CHAPTER XXIII

PHYSIOLOGY

Introduction. It has been pointed out that what is called life consists of a characteristically complex series of changes exhibited by a certain kind of organization of chemical elements and compounds, called protoplasm. The preceding pages contain brief descriptions of different types of organizations considered chiefly from the morphological point of view. As each group was taken up, general statements with regard to physiological processes were made. For convenience these functions were divided into three groups: first: those of *metabolism;* second: processes of *adjustment;* third: processes of *reproduction.*

In single-celled Protozoa all these processes are carried out by one cell. Moreover, it is altogether likely that more than one process is going on simultaneously in any single Protozoan.

The evolution of the Metazoa, from the simpler types to the highest, involved the gradual building up of special groups of cells, tissues, organs or organ systems for the more efficient carrying out of particular functions. Yet all the functions are necessarily displayed by both Protozoa and Metazoa.

Physiology of Specialized Cells. (See Chapter XVIII, Part III.) The *chief function* of a muscle cell is to contract. It does this better than any other type of cell. But at the same time it is sensitive and can also conduct; it respires, excretes and circulates. Many different chemical processes occur in every cell. It must not be forgotten however that, as differentiation increases in the evolution of specialized types, one type of cell, now being a specialist in one type of work, does not perform other types of work but only its own particular life function.

The import of all this is, that if a general science of physiology of receptors is desired, then one should study the most specialized organs of sense where the receptive function exists in its purest form. And so with contraction, conduction, excretion, etc. In the higher Vertebrates with their special systems of organs, functions are segregated, there is a natural sorting out, enabling us to study special functions. More is known of the physiology of the Vertebrates and therefore a brief summary is presented here of physiological processes in forms more closely related to man.

FUNCTIONS OF METABOLISM

Cell metabolism refers to the totality of chemical activities which occur *in cells*. Metabolism takes place in *every cell;* in egg cells, nerve cells, muscle cells, in stomach and kidney cells and those of all other organs.

Our classification of functions is a matter of convenience. What we term "functions of metabolism" are those more intimately concerned in *preparing* and furnishing to cells, the materials for cell metabolism and also getting rid of the wastes of cell metabolism.

Digestion (Fig. 339). Animals ingest substances from which, by the processes of metabolism, they will obtain materials for the

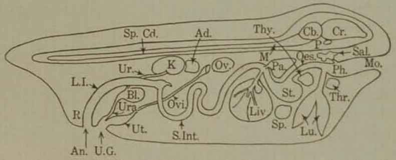

FIG. 339. — Diagram of digestive tract and other organs of a female mammal. Cr. Cerebrum; Cb. Cerebellum; P. Pituitary gland; M. Medulla; Sp. Cd. Spinal cord; Mo. Mouth; Ph. Pharynx; Sal. Salivary glands; Oes. Oesophagus; Thr. Thyroid; Lu. Lungs; Thy. Thymus; St. Stomach; Sp. Spleen; Pa. Pancreas; Liv. Liver; S. Int. Small Intestine; L. I. Large Intestine; R. Rectum; An. Anus; Ov. Ovary; Ovi. Oviduct; Ut. Uterus; Ad. Adrenal; K. Kidney; Ur. Ureter; Bl. Bladder; Ura. Urethra; U. G. Urino-genital sinus.

repair of cell and tissue; for growth; for reproduction and energy by which vital processes can be maintained. We call these substances foods. They are partly inorganic, *i.e.*, water and inorganic salts, and partly organic, *i.e.*, proteins, carbohydrates, fats, oils and vitamins. The nature of proteins, carbohydrates and fats has already been explained. Vitamins are discussed later.

Digestion changes complex compounds taken in, as food, into simpler compounds suitable for use by the various cells of the body. Proteins are changed to amino-acids; carbohydrates to monosaccharids and fats to fatty acids and glycerine. The useful parts of the food are separated from the useless, and for purposes of circulation, the useful constituents are rendered soluble.

In most invertebrates and in vertebrates, foods are ingested and pass into and along the intestinal tract into which digestive glands (or cells) secrete enzymes which accomplish the simplification of the complex compounds referred to above. The movement of the food mass is brought about by the contraction of smooth muscle cells in the wall of the alimentary tract (peristalsis). Complicated and orderly mechanisms are concerned in the process.

Mouth. Food does not remain long in the mouth cavity of many vertebrates, passing quickly down the oesophagus into the stomach. Man normally masticates his food, changing the pieces to a mass of finely divided particles mixed with fluid. Saliva, derived from the salivary glands, is mostly (99.5%) water, but contains inorganic salts, a protein compound called mucin and in some animals, an enzyme called ptyalin which partially digests starch. There are three main pairs of salivary glands. First, parotids (near the ear); second, submaxillaries and third, sublinguals. From the salivary glands, secretions pass into the mouth cavity, where they are mixed with food. The production of saliva depends on stimuli, such as tasting, smelling, seeing or even thinking of food. In some emotional states, salivary secretion is inhibited.

From the mouth cavity the food is passed along the oesophagus and by *its* contractions to the stomach.

Stomach. Layers of smooth muscle in the walls of the stomach make possible a series of peculiar peristaltic movements, following each other at the rate of three or four per minute. At the same time it persistently accommodates itself to the amount of food inside. The larger left end (cardiac portion or fundus) maintains a continuous pressure on the food all the time, while peristaltic movements at the right end slowly churn the food. The movements persist after connections with the nervous system are cut. And yet although the movements originate independently of nerve impulses, they may be modified through nerve reactions. If impulses pass over fibers of the vagus (tenth cranial nerve), violent and painful reactions may take place. Certain emotional states may produce this result. Impulses over sympathetic nerves to the stomach cause an inhibition of stomach movements.

The wall of the stomach contains glands (Fig. 340) which secrete gastric juice which contains water, mucin, rennin, pepsin, inorganic salts and from 0.2 to 0.5% hydrochloric acid. The flow of gastric juice is initiated in two ways, (*a*) reflexly and (*b*) by a hormone, *i.e.*, a chemical messenger. (See below.) The chemical control of secretion of gastric juice is as follows. Meat extractives, such as are found in soups and beef sauces, when present in the stomach excite secretion and are called secretogogues. It is supposed that secretogogues cause cells lining the pyloric end of the stomach to produce a substance called *gastric secretin* or *gastrin* which is absorbed by the blood and so taken to all the glands of the stomach, causing them to secrete. *Gastrin* is therefore an internal secretion which acts as a specific exciter of other cells. A general name for such a substance is *hormone*.

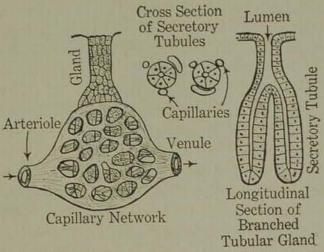

FIG. 340. — Scheme of simple branched tubular gland. At left, relation to capillaries; at right, section of the gland.

The stomach glands secrete *pepsinogen*. This in the presence of hydrochloric acid becomes *pepsin*. Pepsin causes the hydrolysis of proteins to simpler protein compounds, *proteoses* and *peptones*. Further digestion is completed in the intestine. Rennin coagulates milk. Calcium plays an important part in milk coagulation and in the absence of calcium, coagulation does not occur. Clotted milk is retained in the stomach for some degree of gastric digestion. There is also present in the stomach a weak, fat-splitting enzyme which is capable of acting only on emulsified fats such as are present in milk.

Every now and then the pyloric sphincter muscle, at the junction of the right end of the stomach and the first part of the duodenum, opens and permits the *chyme*, which is the partially digested contents of the stomach, to be discharged from the stomach into the intestine.

Intestine. The first portion of the small intestine is called the *duodenum*. The duct from the pancreas pours pancreatic juice into the duodenum to mix with the food. The duct from the liver, the bile duct, pours bile into the duodenum also. Glands in the walls of the intestine secrete *succus entericus*, intestinal juice. Bile, pancreatic juice and succus entericus bring about the main digestion of food.

Pancreatic juice is similar in appearance to saliva. Carbonates and phosphates make it alkaline. It contains the following enzymes: *trypsin*, *amylopsin* and *lipase*. Trypsin, a powerful proteolytic enzyme, is not secreted by the pancreas as trypsin, but in an inactive form called trypsinogen. Another catalyst called *enterokinase* is secreted by the intestinal mucosa which activates trypsinogen to trypsin. Trypsin acts on proteins which have been previously acted on by pepsin or on proteins which have escaped the action of pepsin and completes their hydrolysis to amino-acids. Amylopsin acts as ptyalin does. It changes starches to maltose. Maltose is further split by *maltase* to glucose. *Lactase* splits lactose to glucose and *sucrase* changes sucrose to glucose. Maltase, lactase and sucrase are produced by the intestinal mucosa. Lipase hydrolyzes fats into fatty acids and glycerine. The fatty acids form soaps with sodium and potassium ions of the intestinal contents.

Prior to the discovery of gastrin, Bayliss and Starling discovered that the hydrochloric acid of the chyme, discharged from the stomach to the duodenum, coming into contact with the mucosa of the duodenum, causes the production of a hormone, probably of simple organic composition. This hormone, absorbed into the blood stream and circulating throughout the body, is called *secretin*. As it circulates through the pancreas it causes this gland to secrete pancreatic juice and in the liver it promotes the formation of bile. Since the latter is alkaline, it thus indirectly promotes the neutralizing of chyme.

Bile salts are effective emulsifying agents. They aid in the emulsification of the fats and thus promote the action of the fat-splitting enzyme, lipase. Unemulsified fat is apt to form an oily coating over other foods and so the emulsifying action of bile is important in the digestion of protein and carbohydrate substances in food. Digestion of fats practically ceases in jaundice, a condition in which bile is prevented from getting from the liver to the duodenum.

The bile of most herbivorous animals is green while human bile is golden brown in color. Bile pigments are excretions and leave the body with the feces. Cholesterol is also a waste product thrown out by the liver with the bile. Cholesterol has a tendency at times to crystallize in the gall bladder, causing 'gall stones.' Solutions of bile salts dissolve these. The presence of bile in the intestine also stimulates bile secretion in the liver. It is probably the bile salts that are responsible for this. They are probably reabsorbed into the blood and thus conserved, for they do not appear in the feces. They also stimulate peristaltic movements. Constant peristaltic movements of the intestine serve to thoroughly mix food with enzymes and thus promote digestion. Intestinal juice contains enterokinase referred to above. Another proteolytic enzyme, *erepsin*, found in the walls of the intestine, supplements the work of trypsin and pepsin by hydrolyzing certain combinations of amino-acids not attacked by either pepsin or trypsin.

Most of the absorption of food into the blood stream takes place from the small intestine. Water is taken into the blood from all parts of the intestine, but principally from the large intestine. There semi-fluid or solid feces are thus formed. The process of absorption is not yet understood, but a living membrane is necessary.

Proteins are absorbed into the blood as amino-acids. They pass by way of the portal vein to the liver. Blood from the liver is sent toward the heart through the hepatic vein. Monosaccharids are the only carbohydrate compounds taken up by the blood vessels. They are carried by the portal vein to the liver. Fats are absorbed by the intestinal cells into the lymph stream in a hydrolyzed form, are reunited and given to the blood in form of fat. These fats pass into the lacteals and on into the thoracic duct and so on into the heart. The hydrochloric acid of gastric juice and bile in the intestine act as sterilizing agents. The contents of the small intestine are relatively free from Bacteria.

The bacterial flora increases toward the posterior end of the intestine. Bacteria probably produce enzymes which act on proteins, carbohydrates and fats, digesting these to a certain extent. Animals, such as the rabbit, have a large coecum. Cellulose stored there is broken down by the Bacteria present. Bacteria of the large intestine break down proteins into simpler compounds such as skatol, indol, phenol and putrescin. They are formed by putrefaction in the intestine. They are toxic, but are conveyed to the liver, which can usually render them harmless. When there is an excessive production of them, they escape as toxins into the general circulation, producing a condition known as auto-intoxication. *Ptomaines* are highly toxic substances produced by certain Bacteria from food products. These Bacteria are not normal inhabitants of the intestine, but are accidentally introduced with infected food. Bacteria produce gases in the intestine. CO_2 and CH_2 result from fermentation of carbohydrates and H_2S from proteins.

It is probable that, in many cases, Bacteria play no essential part in digestion. Metchnikoff urged the plan to rid the intestine of its usual bacterial flora by the introduction of special harmless lactic acid Bacteria found in certain types of buttermilk. Feces are composed of undigested starches, meat and cellulose and part may be dead or living Bacteria, bile and inorganic salts, such as those of calcium. They should not be regarded as containing the general *cell wastes* of the body. Sooner or later the peristalsis of the intestine causes the accumulation of feces in the posterior end of the intestine (rectum). Its presence there acts as a stimulus for defecation. The relaxation of the anal sphincter muscle is under voluntary control, although this is an acquisition. For some time after birth it is a simple reflex.

Blood and Lymph. Blood is a fluid-circulating tissue. It conveys substances from one part of the body to another. Blood constitutes from 5% to 7% of the body weight of most Mammals. It consists of a liquid plasma in which are the white and red corpuscles. Plasma constitutes about three fifths of the total volume of human blood, while in other Mammals it varies from two thirds to one half of the total volume of blood.

Blood clots or coagulates soon after leaving the blood vessels, either outside the body or among tissues, as in a bruise. This prevents the excessive loss of blood from small wounds. The blood of some persons does not clot readily. This condition is called *hemophilia* and is hereditary. A clot is a jelly-like mass which enmeshes the corpuscles and contracts, squeezing out the clear yellow serum. The clot is composed of a protein network called *fibrin*. Fibrin is produced from a compound called *fibrinogen*, soluble in the circulating blood. The formation of fibrin is the result of a series of cooperating and sequential factors. Calcium salts are necessary, and, in addition, thrombin must be present.

One idea is that fibrinogen + thrombin = fibrin. Inasmuch as thrombin does not exist as such in circulating blood, it must be formed from an inactive agent or precursor, *i.e.*, prothrombin, through the activation of calcium salts. Prothrombin, however, is never found free in circulating blood as it will always be activated by calcium ions (Ca^{++}) and produce a clot. Prothrombin is thought to be combined in a loose form with anti-prothrombin. To disturb the equilibrium of this loose combination so as to liberate the desirable prothrombin, there is brought into play another substance called thromboplastin, *produced when blood vessels are cut.* The *above* theory of Howell may be presented by the following summary, which indicates the series of events in this theory of clotting.

I. Blood Vessels Intact

A. Blood Corpuscles.
B. Plasma.
  (*a*) Prothrombin-antithrombin combination.
  (*b*) Calcium.
  (*c*) Fibrinogen.

II. Blood Vessels Injured

1. Release of thromboplastin.
2. Upsets prothrombin-antithrombin combination and releases prothrombin.
3. Prothrombin, activated by calcium ions, forms thrombin.
4. Thrombin and Fibrinogen forms Fibrin.
5. Fibrin enmeshes corpuscles forming the blood clot.

Sometimes clots form inside blood vessels. This is known as *thrombosis.* If such a clot is carried along in a vessel and lodges in an essential organ such as the heart or brain, it will cause death.

Plasma contains about 80% water; 6% to 8% proteins, such as (*a*) fibrinogen, (*b*) serum albumin, (*c*) serum globulin and (*d*) amino-acids; normally about 0.1% glucose; 0.2% fats; inorganic salts; enzymes; hormones; probably vitamins; gases; immune substances among which are antitoxins and waste products such as urea.

The histology of the cells, erythrocytes and leucocytes, has already been described (p. 370). Corpuscle number is important in diagnosis of some diseases. The important constituent of the erythrocyte is hemoglobin. These cells also contain about 60% water. Hemoglobin functions properly in vertebrates only when it is confined to the corpuscle.

Hemoglobin with carbon monoxide forms carboxyhemoglobin, a more stable compound than oxyhemoglobin, which is the normal combination, when the corpuscle comes in contact with air. Thus, illuminating gas is a deadly poison since it destroys the oxygen-carrying power of the blood and brings about a rapid cessation of all vital chemical processes in the entire cell population of the body. Nitric oxide is a poison also for a similar reason. In the disease known as chloroanemia, the corpuscles contain little hemoglobin.

After birth, erythrocytes are formed from cells located in the red bone marrow. After severe hemorrhage, there is a rapid production of new red cells although there is a less marked but steady production constantly. The need for this follows from the fact that red cells live only a short time, *i.e.*, from ten to thirty days. It is estimated that 5% to 10% are destroyed daily as they circulate and that special cells in the liver, spleen and elsewhere act on the fragments, conserving the iron and other portions for future use in other new corpuscles and changing the remaining parts into bile pigments.

A description of the white blood cells or leucocytes has already been given. Normal human blood contains about 8000 per cubic millimeter. Certain types increase greatly in certain diseases, others in other diseases; hence a study of the relative numbers of the various types is an important part of the diagnosis of these diseases. Some of the white cells have amoeboid motion and engulf foreign bodies such as Bacteria, rendering them harmless. Such a process is called phagocytosis. Large numbers of certain types of white cells gather wherever there is an infection. They pass easily through the capillary walls into the tissue spaces involved in the inflammation. The phagocytic power varies from time to time, due, it is thought, to a variation in the amount of a hypothetical substance called an *opsonin*. Fat is carried from absorbing cells to lacteals by leucocytes. White blood cells probably have to do with the regeneration of fibrinogen after hemorrhage. They probably aid in the formation of the other plasma proteins. They are thought to have a part in the formation of immune bodies.

Blood is constantly giving and receiving contributions to and from tissue cells. In spite of the constant exchange, its physical condition remains *remarkably constant.* Its reaction is slightly alkaline, the normal variations of the pH being from 7.2 to 7.4. Its osmotic pressure is also quite constant, being equivalent to that of a 0.9% NaCl solution. The inorganic salts are relatively constant in their concentration. The concentration of glucose in health is from 0.1 to 0.12, although it may rise for a short time above this, after a meal. It is well to recall that glucose is the chief energy-producing food, furnishing probably two thirds of all the energy for cell metabolism. There is also a constancy in the percentage of fat and proteins. This equilibrium is very remarkable in view of the in-go and out-go that is taking place. Between blood capillaries and tissue are lymph spaces containing lymph, a fluid something like plasma without red blood cells. Lymph is the middleman between capillaries and cells. The lymph spaces, which are everywhere, communicate with lymph vessels which convey lymph from all parts of the body ultimately to the heart. An abnormal production (collection) of lymph at any part is called *oedema.* Some substance is present in such food as crab meat or strawberries, which has a specific effect in certain individual cases. It is supposed that these foods increase the permeability of capillary walls and so cause local small oedemas to form, known as " hives." These specific substances are *secretogogues.*

The bactericidal power of leucocytes is increased by the injection of dead Bacteria. Preparations of these in physiological saline solutions are *bacterial vaccines.* Inoculation with typhoid vaccine prevents typhoid fever. The presence of special antibodies is an indication of certain diseases. Such a determination is known as *serum diagnosis.* Several types of Bacteria which thrive in the body produce specific poisons or toxins. But the body has a certain power of forming substances called antitoxins or antibodies which neutralize the toxin, and thus develop immunity.

If a rabbit is injected with human serum a few weeks after a previous injection, its blood pressure is lowered, its heart action weakened and breathing is labored. This resulting condition is known as anaphylactic shock. It is supposed that the first injection produces a powerful proteolytic enzyme which rapidly breaks down the protein of the second dose and these broken-down proteins are very toxic.

Spleen. The spleen is a pulpy lymphatic gland. It differs structurally from other glands. For example, blood flows from arterioles into blood spaces, from which it is returned by small veins. In the spleen are reticulo-endothelial cells which are macrophagic, *i.e.*, they engulf foreign particles (except Bacteria) which happen to be present in the blood. The monocytes, a type of white blood cell, have the same property. Some investigators regard monocytes as free reticulo-endothelial cells. The fragments of worn-out red blood cells are engulfed by the reticulo-endothelial cells and monocytes which save the iron and proteins for further use. The remaining portion of the red blood cell is changed to bile pigment and excreted by the liver. Phagocytosis of Bacteria is accomplished chiefly by other types of leucocytes such as the neutrophiles. It has already been stated that in the embryo, red blood cells are made by the spleen and liver and that they are made in the adult from cells in red marrow of bones. However, after severe hemorrhage, the spleen takes up again for a time its old embryonic function. The spleen is not absolutely essential to life, for it has been removed without serious consequences. After removal of the spleen, it seems that yellow marrow of bones takes over the function of iron conservation referred to above.

Circulation of Blood (Figs. 326 and 341). The first correct idea of the circulation of the blood was developed by William Harvey in 1628. The heart contracts and relaxes rhythmically. It contracts completely and all it possibly can each time. The cause of the apparently automatic beat is unknown. According to the *myogenic theory* the rhythmical beat is independent of any nerve impulse although such a cause is claimed by the defenders of the *neurogenic theory.*

A wave of contraction passes over the heart, beginning near the entrance of the large veins. The wave spreads to the auricles, thus causing their contraction; thence to the ventricles, causing *their* contraction and so forcing the blood from auricles to ventricles and from ventricles into the great efferent vessels of the ventricles.

Sometimes the tissue between the auricles and ventricles is diseased and the normal passage of the wave is interfered with.

Potassium salts in the blood favor relaxation of the heart and calcium salts favor contraction. The normal or abnormal heart beat is identified by listening to the sounds of the heart or by the still more modern method of electrocardiography.

Mitral stenosis is a disease of the mitral valve which retards flow of blood from left auricle to left ventricle. When this valve does not close tightly and lets the blood flow back into the auricle, it is known as mitral insufficiency. Similar diseases involve the semilunar valves between the left ventricle and the great aorta.

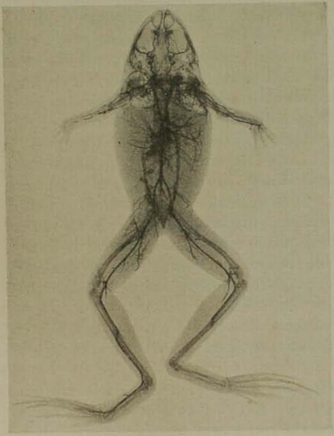

FIG. 341. — X-ray photograph of circulatory system of frog.

At each contraction, from 60 to 90 cc. of blood are forced into the aorta. Contraction lasts about 0.3 second and relaxation 0.5 second. The left ventricle forces blood into the aorta with a pressure sufficient to raise a column of mercury 120 mm. to 160 mm. During the time that the semilunar valves are closed, the elastic recoil of the distended arteries serves to maintain the flow of blood. It will readily be understood that a certain quite definite degree of blood pressure must prevail to keep the tissues supplied with blood. However, if the walls of the arteries become hardened or calcified, as is often the case in old age, there results great fluctuations in arterial pressure. One result may be the bursting of a blood vessel in the brain. The clot of blood formed there puts certain nerves out of commission and causes paralysis, if not immediate death. The normal human heart beats about 72 times per minute, that of the elephant 25 times, that of a frightened mouse is said to be 600 times. The blood makes a complete circuit in from 25 to 30 beats of the heart.

Efferent impulses come to the heart over the fibers of the sympathetic nerves and over the *vagus* (tenth cranial nerve). Impulses over the sympathetic fibers cause an acceleration of the heart beat, while those over the vagus cause a slowing down or inhibition of the heart. Thus the heart can respond to any demand made upon it and adapt itself to varying conditions. External stimuli or emotions may change its action. The size of blood vessels and therefore their blood-carrying capacity, varies with vaso-constrictor and vaso-dilator impulses. These impulses are influenced by afferent impulses from brain or body surface to the *vasomotor center* of the brain. Blood pressure may fall, so that the brain does not contain enough blood to function. The person is pale, dizzy and may faint. If the legs and body are raised and the head lowered, the brain is supplied with blood and consciousness returns. Hemorrhage, or loss of blood, causes low blood pressure. Adrenalin, the hormone secreted by the adrenal glands, causes constriction of blood vessels and therefore aids in maintaining blood pressure. It is used in some operations to decrease bleeding.

Respiration. In Mammals, the increase in size of the thorax at every inspiration lowers the air pressure in the lungs, so that air flows in through the air passages such as the trachea, bronchi and smaller bronchioles to the air sacs. These are minute sac-like cavities whose walls are very thin and composed of elastic tissues lined on the inside with a layer of flat epithelium. In the wall is a rich capillary network. In expiration, the decreased volume of the thorax increases the pressure in the lungs so that some of the contained air is forced out over the same route as it entered. The air does not actually flow from the outside directly into the alveoli at each inspiration, for the air in the alveoli is quite stationary. The rapid in-go and out-go has to do chiefly with the larger passageways. The movement of oxygen and carbon dioxide for the remaining distance is a matter of diffusion.

In a quadruped, the contraction of the diaphragm increases the anterior-posterior diameter of the thorax while the contractions of the muscles of the ribs increases the thoracic cavity in other directions. Expiration is ordinarily a passive act. The diaphragm muscle and tissue relaxes, — this is true also of the muscles of inspiration of the ribs, — while rib muscles of expiration contract. The smooth muscle and elastic tissues of the lungs contract and so the air is squeezed out. In man, there are usually from 14 to 18 respirations per minute. The respiratory epithelium of the human lungs has an *estimated* surface area of about 1000 square feet, 60 times the area of the body surface. The respiratory surface of an Amoeba, a Hydra or a worm is limited to the body surface area.

A chemical analysis of in-going and out-going air reveals that important changes have taken place. This is shown in the following table:

	Nitrogen	Oxygen	Carbon Dioxide
Inspired air	79	20.96	0.04
Expired air	79 +	16	4.38

There is a little change in the nitrogen. A loss in oxygen has taken place, and carbon dioxide is given to the air leaving the lungs.

The following table shows the volumes of gases found in body blood before entering the lungs and also in aerated blood leaving the lungs:

	O_2	CO_2	N
100 volumes venous blood contains . . .	10–12 vol.	45–50	1–2
100 volumes arterial blood contains . . .	20	40	1–2

The arterial blood which is to be distributed to the tissues contains more oxygen and less carbon dioxide. How does this take place? The partial pressure of oxygen in the alveoli is equivalent to a pressure of about 100 mm. of mercury. In the walls are capillaries containing blood. The hemoglobin of the blood entering the lung capillary contains about half as much oxygen as that of arterial blood, *i.e.*, it is not all saturated. Such hemoglobin, when exposed to air at the pressure above named, easily becomes saturated. The cells forming the wall of the alveoli, the cells forming the capillary wall and the surface membrane of the red cells are all permeable to oxygen so that because of its greater partial pressure in the alveolus it is forced through all these into the corpuscle. The hemoglobin which is only half saturated combines with oxygen. The physical aspects of the process are apparent. In the hemoglobin of the corpuscle there is an affinity between hemoglobin and oxygen, forming oxyhemoglobin. When the blood reaches the tissues, the cells may have a lack of oxygen, for they have lowered the supply in the lymph. This causes a lower oxygen pressure in the plasma, and so the oxyhemoglobin breaks down, giving oxygen to the plasma and thence for the same reasons from plasma to lymph, from lymph to cells. Oxyhemoglobin is ordinarily never completely reduced owing to rapidity of the circulation.

Starting with a partial oxygen pressure of 100 mm. of mercury in the alveoli of the lungs, there is a considerable decrease in the cell.

The movement of CO_2 is just the reverse. It passes from cell to lymph to plasma. In the lung it passes from the blood of the capillary into the alveolus. In venous blood it has a pressure of about 5% of an atmosphere, in the outside air it is far less than this. The CO_2 is carried in the blood in the form of sodium bicarbonate.

The problem of exchange of gases between the atmosphere and the blood and tissue cells is therefore solved by physical and chemical means. The physical laws governing gases are in operation here. Gases exert pressures. In a mixture of gases each gas acts as if it alone were present. This is borne out by the behavior of oxygen and carbon dioxide. The amount of gas that will go into solution depends on the temperature of the solvent, the pressure of the gas on it and the degree of solubility of that gas in that solvent. But solubility alone is insufficient. For it has been found that blood takes up forty times the amount of oxygen that would be absorbed by water. This great discrepancy is due to the great combining power of hemoglobin with oxygen.

The energy used in vital functions is produced by processes of oxidation in cells. The oxygen of the air combines with hydrogen and carbon of foods and forms water and carbon dioxide, thus releasing the energy stored up in the foods. The actual mechanism is not understood. These combinations take place at lower temperatures than when oxidation of alcohol, gasoline, wood or coal take place outside the body. This organic oxidation at such comparatively low temperatures is made possible by the presence of intracellular enzymes or catalysts called oxidases. Oxidative processes are governed by the needs of the tissues and not by the supply of oxygen and food available.

The problem of oxygen supply and carbon dioxide removal becomes vital. The evolution of respiratory devices alone do not solve the question. The evolution of blood and circulatory systems are just as necessary. The study of such forms as the earthworm shows that blood and blood systems are evolved before specialized respiratory systems. The peculiar highly specialized respiratory mechanism of insects carries with it a simplified blood system. The regular sequence of inspirations and expirations in mammals is due to nerve impulses arising in a clump of nerve cells in the medulla, the so-called *respiratory center*. Destruction of this causes cessation of breathing and death. Cells are deprived of oxygen, hence oxidations cease, and this involves the heart and brain.

Normal respirations may be modified by various external stimuli, causing nerve impulses to the muscles of respiration to depart from their normal activities. Respiratory rates may be increased or decreased. Respirations may become deeper or more shallow.

A chemical control of respiration is present also. While the nervous system plays a necessary rôle in control of respiratory movements, it has been found that the hydrogen ion concentration of the blood is also of great importance. Apparently the nerve centers of respiration are very sensitive to this, so that a slight increase of hydrogen-ion will initiate a respiratory movement. On the other hand, a *marked* lowering of the hydrogen-ion will cause apnea. Since the hydrogen-ion is proportional to the amount of CO_2 present, it often appears as though the respiratory movements were controlled by the amount of this gas present.

The movement of air in the smallest bronchioles and alveoli is probably molecular and not molar. The exchange of gases between the air in the alveoli and the air in the ducts where the air is in motion takes place because of the differences in gas pressure and temperature.

In high altitudes the oxygen tension of atmospheric air is very much reduced. At 16,000 feet it is only about half what it is at sea level, to which, in a general sense, the animal respiratory mechanism is adapted. To supply the necessary oxygen, more rapid and deeper respiratory movements are required. But these cause a diminution of the carbon dioxide of the blood. The respiratory center does not get the necessary stimulus and the whole body suffers. The heart is weak, and symptoms such as headache, nausea and dizziness show that the brain and nervous system are affected. This is called Mountain Sickness. But a physiological adjustment takes place. The blood system permits the body to function in this rarefied atmosphere. The red blood cells, the carrier of O_2, increase in number, so that the red cell count is quite often found to be between 7,000,000 and 8,000,000 per cu. mm. The process has been carefully studied by Barcroft, who states that it takes from 2 to 4 weeks to cause the proliferation of erythrocytes.

Temperature of the Body. This is only slightly above that of the surrounding air in the case of most animals. As this changes, the temperature of their body changes accordingly. Such animals are termed 'cold blooded.' This is not a good term, for it does not necessarily describe what is referred to. Changeable temperature is a better name. Invertebrates, Fishes, Amphibia and Reptilia belong to this group. On the other hand, Birds and Mammals are constant-temperatured. In spite of variations in the temperature of the surrounding medium, their body temperature is constant. They are said to be *homoiothermic*, while the so-called cold-blood forms are *poikilothermic*. The latter forms do not possess any temperature-regulating apparatus, or, at best, a very primitive one. In cold weather bodily processes slow down in such animals. If the temperature is lowered far enough, life may cease. Fishes have been frozen and later, after slowly thawing out, have resumed active life. In contrast to these, freezing would doubtless kill Birds and Mammals. And yet the latter maintain the same constant temperature of the body in very cold weather as in warm weather.

It is said that Echidna, a Monotreme, and one of the lowest of mammals is not altogether homoiothermic. When the air is changed from 5° C. to 35° C., the temperature of its body changes 10° C. In cold weather it hibernates and its body then is only 0.5° C. above that of the surrounding medium. Higher animals (such as the hedgehog) that hibernate have a lower body temperature during their winter sleep. The average temperature of human beings (just under the skin) is 37° C., but it ranges daily 0.5° C. above and below this. Fever is a high temperature due to the breaking down of the heat-regulating mechanism which functions as follows: the dilatation of the blood vessels of the skin (nervous mechanism) brings more blood to the surface, where some of the body heat is dissipated. The sweat glands also secrete a watery and warm fluid. The air leaving the lungs in expirations is warmer than that entering. The air contains a certain amount of warm moisture. Evaporation of sweat from the surface of the body tends to reduce the temperature. In humid weather this is interfered with and thus the heat is retained. If the superficial blood vessels are contracted, less blood is at the surface and so less heat is dissipated. Temperature regulation is under control of a nerve center, as is indicated by the fact that destruction of the vasomotor center in the medulla upsets normal body temperature relations.

Metabolism of Foods. Proteins, carbohydrates, fats, oxygen, water and inorganic salts are used in various ways by cells and reappear as waste products which are expelled from the body. One can obtain information as to what takes place with regard to foodstuffs in the body. To do this, the balance sheet of the intake and outgo of carbon and nitrogen; the ratio between the amount of oxygen consumed and the carbonic acid (H_2CO_3) excreted and the energy produced are ascertained.

The chief process concerned in the chemical changes involved is one of oxidation. Lavoisier thought that oxidations in animals were similar to those in the burning of fuel. The two are in many ways alike. But oxidations in organisms occur at low temperatures. This is made possible by the presence of catalysts called oxidases.[1]

In the process of oxidation in the body the energy of food fuels is released. Some of this is used in the other chemical changes taking place, some appears in movements, some as heat. Energy exchange in an animal can be determined. The physical unit of energy used in metabolism studies is the large calorie (C.), *i.e.*, the amount of heat required to raise the temperature of one kilogram of water one centigrade degree of temperature. The energy value of a substance is learned by burning it in a specially made steel bomb in an atmosphere of pure oxygen. The bomb is immersed in a known volume of water. The temperature of the water is obtained before and after the experiment, and the calorific value of the substance is determined by multiplying the increase in temperature of the water by its volume in liters.

By the use of this method it has been determined that oxidation of one gram of protein releases about 5 C. of heat; one gram of carbohydrate about 4 C. and one gram of fat about 9.3 C. Car-

[1] An interesting and unusual example of these is luciferase. Luciferase has been obtained in pure form from certain dried luminescent animals. This catalyst attends the oxidation of a compound known as luciferin. During the reaction light is given off but practically no heat.

bohydrate and fat are completely oxidized in the body and give off the same amount of energy there as in a calorimeter. On the other hand, protein is not completely oxidized in the body. The wastes of protein metabolism are compounds which still possess a certain amount of heat energy. This can be determined and must be subtracted from the total physical heat value of proteins, to obtain the physiological value of protein foods.

The energy released in animal metabolism is determined by means of an *animal calorimeter.* Calorimeters are now in use for studying energy production of animals, and also of human beings under all sorts of conditions of health and disease. The general principle is the same as that involved in the use of a bomb calorimeter. They are constructed to measure energy production to the same degree of accuracy. In one experiment performed by Benedict it was estimated that during the time involved, the human subject investigated had consumed 5459 calories, and the amount actually measured by the calorimeter was 5435 calories, which, from the point of view of the scientist, is close agreement. The subject of the experiment was busy at work pedaling a stationary bicycle in the calorimeter. The work performed was recorded and converted into calories and these were added to his other energy output.

Another type of experiment is to determine the basal metabolism of the body as a whole, *i.e.*, the least amount of heat energy produced by physiological processes in a healthy person when the subject is resting quietly in bed. This was found to be 1680 calories in the case of a person of average weight.

Food taken in stimulates heat production.

A considerable amount of the energy of food is also used in muscular work. The atmosphere is colder than the body and so the body is constantly losing heat to the atmosphere. This must be made good by the intake of food. Small animals give off more heat per unit of weight than large animals because they have a relatively greater surface area. Energy is *also* needed by immature animals for growth in addition to the basic energy requirements for fundamental physiological needs; and to the specific production of heat caused by the intake of food; and to the energy needed to maintain the temperature of the body. They actually need more food than adults and so famine affects children more seriously. Inorganic substances of the food furnish no energy.

Proteins are absolutely necessary foods since protein compounds are essential components of cells. When broken down, they appear as waste substances of excretion, as urea and ammonia, which constitute part of urine. The primary use of proteins is to rebuild protoplasm. It has been found that only about 100 grams of protein are needed in the daily diet of the average person. Excess proteins ingested, *i.e.*, amino-acids, are deaminized, the nitrogen usually being eliminated as urea. The remainder is either oxidized in a manner similar to that of carbohydrates or is converted into carbohydrate. The animal body cannot store up proteins. Proteins tend to speed up metabolism and excess energy produced is lost in heat. In diets low in protein, the body protein is saved to a certain extent if carbohydrate food is included in the diet.

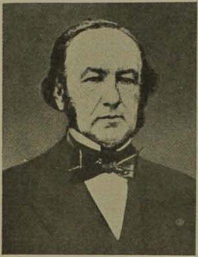

Fig. 342. — Claude Bernard. Pioneer in experimental physiology; created new conceptions of nutrition and metabolism; said to be greatest physiologist of his time. He described the liver as "un véritable laboratoires vital." Courtesy H. Holt and Co.

Carbohydrates are the best source of energy. They are cheaper than proteins; also they are completely oxidized into carbon dioxide and water. These wastes are given off by the lungs and by the kidneys. They are thought to be not as harmful as the excess wastes involved by an unnecessary intake of protein.

In the metabolism of carbohydrates, digestion changes them to monosaccharids, which pass via the portal vein to the liver (Fig. 342). This converts them to animal starch or glycogen, which is stored in the liver up to a certain amount. If an excess of carbohydrate is taken, *sugar* may appear in the urine shortly after meals. This may be considered a defense mechanism. It is an important physiological fact that there is a normal level of glucose (sugar) in the blood amounting to about 0.1 %. The muscles take up glucose from the blood for fuel. Some of it is changed into fat, which is deposited in various tissues. The control of glycogen formation and its release is of the utmost importance. It has been found that a certain hormone produced by the pancreas is concerned in this process. If carbohydrate cannot be converted into glycogen, the animal cannot use it all. And, moreover, if carbohydrate metabolism cannot go on, it has been found that this affects fat metabolism also and, in time, protein metabolism. The result is that no food is of any use, and death takes place, not, however, from the same causes as in ordinary starvation, but rather from poisoning due to an unsuccessful attempt to burn other substances such as fats with the excess production of free acids. Fats are oxidized with much more difficulty than carbohydrates. They oxidize more readily when carbohydrates are being burned. There is a tendency to convert excess carbohydrates into fat.

When glycogen is plentiful in the liver, it is this which is first consumed in muscular work. If there is none of this on hand but plenty of fat, then this is burned. A fat man can live for a number of days chiefly on the fat stored in his body. If a person is starving, the glycogen first disappears, then the fat, and last of all, the protein. Death occurs before the heart muscle or the nervous system is attacked.

Muscular work involves the metabolism of carbohydrate or of carbohydrate and fat. If there are no carbohydrates, then proteins are broken down, yielding over 50% of their weight as carbohydrates. But if carbohydrate and fat are present in the food, then there is no general increase in protein destruction during hard work.

It has been found that a man who does not perform much physical work needs about 2600 calories of food per day, and a working man about 3000 calories. There should be about as much fat as protein and more than twice as much carbohydrate. For example, one analysis of the diet of the professional class indicated 100 grams protein, 100 grams fat, 240 grams carbohydrate, with a total fuel value of 2324° C. Tables showing the protein, carbohydrate, fat and calorific values of our common foods are now available, and from these can be prepared varied menus of proper food values.

Vitamins. However, it is possible to conceive of a diet, prepared from such food tables, that would appear to be perfect in so far as the proper proportions of proteins, carbohydrates, fats and inorganic salts are concerned, but on which animals would starve, or fail to grow, or would develop certain diseases. It is now known that the food must contain at least small quantities of certain obscure compounds which are called vitamins. This name was given by Funk, in 1911, to one of these substances because he thought that it was chemically similar to the amine bodies and that this unknown substance was necessary for life. The words *accessory food substances* have been suggested, but the word *vitamin* is generally used. The function of these is indicated in experiments conducted on animals fed on a diet which lacks individual vitamins.

Vitamin A. This is sometimes called *fat-soluble A*. When it is absent, the animal does not grow and the glands of the eyelid do not function. This leads to inflammation and infection of the eyes and possibly complete blindness. The oil glands in the skin do not function and the fur becomes rough. There is loss of appetite and so loss of weight and lassitude. There is also a high percentage of pneumonia and lung diseases. If the diet continues to lack vitamin A, death eventually occurs. It has been found in nutrition experiments that this vitamin accompanies certain fats. Cod-liver oil is very rich in it. It is also in butter, cream, whole milk and in the yolk of eggs. It is plentiful in the green leaves used as food, such as spinach, clover and alfalfa. It is not plentiful in meats, and plant oils do not contain it. It is present in vegetables that contain the yellow pigment carotin, *i.e.*, in carrots and sweet potatoes. Only small amounts are necessary. Addition of small amounts of butter, cod-liver oil or spinach to the diet corrects the conditions caused by the lack of it. It is not a nitrogenous compound.

Vitamin B, also called *water-soluble B*, was the first to be discovered. When it is absent, there follows failure of growth, lack of appetite, indigestion, anemia and emaciation. A more serious condition is general inflammation of the nerves, leading to paralysis and death. Such a condition has long been known and has received the name *Beri-Beri*. It has occurred for ages in countries where rice is polished, *i.e.*, the outer hulls are removed to make a better appearing and finer food. Eijkmann, in 1897, found after producing beri-beri in chickens by feeding them on polished rice, that he could cure them by feeding them whole rice or the outer hulls. This was also the experience of Funk, in 1911, in experiments on pigeons, and of Susuki in Japan at about the same time. The results are startling. Birds almost entirely paralyzed completely recover in from three to six hours. Vitamin B is not stored in the body, as is true to a certain extent of vitamin A, but must be more or less constantly present in the diet. Animal foods do not contain much of it, but apparently enough for carnivorous animals. It is more evident in plant foods, especially in yeast and wheat germs. It is also present in nuts and fruits, in the green leaves of spinach, and in the common fleshy roots of carrots and beets, and in potatoes.

Vitamin C, or *water-soluble C*, is the anti-scurvy or anti-scorbutic vitamin. Lack of it results in lack of growth. Scurvy eventually appears. Some of the conditions accompanying scurvy are bleeding under the skin or from internal organs, bleeding of the gums, and soreness of the joints with accompanying great pain. The ends of bones become brittle and are easily broken. The heart is also seriously affected. It is said that of all animals studied, the guinea-pig is most susceptible to it and that next to the guinea-pig is man.

Fresh fruits and vegetables contain vitamin C. It is richest in the juices of such fruits as oranges and lemons, and in uncooked tomatoes and cabbages. Meats are not very rich in it. Cows feeding on green grass produce milk that has anti-scorbutic power, but milk from cows that are fed on hay during the winter lacks this substance. Vitamin C is destroyed by heating or storage. Children fed only on pasteurized milk develop scurvy. Orange juice or even the juice of canned tomatoes prevents it.

Vitamin D. Cod-liver oil cures and prevents rickets, a disease in which the course of metabolism is abnormal. Bones do not receive the proper complement of lime salts. Lime and phosphoric acid are needed to make proper bone tissue. But vitamin D is also necessary. At first it was thought that vitamin A substances were sufficient. Butter, however, contains vitamin A but does not prevent rickets. Cod-liver oil contains not only vitamin A but also vitamin D, the anti-rachitic specific. Certain treatment destroyed the vitamin A property of the oil but not the vitamin D. During recent years there have been many evidences that rickets could be cured by exposing the body to radiations of ultra-violet light. Recently both Hess and Steenbock have demonstrated that oils or fats that had no vitamin D properties would take on such properties if they were exposed to ultra-violet radiations. And so, fats, circulating in the blood just under the skin, if exposed to ultra-violet radiations, take on the vitamin D or anti-rachitic properties.

Vitamin E. This promotes fertility. If it is lacking in foods otherwise adequate, sterility results. It is present in such foods as lettuce, wheat embryos, meat, rolled oats, in large amounts of milk fat, in yellow corn.

Inorganic Substances. Certain inorganic substances in food are also necessary. Iron, so necessary for hemoglobin, is best furnished by green vegetables in the diet. It is also found in red meats, eggs and milk. Phosphorus is also necessary to provide for growth of the bones; it is present in sufficient quantities in milk, meats, egg yolk, beans, peas and nuts. Calcium is also needed for bone formation and other purposes. For mankind the principal source of calcium is in milk. " Hard " drinking water also contains calcium in a form that can be used by the body.

A small amount of iodine is necessary. Some investigators believe that water and food supplies in certain regions do not furnish the adequate iodine supply resulting in abnormal conditions associated with the thyroid gland.

Excretion. Excretion begins in the various cells of the body. Wastes of cell activity are discharged from them and find their way eventually into the blood. The amino-acids of proteins are taken up from the blood by the cells. In the process of metabolism the broken-down proteins and amino-acids appear as ammonia. This is toxic. It is rendered harmless by the ever-present carbonic acid of the blood with which it forms ammonia carbonate, This is carried to the liver and there the ammonia carbonate loses two molecules of water, forming urea $(NH_2)_2CO$. The ammonia is thought also to neutralize other harmful acids, such as lactic acid, that develop during muscular exercise. The urea is discharged from the liver along with other nitrogenous wastes into the blood stream.

Fat circulating in the blood may be used as fuel. Fat stored in adipose tissues is later taken up by the blood also. Before being burned it is probably changed to fatty acid and glycerine. By a series of physiological oxidations they are eventually changed to carbon dioxide and water. Oxidation of carbohydrate (glycogen or glucose) also occurs by a series of steps resulting in the formation of carbon dioxide and water.

The blood is the vehicle by which waste products such as CO_2, H_2O, urea, etc., are carried to the organs of excretion. Here waste products are constantly being removed, although it must be remembered that the blood constantly contains waste products. Gases leave the body via the lungs or gills. Water is excreted from the lungs. The sweat glands, used primarily as part of the heat-regulating system, also give off water, nitrogenous wastes, inorganic salts and gas. The liver excretes bile pigments and cholesterol into the intestine. It is known that the cells of the intestinal wall excrete inorganic substances present in excess, such as calcium or magnesium. The salivary glands, tear glands and mammary glands may also secrete traces of waste substances.

The kidney, however, is the chief organ of excretion of wastes of protein metabolism. The vertebrate kidney is a mass of tubular glands all joining to discharge the liquid waste products by a few main ducts into a space from which the wastes pass into a ureter and from this to the outside. These tubular glands radiate out toward the periphery, not as simple straight tubes but each unit or urinary tubule is coiled (Fig. 343). The outer terminus is enlarged and is called a *Malpighian body.* This consists of a sac containing a network of capillaries. Portions of the nephridial tubule adjacent to the Malpighian body are composed of larger cells. This part of the gland is invested with an especially rich capillary network. It is the function of these glands to remove waste substances from the blood. This may be done in part by the physico-chemical processes of filtration, and osmosis, but careful experiments show that selective secretion of the cells is concerned.

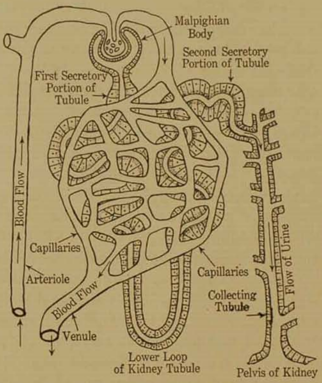

FIG. 343. — Plan of a nephridial (urinary) tubule and its blood supply.

During excessive secretion of urine, an increase in oxygen consumption of kidney cells takes place, indicating activity of the kidney cells. Urea and glucose in the blood act similarly in a physico-chemical way, but urea is excreted and glucose is retained.

Urine is an aqueous solution of waste compounds, a little heavier than water and slightly acid in Man and Carnivora but alkaline in Herbivora. Eighty-five per cent of its organic wastes is in the form of urea. It contains other organic wastes such as uric acid and inorganic salts — chlorides, sulphates and phosphates of sodium, potassium, calcium and magnesium. When Wöhler made urea synthetically, in 1828, the barrier separating organic from inorganic chemistry was broken down. It indicated that the same chemical laws operate in the living and non-living world.

Ductless Glands and Hormones (Fig. 339). There are certain glands present in Vertebrates which secrete chemical compounds directly into the blood stream. These glands have no ducts and are therefore called ductless glands, or *endocrine organs*. Some of them are visible to the naked eye while others are seen only under the high powers of the microscope. It is entirely possible that there exist some endocrine organs concerning which nothing is known at present. Their secretions contain vitally important substances called *hormones*, which control or regulate physiological processes. This means that in addition to the nervous control of physiological processes there is present a system of *chemical control*.

The Thyroid gland is located just below the larynx and in front of the trachea. It consists of a right and left lobe connected by a middle isthmus. It is composed of very small more or less spherical sacs whose walls consist of a single layer of short columnar epithelium. In the cavities of these sacs is a colloid substance. Located in the substance of each lobe are two small parathyroid glands. Both these glandular structures are richly supplied with blood vessels.

Sometimes the thyroid does not develop in children. Such individuals are known as *cretins*. They fail to grow physically or mentally. The growth of the brain is interfered with. Although these persons may live for a number of years, yet they remain idiotic and infantile. If this condition is discovered early enough, the administration of thyroid extract from the gland of the sheep, for example, will entirely change the individual from abnormal to normal. The hormone necessary for growth and normal development, lacking in the cretin, is supplied by the thyroid extract. It is known that iodine is concerned in this substance, and a compound called *thyroxin*, obtained from thyroid glands of animals, possesses it. The formula of thyroxin is $C_{15}H_{11}O_4NI_4$.

Sometimes the thyroid atrophies in adults and causes marked abnormalities. This is known as *myxoedema*. The hands, feet, face and lips become enlarged, the skin dry, the rate of metabolism decreased and deranged. The general intelligence is lowered. Administration of thyroid extract corrects these abnormalities due to the absence of the hormone. In some cases where the body cannot get a supply of the iodine compound from which to manufacture the hormone, an excessive development of the gland takes place. The vesicles coalesce and fill with useless colloid secretion. The gland eventually becomes an enormous cyst or tumor which can be removed surgically. This is known as *chronic goiter*. It has been found to be especially frequent in certain lake and river districts. Attempts have been made to correlate it with the absence of iodine in the food and water of these localities. *Exophthalmic goiter* is a more serious type. In this case, an excess of the secretion is produced. Metabolism is speeded up, the heart beats faster, there is loss of muscular power and development of bodily weakness, the person is very nervous and the eyeballs protrude. This is often fatal. When the entire thyroid is removed, death ensues. This is probably due to the removal of the parathyroids which are embedded in the thyroid substance. When the parathyroids are removed from a dog, convulsive contractions of the muscles follow. The animal has no muscular control. Death occurs in about ten days. Certain very toxic substances appear in the urine. There is also an unusual elimination of calcium. A certain type of convulsions in very young children is thought to be due to a deficiency of parathyroid secretion. The feeding of calcium salts results in a disappearance of the symptoms. Deficiency in parathyroid secretion results in changing the reaction of the blood to a more acid condition, and decreased metabolism of protein. In the removal of chronic (colloid) goiter, surgeons are careful not to remove the parathyroids.

Thymus. The thymus is not found in Invertebrates but occurs in all Vertebrates. It is functional in man at birth and is active in early life. Certain evidence indicates that it is a gland of internal secretion. It grows for the first two years of life, then degenerates, and this is usually complete at puberty. If it persists longer, the period of childhood is prolonged. Its secretions appear to retard the attainment of the mature condition. It seems to check the action of other glands having to do with normal development.

Pituitary Gland. It is located in the under side of the front part of the brain. It has three parts and it is probable that each part has distinct functions. Removal of the pituitary produces profound disturbances, but not necessarily death. When it is removed in young dogs, they fail to grow and remain sexually and mentally undeveloped. These effects are supposed to be due to the removal of the anterior lobe. Removal of the posterior lobe results in the production of a great amount of urine. This is similar to a disease called *diabetes insipidus*, which is supposed to be due to an affected posterior lobe of the pituitary. Some dwarfs have very small pituitary glands. In human beings with deficient anterior lobe secretions, the individual shows conditions similar to those in which this gland was removed in young dogs. Some giants have unusually large pituitary glands. Sometimes this gland begins a sudden growth in the adult. The bones of the head, hands and feet increase greatly in size, the lower jaw develops to an unusual size and severe headaches accompany these changes which result from an increased secretion of the gland. Some cases are benefited by surgical removal of the pituitary tumor. Administration of pituitrin, obtained from the pituitary glands of animals, helps to correct abnormal conditions produced by the lack of pituitary hormone.

Pancreas. Located among the ordinary glandular cells of the pancreas are small clumps of cells known as the *Islands of Langerhans.* It is now known that these cells secrete into the blood a hormone called *insulin.* This is necessary for the normal metabolism of sugar in the body. When sugar is not metabolized, it produces a disease known as *diabetes mellitus*, which appears to be caused by a failure of the islands of Langerhans to produce insulin or pancreatic hormone. In diabetes, the sugar absorbed from the intestine is carried to the liver by the blood. But in the liver, this sugar cannot be changed to glycogen nor stored, due to the absence of the hormone. Neither can sugar be oxidized. It is thrown back into the blood stream. As a consequence, metabolism of fats and proteins is interfered with and, due to the general derangement of metabolism, death results from *ketosis.* This is a condition in which bases are decreased, due to the excessive formation of acids in the body. Powerful neutralizing devices are present in health to prevent this, namely, the buffer substances.

Adrenals. These are a pair of small glands near the kidneys. In man there is one just above each kidney. Their secretions (hormones) are necessary for life. When diseased, the person is physically prostrated and the condition is accompanied by vomiting. The skin becomes bronzed in color. Death follows. This is called *Addison's disease* because it was shown to be connected with a disease of the adrenals by Thomas Addison in London in 1849. When the gland is removed in animals, death occurs in a few days. A hormone from one portion of the gland can be isolated in pure crystalline form. This was done in 1901, and in 1906 it was made synthetically and is sold under trade name of "*Adrenalin.*" A certain quantity of adrenalin in physiological saline solution causes the contraction of arteries. It is used therefore in checking the flow of the blood from wounds and also hastens the formation of a blood clot. There is one part of adrenalin to 500,000,000 to 1,000,000,000 parts of blood.

Adrenalin effects a rise in blood pressure; produces a quickening of the heart; inhibits the contraction of the smooth muscles of the respiratory passages, causing them to relax, and hence affords relief in spasmodic contractions of asthma; it causes a mobilization of sugar from the liver glycogen; hastens clotting of blood and counteracts fatigue at the myoneural junctions. In excitement the adrenals produce more adrenalin. As a result the blood contains more sugar. The muscles have more fuel at hand. And this means that the animal is in better condition to fight or fly as the case may be.

Sex Organs. The processes by which mature eggs are produced from the ovary; by which sperm are produced from the testis; fertilization; development; preparation of uterine tissues for the developing embryo; of intra-uterine feeding, are all physiological and much remains to be discovered regarding them. We are here concerned particularly with the hormones produced by endocrine tissues in the gonads.

The interstitial cells, located between the tubules of the mammalian testis, produce a hormone that has to do with the development of secondary male sex characters; as, for example, the antlers of the male stag; the plumage of the male fowl; and in man, the masculine figure that develops after puberty and his beardedness and deeper masculine voice. There are endocrine tissues in the ovary also and these activate the development of secondary female sex characters. In the castrated cock, the plumage and other male characters change so that the animal takes on the general appearance of a female. A corresponding operation on a female causes a change from female to male plumage. Subtraction of hormones are believed to cause these changes (Fig. 344 *A*). It is said that after castration of male cattle, there is a change in the flavor of the flesh; there is a tendency toward the development of adipose tissue and the temperament is mild.

FIG. 344*A*. — Buff Orpington hen with ovarian tumor. It had head furnishings, plumage and spurs of a cock. Its entire behavior was like that of a male bird. (From Crew: 1922.)

The endocrine tissue of the ovary produces a hormone which causes marked changes in the tissues of the uterus, whereby the latter is made ready to receive the egg. The special preparation of the uterus is even more marked if the egg has been fertilized and this further change is activated by ovarian hormone. This hormone production ceases when the young animal is born and the uterus soon thereafter resumes its normal condition (Fig. 344 *B*). An ovarian hormone also stimulates the mammary glands to develop.

After a certain period of years the mammalian female ceases to produce eggs. The ovaries diminish in size; the hormones referred to above are no longer formed and the reproductive period is at an end.

8. *Interdependence of the Endocrines.* When the thyroid is removed experimentally,

FIG. 344 *B*. — Photomicrograph of part of cat's ovary. The large space indicates a Graafian follicle. At one side is an ovum. The cavity is filled with follicular liquid. At ovulation, this and the egg are discharged and the space is filled with *corpus luteum* tissue. This produces a hormone as described in the text. (Photo by Cooper.)

the anterior lobe of the pituitary increases in size. When a gonad is removed, the cortex of the adrenal grows larger. On these and other grounds, the endocrinologist is convinced of an interdependence among the endocrine glands. To unravel this intricate relationship is one of the problems of modern physiology.

PHYSIOLOGY OF ADJUSTMENT

Function of Irritability — Receptors. Amoeba is irritable to external stimuli. Different parts of its protoplasm do not respond respectively to special stimuli. At the other end of the animal series, however, the mammal has many special (see page 397) organs of sense, each of which is aroused by certain particular stimuli. As with all organs, a study of the comparative anatomy and physiology of animals shows a gradual evolution of special sense organs. Space does not permit of more than an enumeration of these special sense organs as they occur in higher Mammals.

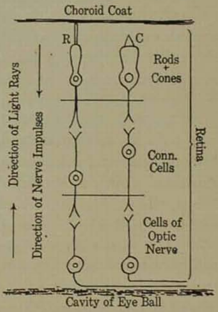

Fig. 345. — Cell arrangment in retina. Compare with Figure 338.

1. *Light.* The sense organ in the Vertebrate is the eye (Fig. 338). The parts of the eye sensitive to changes in light are the sensory cells of the retina. Different light rays (color) and rays of different intensity produce some change in the protoplasm of the sensory cells of the eye (Fig. 345). These cells are connected with fibers of the optic nerve. Nerve impulses are consequently aroused in these nerve fibers, which impulses pass along into the brain stimulating certain brain cells.

2. *Sound.* The sense organ concerned with this type of stimulus is the ear (Fig. 337 *B*). Sound waves cause the ear drum to vibrate. Vibrations of the ear drum are communicated by the chain of three small bones in the middle ear to the membranous window (*fenestra ovalis*) between the middle ear and the inner ear. On a spiral shelf of the membranous inner ear are thousands of sensory cells (of hearing) immersed in a fluid in the membranous

cochlea. Vibrations of the fenestra ovalis sets up vibrations in this inner fluid (*endolymph*). Certain vibrations stimulate certain sensory cells. The nature of the endolymph vibration depends, as is evident, on the nature of the external sound. Once these sensory cells are stimulated, the momentary change produced in their protoplasm is communicated to the nerve cells with which they are connected and so particular nerve impulses pass over fibers of the eighth nerve, to arouse certain cells in the brain.

3. *Equilibrium.* When the body, or especially the head, changes its position in any way, certain brain cells are aroused and thus the body is aware of the change in position. The external sense organ involved is not only that of the eyes but also the semicircular canals associated with the auditory apparatus. There are three of these membranous canals or tubes in each ear. One is horizontal, two are vertical to this and at right angles to each other, as shown in the diagram. Each semicircular canal possesses an enlargement known as an ampulla and in these ampullae are sensory cells. The canals are filled with endolymph and in this endolymph are fine calcareous particles. Suppose the head falls forward. Then certain cells on one side of this apparatus will be stimulated. Impulses pass at once from these cells over nerve fibers to appropriate cells in the brain. Suppose the head is erected again, then other sensory cells are stimulated. If the head falls to one side, then certain other cells will be stimulated. So the animal is constantly informed of its position.

4. *Odors.* In the mucous membrane of the upper back part of the nasal cavities are sensory cells, which are stimulated by odoriferous particles given off into the air by certain substances. These sensory cells of smell are connected with fibers of the olfactory nerve, and hence impulses are carried to special cells in the brain.

5. *Chemical.* On the tongue (Fig. 337 *A*) and back part of the mouth are located special and various sensory cells which are stimulated by certain components of the food in solution. These taste cells occur in special organs. Impulses aroused in this way in these sensory cells of taste are carried by certain nerve cells to certain other nerve cells in the brain.

6. *Touch.* The contact of external objects with the surface of the body stimulates appropriate sensory organs located in the skin. These impulses aroused pass on to certain nerves and from these to certain nerve cells in the brain. There are over 500,000 such

sense organs distributed over the surface of the body. They are closer together at some places than others and so some portions of the skin are more sensitive than others. The tip of the tongue is most sensitive, while the back of the neck is least sensitive.

7. *Muscles.* When weights are held in the hand, or when parts of the body support a weight or when a movement takes place, then the consequent contraction of muscles involved stimulates end arborizations of certain nerves or sense organs, with the result that appropriate impulses are sent over nerves to cells in the brain. Thus we are not only aware of differences in weight of objects, but what is more useful and usual, we are constantly informed of changes in the muscular system. That is, we are aware of our muscular movements. This muscle sense works with the sense of equilibrium and vision in making locomotion possible.

8. *Pain.* There is evidence that widely distributed over the body are special nerve endings which are aroused by injurious stimuli. The sensations aroused in the brain are those of pain.

9. *Heat and Cold.* Two special groups of end organs distributed like points throughout the surface of the body are stimulated by changes in the temperature of the external medium. The so-called heat spots are stimulated by temperatures higher than that of the skin, while the cold spots are stimulated by temperatures lower than that of the skin.

10. *Hunger.* This is an ill-defined sensation aroused by lack of food. It is natural to associate it with the stomach. It is now known that, accompanying hunger pains, there occur violent contractions of the wall of the stomach, so that the sense organ of hunger may be regarded as consisting of ends of sensory nerves located in the stomach. These sensations inform the individual that the cells of the body need more food.

11. *Thirst.* When very thirsty, we note a feeling of dryness in the membranes of the throat and pharynx. The sensation informs the individual that the body cells generally need more water for the chemical changes incident to life.

12. There are a great many other kinds of sensations aroused by a variety of stimuli. Although special sense organs and conducting nerves are not known, yet it is believed that some sort of apparatus must be present to carry out these functions. The feeling of fatigue, sexual feelings and the sensation of nausea are examples of these; the vague feelings of well-being or malaise

are other examples. All these structures in which sudden changes in the conditions of the environment produce changes in certain definite portions of their protoplasm are called *receptors*. They are sentinels in the front-line trenches. In some cases special epithelial cells are arranged in special sense organs, in others the end of a nerve has to suffice and this is probably not as sensitive as the first. If we stimulated the sensory cells of the eye with a small object directly, we probably would " see " a flash of light. But it would all be quite useless to us. Each type of receptor is specialized to react best to its own appropriate stimulus, *i.e.*, it is selective. Sound waves beat against the skin, but the skin is not affected by them.

Function of Conduction. Protoplasmic changes produced in receptors are continued along definite conducting organs called *nerves*. The superficial protoplasm of the Amoeba is receptive, but the change in it is carried into the deeper protoplasm, and the Amoeba responds by some sort of contraction. In the study of Hydra, we found indications of the early appearance of special structures for each of these functions of adjustment. There are two muscles of our upper arm concerned in bending movements of the forearm. In front of the upper arm is the biceps muscle. Just opposite it on the other side is the triceps. When we flex the forearm against the upper arm, the biceps contracts and the triceps relaxes. This shows that the bending of a part of the body involves the contraction of certain muscles and relaxation of others. Or, one is a case of excitation while the other is a case of inhibition. Strychnine injected under the skin of a live frog upsets all normal muscular coordination. On the slightest stimulus from without all the skeletal muscles of the frog contract simultaneously and the body and the legs are stretched out in a convulsive rigidity, making locomotion impossible. It is hard to conceive of locomotion in any animal where contraction of one part is not compensated for by relaxation in another. This is true even of the Amoeba. While the protoplasm of one part of the Amoeba's body is contracting it is relaxing at another part.

Nervous System. In the higher animals this coordination is accomplished by the nervous system. The nervous system, we have seen, has evolved from the generalized condition seen in lower animals like the Coelenterates and Flatworms to the highly complicated nervous systems of a Vertebrate and finds its highest expression in man. The nervous system not only is concerned in bringing about proper muscular contractions by which the skeletal levers act so as to move the animal either toward or away from certain stimuli, but it regulates the activity of certain vital internal organs. For example, modifications in the rate of the heart beat and the regular rhythm of respiration are under nervous control. That part of the nervous system that in a sense lies outside of the central system, the so-called sympathetic, has nerves which follow the blood vessels. It forms a network or plexus of nerves about the stomach, heart, intestines and kidneys. It controls involuntary or smooth muscle. We have already shown that certain physiological processes are also under the chemical control of hormones. The central nervous system is somehow changed by repeated stimuli of the same sort. Although we do not know the anatomy involved, yet there is no doubt that memory has some neurological basis. Moreover, the appearance of memory leads to possibility of making generalizations and so rational thought comes into existence. Discussion of such matters is beyond the scope of this volume. It should be kept in mind that reason, and the appreciation of art and even the knowledge of right and wrong, are all in a sense physiological and have a morphological background. It is possible here to present only a brief picture of the anatomy and physiology of the *nervous system.*

The simple apparatus which brings about adjustments in a Hydra soon appears in higher animals as a definite mechanism called a *reflex arc.* This in its simplest form consists of three parts: (*a*) *receptor;* (*b*) *adjustor;* (*c*) *effector.* These are physiological rather than anatomical terms. An anatomical picture gives a clearer explanation of just what is meant by it. Among the cells of the skin is a sensory or afferent nerve cell. This is not only a receptor, but the impulse aroused passes over its axone to a central organ, such as a ganglion in the nerve cord of the earthworm or to the spinal cord of a Vertebrate. In most cases, as shown in the description of the receptor system, special sense cells (of the sense organs) are acted on by the stimulus, and these sense cells are connected with afferent nerves.

The sensory or afferent impulses pass over connecting nerve branches (*synapsis*) into a motor nerve-cell body. It arouses an impulse in this cell and the impulse continues out (efferent) over its axone. This is the adjustor part of the reflex mechanism. The impulse is carried out over the motor cell axone to a muscle (effector), causing a chemical change in the muscle which is expressed by a contraction. Nerve impulses pass over axones in one direction; over sensory nerve axones towards a nerve center; over motor nerve axones outward toward a muscle or gland. The nervous system of Vertebrates is made up of a great many; some relatively simple and *many complicated reflex arcs.*

The nervous system of a Vertebrate may be thought of as consisting of thousands of pathways or nerve tracks along which sensory impulses, aroused by this or that form of stimulus, pass into the central system to the higher centers in the brain, and also of thousands of tracks of neuraxones over which motor impulses pass from the higher centers out to muscle or gland. The nerve tracks involved may consist of a chain of nerve cells. Another complication consists in the fact that although the activities of lower animals may at times appear to be a mass of reflexes, yet only too often they are not all simple and machine-like as the extreme mechanist would claim.

One afternoon the writer observed a wasp dragging a very much larger black spider over the ground. After proceeding laboriously for about fifty feet the wasp encountered a pile of stones. In the attempt to pass this obstruction the spider was dropped far down between two stones. The wasp flew about, then returned, and in a few moments reappeared dragging its prey successfully to the other side of the barrier. To say that this series of movements is merely a succession of complicated reflexes would be an unsatisfactory explanation. In man, moreover, some incoming impulses are referred to higher centers which somehow block the reflex response. Memory or better judgment, we say, urges delay or caution. The nervous system is composed of many millions of cells, and it is a reward of the long, arduous labors of neurologists that their work has been crowned with the discovery of some idea of order underlying this great complexity.

1. Spinal Cord. In the Vertebrate a slight skin stimulus arouses a receptor in the skin. A nerve impulse passes over the sensory nerve cell to the sensory cell body in the ganglion on the posterior root of a spinal nerve. The impulse continues from this via the posterior root into the posterior horn of gray matter of the spinal cord (Fig. 346). (1) The nerve fiber involved may pass around in the gray matter of the same side and connect with a

motor cell in the anterior horn. In this case, a motor impulse would pass out along its axone in the anterior horn, and out in the same spinal nerve and end in a muscle directly under that portion of the skin stimulated, (2) or the sensory nerve cell spoken of, may also join with an intermediate neurone which extends for some distance up or down the cord in its white matter and has branches

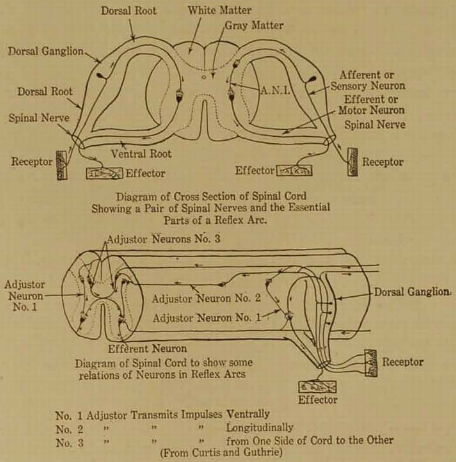

Fig. 346. — Neuron relations of the reflex mechanism. The brain would be at the right of the lower figure. Arrows indicate direction of flow of nerve impulses. (From Curtus and Guthrie, *Textbook of General Zoology*. Copyright 1927, John Wiley and Sons, Inc. Reprinted by permission.)

which connect with motor nerve cells at several levels of the cord so that motor impulses may go out over several spinal nerves, (3) or motor cells on the other side of the cord may be affected as well; (4) or this sensory nerve cell spoken of may connect with a cell whose axone extends up the cord to the medulla. Here it connects with other neurones which carry the impulse higher up. For example, it may connect with neurones whose axones extend up to the cortex (outer rind of gray matter) of the cerebellum, or it may go up to a center in the brain, and from this to the cortex of the cerebrum (Fig. 347).

The spinal cord, therefore, consists of a segmental series of reflex centers. It is also a highway over which stream two sets of impulses. Over fibers lying in posterior region of the cord (sensory) impulses stream upward toward the brain. Over fibers lying in the anterior region of the cord, motor impulses are streaming down the cord, some passing out over spinal nerves at this level and others at another level.

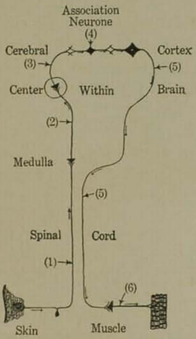

FIG. 347. — Diagram showing chain of neurons over which an impulse may pass from skin to cortex of cerebrum and back to a muscle.

2. Medulla. Some afferent impulses end in the medulla and are there shunted off into motor impulses. The medulla is an automatic center of the most vital sort. It regulates heart action, it controls respiration and the contraction of the arteries and, therefore, has a great deal to do with blood pressure, so important in all physiological activities. It is the control center of such simple reflexes as winking, chewing, swallowing, vomiting, sneezing and coughing. It is also a relay station from which afferent impulses are continued on up to the brain, and from which motor impulses from the higher centers are sent on down the cord.

3. Cerebellum. This is relatively larger in man and apes than in other Vertebrates. Experimental evidence and observations on human beings with a diseased cerebellum indicate that the cerebellum is not an organ of intelligence but governs the coordination of muscular movements, especially those concerned with locomotion. For example, a pigeon from which the cerebellum has been removed cannot fly or walk. It tumbles over. Dogs thus operated on behave similarly. They may recover partially in time, but this is because a coordinating mechanism of a sort is set up in the cerebrum between the eyes and limb muscles. The result is similar if there is injury to the sensory organ of equilibrium, namely, the semicircular canals (Fig. 348).

4. Cerebrum. The brain consists of an outer rind or cortex of gray matter in which are located millions of nerve-cell bodies.

The convolutions and fissures increase the area for location of these cells. From them, axones extend down into the interior, and other axones from centers in the interior pass up to the cortex. *Association neurones* connect one part of one side of the cortex with another portion of the same side. *Commisural neurones* connect one hemisphere of the cerebrum with the other. The brain is not a solid mass, but contains cavities or ventricles which can be traced back to the canal of the embryonic nerve cord. The *optic thalami* are a pair of large internal ganglia or nuclei which receive impulses from neurones extending into them from centers in the medulla. These sensory impulses pass up over other neurones to

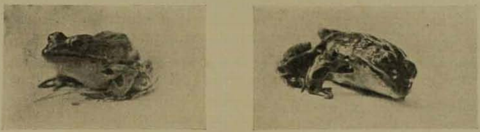

Fig. 348. — Relation of semicircular canals to equilibrium. Frog on the left is normal; in the other frog the equilibrating apparatus of the right ear is not functional. Note that the head is turned to the left. (Courtesy of Dr. Joseph Tulgan.)

the cortex. Motor impulses arising in the cortex pass down over certain groups of fibers to motor centers in the interior, and from these over other neurones to centers in the medulla, and from this possibly down the cord to the sciatic nerves and down to the toes.

A dog from which the cerebrum has been removed (and in one case the animal survived for a year and a half) breathes, walks, runs and swallows, if food is placed in its mouth. It is a mere automatic machine. It has no memory, no fear, no feelings. A similar experiment on a series of Vertebrates from lower to higher indicates the increasing importance of the cerebrum as one goes "higher" in the scale. There are two chief fissures on the outer side of each hemisphere. One of these, the *fissure of Rolando*, begins at about the middle of the upper surface and extends downward and forward. The *fissure of Sylvius* is on the lateral face of the hemisphere and extends from in front toward the rear. The frontal lobe of the brain is above the fissure of Sylvius and anterior to the fissure of Rolando. The *temporal lobe* is below the fissure of Sylvius. The *parietal lobe* is behind the fissure of Rolando.

The *occipital lobe* is most posterior of all, being behind the parietal and temporal lobes.

By various lines of evidence it is known that the cortex has a geography of its own (Fig. 349). In apes and man, the cortex just in front of the fissure of Rolando contains motor neurones which control the movements of the body. There is evidence also of an orderly distribution. Beginning with the upper reach of this region and passing down and toward the fissure of Sylvius occur: (1) neurones which control the movements of the legs; (2) lower down, neurones which control movements of the trunk; (3) cells which control the arms; (4) cells which control facial muscles. (5) On the left side near the cells which control the movements of the hands are probably special cells controlling the writing of words. (6) Near the face and tongue center on the left side are probably cells controlling speaking of words.

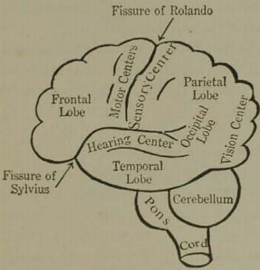

Fig. 349. — Side view of human brain showing sensory and motor centers.

In the back part of the occipital lobe is a region containing cells which control vision. This is called the *visual center*. On the side of the hemisphere just below the back end of the fissure of Sylvius are cells which control hearing. This is the *auditory center*. Associated with both the visual and the auditory centers (on the left side) are probably cells which are associated with reading words and hearing words. In the cortex on the inner face of each hemisphere are the *centers for smell and taste*. Just back of the Rolandic fissure is the cortical center of cutaneous senses.

Observations of certain kinds indicate that the frontal lobes in front of the motor center are the centers of intelligence, ideas, memory, judgment and will. Notwithstanding the fact that the function of a large part of the cortex is not known, it is remarkable that such a considerable part of its area is so well understood.

The cerebrum is a central office to which a multitude of messages concerning the external world is referred. Messages received via the eyes, ears, nose, tongue, skin and muscles are for the most part relayed to it. In the normal brain this does not result in confusion but all is order. These impulses arouse some change within. It is possible that the response will be immediate and may involve many motor outlets. If this is necessary, the apparatus is well equipped to make a complicated response, because of the property of coordination which the brain possesses. It is also possible that there will be no response, for the brain is somehow equipped to sidetrack and inhibit incoming messages.

The brain is able to record and store previous messages received and also its reactions to them. The conduct of the individual may be either immediate response or no response. But this is already getting beyond the boundaries of pure biology. It is the duty of the psychologist to explain further.

Function of Contraction. Animals provided with a skeletal framework, to which voluntary muscles are attached, are capable of more active movements than such animals as the earthworm without such a framework. The bones serve not only as a central support to which the central ends of the muscles are attached, but the outer ends of the muscles are attached to levers (bones) forming the skeletal features of fins or limbs. These muscles (striated) are provided with sensory and motor nerves. Muscle sense organs are located in the muscle. When the muscle contracts, these sense organs are excited and a sensory impulse is sent to the central organ which thus receives information of the condition of contraction and from the mass of such information the animal is able to judge of its position and progress.

On the other hand, motor impulses coming from the central organ to the muscles cause them to contract. Levers are moved in a certain orderly way, and thus locomotion is possible. The muscles of the locomotor organs are arranged in pairs so that when one muscle contracts, another relaxes. All the work is carried out usually in a coordinated fashion. If this were not the case, no progression of the body would be possible.

Muscles are naturally elastic. In the living animal they are always partially contracted and it is known that when they have to actively contract, this preliminary state of partial contraction is advantageous. The amount of contraction depends on the degree of stimulus up to a certain maximum stimulus, beyond which greater stimuli do not produce any greater contractions. Heat increases the height of contractions of isolated muscles and also increases the speed of the contraction, while cold has just the opposite effect. Chemicals and drugs modify normal contractions. Potassium salts depress and calcium salts excite. Caffein and strychnine are stimulants of cardiac muscle.

Muscles are fatigued after repeated contraction. Their store of fuel is consumed and, in spite of more being carried to them by the blood, a change has taken place, rendering this ineffectual. The blood is also flushing out waste products, and the inability of the muscle to continue to contract is probably due to the accumulation in it of waste products. It is believed that the chief fatigue substance is a form of lactic acid peculiar to muscle and called *sarcolactic acid.* Rest is necessary to enable the muscle to return to its normal condition. Anything which favors the carrying away of fatigue products assists in the recovery from fatigue. Taking on of additional fuel does not necessarily help the condition. Warm baths speed up circulation in the muscle. Water taken internally is taken up by the blood and so carried to the muscles and aids in the removal of wastes of catabolism. Muscle fuel has been mentioned. *This is carbohydrate food.* In the blood it is present in the form of a monosaccharid, glucose.

It has been found that furnishing cane sugar to soldiers on a hard day's march quickly energizes them. What probably happens is that the cane sugar is easily changed to glucose in the intestine and is soon supplied to the muscles. Meat is not a good fuel because it is largely protein. As such it is useful chiefly in replacing worn-out protoplasm of muscles. But surprisingly little muscle protoplasm is broken down in muscular activity. The great fuel supply is carbohydrate. Ordinary muscular fatigue is due to muscle deterioration and not to changes in nerves. This does not mean that nerve centers are not fatigable. The amount of energy produced by an active muscle that is available for work compares favorably with the best engines invented by man. In both cases, most of the energy (roughly 75% of the fuel involved) is dissipated in the form of heat.

It must not be forgotten that the muscles of the trunk, though apparently not taking part in locomotion, yet do play a necessary part. Certain of these muscles move the head. Others assist in keeping the body erect. Others assist in chest movements necessary for respiration.

In addition to the muscles attached to bones and used in locomotion, important muscle of another type is found in the wall of the intestine, of the blood vessels, of the ureters, bladder and oviducts. This is *smooth muscle.* Its physiological properties are similar in nature to those of striated muscle. However, it reacts to stimuli much more slowly and it is not under the control of the higher centers, *i.e.*, it is said to be involuntary. This muscle is essential to the circulation of the blood, to the functioning of the glands, to respiration, to the movement of foods through the intestine and to digestion. It is as vitally important as *striated muscle,* which is concerned with physiological processes of adjustment to external stimuli, while smooth muscle takes part in this also in furnishing the striated muscles with blood. Smooth muscle is more actively concerned with those processes which we termed metabolic. Reference has already been made to cardiac muscle.

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