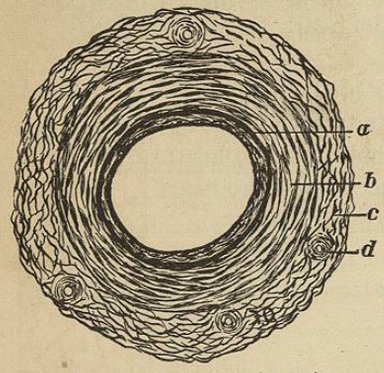
CHAPTER XX

THE FLOW OF BLOOD IN THE BODY

298. Arteries. — The tubes which conduct the blood away from the heart are called *arteries*. From the left ventricle there goes a single tube called the *aorta*. It gives off branches, which subdivide again and again, until they are of microscopic size and penetrate to every part of the body.



An artery cut across (× 200).

a smooth inner coat.
b middle or muscular coat.
c outer or connective tissue coat.
d small artery to nourish the large one.

From the right ventricle there extends another tube, called the *pulmonary artery*, which conducts blood only to the lungs, where it is purified.

299. Structure and action of arteries. — An artery is a muscular tube covered with a tough layer of connective tissue and lined with a layer of very smooth, platelike cells. Its muscle can diminish the size of the tube. The arteries are elastic, and are always so full of blood that they are somewhat distended. At each systole of the heart, from two to four ounces of additional blood are suddenly forced into the already full aorta. During the heart's diastole, the elasticity of the

artery causes it to contract, forcing the blood onward in a steady stream. But the artery can exert no more power in contracting upon its blood than the heart exerted in distending the artery, and so it is really the heart's force which propels the blood.

300. The pulse. — The extra distention of the aorta by each systole of the heart produces a wave in the blood which runs along the arterial tubes. Wherever an artery runs near the surface, as in the wrist, the wave may be felt, and is called the *pulse*. The pulse is not a sudden current of blood shot through the artery, but is a *wave* in the steady stream. By means of the pulse the frequency and regularity of the heart beats may be determined. When an artery is cut, a continuous jet of blood spurts out to a considerable distance, which momentarily increases in size with each wave beat.

301. Capillaries. — The smallest arteries suddenly divide into an extremely fine network of tubes, called *capillaries*. Each capillary tube is from $\frac{1}{2000}$ to $\frac{1}{3000}$ of an inch in diameter, and from $\frac{1}{1000}$ to $\frac{1}{50}$ of an inch in length. It is composed of the same kind of smooth and flat cells as those which line the arteries; in fact, the capillaries are the prolongation of the linings of the arteries. They penetrate the spaces between the cells of the body in such a close network that several capillaries may be in contact with each cell, and the point of a fine needle cannot be thrust into the body without wounding some. The blood in the capillaries gives the pink tinge to the skin, which disappears when the blood is pressed out. The total capacity of the capil-

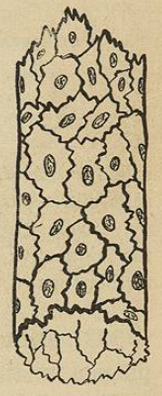
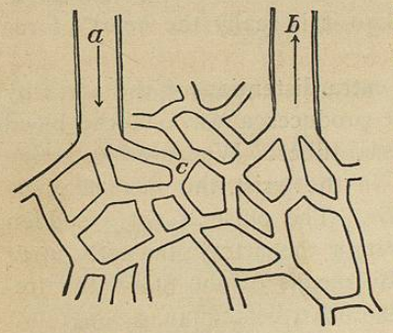


Diagram of a capillary, showing the platelike cells of which it is composed (× 500).

laries is about three hundred times that of the arteries, and hence the blood pressure is much less than in them; yet the pressure is always sufficient to keep the blood in steady motion.



Arrangement of capillaries.

a smallest artery.
b smallest vein.
c network of capillaries.

302. Action of the white blood cells in the capillaries. — Often a white blood cell will adhere to the wall of the capillary and partially block the blood stream for a moment. It may work its way through the wall of a capillary, and yet leave no hole behind it. Many are thus found in the spaces outside the capillaries, and are finally returned to the heart by means of another set of tubes called *lymphatics*. When a capillary is injured, many of the white cells adhere to the injured spot and furnish food for its repair. They may even grow and change to connective tissue for its further repair.

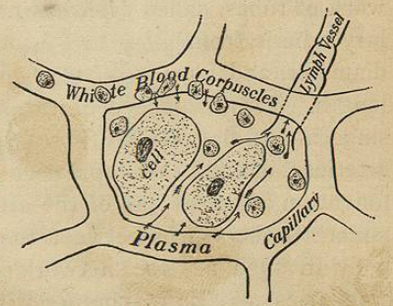


Diagram showing how food reaches the cells from the capillaries.

303. Diffusion of blood plasma in the capillaries. — The slight pressure to which the plasma is subjected is just sufficient to cause it with its albumin to diffuse through the exceedingly thin wall of the capillary. It fills the spaces between the capillary network and bathes each cell of the body with an abundant supply of nourishment.

304. Exchange of oxygen and carbonic acid in the capillaries. — The blood in a capillary is separated from a living cell of the body by a wall so thin that it is no hindrance to the passage of oxygen from the red blood cells. In return for the oxygen received from the blood, the body cells give out carbonic acid gas, which passes through the capillary walls into the blood as readily as the oxygen passes in the opposite direction. A given particle of blood remains in a capillary only a second at most, and in that time there occurs an exchange of oxygen and nutritive matter between the blood and the body cells. Arteries are simply tubes which conduct blood to the capillaries, where all the actual work of nourishing the cells is performed.

305. Veins. — The network of capillaries at the end of each artery unites to form a single tube, called a *vein*. Each vein unites with others again and again, to form larger tubes which run alongside of each artery, and finally all unite to form two main veins. One vein, called the *descending vena cava*, returns blood from the head and arms; the other, called the *ascending vena cava*, returns blood from the lower extremities and trunk. Each opens into the right auricle. The veins have about three times the capacity of the arteries. Their walls are composed of the same material, but are very much thinner, for they do not have to stand much pressure of blood. The blood current is correspondingly slow. The veins have *valves* at intervals which permit of a free flow toward the heart, but oppose its passage backward, so that when a vein is pressed the blood is forced only toward the heart. The contraction of the muscles pressing upon the veins is thus a great aid to the flow of blood. The flow of blood is also aided by the movements of the chest in breathing,

which suck venous blood toward the heart just as it sucks air into the lungs.

306. Pulmonary circulation. — As the blood enters the veins from the capillaries, it has lost some oxygen and gained carbonic acid gas and other waste matter. This makes it much darker in color. Before it is used again it is purified and given a new supply of oxygen. For this purpose it is sent to the lungs as soon as it reaches the heart.

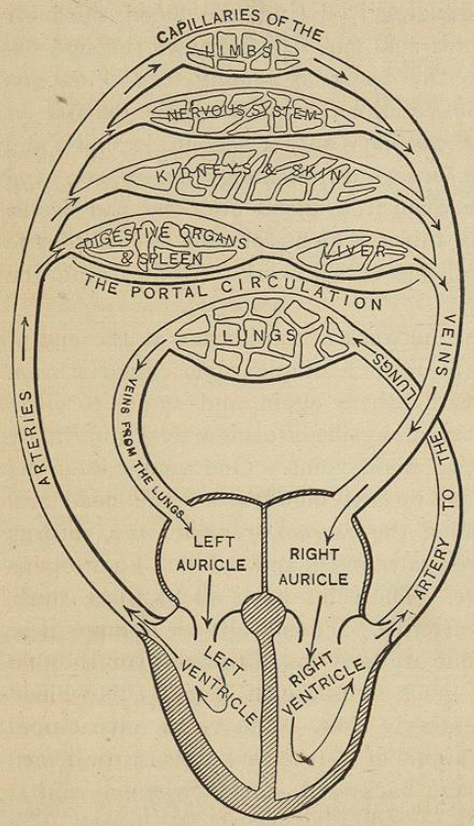


Diagram of the course of the blood in the circulation.

From the veins the blood flows into the right side of the heart, and then to the lungs through the pulmonary artery. The pulmonary artery divides again and again into small twigs, and these divide into a close network of capillaries within the lungs, where the blood is separated from the air by only the thin walls of the capillaries. Through these thin walls the oxygen of the air readily penetrates to the red blood cells; and the carbonic acid gas just as readily passes from the blood to the air. As a result of this change, the blood becomes of a bright red color, and is called *arterial* blood. From the capillaries of the lung the arterial blood is collected into the *pulmonary veins* and carried to the left auricle, and then to the left ventricle, where it is ready to make another circuit of the body.

307. Summary of the circulation of the blood. — In making a complete circuit of the body the blood passes through the *left auricle*, and through the *mitral valve* to the *left ventricle*; then past the *left semilunar valve* to the *aorta*, and then through the *arteries* to all parts of the body; then through the *capillaries* into the *veins*, and back to the heart; next through the *right auricle*, then the *right ventricle*, then through the *pulmonary artery* to the *capillaries* of the *lung*; then through the *pulmonary veins* to the *left auricle* once more. Thus in making the complete circuit of the body, a drop of blood passes through the heart twice, and through *two* different sets of capillaries. The circuit of the body in general is called the *systemic circulation*, and that through the lungs is the *pulmonary circulation*.

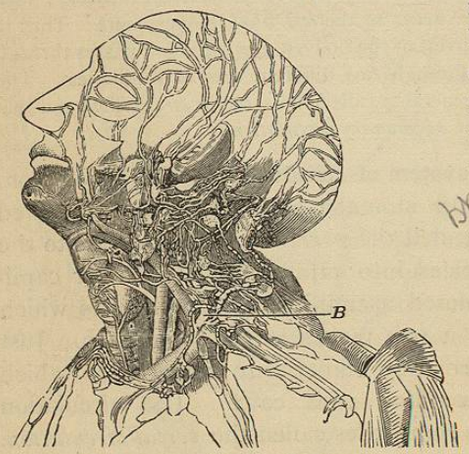
308. The portal system of circulation. — The blood from the capillaries of the stomach and intestine is collected into a single vein, called the *portal vein*, which goes to the liver and there divides into capillaries. The liver capillaries can be considered as millions of small tubes which are substituted for a few inches of the portal vein. Just outside of the liver they empty into three veins which open into the ascending vena cava. The circulation through the liver is sometimes called the *portal circulation*.

309. Time required in the complete circulation. — It requires about twenty seconds for a drop of blood to go the round of the circulation from the left ventricle back to its starting point. All the blood passes through the heart about once every two or three minutes. All the arteries, except the pulmonary artery, carry bright red arterial

blood, while all the veins, excepting the pulmonary veins, carry dark red or venous blood.

310. The lymph. — In order to nourish the body, the plasma of the blood is continually being diffused through the capillaries into the spaces between the living cells. Each cell is thus bathed in a plentiful supply of plasma, from which it absorbs its nutriment. The spaces also contain many white cells, which have left the capillaries. The blood plasma and blood cells filling the spaces between the cells are called the *lymph*, and the spaces are called *lymph spaces*.

The lymph is a thin, colorless fluid. In fact, it is blood without the red corpuscles, but with many waste matters from the cells of the body added. The lacteals of the intestine are also lymphatics which carry the digested fats, and hence their lymph is of a milky-white color.



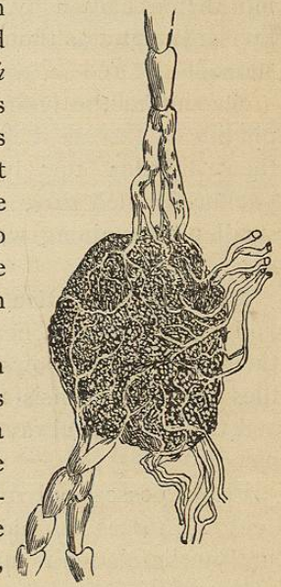
Lymphatics of the head and neck.
B thoracic duct.

311. Lymphatics. — Lymph is continually collecting, and its removal is provided for by means of a set of tubes, called the *lymphatics*. The smallest lymphatic tubes are much smaller than a capillary, and their walls are so thin that they can scarcely be seen with a microscope. Each begins in the open space between a capillary and a cell of the

body. They unite again and again to form about twenty main trunks for each limb. Each trunk extends upward, and most of them finally unite to form a tube of the size of a goose quill, called the *thoracic duct*.

The thoracic duct lies upon the spinal column, and extends upward into the neck, where it opens into a large vein. The lymphatics have numerous valves, all opening toward the heart. They prevent the backward flow of lymph.

312. Lymph nodes. — At irregular intervals the lymphatics open into small, baglike bodies composed of a spongy network of fibers filled with cells which look like white blood cells. Each body is called a *lymph gland* or *node*. The lymph flows through these nodes as water flows through a filter. They strain out matters which are injurious to the system, while their cells envelop and destroy poisons. Some of the cells also flow on with the lymph and become white blood cells.



Lymph node and vessels (× 10).

The lymph nodes may be felt in the neck and groins and armpits, as small kernels about the size of a grain of wheat or corn. When the lymph carries certain kinds of poisons, they swell up and produce the disease called *scrofula*. In boils, erysipelas, and other inflammations, they swell and become very tender and sometimes break down and form abscesses.

313. Flow of the lymph. — A little pressure transmitted from the blood in the capillaries is exerted upon the lymph,

but not enough to force it along the lymphatics. Its flow is aided by the pressure of muscles upon the spaces and the tubes. Its current is slow and unsteady. It is finally poured through the thoracic duct into a vein at the root of the neck, where it mingles with the blood. About two quarts of lymph pass through the thoracic duct daily. If a hollow needle is thrust into the skin, and through it water containing medicine is forced, the medicated water spreads through the lymph spaces between the living cells. Some is taken up by the capillaries, and some passes into the circulation by means of the lymph, and produces the same effect as though it entered the blood through the stomach.

Sometimes the lymph cannot be removed by the lymphatics so fast as it is poured out by the capillaries. It then distends the lymph spaces, producing uniform swellings called *dropsy*. Dropsy can be recognized by a small pit remaining when the finger is pressed into the skin.

314. The circulation in lower animals. — Land animals and birds possess a heart and blood tubes like man's, and their circulation follows the same order. The heart of reptiles and toads consists of two auricles and one ventricle, and the ventricle always contains both arterial and venous blood.

Fishes possess only one auricle and one ventricle. The ventricle forces the blood through two sets of capillaries, and the circulation is made correspondingly sluggish.

Insects possess a row of eight or nine sacks connected by a tube, with valves opening toward the head. The contraction of the sacks forces the blood toward the head, where it escapes into the lymph spaces between the cells. There are no arteries or veins, and so the blood is slowly

forced toward the back part of the body through the lymph spaces until it again reaches the tube. Their circulation is thus like the circulation of lymph in man.

Shellfish usually possess a heart and arteries and veins. In the very lowest animals, like the ameba, there seems to be a flow of fluid within the body, but no part of the body is set aside for the purpose.

315. History of the knowledge of the circulation. — The ancients thought the heart was the seat of life, because the heart was seen to be the first organ formed in an egg which was being hatched. The idea was confirmed to them by the heart's constant action, which they thought was caused by the boiling of the animal spirits. The spirits then flowed away in a sluggish stream through the veins, and were not supposed to return to the heart.

They concluded that the arteries carried only air, because they always found them empty after death. They knew nothing whatever of the capillaries. They thought that food was carried to the liver and was there partly cooked, and was then sent on to the heart where it was cooked still further in the heart's vital flame, until it was turned to blood. Then it was sent out by way of the veins to irrigate the body. The valves of the veins were supposed to oppose its flow and to render it sluggish. The boiling in the heart was supposed to heave the chest up and down, and cause air to rush in and prevent too great a degree of heat. The brain also was supposed to cool the blood. Because of its more violent action during physical exertion or emotion, they concluded that the heart, instead of the brain, was the seat of the mind and feelings. We still use the word *heart* with this meaning in such expressions as *kind-hearted* and *free-hearted*.

Incredibly few discoveries were made for thousands of years, for until within two hundred years the law forbade any one to dissect a human body. In 1628 a true explanation of the heart and the course of the blood was first published by Harvey, an English physician. The only point which he omitted was the explanation of how the blood gets from the arteries to the veins. Three years after his death microscopes were made powerful enough to reveal the capillaries for the first time, and thus the truth of our present ideas concerning the circulation was fully established.

SUMMARY

1. The tubes carrying blood away from the heart are called *arteries*. They are thick-walled and elastic, and in them the blood is under considerable pressure. Each heart beat causes a perceptible wave in the artery, which is called the *pulse*.
2. The arteries divide and finally break up into fine tubes called *capillaries*, which touch each cell of the body.
3. In the capillaries some of the plasma passes outside the tubes and bathes the cells in nourishment. Some of the oxygen leaves the red blood corpuscles to go to the cells of the body. Some carbonic acid gas also leaves the cells of the body and combines with the plasma within the capillary.
4. The capillaries join together to form thin-walled vessels called *veins*, which return the blood to the heart.
5. The plasma which has left the capillaries is called *lymph*. It is returned to the blood by means of a set of fine tubes called *lymphatics*.
6. The lymphatics unite to form a tube called the *thoracic duct*, which runs up the backbone and opens into a vein at the root of the neck.
7. The right side of the heart sends the venous blood to the lungs, where it passes through the capillaries and is freed from its impurities, and then returned to the left side of the heart as arterial blood ready for another circuit of the body. This is called the *pulmonary circulation*.
8. The venous blood from the stomach and intestine passes through a second set of capillaries in the liver. This is called the *portal circulation*.

DEMONSTRATIONS

73. The flow of blood in the veins and the action of the valves of the vein can be shown by placing a finger upon a vein in the skin upon the back of the hand. Then press out the blood by running another finger a few inches up the vein. When the second finger is removed, notice that the blood does not return in the vein, for the valves stop the backward flow; but if the first finger is removed, the vein at once fills up. This is one of the proofs which Harvey used to prove the circulation of the blood.

74. The position of the main arteries upon the limbs should be shown upon the body. Remember that they are usually over the middle of a joint upon the side toward which it can be bent. Explain that wherever a beating can be felt there is a pulse and an artery.

75. Examine an artery and vein prepared for the microscope. Notice its smooth and thin inner layer puckered because of the contraction of its outer coats. Next is the muscular layer, each cell wrapped around the tube. The next and outermost layer is composed of connective tissue. Notice that the main difference between the artery and the vein is that the artery is thicker.

76. Tie a string or a rubber band rather tightly around the finger. Notice that in a few minutes the finger becomes purple, cold, swollen, and painful. Explain that the string does not exert enough pressure to close the thick arteries which are under high pressure, but that it readily closes the veins.

77. Show the capillary circulation in a frog's foot. Place the frog in a covered glass of water to which a teaspoonful of ether has been added. When it ceases to move, spread its web over a hole cut in cardboard. A ring of dried mucilage will hold it in place. Examine it under a microscope with a magnifying power of about 200 diameters. Oval cells will be seen shooting through a network of capillaries. The tail of a small fish also will show the circulation.

REVIEW TOPICS

1. Describe the tubes which conduct blood to the cells of the body, their structure, situation, arrangement, action, and pulse.

2. Describe the *capillaries*, their structure, and action in regard to nutrition and respiration.
3. Describe the *veins*, their structure and action.
4. Describe the pulmonary circulation and the portal circulation.
5. Give the time required for a drop of blood to make the complete round of the circulation.
6. Describe the lymph, the lymphatics, the flow of lymph, and the use of lymph.
7. Describe *lymph nodes* and give their use.
8. Describe the circulation in reptiles and toads, in fishes, in insects, in shellfish, in the ameba.
9. Give an outline of ancient ideas concerning the circulation of the blood, and tell when and by whom the true circulation was discovered.

CHAPTER XXI

REGULATION OF THE FLOW OF BLOOD

316. Vaso-motor nerves. — The muscles in the walls of the smaller arteries regulate the amount of blood passing through them. A special set of nerves, called *vaso-motor nerves*, causes the arteries to contract. When these nerves are paralyzed, the muscles relax, and the artery becomes fully distended by the pressure of the blood. When any part of the body is working, its arteries dilate in order to supply a greater amount of blood to the part.

The vaso-motor nerves are affected by influences from the brain. Embarrassment and bashfulness paralyze those of the head, so that more blood goes to the face and it becomes redder, or blushes. On the other hand, fear and grief stimulate the nerves and cause a contraction of the arteries, which drives the blood from the face so that paleness results. *Heat* applied to the skin causes the arteries to *dilate*, and thus to contain more blood.

317. Congestion. — More than the natural quantity of blood remaining in a part for some time is called *congestion*. It is liable to injure the cells. Cold causes the arteries of the skin to *contract* so that less blood can pass through them. The blood intended for the skin is thus directed through the deeper arteries which already contain their full amount of blood. So congestion of the deeper parts often results. In this way we get cold in our throats.

318. Secondary effects of heat and cold. — When heat has acted upon the skin for some time it causes a contraction of the blood tubes. When first put into a tub a washerwoman's hands become