CHAPTER XXIII

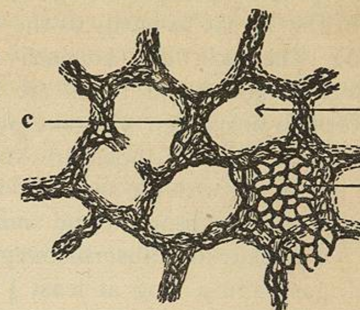
RESPIRATION OF THE TISSUES

351. Changes in respired air. — The air is composed of about 80 per cent of nitrogen, 20 per cent of oxygen, and $\frac{4}{100}$ per cent of carbonic acid gas. The nitrogen has no effect upon the body, but acts simply by diluting the oxygen. Air which is ordinarily breathed out from the lungs contains 16 per cent of oxygen and 4 per cent of carbonic acid gas, while the amount of nitrogen remains unchanged. Thus, in breathing, the air gains as much carbonic acid gas as it loses oxygen. Expired air is warmer and contains more watery vapor than inspired air, and sometimes contains a trace of a very poisonous organic gas.

352. Blood changes in the lungs. — Every 100 cubic inches of venous blood entering the lungs contain 46 cubic inches of carbonic acid gas, and from 8 to 12 cubic inches of oxygen gas. As it leaves the lungs the same amount of blood contains about 40 cubic inches of carbonic acid gas, and 20 cubic inches of oxygen gas, and it has changed its shade from the dark red of venous blood to the bright red tint of arterial blood. It has also lost a small amount of water and some heat. The essential change which occurs in the passage of blood through the lungs is the exchange of carbonic acid for a corresponding amount of oxygen gas. In health, during quiet breathing, the blood becomes completely saturated with oxygen.

353. Affinity of blood for oxygen. — Blood exposed to

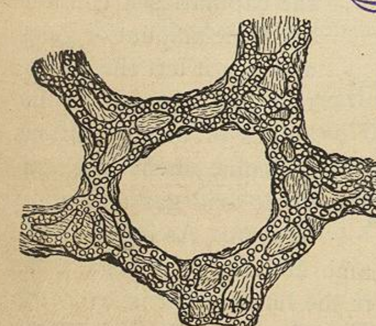
the air takes up oxygen very readily and becomes of a bright red color. Thus, blood as it usually flows from a slight wound, takes up oxygen gas almost immediately and becomes the color of arterial blood, and venous blood is seldom seen. Between the dark color of the venous blood in the veins of the hands, and the brighter pink hue of the surrounding skin due to the capillaries, there is a contrast which is a good indication of the usual difference between venous and arterial blood.



Sketch of a thin slice of a lung, showing the arrangement of capillaries upon the walls of the air sacs (× 50).

a interior of an air sac.
b bottom of an air sac covered with capillaries.
c side of an air sac with capillaries.

354. Exchange of oxygen and carbonic acid in the lungs. — The blood in the capillaries of the lungs is separated from the air in the air sacs by only the thin walls of the capillaries. Oxygen from the air in the air cells passes through the capillary walls into the blood almost as readily as though there were no walls at all. In the blood the oxygen combines with the hemoglobin of the red blood cells, and the blood be-



Capillaries upon the sides of an air sac (×200).

comes of a brighter red color as it gains oxygen. Carbonic acid, which was combined with the alkalies of the blood plasma, passes through the capillary wall into the air of the air sac as easily as the oxygen entered the blood.

355. The skin and stomach as respiratory organs. — Wherever the blood tubes are in contact with the air, absorption of oxygen will take place. In the stomach and intestine the blood tubes are very near the surface, and are in contact with air swallowed with the food. So some oxygen will be absorbed and some carbonic acid gas given off. The skin also absorbs oxygen and gives off carbonic acid gas. In a frog at least $\frac{1}{8}$ of the respiration is performed in this way. In man, about $\frac{1}{200}$ as much respiration is carried on by the skin, stomach, and intestine as by the lungs.

356. Respiration of the cells of the body. — After leaving the lungs, the blood is distributed through the arteries, and enters the capillaries of the body. As it enters the capillaries it contains the same amount of gases as when it left the lungs; that is, each 100 cubic inches of blood contains 40 cubic inches of carbonic acid gas and 20 of oxygen. As it leaves the capillaries, it contains the same amount of the gases as the venous blood which enters the lungs; that is, each 100 cubic inches contains 46 cubic inches of carbonic acid gas and 12 of oxygen. The exchange in the capillaries balances the exchange in the lungs.

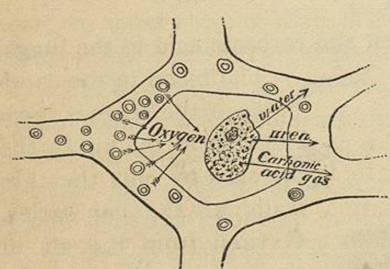


Diagram of the respiration of cells.

When a piece of flesh is put into a dish of blood, oxygen

will leave the red blood cells and combine with the cells of the flesh. In a similar way oxygen leaves the red blood cells in the capillaries and, passing through their thin walls, unites with the cells of the body, producing carbonic acid gas, water, and urea. The water and urea go back to the blood and are thrown off by the kidneys. The carbonic acid gas passes through the capillary wall into the blood and unites with the alkalies of the plasma. This goes on in every capillary and cell of the body and constitutes the real act of respiration. The lungs and red blood cells are only devices for carrying oxygen to the deep cells of the body.

357. Oxidation of sugar and fat. — Neither sugar nor fat becomes a living part of the cells of the body, but after being absorbed both are oxidized at once and furnish about three times as much heat and energy as the albumin, which forms a part of the cells. But oxidation in the body is a living process, and requires the operation of living tissues. So it is unlikely that it occurs in the blood stream. As sugar is absorbed, the cells of the liver take it into their own substance, and probably oxidize it there. In the same way the fat is probably taken up by the epithelial cells of the air sacs of the lungs and oxidized. In each case the heat is distributed through the whole body by the blood.

358. Respiration a continuous process. — When the breath is held, the oxygen in the lungs and that carried by the red blood cells is sufficient to supply the body for only about half a minute. By the end of that time all the blood becomes venous and a great shortness of breath is felt.

Oxygen passes from the lungs through the blood tubes to the cells of the body with great rapidity, so that by a few deeper breaths enough extra oxygen is taken up by the red blood cells to relieve shortness of breath caused by their lack of oxygen.

359. Amount of oxygen used daily. — The amount of oxygen used in the body is constantly varying. During muscular exertion greater power is required than when the body is at rest. To keep up the increased power, more oxygen must leave the blood and unite with the muscle cells. During sleep less oxygen is needed, but the average amount used each day is fairly constant.

It is a simple example in arithmetic to calculate how much oxygen the red blood cells usually carry.

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18    = no. of respirations per minute.
30    = no. of cubic inches of air in each inspiration.
540   = no. of cubic inches of air inspired each minute.
60
32400 = no. of cubic inches of air inspired each hour.
.04   = per cent of air which enters the red blood cells as oxygen.
1296  = no. of cubic inches of oxygen entering the blood each hour.
1296 ÷ 1728 = 0.75 = cubic feet of oxygen entering the blood each hour.
0.75
1.2   = ounces weight of a cubic foot of oxygen.
0.9   = ounces of oxygen entering the blood each hour.
24
21.6  = ounces of oxygen entering the blood each day.
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Allowing two or three ounces more for extra exertions, about 25 ounces of oxygen enter the body each day. This is about the amount needed to oxidize the food which a man usually eats.

The amount of carbonic acid given out is about the same as the amount of oxygen taken in, if it is measured in cubic inches. But since the carbonic acid is heavier, it amounts to about 30 ounces a day. About 20 ounces of water are also breathed out each day.

360. Effect of exercise upon the amount of oxygen absorbed. — In quiet breathing each red blood cell is loaded with oxygen to its full capacity. During muscular exertion the heart beats more forcibly and faster, driving the red blood cells more rapidly, and thus, in a given time, more oxygen will be carried. But when the cells are shot

through the capillaries too rapidly, there is no time for either giving or receiving oxygen, and the body may be actually starved of oxygen. So the average amount of oxygen which the blood can carry is found to be about 25 ounces daily.

It is possible to educate the respiratory muscles so that during physical exertion they act more regularly and strongly. As a result, the lungs are expanded more, and a greater area of capillaries is exposed to the air. The heart also may be trained to restrain its violent action, so that the blood is not shot through the capillaries of the lungs too rapidly to take up oxygen. An athlete trains his body so that it can absorb more than 25 ounces of oxygen daily, and thus he can put forth a greater amount of exertion. Such a person is said to be *long winded.*

361. Causes of shortness of breath. — The sensation of shortness of breath is usually due to a deficiency of oxygen in the blood which circulates through the respiratory center. The blood contains too little oxygen when an extra amount of oxygen is used during great physical exertion. At first, the heart pumps the blood faster so that it carries more oxygen in a given time, but when the blood is pumped very rapidly, the red blood cells are shot through the lungs so quickly that they cannot obtain the necessary oxygen. When, as in heart disease, the blood is pumped too slowly, only a small amount of oxygen will be carried through the respiratory center, and there will be continuous difficulty in breathing. Shortness of breath is often the first sign of heart failure. After severe hemorrhage there are too few red blood cells to carry the full amount of oxygen, and so shortness of breath will be felt. Death by bleeding is due to suffocation and lack of oxygen. In the disease called *anemia* there are too few red blood cells to carry oxygen, and so there is shortness of breath on exertion. When the larynx or the trachea is compressed or obstructed, as in choking, or when the smaller bronchi are filled with mucus, as in bronchitis, oxygen is prevented from entering the blood, and the respiratory center feels a great shortness of breath.

362. Oxygen inhalations. — Since the red blood cells are loaded with oxygen to their full capacity as they leave the lungs, they could absorb no more even if it were inhaled in a pure form. When there is a shortness of breath during disease, pure oxygen is sometimes inhaled to take the place of the diluted oxygen of the air. When the lack of oxygen is due to a diminished number of red blood cells, or if the blood flows too slowly to carry enough oxygen, inhaling oxygen can do no good, for the blood cells leaving the lungs are already loaded with it. The poisons of certain diseases may cause the arteries to contract and the heart to beat with great force and rapidity. Then the blood cells may move so quickly that they have no time to take up oxygen from the lungs. Neither rest nor violent inspiratory efforts will relieve the resulting shortness of breath, but more oxygen may reach the blood cells if it is inhaled in a pure form.

If there is an obstruction to the entrance of air into the lungs, more oxygen may pass the obstruction if it is inhaled in an undiluted form. When the larynx or trachea is obstructed by a membrane in diphtheria, or when the small bronchi are filled with mucus, as in bronchitis and pneumonia, then the inhalation of pure oxygen may be of great benefit.

363. Asphyxia. — When the breath is held, a feeling of discomfort comes on in about half a minute, which soon becomes great distress. If a person is prevented from taking a breath, he will become unconscious in a few seconds, but will make great inspiratory efforts for a minute or more. There will be convulsions, and the face will turn purple, for all the blood is venous. Death will take place in less than five minutes. This is called *asphyxia*. At any time before death actually takes place life can be restored by artificial respiration.

364. Drowning. — Drowning is a form of death by asphyxia, but is complicated by the entrance of water into the lungs.

The treatment of drowning is simply to perform artificial respiration. In order to do it, it will be necessary to remove the water from the lungs. This can be done by turning the person upon his face and forcibly compressing his back. It will be still better to suspend him head downwards for a few seconds, or standing astride him to raise him up and down about twenty times a minute by grasping him about the lower part of the chest. This performs artificial respiration and lets out the water at the same time.

The person's limbs should be rubbed vigorously toward the heart and kept warm by hot water bottles. No time should be lost by carrying him to a building, but artificial respiration should be done on the spot. Even if the person has been in the water half an hour or more, it is possible to restore life.

365. Electric shock. — A shock of electricity kills by overwhelming the nervous mechanism which controls the heart and lungs. A shocked person is unconscious, and apparently lifeless, and yet life may be restored by artificial respiration. It should be done at once, and continued for a long time if life is not quickly restored.

366. Effect of alcohol upon the lungs. — Alcohol partially paralyzes the arteries of the body so that they dilate and permit a larger quantity of blood to pass through. Thus, the capillaries of the lungs may be distended with the rest. Then they may partly fill the air sacs so that less air can enter. If the distension continues for some time, the walls of the capillaries may thicken so that oxygen will pass through them less readily. The walls of the air sacs themselves may become thickened, and the exchange of oxygen and carbonic acid impeded. This effect may be produced by continuous moderate drinking.

367. Alcohol interferes with the respiration of the cells. — Alcohol is quickly absorbed from the stomach and intestine and as quickly disappears. After it is taken, little or no alcohol, or any substance like alcohol, or any substance containing so little oxygen as alcohol, can be found in any waste of the body. Hence the inference is that it must be oxidized, although the exact point and the manner of its oxidation may not be known. But the evidence for its oxidation is the same as that for the oxidation of sugar.

Every ounce of alcohol requires nearly two ounces of oxygen to oxidize it fully. Taking twenty-five ounces of oxygen gas as the amount used in a day, there will be only one ounce used in an hour. So to oxidize an ounce of alcohol takes an amount of oxygen equal to the whole supply of the body for two hours. Three or four drinks of whisky contain this ounce of alcohol. If this amount is drunk, there will soon be a lessened action and a narcotic effect throughout the body, due mainly to the lack of oxygen. A noticeable degree of uncertain action is called *intoxication*.

Using alcohol in the body is like burning kerosene in a coal stove. By taking great care a little kerosene can be made to give out some heat from the stove, but the operation is dangerous. Some people seem to oxidize alcohol within the body with but little harm; but they run great risks of doing themselves harm, and the result is not nearly so good as if they had used proper food.

368. Poisons produced by alcohol. — When too little oxygen enters the draft of the stove, the wood is burned imperfectly, and there are clouds of smoke and irritating gases. So, if oxygen goes to the alcohol and too little reaches

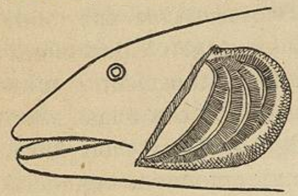
the cells, instead of carbonic acid gas, and water, and urea being formed, there are other products, some of which are exceedingly poisonous and which the kidneys handle with difficulty. The poisons retained in the circulation never fail to produce their poisonous effects, as shown by headaches, clouded brain, pain, and weakness of the body. The word *intoxication* means, "in a state of poisoning." These poisons gradually accumulate as the alcohol takes oxygen from the cells. The worst effects come last, when the brain is too benumbed to judge fairly of their harm. It is not true that alcohol in a small amount is beneficial. A little is too much, if it takes oxygen which would otherwise be available to oxidize wholesome food.

369. Effects of tobacco. — Tobacco smoke contains the same kind of poisons as the tobacco, with other irritating substances added. It is usually sucked into the mouth and at once blown out again, but cigarette smoke is commonly drawn into the lungs and afterwards blown out through the nose. It is irritating to the throat, causing a cough and rendering it more liable to inflammation. If inhaled into the bronchi, it produces still greater irritation, and the vaporized nicotine is more readily absorbed as the smoke is inhaled the more deeply. Cigarettes contain the same poisons as other forms of tobacco, and often contain other poisons which are added to flavor them.

370. Respiration in birds. — The lungs of all land animals are like man's lungs, and the process of respiration is the same. The lungs of birds are fixed in the upper part of the thorax, and in addition they are provided with two smooth bags, each somewhat larger than the lung. Each bag connects with the air sacs of the lung, and also with the interior of the larger bones. Respiration can occur in the bags and bones as well as in the lungs.

The air bags are expanded with air during flight, and thus the body is made lighter in proportion to its size, in order that the bird may fly more easily.

371. Respiration in amphibious animals. — Some water animals, like the porpoise and whale, possess lungs like land animals, and are compelled to come to the surface of the water in order to breathe, but fish have a special apparatus so that they can use the oxygen which is dissolved in water. On each side of a fish's head is a slit-like opening reaching from the interior of the mouth to the surface of the body. In each opening are four half circles of limber bone. From the back of each circle a row of thin fingerlike plumes projects, so that it looks like a red feather with plumes only on one side. These half circles are the *gills*. Each plume contains a blood tube which is separated from the water by a very thin wall. The fish forces the water through his mouth and out between the gills, and the oxygen contained in it readily passes through the thin wall of the blood vessel into the red blood cells.



Gills of a fish.

372. Respiration in a frog. — A frog in the tadpole form is provided with gills which project into the water from its neck, but when it becomes a perfect frog the gills disappear and lungs are formed. But the frog's skin is able to absorb oxygen and to give off carbonic acid gas about one eighth as rapidly as the lungs.

373. Respiration in insects. — In insects from three to nine tubes extend into each side of the abdomen and divide into small branches, but do not communicate with any cavity. The fluid which answers for the insect's

blood comes in contact with the surface of the tubes and absorbs oxygen from the air in them. As they possess no hemoglobin or red blood cells, oxygen is simply dissolved in the blood; but owing to the small size of their bodies, this is sufficient for their use.

374. Respiration in shellfish. — Shellfish, such as oysters and clams, have gills like fringes along their front edges. The gills are covered with cilia which cause currents of water bearing food and air to flow through the shell.

375. Respiration in plants. — A plant also breathes. While it uses heat from the sun in the manufacture of starch from the carbonic acid gas and water, yet for its own movements it requires a production of heat within itself. In order to climb a pole and unfold its flowers, a vine requires power which is furnished by the oxidation of its own substance. At the height of the flowering season the temperature of the plant is raised slightly above that of the surrounding atmosphere, and carbonic acid gas is given off. In every case the heat and power is furnished by oxidation of some of the plant's own substance, but the amount of carbonic acid gas given off is insignificant in comparison with the amount of carbonic acid gas which the plant uses as food. A little oxygen is absorbed by the leaves, but it is small in amount compared with what is given off by the plant.

SUMMARY

1. As blood passes through the capillaries of the lungs it gives carbonic acid gas to the air and takes about the same amount of oxygen from the air.
2. As blood passes through the capillaries of the body it gives up oxygen to the cells and takes carbonic acid gas from the cells.

3. The exchange in the two sets of capillaries balances.
4. Within the living cells the oxygen unites with the albumin, fat, and sugar, producing carbonic acid gas, water, and urea.
5. About twenty-five ounces of oxygen are used daily in oxidizing the body.
6. When not enough oxygen is present within the body, there is a shortness of breath.
7. Alcohol often causes distension and thickening of the capillaries and of the walls of the air sacs, so that oxygen passes through them less readily.
8. The alcohol of three or four strong drinks of liquor uses as much oxygen as would supply the whole body for two hours.
9. As a result of taking oxygen from the cells of the body, the cells act in an uncertain manner, which is called intoxication.
10. Tobacco smoke irritates the air passages. It contains nicotine, which can enter and poison the body.
11. All kinds of animals and plants breathe in oxygen and give off carbonic acid gas.

DEMONSTRATIONS

89. With a glass tube, blow air through some limewater, and notice that it grows milky, showing the presence of carbonic acid gas. Breathe upon a cold glass and notice that moisture collects from the breath. Call attention to the fact that bad odors in the breath are due to decayed teeth, a coated tongue, or foul stomach, or possibly to a dirty nose.

90. The change in color from venous to arterial blood can be illustrated by cutting into a thick slice of beef. At first the cut surface is dark and purplish, and of the color of venous blood. But in a few seconds the blood in the meat absorbs oxygen from the air and becomes bright red in color like arterial blood.

91. With two needles tease apart a bit of gill from a shellfish and examine it with the microscope for the waving cilia.

92. Show a fish's gills and if possible a tadpole's also. "Wrigglers," or the young of mosquitoes, can be found in a rain barrel, and are very interesting. At the tail there is a tuft of stiff hairs through which it breathes. They wriggle about in the water and at intervals come to the surface and thrust out the tuft of hairs so as to get a supply of oxygen.

REVIEW TOPICS

1. Give the changes occurring in the air within the lungs.
2. Give the changes which occur in the blood within the lungs.
3. Show that the blood carries oxygen.
4. Show that the skin and stomach are respiratory organs.
5. Show that the cells of the body take oxygen and give off carbonic acid gas.
6. Show that the blood carries carbonic acid gas.
7. Show that respiration is a rapid and continuous process.
8. Calculate how much oxygen is used daily and how much carbonic acid gas is given off.
9. Show why a person becomes *long winded* by training.
10. Give some causes of shortness of breath.
11. Tell when and why inhalations of pure oxygen are of benefit.
12. Give the effects of alcohol upon the walls of the air sacs.
13. Show how alcohol affects the respiration of the cells.
14. Show how alcohol causes poisons to develop within the body.
15. Give the effects of tobacco upon the air passages.
16. Show how respiration is modified in birds, in fish, in frogs, in insects, and in shellfish.
17. Explain the respiration of plants.