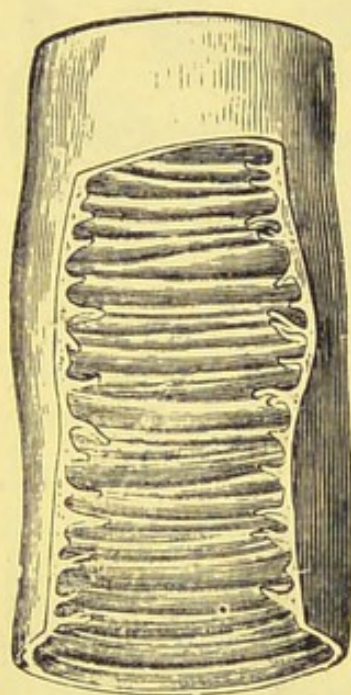


FIG. 35. A piece of the small intestine cut open to show the valvulae conniventes.

less little finger-shaped processes called **villi**. Between the villi little pits open which lead into gland-tubes, called the **glands of Lieberkühn**. The mucous membrane of the small intestine is thus folded in a most remarkable manner. It is thrown into big folds—the valvulae conniventes; these are covered with tiny folds—the villi, and between the villi are the tubular glands. Each villus contains a few muscle-cells, a close network of capillaries, and a lacteal. A layer of columnar cells covers the villi and separates the food within the intestine from the lacteals and capillaries. The

cells absorb the food, and pass the sugar and proteid into the blood-vessels and the fat into the lacteals.

The muscular wall of the intestine contracts in a worm-like manner, and passes the food slowly onwards towards the large intestine. If from irritation by wrong feeding the contraction become violent, griping pain is produced, and the contents of the intestine are hurried out as in diarrhoea.

Here and there in the small intestine are little masses

of lymph-cells, and in the lower part the masses are larger and produce white patches, one-half to one inch long, called **Peyer's patches**. The lymph-cells probably help in the absorption of food, and guard the body from the bacteria which swarm in the lower parts of the intestine.

The great function of the small intestine is to absorb the food, the digestion of which has been completed by the

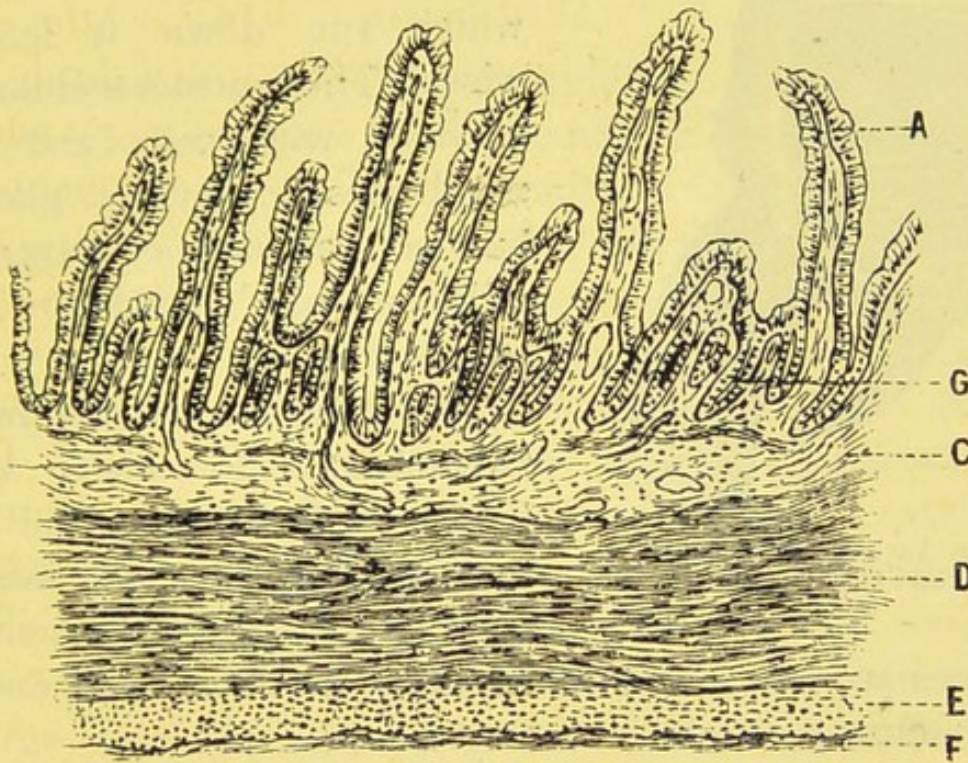


FIG. 36. Section of the wall of the small intestine as seen under the microscope. A. Villus. C. Connective tissue carrying the blood-vessels and lacteals. D, E. Muscle. F. Peritoneum. G. Gland of Lieberkühn.

bile and pancreatic juice, and this is the reason why its absorbing surface is enormously increased by the valvulae conniventes and villi. The cells of the mucous membrane not only absorb the digested food, viz. peptone, sugar, fatty-acid and glycerine, water, and salts, but change the peptone back into albumen, and combine the fatty-acid and glycerine again into fat. The blood receives the sugar, albumen, water, and salts, and the lacteals the fat.

The large intestine is about five feet long. Leaving the small intestine by a valvular opening it runs up the right side of the abdomen, crosses over the stomach, and passes down the left side of the abdomen. It is wider than the small intestine and is gathered into puckers by three thin bands of muscle which run down it lengthwise. The mucous membrane is lined with cells and has numberless tubular glands, but no *valvulae conniventes*, villi, or Peyer's patches.



FIG. 37. Valve between small intestine (a) and large intestine (b).

The function of the large intestine is to absorb what food is left by the small intestine, and especially water. Finally only the waste matters

or faeces are left, which are expelled from the lower end of the alimentary canal.

CHAPTER X

THE LIVER AND SPLEEN

The liver is a large organ weighing about $3\frac{1}{2}$ lb. It extends almost across the abdomen, filling up the dome-shaped space beneath the diaphragm on the right, and partly overlapping the stomach on the left side. A cleft, or **fissure**, divides the liver into a right and left mass, or **lobe**, the former of which is much the larger. On its under surface the right lobe is subdivided by fissures into three smaller lobes. Into one of these fissures pass (1) the **portal vein**, (2) the **bile-duct**, and (3) a branch of the aorta called the **hepatic artery**. These three vessels run into the substance of the organ and send branches to all its parts. Out of the back of the liver, at its upper part, there passes a large vein, the **hepatic vein**, which carries the blood from the liver into the vena cava inferior. The branches of the hepatic vein appear as gaping tunnels when the liver substance is cut open. The liver contains almost one-fourth of the blood in the body, and is dark brownish-red in colour. At each inspiration the liver is pressed downwards by the diaphragm, and the pressure squeezes blood out of the organ into the vena cava inferior. The circulation is thus quickened and sluggish action of the liver prevented by active respiration, as in taking of exercise. The liver substance consists of cells arranged in numberless little masses, or **lobules**. The lobules are bound together by connective tissue. The cells secrete

bile, and the bile, trickling out of the lobules by little passages which exist between the liver-cells, collects in the bile-ducts. From the main bile-duct the bile passes into a little bag attached to the liver, called the gall-bladder. When food enters the small intestine the bile is squeezed out of the gall-bladder into another branch of the main bile-duct which passes to the intestine. **To** each lobule of the liver blood is brought by branches of the **portal vein** and hepatic artery. The cells are thus surrounded by a network of capillaries. The blood is taken away **from** the lobules by a branch of the **hepatic vein**.

The liver has many important functions. All the substances absorbed into the portal vein from the intestine pass through the liver, and the liver filters off any poisonous matter and works upon the food substances. It excretes **bile**, stores up **glycogen**, forms **fat**, manufactures **urea**, and generally controls the composition of the blood. The bile is golden-yellow or yellowish-green in colour. The pigment of the bile is made from the waste haemoglobin of worn-out red corpuscles of the blood. The bile contains some peculiar organic salts, called **bile-salts**. The bile-salts help to dissolve fatty acids which are produced by the action of pancreatic juice when fat is digested in the small intestine. Only a little of these salts is excreted in the faeces, the greater part is absorbed from the intestine and carried back to the liver to be used again. The bile also contains mineral salts, a slimy proteid resembling the mucus in saliva, and one or two other substances of a complex nature. Little is known about the exact uses of the bile. The sugar absorbed from the intestine, on reaching the liver through the portal vein, is taken up by the liver-cells and turned into **glycogen** or animal starch. On the other hand, during times of hunger and hard work the liver-cells give

up the glycogen to the blood, turning it again into sugar. The liver thus keeps up a steady supply of sugar to the muscles. If the glycogen be not required for purposes of work it is changed into fat, and thus it comes about that lazy people who eat largely grow fat.

The sugar is never allowed to enter the circulation in large amounts. If the liver fails to store up the sugar as glycogen the kidneys excrete it, and thus the sugar becomes wasted. This is what happens in the disease called diabetes.

The liver-cells also deal with the proteid absorbed from the intestine. Any excess of proteid eaten is probably broken up by the liver into glycogen or fat and urea. The nitrogenous waste materials of the tissues, such as ammonia, are also brought to the liver, and are there turned into urea. The urea passes into the circulation and is excreted by the kidneys.

The spleen lies on the left side of the stomach. It is about five inches long, thin and flat in shape. It consists of a juicy dark-red **pulp** enclosed and held together by connective tissue. The pulp contains blood and lymph-cells. A branch of the aorta supplies the spleen with arterial blood, and a vein carries away the blood into the portal vein. Whitish spots are to be seen in the dark pulp when the spleen is cut open. These spots are formed by dense masses of lymph-cells. The spleen, like the marrow and lymph-glands, seems to be an organ which makes and destroys the corpuscles of the blood ; but a man can do quite well without a spleen, so it cannot be an organ of vital importance. The connective tissue which surrounds the spleen contains muscle-fibres, and these cause the spleen to contract and expand, and so pump the blood within on into the portal vein.

There are some other small but very important glands

in the body, the disease of which leads to serious or fatal results. These are the **thyroid** and **supra-renal** glands. The thyroid gland lies in the neck in front of the wind-pipe. A child born with too small a thyroid does not grow properly, and becomes an idiot. He is made better by eating thyroid glands. The supra-renal glands lie one on the top of each kidney. They are very small, and yet death quickly results if these glands are destroyed. All these glands, and the pancreas as well, in some way work on the blood and help to keep it pure and of proper composition.

CHAPTER XI

THE KIDNEYS AND EXCRETION OF URINE

The structure of the kidneys. The kidneys lie, one on each side of the vertebral column, at the back of the abdomen, and behind the coils of intestine. They are dark-red organs about four inches long and two broad, and of the shape of a kidney-bean. A sheep's kidney is very like that of a man. Each kidney receives a large artery from the aorta, and gives off a large vein which enters the vena cava inferior. Beside the artery and vein there passes out of each kidney a white tube—the **ureter**. The two ureters run down the back wall of the abdomen and open into the bladder, which holds the urine until it is voided. The bladder lies in the pelvic basin. It is a muscular bag lined with mucous membrane.

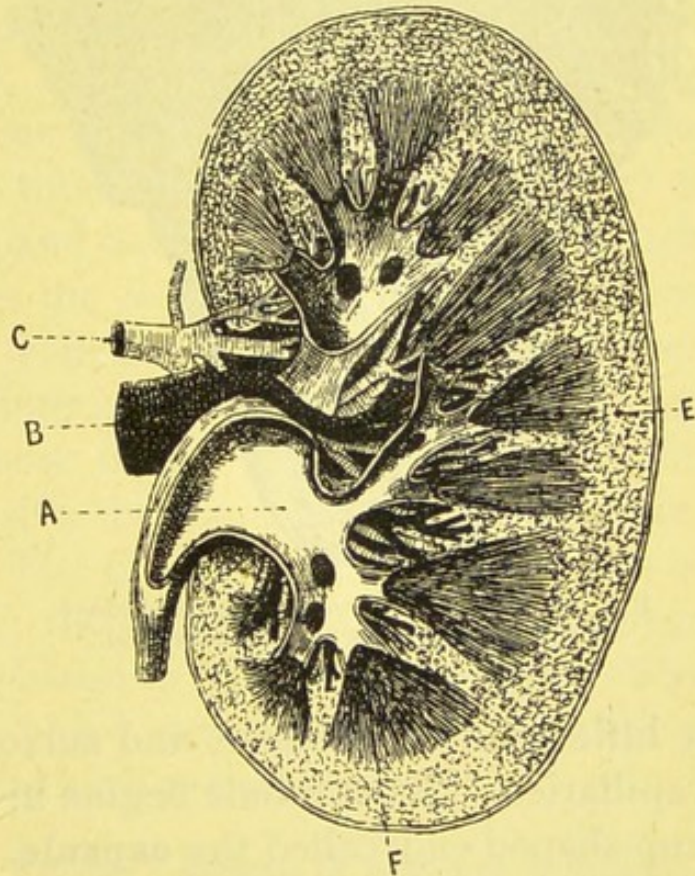


FIG. 38. Kidney cut in half to show the inside. A. Ureter. B. Renal vein. C. Renal artery. E. Cortex. F. Pyramids of medulla.

Cortex and medulla. If you cut open a sheep's kidney you will see the ureter widening to form a funnel-shaped end. Projecting into this funnel are about twelve blunt points of kidney substance. These are the **pyramids** of the kidney. The broad parts of the pyramids stretch about halfway through the kidney and form the **medulla** of the kidney. On the outside of the medulla lies the cortex of the kidney. This is dark brown and of a more granular texture, while the medulla is paler in colour and streaked. Running between the pyramids there may be seen here and there branches of the blood-vessels.



FIG. 39. One of the pyramids of the kidney showing the tubules partly unravelled.

Tubules of the kidney. Unravelled under the microscope the substance of the kidney appears to be made of numberless long coiling tubes—the **tubules of the kidney**. The tubules are knit together by

a little connective tissue, and surrounded by a network of capillaries. Each tubule begins in the cortex by a dilated cup-shaped end, called the **capsule**. A bunch of capillaries pushes itself into the capsule, so that the blood is separated from the inside of the capsule by only one layer of exceedingly thin flat cells. Leaving the capsule the tubule coils about in the cortex, and finally runs down a pyramid to open into the ureter. The coiling part of the tubule is lined by a layer of secreting cells.

The circulation in the kidney. Little arteries carry the blood to the capillaries in the capsules. The little veins, which collect the blood from the bunches of capillaries in the capsules, break up into networks of capillaries round the coiling parts of the tubules. The blood thus passes through a double set of capillaries (1) in the capsules, (2) round the coiling tubes. The blood runs quickly and forcibly into (1), and trickles slowly through (2). By this arrangement water and mineral salts are filtered through (1) into the capsules, while the urea is excreted from (2) by the cells which line the coiling parts of the tubules.

The quantity of urine passed. The quantity of urine voided depends, firstly, on the amount of blood flowing through the kidneys; secondly, on the substances in the blood which excite the tubules to secrete. The artery of the kidney is very large, and the blood flows rapidly through it. Cold weather causes the vessels of the skin to contract, and the blood driven from the skin circulates in greater amount through the internal organs. The kidneys in consequence secrete more urine. In summer the conditions are just the opposite, the sweat-glands secrete more, and the kidneys less. The drinking of large quantities of water dilutes the blood; the kidneys are excited to secrete and quickly restore the blood to its proper strength. The presence of urea in the blood naturally excites the kidney to secrete. Certain salts have the same effect.

The composition of urine. Urine is a straw-coloured, clear, and slightly acid fluid. The quantity passed by a man is two to three pints a day. The quantity of water in the urine varies with the amount taken as drink, and with the amount lost by sweating, but the quantity of solid material dissolved in the urine remains about the same every day. The solids are (1) organic substances—urea

uric acid, &c., (2) mineral salts. About $1\frac{1}{4}$ ounce of urea and one ounce of salts can be separated from the urine passed in one day. The salts include chlorides, sulphates, and phosphates of potassium, sodium, calcium, and magnesium. The chief salt passed is common salt. The brick-coloured deposit which sometimes appears in the urine when it is left standing is due to urates—compounds of uric acid with sodium and potassium. The urates are coloured by the pigment in the urine. A small quantity of uric acid is excreted every day. It is a slightly more complex and less oxidized substance than urea, and takes the place of urea in the renal secretion of birds and reptiles. In gouty people uric acid collects in the joints. The gouty should avoid eating too much, and should not eat sweet-breads, liver, or kidneys, for more uric acid is produced from such foods. Gravel in the urine is due to crystals of uric acid, which form when the urine is too acid. This condition is relieved by a diet containing little meat and plenty of green vegetables, lemons, apples, &c. The urea which the kidneys secrete is made by the liver out of the proteid food and the nitrogenous waste substances of the tissues. The amount of urea passed in a day increases with the amount of proteid eaten.

When the kidneys become diseased, as in Bright's disease, they secrete too much water and urea, and the body wastes and becomes badly nourished.

CHAPTER XII

THE SKIN, THE EXCRETION OF SWEAT, AND THE BODILY HEAT

The structure of the skin. The skin under the microscope is seen to consist of two coats, the **epidermis** and **dermis**. The epidermis is composed of several layers of cells, the outermost of which are horny in nature. The dermis is the inner coat, and is made of tough fibrous and elastic connective tissue. Beneath the dermis there lies a layer of fat which gives roundness and softness to the figure. Underneath the fat lie the muscles. The skin protects the soft tissues, binds them into their proper places, and by its elastic nature prevents the blood and lymph settling down into the lower parts of the body. The fat beneath the skin acts as a soft cushion to the body and prevents the loss of the body-heat.

The horny cells of the epidermis are continually worn off, but are renewed by the deeper layers of soft growing cells. In the hands and feet, where there is much wear and tear, the horny layer is thickened. There are no blood-vessels in the epidermis, but many in the dermis. On applying an irritant to the skin, or after a burn, lymph passes out from the damaged capillaries in large amount and, by raising up the horny layer, forms a blister. In the dermis there are many little round or oval structures, called touch-corpuscles. Nerve-fibres end both in these and among the cells of the epidermis ; it is by their means that we have the sense of touch.

The skin is thrown into ridges and creases. On the balls of the fingers the ridges form peculiar patterns, which are never alike in two individuals. By taking wax impressions of their finger-tips criminals can be identified at any subsequent time. The skin contains **sweat-glands**, **hairs**, and **sebaceous glands**, and forms the nails.

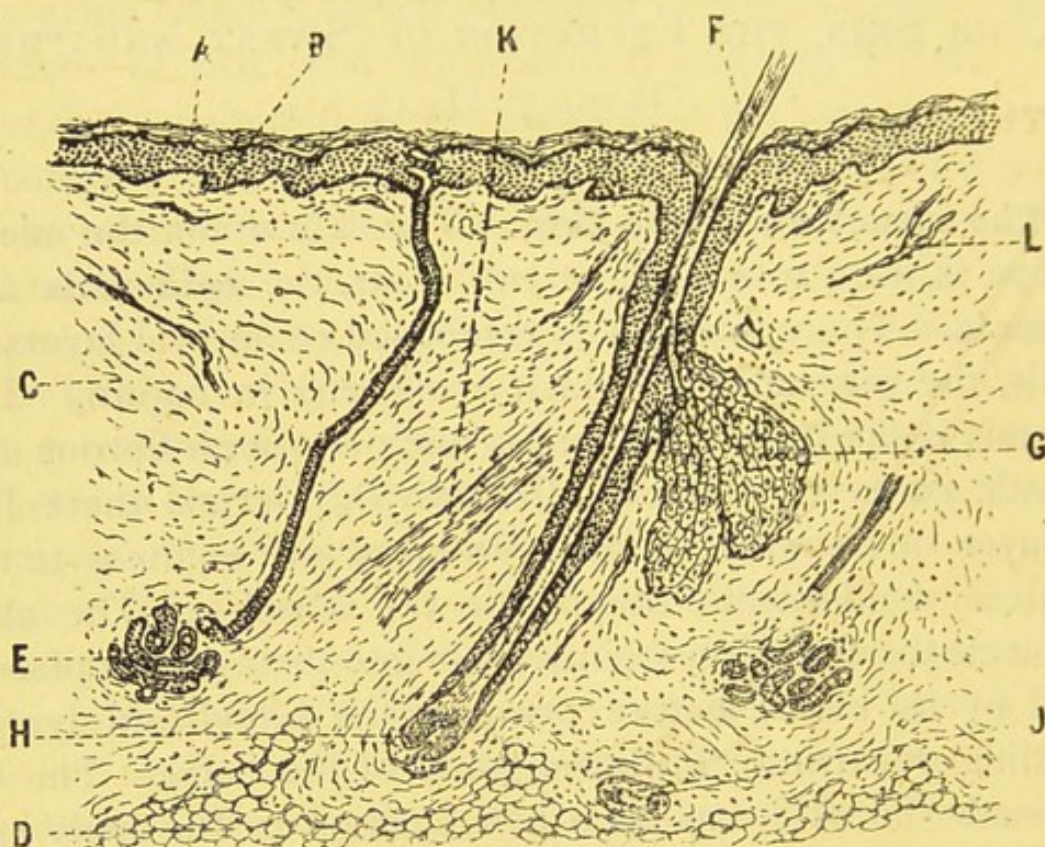


FIG. 40. Section of skin as seen under the microscope. A. Horny layer. B. Soft growing layer of epidermis. C. Dermis. D. Fat. E. Sweat-gland. F. Hair. G. Oil-gland of hair. H. Bulb of hair-root. K. Muscle of hair. J, L. Blood-vessels.

Sweat-glands. The sweat-glands lie in the dermis. Each is made of a little tube coiled into a ball, with a duct opening on the surface of the epidermis. The skin of the whole body is provided with at least two million sweat-glands. The length of each is about $\frac{1}{4}$ inch, and from these figures it is calculated a man possesses about ten miles of sweat-tubes.

The sweat. The sweat is a watery alkaline and salt fluid. It contains a little mineral salt and traces of urea.

Sweat is always being excreted, but so slowly that it evaporates from the pores of the sweat-glands as fast as it is formed. This is the **insensible perspiration**. In hot weather, or during hard muscular work, the sweat is poured out faster than it can evaporate. It collects in drops and runs down our faces and bedews our bodies. This is called **sensible perspiration** because we feel it.

The function of the sweat is to cool the body. On hot days, or when more body-heat is produced by muscular action, the skin becomes flushed with blood, and the sweat pours forth in quantity. The heat in the blood is carried away by currents of air and radiated to surrounding objects. At the same time the evaporation of the sweat rapidly cools the skin, for it takes a great deal of heat to turn water into vapour. On cold days the vessels of the skin are contracted and the sweat secreted only in small amounts. The danger on a cold day of becoming wet through, or of sleeping in damp places, is due to the evaporation of the moisture which robs the body of its heat. So long as the body is warm damp can do no harm. The secretion of sweat is governed by nerves, and when a man sweats with fear or agony it is due to the violence of his nervous agitation.

Cleanliness. By washing the skin is cleansed of bacteria and parasitic animals. In certain trades where poisons such as lead, phosphorus, arsenic, or mercury are used the eating of food with begrimed hands may lead to slow poisoning. Poisons cannot easily pass through the unbroken skin, but are easily absorbed through cuts or places where the skin is broken. A cold bath or sea-bathing is the best of tonics for stimulating the nervous system. The ancient Greeks wisely rubbed oil into the skin after a bath, for the sebaceous glands naturally secrete an oily

substance, which keeps the skin supple and the hair in good condition.

Structure of hair. The hairs consist of a core of cells covered on the outside by horny cells which overlap one another like the tiles on a roof. The cells of the hair contain granules of pigment. The hair-roots lie embedded in little pits in the skin called **hair-follicles**, and a sebaceous-gland opens into the mouth of each follicle. Muscle-fibres are attached to the roots of the hair to make the hairs stand on end. You may have seen the hair of a cat bristling up when the animal is frightened by a dog. Hair becomes white in colour owing to lymph-cells carrying away the pigment of the hairs. Baldness is due to bacteria and moulds growing in the hair-follicles and destroying the roots of the hair. Washing, by removing the natural grease from the hair, favours the growth of moulds. Hard brushing, on the other hand, promotes the growth by irritating the scalp and causing the blood-vessels to dilate and the blood to come thither in greater quantity.

The nails are formed by a thickening of the horny layer of the epidermis.

The hotness or temperature of a healthy man's body. The temperature of the body is always the same. On the coldest day when shivering, or on the hottest day when sweating with heat, you will find the temperature of your mouth to be between 98° and 99° Fahrenheit. While the temperature of the body within is kept constant, that of the skin varies with exposure and with the amount of blood flowing through it. Thus no sure sign as to the warmth of another person's body can be had by feeling the skin. The temperature can be accurately obtained by placing a clinical thermometer in the mouth. The body-

heat depends on (1) the amount of heat produced, (2) the amount of heat lost.

All the living active tissues produce heat, owing to the processes of oxidation which go on within them, but heat is especially produced in the muscles. Hard muscular work on a hot day may raise the temperature of the body to 100° or even 101° F. The following experiment shows how muscular activity produces heat. The temperature of a bee-hive, when the weather is frosty and the bees torpid, may be at freezing-point. On tapping the hive and arousing the bees to muscular activity (buzzing) the temperature of the hive may rise to 60° F. The heat produced in the active tissues is evenly distributed by the circulating blood to all parts of the body. In cold weather a man becomes more active and produces more heat, he beats his hands, shivers, and stamps his feet. At the same time he eats more food, and especially fat, which gives off a great quantity of heat when it is oxidized. In hot weather a man eats less and avoids muscular activity, so that the heat production is less. Heat is lost in the urine, faeces, and expired air, but chiefly from the skin. In cold weather the blood-vessels of the skin are contracted, and the excretion of sweat diminishes. We also warm our rooms and put on more clothes. Thus the loss of heat is reduced. The warmth of clothes depends on the amount of air which is kept stationary by being entangled in and between the garments. Air is a very bad conductor of heat, and the garments prevent the layer of air which is next to and warmed by the body from escaping. Woollen clothes are warmer than cotton owing to their spongy texture. Clothes should be made light and fit the body so as not to cramp muscular activity. Tight shoes and tight lacing often spoil the health by preventing proper muscular exercise. Every man and woman should seek to develop both mind and body, and

not distort themselves by following foolish fashions. In the clothing of children a line must be carefully drawn between prudence and coddling. To over-clothe the body of a child in whom the production of heat is great, to over-heat his nursery, and to prevent him roughing bad weather, are the ways to court disaster. Development of the brain, the eye, the muscles, only comes with use, and so is it with the vigour of the circulation and the power to withstand and enjoy cold and hardship.

CHAPTER XIII

THE NERVOUS SYSTEM

THE nervous system consists of (1) the brain enclosed in the skull cavity; (2) the spinal cord, which is continuous with the brain and lies in the vertebral canal; (3) the nerves, which pass out from the brain and spinal cord to the organs of the body.

The nerves. There are two classes of nerves: (1) the **sensory nerves**, which carry messages from the sense-organs to the central nervous system, i. e. the brain and spinal cord; (2) the **motor nerves**, by which messages are carried from the central nervous system to the various organs. From the spinal cord at regular intervals along its length, and on either side, nerves are given off in pairs. There are in all **thirty-one pairs of spinal nerves**.

The spinal nerves pass out through holes between the vertebrae and supply the skin, muscles, and viscera. In the chest the arrangement of the nerves is very regular, for each pair on leaving the vertebral canal supplies the skin and muscles between a corresponding pair of ribs. Similarly the nerves passing out between the neck and lumbar vertebrae circle round the neck and abdominal wall respectively, and supply the skin and muscles there. Several of the nerves which leave the spinal cord in the lower part of the neck are, however, much thicker, for they not only supply the body-wall, but send large branches to the arms. Likewise thick nerves pass out in the lumbar and sacral region, and send large branches to the legs.

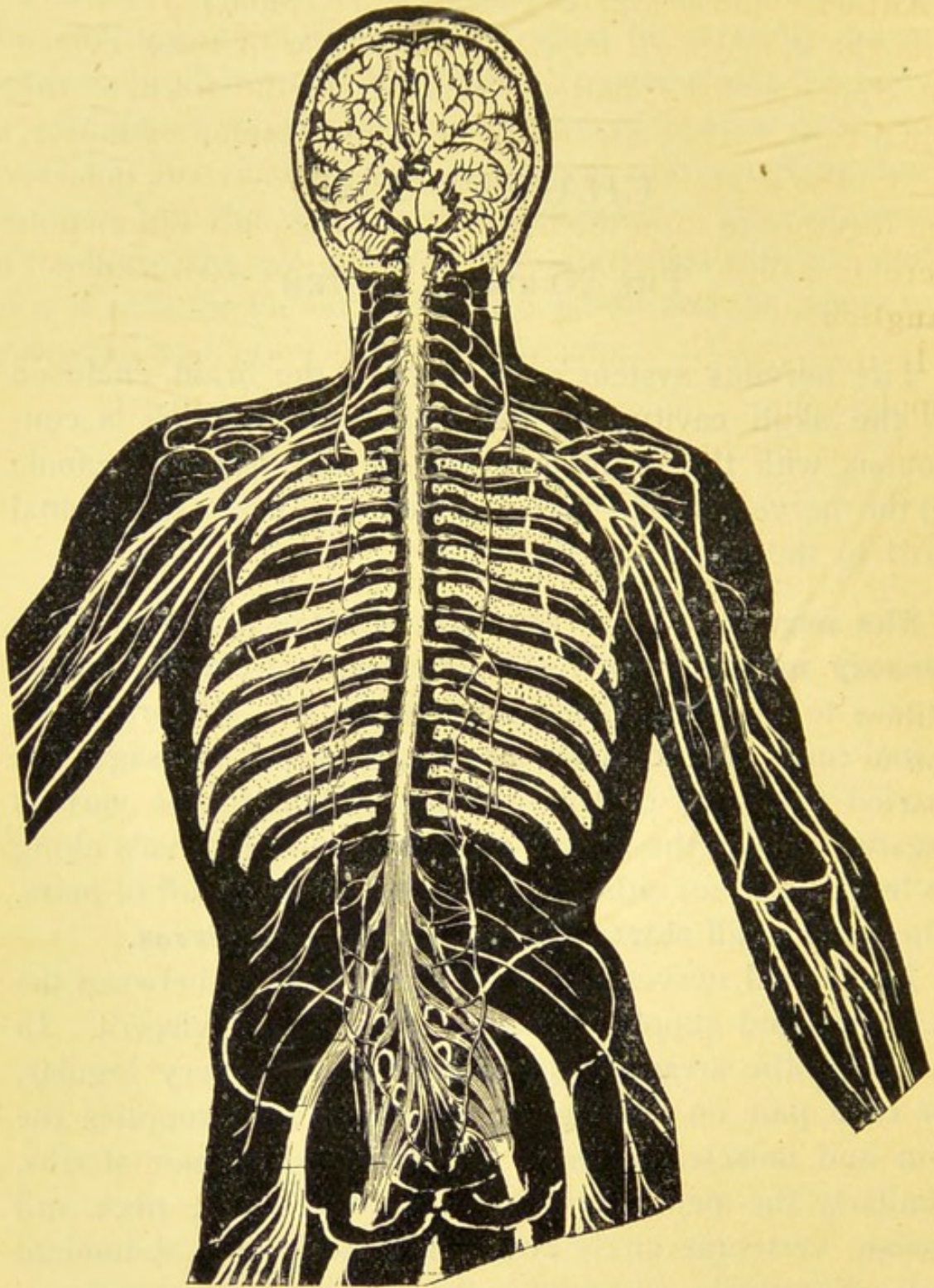


FIG. 41. Diagram of the nervous system. The whole of the face and viscera and the front of the skull and spinal column are removed. The ribs and bony wall of the skull are shown white dotted with black. The shoulder, hip, and arm bones are outlined in white. The cerebrum occupies the upper three-fourths, the cerebellum the lower fourth of the cranium. The pons and spinal bulb occupy the middle of the lower part of the cranium. The cranial nerves (black) are shown arising here. The spinal cord is seen ending below in the cauda equina. Notice the nerves arising from the spinal cord and the ganglion on each nerve-root. Notice also the large nerves going to the arms and legs.

Anterior and posterior roots. Each spinal nerve arises from the spinal cord by two roots. One of these comes out from the back, and the other from the front of the spinal cord. They are called (1) **the anterior or motor**, and (2) **the posterior or sensory root**. The roots quickly join together to form the nerve, and at the place of junction there is a little swelling on the posterior root called a **ganglion**.

If the posterior roots were cut of the nerves which supply your right leg, you would be unable to feel any prick or touch in that leg. The posterior roots carry the sensory nerve-fibres **to** the spinal cord. If, on the other hand, the corresponding anterior roots were cut, your leg would hang limp and paralysed. Although unable to move the leg you would still feel it. The anterior roots carry motor nerve-fibres **from** the spinal cord to the muscles.



FIG. 42. Cross-section of spinal cord, showing H-shaped grey matter inside, the white matter outside, and the anterior and posterior roots of a pair of nerves. There is a ganglion on each posterior root.

Structure of a nerve. A large nerve looks like a white glistening cord; such is the sciatic nerve, which runs down between the muscles at the back of the thigh. The sciatic nerve branches to supply the muscles and skin of the leg. The smaller branches look like white threads. The finest branches can only be seen with the microscope. A nerve, like a thread of cotton, can be separated with needles into tiny threads. It then appears, under the microscope, to be made of extremely fine **nerve-fibres**. The nerve-fibres are bound together into bundles by connective tissue. It would take about 4,000 average-size nerve-fibres to cover an inch when placed side by side. Each fibre consists of a thread of protoplasm surrounded by a sheath of a peculiar white fatty material. The fatty material is in its

turn enclosed by a transparent membrane. The protoplasmic thread, or **axon**, is the process of a nerve-cell, and extends as an unbroken strand from a nerve-cell in the central nervous system to its termination in a muscle or sense-organ. See Fig. 16. The axon is the essential part of the nerve, and conducts the messages, while the fatty coat protects and nourishes the axon, and separates it from the axons of the surrounding fibres. It is necessary that the axons should be insulated from each other just as telegraph wires, so that the messages passing to and fro may not spread from one fibre to another.

Excitability of nerve. If the sciatic nerve in the leg of a frog (killed by chloroform) be excited by a pinch, a hot wire, a chemical irritant, or an electric shock, the muscles of the leg will in each case contract. The irritation excites the nerve and a **nervous impulse** passes down it, and causes the muscles to contract in somewhat the same way as wire transmitting an electric current from a battery causes a bell to ring. As to the nature of the **nervous impulse** we know nothing.

The spinal cord. Look at the spinal cord in the halved carcass of a sheep that hangs in some butcher's shop. It lies in the vertebral canal, and at the point where this canal opens into the skull the spinal cord joins the brain. At the level of the lumbar vertebrae the spinal cord tapers to a point, and is surrounded by a leash of nerve-roots. This part is called the cauda equina, or horse's tail. The nerve-roots forming the cauda equina pass out through the openings between the lower vertebrae. The spinal cord is thickened at the points where the large nerve-roots for the arms and legs arise. It is enclosed in three membranes. The outer, the **dura mater**, is a tough coat of connective tissue; the inner, **pia mater**, is a membrane which carries blood-vessels to supply the cord. A very thin membrane

called the **arachnoid** lies between these two. In the space between the arachnoid and pia mater there is a layer of fluid which surrounds the spinal cord. Enclosed in the strong vertebral column, and surrounded by fluid, the spinal cord is protected from injury, jolts, or jars. On cutting the spinal cord crosswise it will be seen that there is pinkish-grey substance in the middle arranged in the shape of an H. On the outside of this lies white substance. The **grey matter** is composed of nerve-cells and their branches, while the **white matter** is made up of nerve-fibres. The nerve-fibres run lengthwise along the cord. Wherever the cord is cut across there appears the same arrangement of grey and white matter, so it is clear that the cord is composed along its whole length of an H-shaped column of grey matter, surrounded by white matter. From the front tips of the H, or **anterior horns** of grey matter, arise the nerve-fibres of the anterior roots. Into the posterior tips of the H, or **posterior horns**, enter the posterior roots. The fibres of the anterior roots arise from branching cells which lie in the anterior horns

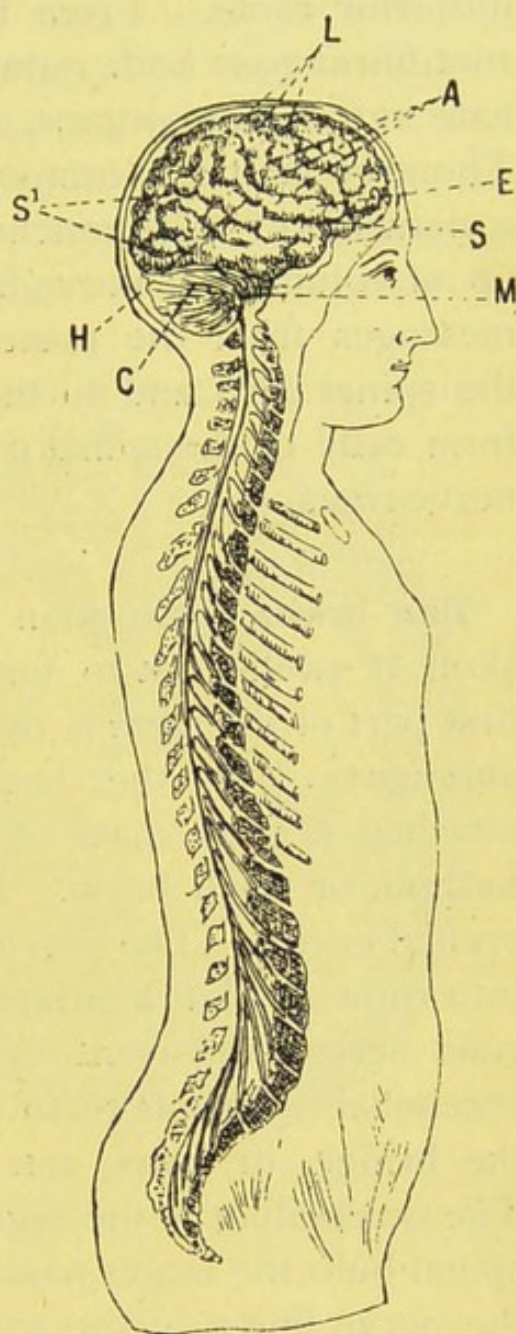


FIG. 43. Skull and spinal column opened to show the side view of brain and spinal cord and nerves leaving the spinal cord. C. The small brain or cerebellum. M. The medulla oblongata or spinal bulb. L, A, E, S. The parts of the great brain which are especially engaged in ordering our movements. S'. The part we see with. H. The part we hear with.

of grey matter. The fibres of the posterior roots, on the other hand, arise from cells in the ganglia on the posterior roots. From the ganglion cells the posterior root-fibres pass both outwards along the nerves to terminate in the sense-organs, and inwards into the spinal cord. The grey matter is composed of branching nerve-cells and a network of cell-branches. The white matter is made up of columns of nerve-fibres, which convey (1) sensory messages from the posterior nerve-roots to all parts of the spinal cord and to the brain, and (2) motor messages from cells of the spinal cord and the brain to the anterior nerve-roots.

The brain. So soon as the spinal cord enters the skull it swells out to form the stem of the brain. The first part of the stem is called the **spinal bulb** or **medulla oblongata**. To the back of the spinal bulb there is attached a large mass of nervous tissue called the **cerebellum**, or small brain. It occupies the lower part of the cranial cavity. The cerebellum is divided by a deep cleft into right and left **hemispheres**. A bridge of nerve-fibres runs across the front of the spinal bulb and joins one cerebellar hemisphere to the other. The cerebellum and the bridge, or **pons**, can be compared to a signet ring. The cerebellum is the signet, the pons the ring, and the spinal bulb the finger passing through the ring. Some of the nerve-fibres of the spinal cord on reaching the spinal bulb turn off into the cerebellum and form its **inferior peduncles**. The fibres of the pons form the middle peduncles of the cerebellum. Leaving the pons and cerebellum and continuing its upward course, the stem of the brain soon divides into two to form the peduncles of the great brain, or **cerebrum**. The great brain consists of two hemispheres, and a peduncle passes into either. Just before cleaving into the two peduncles of the cerebrum,

the stem of the brain shows on its posterior surface four little swellings, called the **corpora quadrigemina**.

The part of the stem of the brain lying between the cerebellum and the cerebrum, where the corpora quadrigemina are situated, is called the **mid-brain**. Each hemisphere of the cerebellum sends some fibres to join the mid-brain; these fibres form the **superior peduncles** of the cerebellum. Thus the cerebellum has six peduncles in all. The two inferior peduncles connect it with the spinal cord; the two middle peduncles connect it with the spinal bulb; the two superior peduncles connect it with the mid-brain and cerebrum.

The great brain occupies the whole of the dome of the cranium. Looking at the top of the cerebrum you would

see that its right and left hemispheres are almost entirely separated from each other by a deep cleft. At the bottom of this cleft there is a bridge of nerve-fibres, called the **corpus callosum**. It joins the two hemispheres together. The base of each hemisphere, where the peduncles enter, contains large masses of grey matter, called the **basal ganglia**. The bundles of nerve-fibres which pass up the stem of the brain from the spinal cord run into and between the basal ganglia, and pass to all parts of the outer grey

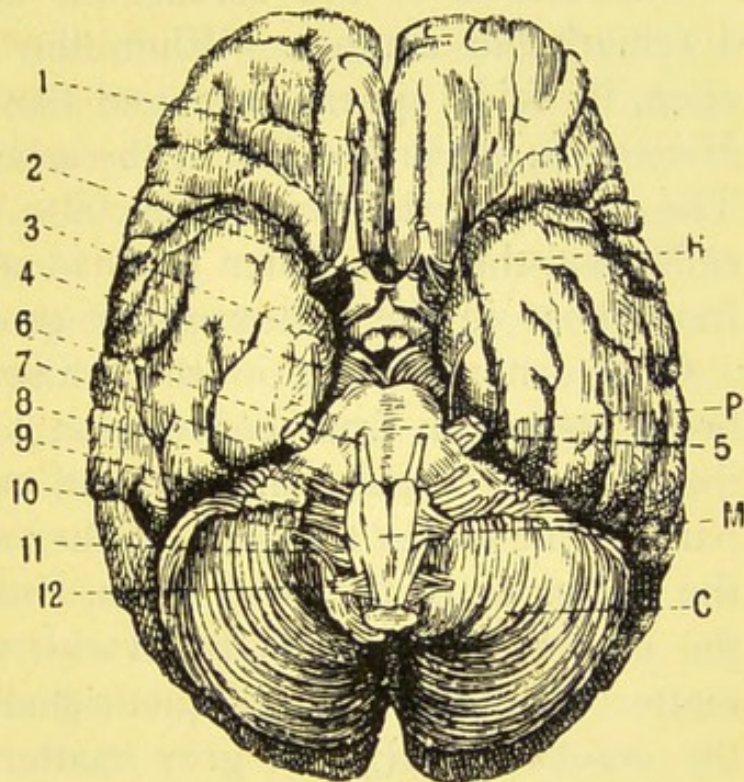


FIG. 44. The under view of the brain. C. Cerebellum. M. Medulla oblongata. P. Pons. H. Hemisphere of cerebrum. The cranial nerves are numbered 1-12.

layer of the cerebrum called the **cortex**. The cortex of each hemisphere is thrown into folds or crinkles called **convolutions**. Between the basal ganglia and the cortex, the substance of the cerebrum is made of white matter. The grey matter of the cortex and basal ganglia contains myriads of branching nerve-cells. One process of each cell becomes the axon of a nerve-fibre. The nerve-fibres form the white matter.

The cortex of the cerebellum is also convoluted in a remarkable manner. When the cerebellum is sliced open, its folds appear arranged like an oak-leaf pattern. Hence the ancients called it the *arbor vitae* or tree of life. The cortex of the cerebellum also contains myriads of cells, but the cells differ both in arrangement and size from those in the cortex of the great brain.

Of the nerve-fibres in the white matter of the great brain some run from convolution to convolution, others through the corpus callosum, and connect the cells in all parts of the cortex together. Other nerve-fibres run down the peduncles of the great brain, and connect the cells of the cortex of the great brain with the cells in the grey matter of (1) the corpora quadrigemina, (2) the cortex of the cerebellum, (3) the grey matter of the stem of the brain, and (4) the grey matter of the spinal cord. Thus all parts of the nervous system are linked together. The **right** half of the cerebrum and the **left** half of the cerebellum together govern the movements of the **left** side of the body.

The brain is enclosed in the same three membranes as the spinal cord. The average weight of the brain is about forty-nine ounces for the male and forty-four ounces for the female. The brains of famous men are by no means always larger than the average, for quality is more important than quantity.

CHAPTER XIV

CRANIAL NERVES

Cranial nerves. In addition to the thirty-one pairs of spinal nerves, there are twelve pairs of cranial nerves which arise from the brain and pass out through holes in the floor of the skull. The brain, compared to the spinal cord, is very large, and this is because the nerves of the special senses (taste, smell, sight, and hearing) enter into it. These, together with the sense of touch, form the five windows of the mind through which we learn to think and act. The brain is the seat of consciousness and memory, the organ by means of which we think and act.

1. The nerves of smell are the **first** pair of cranial nerves. Arising from the front part of the base of the brain the **olfactory** nerves give off a number of fine branches, which pass through holes in the roof of the nose and end in the mucous membrane of its upper part.

2. The **second** pair are nerves of sight. The **optic** nerves arising from the corpora quadrigemina in the mid-brain pass forwards under the base of the cerebrum to the sockets of the eye-balls.

3. The **third** nerves arise from the mid-brain and supply the muscles that turn the eyes upwards, downwards, and inwards, also certain muscles inside the eye-ball which control the iris and the shape of the lens.

4. The **fourth** nerves arise from the mid-brain and supply a muscle in each eye which helps to turn the eye downwards.

5. The **fifth** nerves arise from the pons. They send motor-branches to the chewing muscles, and sensory branches to the outside of the eye-ball, the lower part of the nose, tongue, mouth, teeth, and cheeks. They are the nerves affected in neuralgia of the face and toothache.

6. The rest of the cranial nerves arise from the spinal bulb. The **sixth** nerves control the muscles which turn the eyes outwards. The eye-muscles are thus controlled by nerves 3, 4, and 6. Paralysis of any one of these nerves causes the eye to squint.

7. The **seventh** nerves supply the muscles of the face, that is, the muscles of expression.

8. The **eighth** nerves pass to the ears and are the nerves of hearing.

9. The **ninth** nerves supply the throat and back of the tongue, and are, together with the fifth, nerves of taste.

10. The **tenth** nerves (vagus) arise from the spinal bulb and run down the neck through the thorax and end in the abdomen; they send branches to the gullet, larynx, lungs, heart, and abdominal organs. The swallowing muscles of the gullet, the speech muscles of the larynx, the churning muscles of the stomach, and the secretion of the gastric glands and pancreas are controlled by these nerves; they also regulate the frequency of the heart-beat and the rhythm of respiration.

11. The **eleventh** nerves control certain muscles in the neck.

12. The **twelfth** supply the tongue-muscles.

Functions of the nervous system. An executed criminal ceases to breathe so soon as his neck is broken and the spinal bulb crushed; the tissues and organs die in consequence from lack of oxygenated blood. By blowing air into the lungs the blood could be artificially oxygenated; and in such case the heart would continue to beat. The

body of the man, however, would lie still, and no spontaneous movement of the muscles occur. Suppose, however, the sciatic nerve were pinched, the muscles of the leg would contract. It is evident, then, that the tissues and organs are under these conditions alive and acting; the man, nevertheless, is dead, for consciousness passed from him at the moment when his brain was injured.

A violent blow on the head, too great an emotion of fear or passion, the stoppage of blood to the brain, poisoning with chloroform, &c., will throw out the action of the brain, and cause a man to lose consciousness and faint. When a man faints he loses power over his muscles, and falls senseless to the ground with his limbs huddled in a heap. You see, then, that in order that consciousness may persist, the structure of the brain must not be unduly shaken, while it must be supplied with pure oxygenated blood. In the case of a man who has been half-drowned or suffocated, recovery may generally be brought about by means of artificial respiration. On the other hand, the man whose neck has been broken cannot recover consciousness, even though pure blood be brought to it, for the structure of his brain has been broken.

If the great brain alone be thrown out of action by a blood-vessel bursting within it, as in an apoplectic fit, a man loses consciousness, but continues to live and breathe. This is the case when the spinal bulb is not included in the injury. The spinal bulb controls the breathing, the rate of the heart-beat, the size of the arteries, the swallowing muscles, and other functions of the viscera.

To sum up then: (1) a man loses consciousness and ceases to think and act when his cerebrum ceases to act; (2) a man whose spinal bulb is injured not only loses consciousness from the shock of the injury, but dies from failure of breathing.

Now let us consider the case of a man who, by falling downstairs has broken his spine and severed the spinal cord, say at the level of the first thoracic vertebra. This man will be conscious, his power to reason and talk will be unaffected, his breathing will continue. He will, however, have completely lost both sensibility of, and power over, his legs, and the part of his body below the level of the injury. The whole of the muscles supplied by the spinal nerve-roots below the injury will be paralysed. The diaphragm is supplied by nerves which leave the spinal cord in the neck, and so it will continue to act and enable the man to breathe. The man will feel neither body nor legs, for the sensory impulses which enter the spinal cord below the injury can no longer reach the brain. The man cannot command the muscles of these parts to contract, for the nerve-fibres are broken which convey the messages from the brain to the motor-roots.

Reflex action. On tickling the feet of the man while he lies paralysed in bed, his legs may suddenly jerk up; but of both the tickling and the movement the man will remain unconscious so long as he does not see his legs. The movement of his legs is brought about by what is termed **reflex action**. The sensory nerve-endings in the feet are excited, and a message runs up the afferent nerves, and entering by the posterior roots pass into the spinal cord. Here the message acts on the motor-cells in the grey matter, and causes these to discharge an impulse down the anterior or motor-roots and so to the muscles. These contract and pull the leg away.

Many of our simple and habitual actions are carried out reflexly and unconsciously by the spinal cord and lower parts of the brain. If you raise your hand to your eye the eye-lid closes to protect it. The sight-message runs up the optic nerve to the stem of the brain and causes

a motor-impulse to pass down to the lid-muscles. The movements of walking, swimming, skating, bicycling, &c., are carried on reflexly after we have once learnt them. In walking the sensations of the feet striking the ground, &c., excite the spinal cord and reflexly cause the muscles to make the next movement. While the lower parts of the nervous system carry out these reflex movements, the cerebrum is set free to think and learn how to overcome fresh difficulties.

The function of the cerebellum seems to be to regulate and control the discharge of motor-impulses to the muscles, so as to keep the body balanced and upright. Injury of one side of the cerebellum causes a man to be giddy, and his limbs on that side to give under him and take the wrong position, so that his body is twisted and he falls down.

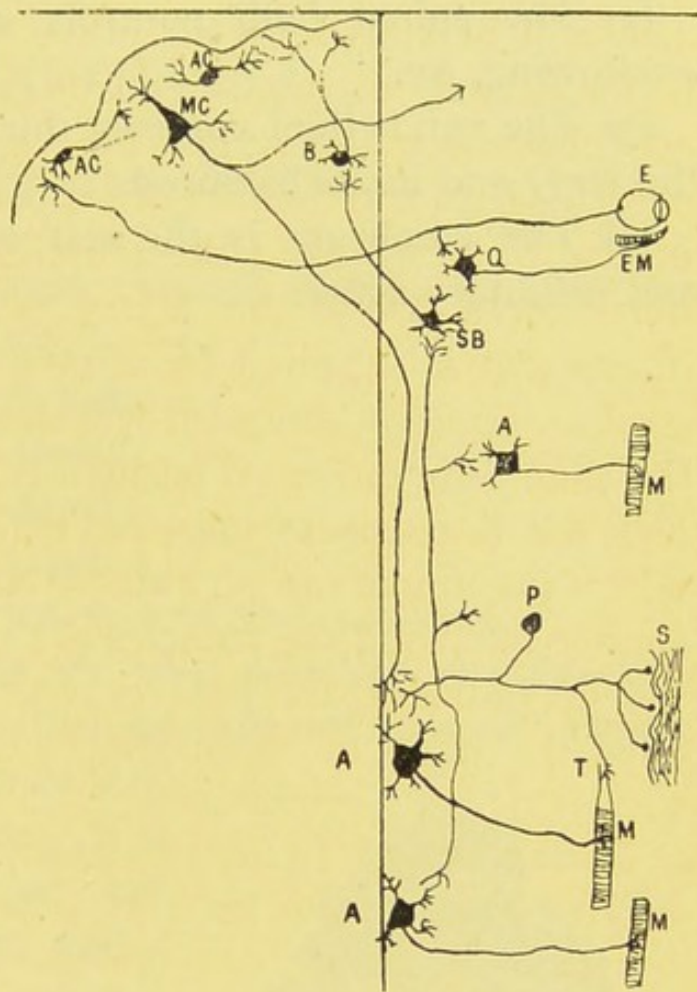


FIG. 45. Diagram to show the course nerve impulses follow in reflex action. S. Skin. M. Muscles. A. Cells in spinal cord from which the motor root-fibres grow. P. Ganglion cells in posterior root ganglion from which sensory fibres grow. A sensation starting from S runs to A, and this causes M to contract. This is a simple spinal reflex action. The sensation may also run up to SB, the cells in the spinal bulb which control respiration, the heart, &c. From thence it may go to AC cells in the opposite hemisphere of the cerebrum. MC are cells in the cerebrum which send fibres to A and cause voluntary movements of the muscles. E. Eye sending sensory nerve-fibres to cerebrum. EM. Muscles controlling movements of eye. Q. Cells in corpora quadrigemina which govern the movements of the eyes.

To sum up :—

(1) The spinal cord carries out simple reflex movements, as the pulling of a leg away from an offending object.

(2) The spinal bulb controls respiration, circulation, swallowing, &c.

(3) The cerebellum controls the muscles so as to keep the body and limbs balanced.

(4) The cerebrum is the seat of mind, consciousness, and voluntary action.

CHAPTER XV

THE SPECIAL SENSES

THERE are five windows through which we learn all about the world around us:—

1. The eye, sensitive to light.
2. The ear, „ sound.
3. The nose, „ smell.
4. The tongue, „ taste.
5. The skin, „ touch, and heat and cold.

Each sense-organ has its own peculiar structure by which it is rendered sensitive to only one form of energy. Thus the eye cannot hear or feel, neither can the ear see. If a man presses his eye he sees curious patterns of light, and if he excites it with an electric shock he sees a flash of light. However it be excited the eye only gives us sensations of light. Likewise the ear can only give us sensations of sound, and the skin of touch and temperature. Excessive stimulation of any sense-organ causes **pain**.

In addition to the five senses there are other sense-organs through which we learn about the condition of our own body. These sense-organs reflexly control the functions of our



FIG. 46. The tongue. A. Circumvallate papillae. B. Epiglottis. C. Vocal cords in the larynx.

body, such as digestion, breathing, circulation of blood, &c. As a rule we are not conscious of these actions, but only of a general feeling of well-being or the opposite.

Taste. The surface of the tongue is roughened by little processes, or **papillae**, formed of horny cells. Some of the papillae are long and slender, others of the shape of a mushroom. At the back of the tongue are a few larger

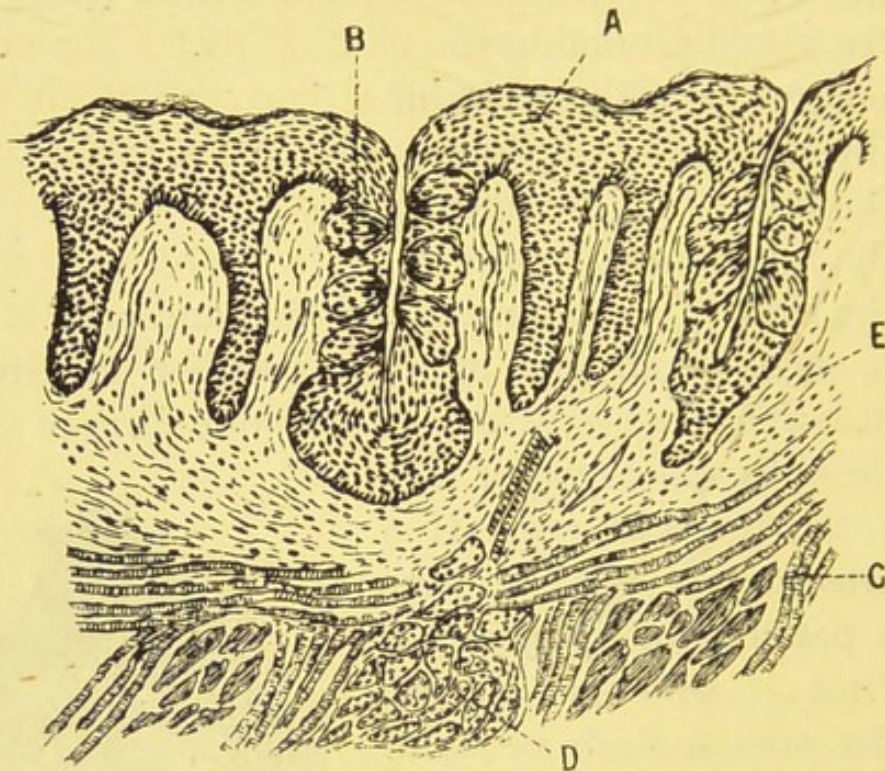


FIG. 47. Circumvallate papillae in a section of the tongue as seen under the microscope. A. Cells which cover the tongue. B. Taste-buds. C. Muscle of tongue. D. Small salivary gland. E. Connective tissue.

circumvallate papillae. They are named so because they are shaped like a mound surrounded by a trench. In the sides of some of these papillae there are little clusters of cells, which form the **taste-buds**. The cells are arranged like the petals of a poppy-bud. In the middle of the bud are some cells with delicate hair-like processes. These processes are chemically excited by the food, and convey the stimulus to a branch of the glossopharyngeal or ninth cranial nerve, which ends in each

bud. Many nerve-fibres end in the tongue by branching among the horny layer of cells. The front of the tongue is supplied by a branch of the fifth cranial nerve.

The tongue tastes (1) sweet, (2) bitter, (3) sour, and (4) salt, and feels the temperature and roughness or smoothness of the food. All other flavours are detected by the nose, for the vapours of the food pass from the back of the mouth into the pharynx, and thence into the nose, where they are smelt. If you hold your nose, and bite first an apple and then an onion, you will hardly tell the difference in flavour. By holding the nose currents of air are prevented from passing through. Similarly a cold in the head lessens your power to enjoy the flavour of food. One part of sugar in eighty-three parts of water can be tasted as sweet, while one part of the poison strychnine in two million parts of water can just be tasted as bitter. So sensitive is our taste for this substance.

Smell. In the middle of the nose there runs a partition which divides it into a right and left chamber.

The floor of the nose is formed by the **hard palate**; the roof by the **ethmoid** bone—part of the base of the

cranial cavity. The ethmoid bone is pierced by a number of small holes, through which the **olfactory nerves** pass into the nose from the brain. At each side of the nose there project three peculiar scroll-like bones. The lining

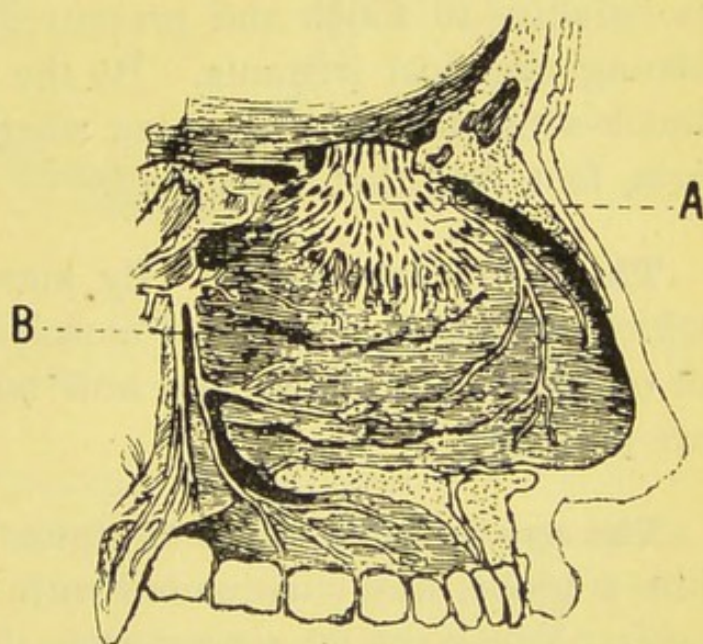


FIG. 48. Section of the nose showing (A) the olfactory nerve, (B) branches of the fifth nerve.

of the nose is a soft mucous membrane containing many mucous glands. We breathe through the lower part of the nose and smell with the upper part. The lower part is lined with ciliated cells and supplied by a branch of the fifth cranial nerve. The cells lining the upper part are several layers thick. Some of them are peculiar cells with hair-like processes, and these form the ends of the olfactory nerve-fibres. By the movement of sniffing, air is drawn into the upper part of the nose. In many animals the sense of smell is far more acute than in man.

Touch. In the papillae of the skin there lie, beneath the epidermis, small oval bodies known as **touch** corpuscles. These consist of a mass of connective tissue. A nerve-fibre winds round each corpuscle and branches within it. Other sensory nerve-fibres end in the epidermis by branching among the deeper layers of cells. The skin is sensitive to touch and pressure, to hot and cold, and to strong chemical irritants. By the varying **quality** of the touch-sensation we recognize whether it is our forehead, arm, foot, &c., that is touched.

The muscular sense. By means of sensory nerves, which end in the joints and muscles, we learn the position of our body and limbs, and how much effort our muscles are making.

The eye and the sense of sight. The eye-ball, shaped like a globe, lies surrounded with fat in the cavity of the orbit. When the fat wastes away the eyes become sunken in appearance. The walls of the orbit protect the eye, except in front, and there it is guarded by the eye-lids. The eye-lids are folds of skin, and their inner moist layer is called the **conjunctiva**. The eye-lashes protect the eye from too much light, and give warning of the approach of twigs, insects, &c.

Muscle-fibres circle round both eye-lids, and by their means the lids are closed. The upper lid can be raised by another muscle which enters it from above. The eye-lids blink every few seconds. Excitation of the eye by light (optic nerve), or of the conjunctiva by touch (fifth nerve), reflexly produces a blink. On the upper and outer side of the orbit is placed the **lachrymal gland**. This is like a salivary gland in structure and secretes the tears. This fluid washes the conjunctiva and cleans dust from

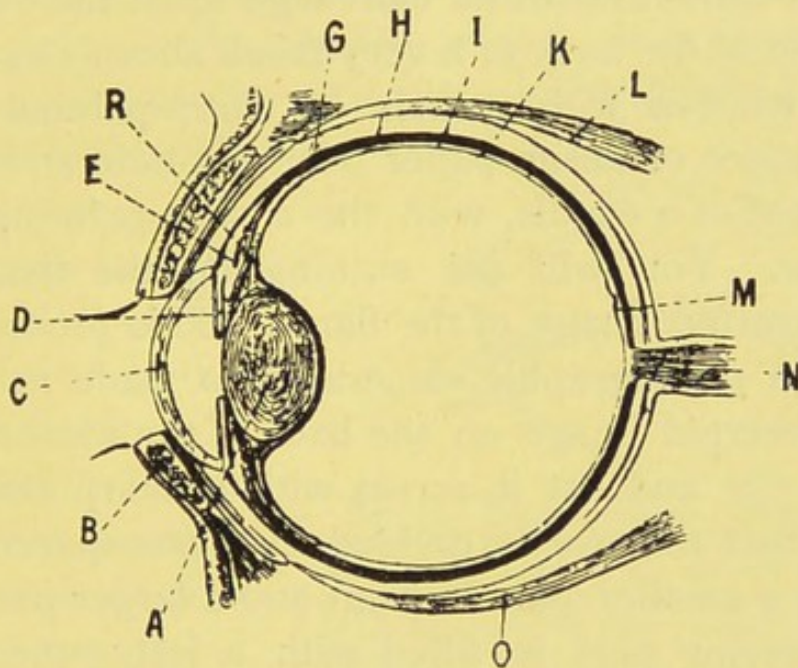


FIG. 49. Section of the eye-ball. A. Lens. B. Eye-lid. C. Cornea. D. Iris. E. Ciliary muscle. G. Sclerotic. H. Choroid. I. Membrane enclosing the vitreous humour. K, M. Retina. L, O. Muscles of eye-ball. N. Optic nerve. R. Suspensory ligament of lens.

the eye. There is a small opening on each eye-lid close to the inner corner of the eye, and through these openings the tears pass down into the nose. The conjunctiva passes from the eye-lids on to the eye-ball. The eye-lids thus form a closed pouch round the eye. To understand the structure of the eye you must obtain one or two sheep's eyes from the butcher's.

In front of the eye there bulges out a transparent curved surface. This is the **cornea**. It may be likened to a small watch-glass. Outside the cornea there lies the

white of the eye. This is formed by the **sclerotic**, or hard coat of the eye. On removing the fat at the back of the eye, you will find a short piece of thick round nerve piercing the sclerotic. This is the **optic nerve**. Six little muscles are attached to the sclerotic just behind the cornea. The other ends of the muscles are attached, when the eye is in its place, to the bony wall of the orbit. By means of these muscles the eye can be turned in any direction. When we look from a far to a near object both eyes turn inwards or **converge** upon the object. In the middle of the back of a very **fresh** sheep's eye, cut out a small window with a pair of sharp-pointed scissors. Place a piece of tissue paper over the hole and hold the eye in front of a candle, with the cornea pointing towards the flame. You will see shining on the tissue paper a little inverted image of the flame. This proves that the eye, like a photographic camera, is so made as to throw a little inverted image on the back of the eye-ball. Now take the eye and cut it across with a sharp knife. You will see that the eye is divided by a transparent convex lens into a smaller part in front and a larger part behind. The posterior part is filled with a jelly—the **vitreous** (glassy) **humour**. Immediately in front of the lens lies a thin pigmented sheet or curtain, the **iris**. The iris is pierced by a round hole, the pupil. Between the iris and the cornea, there lies the shallow **anterior chamber** of the eye, filled with a watery fluid called the **aqueous humour**. The eye-ball is enclosed by three coats, the **sclerotic**, the **choroid**, and the **retina**. The internal coat, or retina, is very thin, and grey in colour. It peels off quite easily, except at one spot where it is continuous with the optic nerve. The latter on entering the eye-ball expands into the retina. The retina is the sensitive layer of the eye. On peeling off the retina a black coat, the choroid, is exposed. This forms the dark lining of the eye, and, like

the black paint in a photographic camera, absorbs light and prevents its reflection. The choroid contains a rich network of blood-vessels, and so nourishes the retina. The sclerotic, a strong fibrous coat, protects the delicate parts of the eye and holds all together.

The colour of the eye is due to the pigment in the iris. The latter contains muscle-fibres, by means of which the pupil can be made to dilate or become smaller. The pupil allows the light to pass only through the centre of the lens, and thereby helps to make the image on the retina sharp. It acts like a 'stop' in a camera. The pupil becomes smaller when the eye is directed to a near object, and when the light is strong. It dilates when the eye is directed to a far object, and when the light is feeble. It also dilates in fear.

The lens is transparent and **bi-convex** in shape, like a magnifying glass. If

you hold a bi-convex lens between your eye and a candle-flame, there will appear, in front of the lens, an inverted image of the flame. You can focus the image upon a piece of tissue paper. According to the distance of the candle you will have to move the paper near to, or farther from, the lens.

Since, in the eye, the retina or sensitive plate upon which the image is formed is **fixed** in position, it is clear that there must be some other means by which the image, either from far or near objects, can be focussed sharply on the retina. To effect this there is a little muscle which runs from the sclerotic to the choroid, all round the edge of the

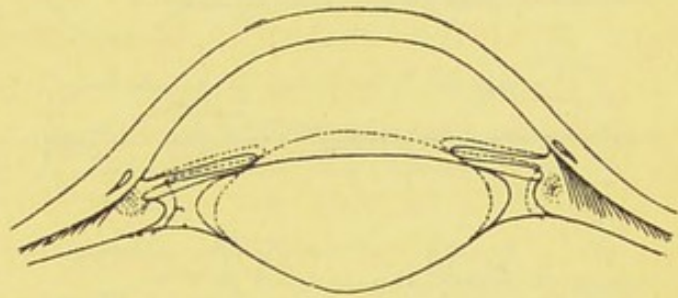


FIG. 50. Section of front part of eye showing the cornea, lens, and iris. The fine lines running from the sclerotic to the choroid represent the ciliary muscle. The dotted line shows the shape of the lens when the ciliary muscle contracts and the eye is accommodated for near vision.

lens. Now the action of this **ciliary muscle** is such that it makes the lens more convex when we look at a near object, and so focusses the image on the retina. On looking at a far object the lens becomes less convex, for the ciliary muscle relaxes. The more convex the lens is, the more it **refracts**, or bends the light. The rays of light **diverge** from a near object thus $<$, while those from a distant object run parallel $=$. The divergent rays must be bent more than the parallel rays to bring them to a focus, and to effect this the lens is made more convex.

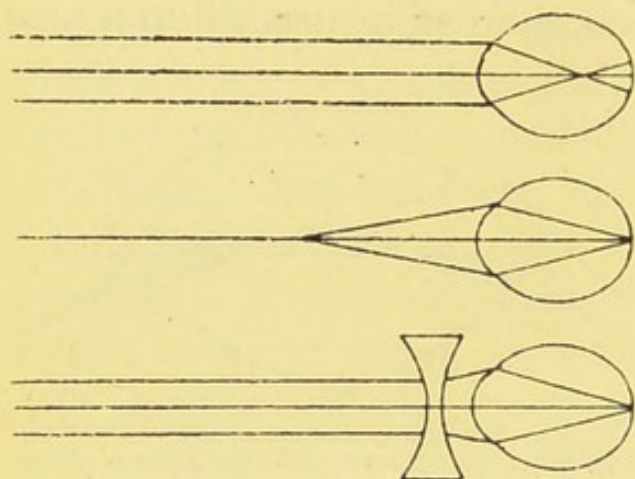


FIG. 51. The short-sighted eye. (1) Far objects (parallel rays) are brought to a focus in front of the retina. (2) Near objects (divergent rays) come to a focus on the retina. (3) Far objects brought to a focus on the retina by a bi-concave glass.

The lens is an elastic substance, and it is confined in its place by a **suspensory ligament** which is attached to the choroid. The ciliary muscle, by pulling on the choroid, slackens the suspensory ligament and thus allows the elastic lens to bulge forward and become more convex.

The lens is not always developed of the right convexity, or, to put it in another way, the retina is sometimes too near or too far from the lens. A short-sighted person has an eye-ball that is too long, while in a long-sighted person the eye-ball is too short, and the retina lies too near the lens. In both cases glasses (lenses) can be worn to correct the defect in the eye. A concave glass is required for short sight, and a convex glass for long sight. Long sight is a common cause of headache, for the nervous system becomes overstrained in trying to bring the image of near objects to a focus.

The optic nerve, on entering the eye, spreads out into a thin film of nerve-fibres, forming the innermost layer of the retina. Blood-vessels enter with the nerve and branch over the retina. The optic nerve itself is not sensitive to light, and a white patch in the retina formed by its entrance is called the **blind spot**. Make a dot and a cross on a sheet of paper about three inches apart, and hold the paper twelve inches away. Shut the left eye and with the right look at the cross. Move the paper nearer. At a certain distance the spot will disappear. Repeat the experiment, this time shutting the right eye and looking at the **spot** with the left eye. At a certain distance the cross will disappear.

The disappearance occurs when the rays of light coming from the spot or cross fall on the blind spot. Normally we do not notice the blind spot. Since the optic nerve is not itself excited by light, we must seek for the sensitive

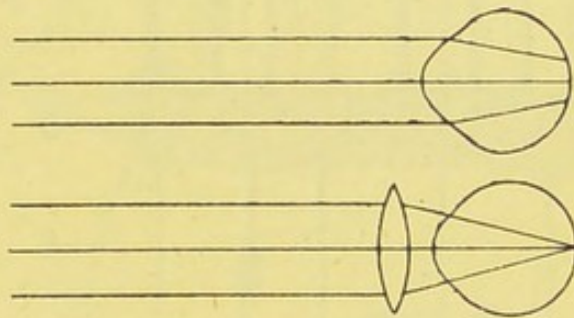


FIG. 52. Long-sighted eye. Objects brought to focus on the retina by a bi-convex glass.

cells in the retina. The retina consists of several inner layers of nerve-cells and their branches, and an outer layer which contains thousands of very peculiar cells shaped some like **rods** and some like **cones**, and coloured with pigment. The pigment probably absorbs the light, and by undergoing chemical change excites the rods and cones. These transmit sensory impulses through the inner layers of the retina to the optic nerve-fibres. In a photographic camera the lens throws a little inverted image of the landscape on the sensitive plate. The latter undergoes chemical change under the influence of the light. In the eye it is much the same, only the retina,

which corresponds to the sensitive plate, in some unknown way transmits the image through the optic nerve to the brain.

In the centre of the back of the eye-ball there is a small yellow spot, where the inner layers of the retina are thinned down so that the rod and cone layer may be directly exposed to the light.

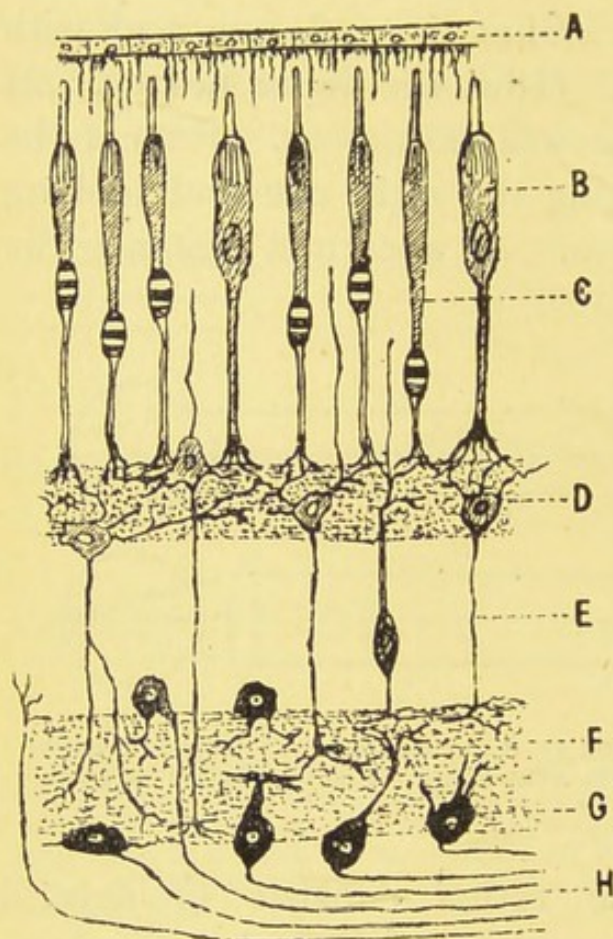


FIG. 53. Diagram of retina as seen under the microscope. A. Outermost layer of pigment cells. B. Cones. C. Rods. D, E, F, G. Inner layers of nerve-cells and cell branches. H. Fibres of optic nerve.

If we want to see an object distinctly we look straight at it, so that the image is focussed on the yellow spot of each eye. Since the yellow spot is the seat of acute sight, it is clear that the rod and cone layer must be the excitable part of the retina, for this layer is alone present there. The eyes are for ever in motion, turning this way and that, so that the images of each object before us may in turn be thrown on to the yellow spots.

If the eye-muscles are not properly balanced in their action, or if

one muscle be paralysed, squinting results. In young children a squint is generally due to the focussing power of the two eyes being unequal. The squint can be cured by wearing proper glasses. When we look straight at an object with both eyes two images are formed, one on each retina. The brain combines these two images into

one, but single vision occurs only so long as the two images are formed on those parts of the retinae which habitually act together. With both eyes look at a pen on a table: then press one eye-ball to one side. The pen will appear double. A drunken man sees double because he has lost control over his eye-muscles.

The ear and the sense of hearing. From the outer ear a tube about one inch long runs inward—the **external**

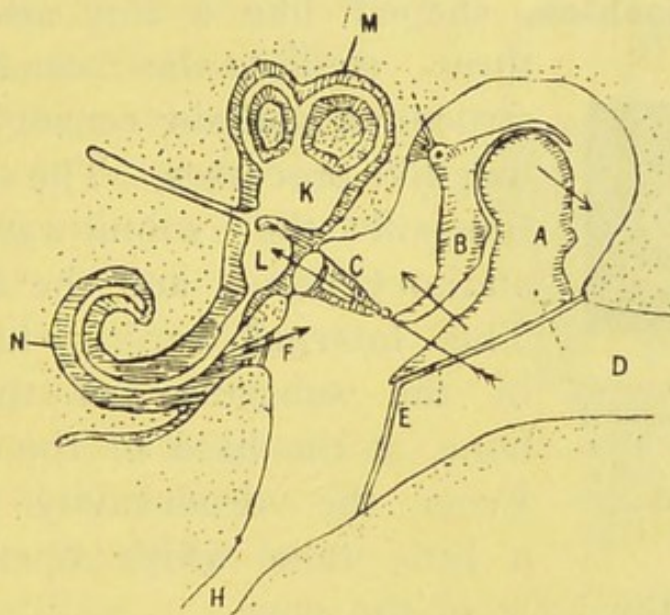


FIG. 54. Diagram of the ear. A. Hammer. B. Anvil. C. Stirrup bone in middle ear. D. External auditory canal. E. Tympanic membrane. M, N, K, L. Parts of internal ear. M. Semicircular canals. N. Cochlea. H. Tube leading to pharynx.

auditory canal. It ends at the drum of the ear, a small cavity, full of air, hollowed out in the substance of the temporal bone. Between the canal and the drum-cavity there is stretched the **tympanic membrane**. This may be compared to the parchment end of a drum. On the inner bony wall of the drum-cavity there is a little opening, oval in shape, which leads into the **internal ear**. The opening is covered with membrane. Stretching from the tympanic membrane to the oval opening is a chain of three tiny little bones. The three bones of the ear are

called, from their shape, the **hammer**, the **anvil**, and the **stirrup**. The waves of sound passing through the air enter the external auditory canal and strike the tympanic membrane. This vibrates and sets the chain of bones in motion, for the hammer-bone, attached to the tympanic membrane, is jointed to the anvil, and the anvil to the stirrup-bone. The stirrup-bone communicates the vibration to the membrane covering the oval hole, and this in its turn causes waves in the fluid which fills the internal ear. In the internal ear are certain complicated structures, the **cochlea**, shaped like a tiny snail-shell and three semicircular canals. These



FIG. 55. Bony case of the internal ear separated from the tympanic bone. *a*. Oval window. *c, d, e*. Semicircular canals. *f*. Cochlea.

structures contain sensory cells with hair-like processes. The sensory cells transmit the sound-waves to the auditory nerve, and the brain hears. The internal ear is hidden away in the substance of the temporal bone, at the base of the skull-cavity. From the drum-cavity there runs a little tube which opens into the pharynx at the back of the nose.

Through this tube the air in the drum-cavity is renewed. A cold in the nose sometimes spreads up this tube to the drum-cavity, and causes inflammation and deafness. A discharge from the ear should always receive medical attention, for the drum-cavity is only separated from the cranial cavity by a thin layer of bone, and inflammation may and does, in some cases, spread from the ear to the brain.

The voice. At the top of the wind-pipe lies the **larynx**, or voice-box. The opening into the larynx lies at the back of the tongue, and is called the **glottis**. Purchase from the butcher a sheep's tongue with the larynx and part of

the wind-pipe attached. On looking into the glottis you will see that it is a slit-like opening. The edges of the slit are called the **vocal cords**. Each cord is set like the reed in a whistle, and its edge is sharp cut. By means of certain little muscles in the larynx the vocal cords can be tightened or relaxed, brought near together or drawn apart, and thus different notes can be sounded when a blast of air is driven through the larynx. On cleaning off the muscles and fat from the front of the larynx you will see the cartilages which form its walls.

At the top of the trachea lies the **cricoid** cartilage. This is shaped like a signet-ring, the broad part being behind. On the top of the broad part of the cricoid there rest the **arytenoid** cartilages. These are pyramidal in shape, and are jointed to the cricoid. The front of the larynx is formed by the **thyroid**, a broad V-shaped cartilage.

While the thyroid and narrow part of the cricoid form the front and sides of the larynx, the broad part of the cricoid and the arytenoid cartilages form the back wall. The vocal cords arise from the thyroid in front, and are attached behind, one to each arytenoid cartilage. On each side of the larynx there is a muscle, the fibres of which run from the thyroid to the cricoid cartilage. The function of this muscle is to tilt back the broad part of the cricoid. This carries the arytenoids with it, and so tightens the vocal cords. In addition there are small muscles that run from the cricoid to the arytenoid cartilages. These muscles cause the arytenoids to turn round upon the top of the

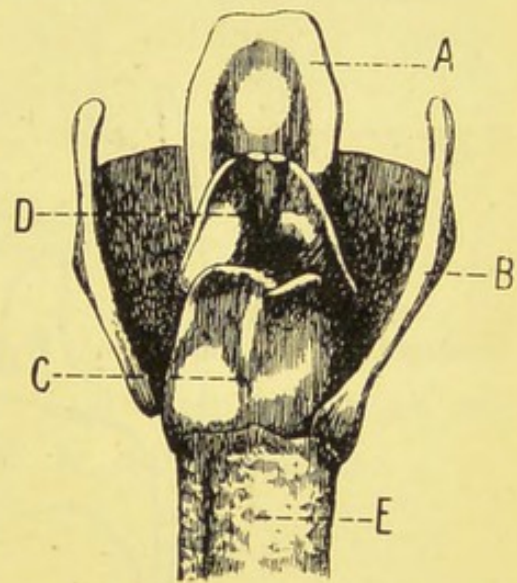


FIG. 56. Back view of cartilages of larynx. A. Epiglottis. B. Thyroid cartilage. C. Cricoid cartilage. D. Arytenoid cartilages. E. Wind-pipe.

cricoid, and so bring the vocal cords either near together or far apart. The chink of the glottis appears V-shaped when the vocal cords are at rest. So soon as the voice sounds the arytenoids are drawn together, the vocal cords are made tense and parallel, and the glottis becomes a narrow slit. The voice is produced by the vibration of the vocal cords, and the tighter the cords are pulled by the muscles of the larynx the higher becomes the pitch of the voice. The form of the air-passages, pharynx, mouth, &c., is of great importance in the production of the voice, for

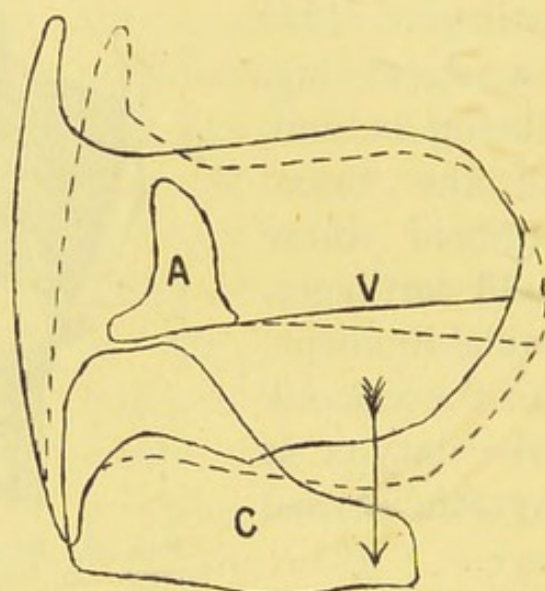


FIG. 57. Side-view of cartilages of larynx. A. Arytenoid cartilage. C. Cricoid cartilage. V. Vocal cord running from the arytenoid to the thyroid cartilage. The arrow shows the pull of the muscles which run from the cricoid to the thyroid. When the thyroid is pulled down into the position marked by dotted lines the vocal cord is stretched.

these chambers act as resonators or resounding chambers, and, like the box of a fiddle, intensify the sound and vary its quality.

The vowel sounds are produced by varying the form of the cavity and the shape of the opening of the mouth. The consonants are produced by closing more or less certain doors on the outgoing blast. If the door be partly closed by the lips, or by the tongue touching the palate, the result is an 'aspirate' (F, V, W, S, Z, L, Sch, Th, J,

Ch). If the door be partly closed, and the margin of the opening be thrown into vibration, there results a 'vibrative' (R). The 'resonants' M and N are formed by

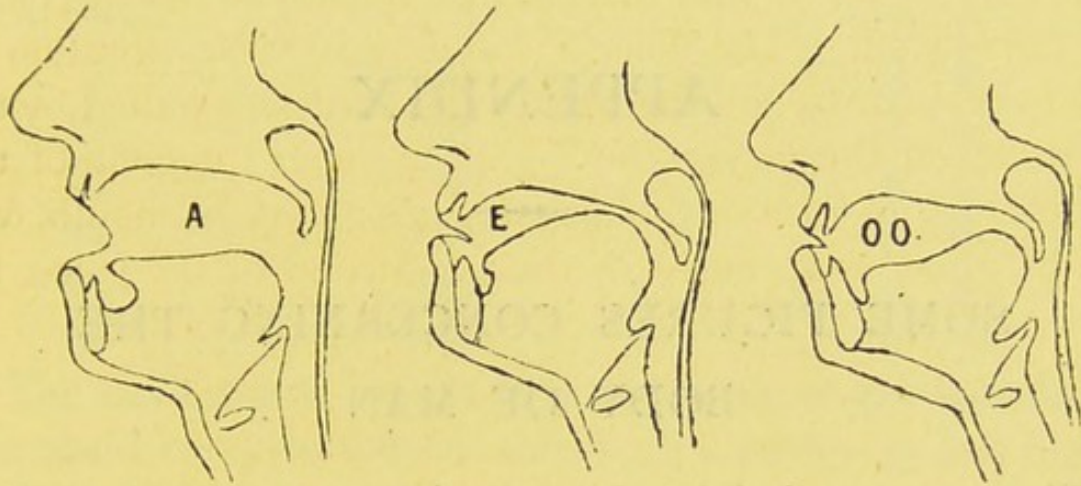


FIG. 58. Shape of the mouth in sounding the vowels A, E, OO.

sending the current of air through the nose. The remaining consonants are explosive. The door is closed and suddenly burst open (B, P, T, D, K, and G hard).

APPENDIX



SOME FIGURES CONCERNING THE BODY OF MAN

THE average height of a man is about 5 ft. 8 in. The average weight about 140 lb. The body of such a man would be made up of:—

Muscles and tendons	.	.	.	.	.	.	<i>about</i> 60 lb.
Skeleton	.	.	.	.	.	.	" 22 "
Fat	.	.	.	.	.	.	" 25 "
Skin	.	.	.	.	.	.	" 9 "
Brain	.	.	.	.	.	.	" 3 "
Heart	.	.	.	.	.	.	" 10 ozs.
Lungs	.	.	.	.	.	.	" 2 lb.
Liver	.	.	.	.	.	.	" 3 "
Kidneys	.	.	.	.	.	.	" 9 ozs.
Spleen	.	.	.	.	.	.	" 5 "
Intestines and remaining abdominal viscera	.	.	.	.	.	.	" 5 lb.
Blood	.	.	.	.	.	.	" 8 "

The average height of a woman is about 5 ft. 3 in., and the average weight about 120 lb.

The average weight of a new-born child is about 7 lb. A new-born child grows about 1 oz. in weight every day during the first month. By the fourth month the increase has fallen to about $\frac{1}{3}$ oz. a day.

Weight and length of a man at different periods of life:—

<i>Age.</i>	<i>Body-weight.</i>	<i>Body-length.</i>
	lb.	ft. in.
At birth	7	1 7
5	35	3 3
10	55	4 3
15	90	5 4
20	132	5 8
25	140	5 8
60	135	5 7

The work a man can do in a day is about 450 foot-tons. He could carry 10 tons of bricks up a ladder 45 feet high. This is equivalent to about $\frac{1}{8}$ horse-power.

The average circumference of the thorax measured during expiration just beneath the angle of the scapula is 33 in. The increase in inspiration is 2-3 in. The respiration takes place about 16 to 18 times a minute. The amount of air respired each breath is about half a pint. The amount of oxygen taken in, or carbonic acid given out, each day is about half a cubic yard.

The heart is about the size of a man's fist. The width of the aorta is a little more than an inch. The width of a capillary $\frac{1}{3500} - \frac{1}{2000}$ th of an inch. The width of the superior or inferior vena cava a little less than an inch. The pulse beats 72 times a minute. The pulse-wave travels down the arteries at a rate of about 9 yds. a second. The blood flows at the rate of about 1 ft. per second in the large arteries, and about 1 in. per second in the capillaries. The heart drives out about 3 ozs. of blood at each beat. The left ventricle exerts a pressure sufficient to lift the 3 ozs. of blood about 5 ft. high. The work of the heart during the day is equal to about 60 foot-tons.

The body throws off from the skin about 20 ozs. of water, from the lungs about 9 ozs. of water, from the kidneys about 50 ozs. of water.

From the kidneys the body throws off about $1\frac{1}{4}$ oz. of urea, about 1 oz. of mineral salts, and a small quantity of other solid matters.

The body loses about $\frac{1}{2}$ oz. of nitrogen, 8 ozs. of carbon, 1 oz. of salts, and four or five pints of water a day.

The diet required to replace this loss should contain

	OZS.
Dry proteid	$3\frac{1}{2}$
Dry carbohydrate	16
Fat	3

and a sufficiency of mineral salts and water.

The average temperature is $98\cdot4^{\circ}$. The heat given off by a man in a day would be sufficient to boil five or six pints of water.

The size of certain structures :—

Red corpuscles, breadth $\frac{1}{3200}$ th of an inch.

Striated muscle, breadth $\frac{1}{400}$ th "

" " length 1-2 inches.

Nerve fibres, breadth $\frac{1}{12000}$ - $\frac{1}{2000}$ th of an inch.

Nerve cells, breadth $\frac{1}{500}$ - $\frac{1}{250}$ th "

A nerve impulse travels at the rate of about 100 ft. a second. The brain can send about ten messages to the muscles a second. A man can think of ten syllables a second. A muscle takes about $\frac{1}{10}$ second to contract.

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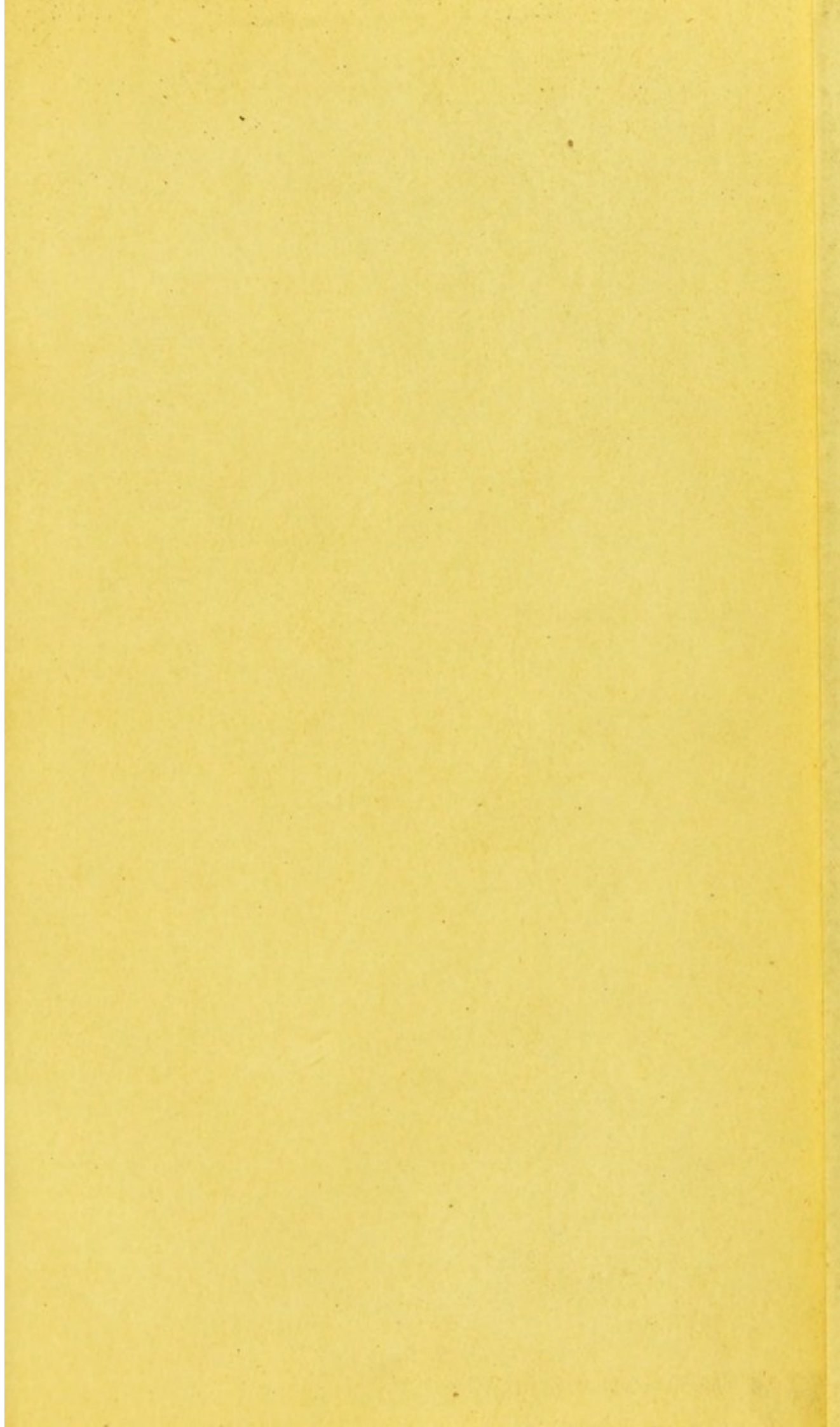
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