NUTRITIONAL PHYSIOLOGY

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TO

Graham Lusk

WHOSE DELICATE KINDNESS NO LESS THAN HIS SCHOLARLY POWER MADE MEMORABLE THE YEAR OF OUR ASSOCIATION

PREFACE

The making of this book has been a study in elimination. It is, therefore, necessary at the outset to indicate the limits of its scope. It is intended that it shall be used with other books. Supplementary reading upon general biology, human anatomy, food chemistry, and dietetics is greatly to be desired. In the field of physiology itself many fascinating topics are entirely ignored and others treated in bare outline, with the purpose of subordinating all else to the subject of nutrition. Chemical formulæ have been excluded from the text and used but sparingly in the notes.

A certain preliminary knowledge of elementary science is assumed. The key-word of the following discussion is "energy." The success of the reader in gaining clear conceptions of what is presented will depend upon his familiarity with the meaning of that term. It is essential that he shall understand that energy is latent or potential in those chemical compounds which are susceptible of oxidation. He must have learned to recognize the possibility of its unending transformation. The more readily he thinks in terms of molecules, the more profitably he can read these chapters.

Miss Ruth Bryant, Instructor in Biology in Simmons College, has borne a part in the work, which is to be described as collaboration rather than assistance.

P. G. S.

Boston, Mass.,
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CHAPTER I

INTRODUCTION

The Modern Emphasis in Biology.—Living things are transformers of matter and energy. When we say *transformers* rather than *generators* we indicate the modern as contrasted with the old-time view. When we say that physiology is the physics and chemistry of living matter we suggest the same significant tendency to bring living and lifeless matter into direct comparison and to recognize the same laws as operating in both. The teaching that the same laws do hold sway in the living and the non-living is covered by the term "*mechanism*"; the earlier view that living things are not fairly to be compared with lifeless, and are to some extent exempt from physical principles and limitations, is expressed by the word "*vitalism.*" We have every reason to believe that the principle of the conservation of energy holds as rigidly for the plant or the animal as for the clock or the locomotive. This is perhaps the most important generalization of nineteenth century physiology.

But while scientific workers are now seeking to analyze the reactions of organisms in accordance with the data furnished by chemists and physicists whose work has been with materials not living, it is probable that the difficulties of their problems are better appreciated than was the case a few years ago. Living matter is found to be more complex in structure and more varied in response than had been supposed. Physiologists are bound to be modest in their claims for progress. They are ignorant of many factors at work in even the simplest forms of plant and animal life. And the mystery of consciousness with its relation to nervous systems seems ever to defy approach.

Free-living Cells.—About seventy years ago, at a time when investigators were profiting by important improvements in microscopes, it was found that the larger plants and animals are made up of structural units assembled in vast numbers. These units are generally much too small to be seen without magnification. They are called *cells*, a term which is not especially appropriate, but not likely to be abandoned. Many microscopic forms, such as the swarming *Infusoria* of pools and ditches, are cells leading an independent existence. It will be helpful to consider what are the characteristic activities of such cells. They are for the most part equally characteristic of the higher forms.

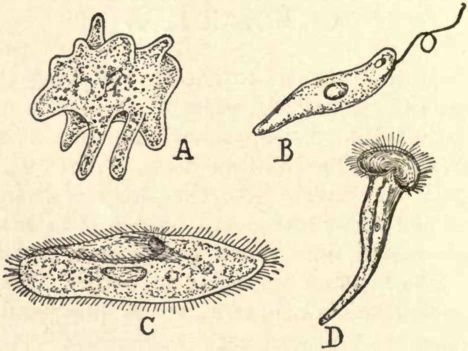

Fig. 1.—Four types of free-living animal cells: *A* is the ameba, distinguished for its changeable form; *B*, the euglena, shows the peculiar feature known as a flagellum, a writhing filament, which is its means of locomotion; *C* is the paramœcium, or "slipper animalcule," which has a ciliated surface; *D* is the interesting form known as the stentor.

The free-living animal cell takes something from its environment and returns something to it. It takes into itself a variety of organic substances together with small quantities of mineral salts. These constitute its *food*. It receives also a supply of *oxygen*. This is not ordinarily reckoned as a food and for a good reason. The term *food* is best restricted to material which can serve constructive purposes or at least be stored in the cell. The function of oxygen is not to promote constructive processes, but to release energy, a process of decomposition in which the stores of the cell are sacrificed. The process in which oxygen reacts with substances within the cell, giving rise to simple oxidized products in place of complex material rich in potential energy, is called *respiration*. (The word is, indeed, frequently used as a synonym for *breathing*, but we shall use it in its chemical sense.) Respiration is often compared with combustion, and while the two are not identical in all their stages, the fact remains that the initial and the final conditions are essentially the same for both. The release of energy is generally just as great in the physiologic change as in the actual burning of like quantities of the cell constituents.

The free-living animal cell is thus an accumulator of fuel and a furnace in which it is burnt. But this is a very imperfect comparison, for it has in addition the property of *self-repair*, and under favorable circumstances capacity for *growth* and *reproduction*. Cells multiply by cleaving into two similar parts, and the tendency to do this after a certain increase in size usually limits very definitely the dimensions to which a single cell may attain. When growth is taking place it is evident that not all the food is serving as fuel; a certain portion is becoming incorporated with the more permanent substance of the cell and is so changed as to become entirely typical *protoplasm*. The process through which food becomes an integral part of the cell is called *assimilation*. The word emphasizes through its root-meaning the attainment of *likeness* to the material of the cell and indirectly implies that the food was originally foreign in its nature. We use the expression in much the same sense when we speak of the assimilation of immigrant peoples. The word *nutrition* is used in about the same way as assimilation, the only distinction being that we speak of the nutrition of *cells* (or cell-aggregates), while we speak of the assimilation of *food*, the former term referring to the structure nourished and the latter to the supplies worked over for the purpose. The word *digestion* is best restricted to the preliminary stages of the assimilation process; its application will be defined later.

Respiration has been said to be a process in course of which compounds are decomposed that their potential energy may be made available. The greater part of the released energy appears as heat. A smaller part manifests itself in movements through which resistances are overcome. The facts in regard to the production of energy are naturally better known for the larger animals than for the free-living cells, but " the whole is equal to the sum of its parts." The energy from respiration may in exceptional cases become kinetic, in the form of light or electric discharge (firefly, electric eel). The energy which shows itself in movement is of particular interest to us. Motion, when exhibited by animal cells, is almost always the expression of *contraction*, the word being used in a physiologic sense. So used, *contraction* does not mean diminution of volume, but does mean diminution of surface and active shortening in one or more dimensions. Although an increase in other dimensions attends such changes of form, we do not talk of the " expansion " of cells. It is the contraction which is the positive and forcible element in the movement. When this is said we intentionally leave out of account some types of movement occurring commonly in the plant world, in course of which the cells actually change their volume through gain or loss of water. Among free-living cells the type of movement may be " ameboid," that is, a flowing of the cell contents to conform to an ever-changing outline. Contractile power may be limited in other cases to parts of cells, as in those forms which swim by the lashing of slender projections known as *flagella*, or by the waving of an animated nap or pile upon their surfaces, the *cilia*, of which more will be said. In all cases of energetic movement we feel justified in assuming that the source of the power is in destructive chemical reactions, and that a draft is being made upon the fuel stores of the cells.

The Association of Cells.—When many cells are massed, as in the body of a worm, the situation of the single unit differs significantly from that of the cell leading an independent existence. First of all, its environment is made for it to a great extent by other cells. A very small minority are in direct contact with the outside world; the great majority are submerged among their fellows. The typical cell is, therefore, shut in from food supplies of the casual sort on which the free-living cell depends. It is remote from the oxygen of the surrounding air or water. A cell so situated would perish were it not for one of the most striking features of the larger organisms, a *moving liquid medium*, which bathes the cells and acts as a common carrier. This fluid supplies food and oxygen and removes wastes.

The cells composing the body of any animal are of a common descent, but they have taken on widely different characters and have become adapted to particular functions. The cell which is in itself a complete living thing must perform all the essential activities for itself—the preparation of crude food, locomotion, etc. In the multicellular animal the individual cells have come to be far more restricted in their powers. Many have become passive structures serving only for mechanical support or surface protection. Such cells may or may not be living. Others, while clearly alive, have ceased to perform certain functions. With limited exceptions movement is exhibited only by those systematically arranged cells which form the contractile tissues. Almost all the cells require their food to be in solution and of a few standard forms. In other words, the primitive capacity to digest and assimilate every kind of nutriment has been lost, but by a wonderful co-operative activity the internal medium has been made a depot of those particular foods which can still be utilized.

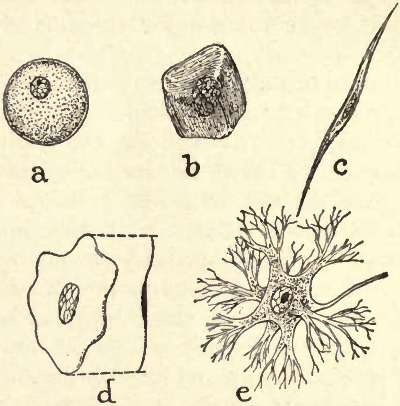

Fig. 2.—Drawings like the above are almost always made from tissues which have been prepared and colored by special means to make clear, minute features: *a* Represents an ovum or egg-cell, the typical cell may be assumed to tend toward this spheric form; *b* is a cell from a compact tissue, to show how mutual pressure produces a faceted or polyhedral form; *c* is a contractile element such as occurs in the walls of the alimentary canal, it illustrates an elongated cell; *d* is an epithelial or lining cell of the order found on the inner surface of blood-vessels; this is an example of extreme flattening; *e*, from the nervous system, exhibits the possibility of a branching development.

As an animal grows larger its directly exposed surface becomes smaller in proportion to its weight. The transfers which must take place between the organism and the external world require ample surfaces, and they are secured by infoldings of the body wall at different places. The lining of the alimentary tract is an example of such an infolding and provides a large area for absorption. Among the higher forms the lining of the lungs constitutes a vastly extended surface for gaseous exchange. The glands are organs in which are concealed great surfaces through which products of cell activity find an outlet.

The specialization which groups the cells of the animal body in a number of classes each with its definite work to do also entails the dependence of each class upon the others. If we compare the life of a savage with that of a civilized man we shall find an analogy not too far fetched to be helpful. We have seen that the free-living cell is self-sufficient, and, indeed, its chances of survival are better when there are but few of its own kind in the neighborhood. Such organisms are competitive rather than coöperative. Somewhat in the same way the solitary savage may be capable of self-maintenance, having the skill to find and prepare his food and after a fashion to shelter and clothe himself. The civilized man is accustomed to look to many other men—and women—to supply his needs. Yet if the man, like the cell, loses something of ruggedness and resourcefulness through becoming a member of a complex society, he evidently gains time and opportunity to concentrate his efforts upon a special pursuit. It is very much the same with the cell. Our analogy fails, as such devices are prone to do, when we consider how the civilized man may become a hermit or a Robinson Crusoe, whereas no single cell detached from one of the higher forms can exist by itself for any length of time.

Co-ordination.—We have emphasized above the services rendered to the organism by its internal medium. The composition of the circulating fluid is influenced by the ever-varying activities of all the organs and tissues. Accordingly, a contribution made to this medium by any group of cells may conceivably modify the conduct of any other group. We shall meet with numerous instances of such influence exerted through the chemical products of one organ upon another or upon the system as a whole. When we speak of an animal as an individual we imply that the parts of the body constantly interact. It is this interaction which makes it appropriate to regard the body with all its complexity as still forming a *unity* rather than a *colony*. The term co-ordination is employed to express this purposeful working together of all parts for the advantage of the whole. The means of co-ordination may be chemical as just now suggested, but a more conspicuous agency in the highly developed types is that of the *nervous system*. While we must postpone until a later time any detailed description, we ought to indicate at this point the essential contrast between the two modes of co-ordination. One part of the body may affect another through the actual despatch of material to it. When the influence is through the nervous system instead of through the circulation there is no transfer of material. The nerves were once supposed to convey a fluid of strange properties, but the fact is established that they transmit a form of *energy* and not of matter. (The temptation to think of the nerves as conductors of electric currents and to compare the nervous mechanism with a telephone system is strong. Guardedly used, the comparison is valuable, but it is a symbolic rather than a literal representation of the facts. "Nerve impulses," so called, are not electric currents in the ordinary sense.)

In a great nation the prosperity of any section must depend to a large degree upon the commercial exchanges taking place between that section and others. Its factories may depend upon the mines of another province for coal and upon still another for raw material. Much in the same way a single organ of the human body is dependent upon others. A muscle, for instance, profits by the prepared foods or fuels forwarded to it from the digestive tract and by the oxygen borne to it from the lungs. The blood in this case is serving the purpose which is effected by trains and steamers in the case of the nation. Nor do we find lacking in our illustration an analogy for the nervous communication between parts of the living body. The type of such intercourse is furnished by the telegraphic messages which pass incessantly from place to place. *News*, in itself immaterial, may affect the course of local events just as surely and much more quickly than can the material exports of another region. Reactions produced through the nervous system are correspondingly sharp and prompt in developing.

Blood and Lymph.—In the bodies of the higher animals the internal medium may be described as existing in two forms. In direct contact with the majority of the cells there is a comparatively stagnant fluid, the lymph. From this they draw their needful supplies of oxygen and food; into it they discharge their waste. The limited resources of the lymph at a given point would be quickly exhausted were it not that the blood is passing close by in vessels whose delicate walls permit the passage of material in both directions. The blood is in rapid movement and it is constantly renewing the oxygen of the lymph with fresh portions just brought from the lungs. It is at the same time receiving from the lymph the accumulated waste.

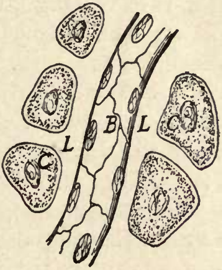

Fig. 3.—*B* is a blood-vessel of the smallest size—a capillary—with walls of flattened cells like that in Fig. 2, *d*. The blood flowing within is removed from direct contact with the cells (*C*, *C*), but dissolved substances may pass from one to the other through the capillary wall and the medium of the lymph (*L*).

CHAPTER II

THE ENERGY RELATIONS OF PLANTS AND ANIMALS

A CHEMICAL reaction can usually be assigned to one of two classes. Either it is exothermic, that is, attended by the evolution of heat, or it is endothermic, in which case heat must be supplied to cause its occurrence. When heat is evolved the products of the reaction are generally simpler and more stable than the original material. The most important reactions of this class are the oxidations. Heat, or other forms of energy applied from without, may effect the synthesis of complex substances rich in fuel value from initial material comparatively destitute of potential energy.

Broadly speaking, the constructive chemical processes in nature are the work of the higher plants. Animals, as well as those forms of plant life which lack pigment, carry on for the most part reactions of a destructive character. This makes evident the dependence of all other forms of living matter upon the pigmented plants. It is through the agency of light-waves, a form of kinetic energy, that the synthetic reactions resulting in the formation of starch and other energetic compounds are made possible. When light is excluded from the green plant it has no advantage over the animal, but pursues a similar course of decomposition. In fact, there is always going on in the plant, even when its constructive activity is most marked, an undercurrent of an opposite trend. Early writers commonly exaggerated the supposed contrast between the chemical conduct of plants and that of animals. They were disposed to deny that an animal could execute any synthesis whatever. It is true that animal cells make no useful application of the energy showered upon them by the sun's rays. Nevertheless they do carry on synthetic reactions, although to a limited extent. Since much energy is released within such cells by the prevailing oxidative changes it is not difficult to see that some portion of it may be applied to promote endothermic reactions. When a hydraulic ram supplies with water a house considerably above the level of the stream which operates the device, we understand that the result is made possible because a great deal of water falls that a little may rise. The principle of the conservation of energy is not violated here, nor is it when animal cells erect from a portion of their food molecular structures more complex and energetic than anything in their current supply. The formation of fat from sugar is a case in point. Weight for weight, the fat is more highly endowed with potential energy than is the sugar, but we must take into account the fact that the quantity of sugar entering into this common transformation is much greater than the quantity of fat which can be produced. The energy in the product is more concentrated, but not absolutely larger in amount than it was in the sugar.

There are many species of green plants which are unicellular, just as there are many single-celled animal forms. It is suggestive to consider the reciprocal relations of one such plant and a solitary animal cell living beside it. A constant and pressing need of the animal is oxygen. Now oxygen is freely produced by plants when they avail themselves of the energy of light to carry on constructive processes. To this extent, then, the proximity of the plant to the animal is advantageous to the latter. This ceases to be true when light is succeeded by darkness. The animal meanwhile is giving off oxidized products, of which carbon dioxid is the most abundant. This, together with water, is the very material out of which the plant can build its stores of starch and sugar. The output of the animal includes also various compounds of nitrogen. These, as well as the carbon dioxid, may be of service to the plant, although to be strictly accurate it must be added that they require some modification, usually effected in nature through the action of bacteria. In view of these exchanges one is tempted to the hasty conclusion that a single-celled green plant and a single-celled animal form a balanced system capable of continued maintenance—in short, a *microcosm*. There is, however, a fatal obstacle to the continuance of the partnership—the animal's need of organic food can only be satisfied by the sacrifice of the plant. To have a truly balanced system of an enduring character we must assume a multiplication of cells descended from the original unicellular plant, providing a surplus of vegetable tissue for the animal's consumption.

The give and take which has been illustrated for single cells is proceeding on a vast scale everywhere. It is hard to realize that the great harvests which support the races of mankind were formed for the most part from a gas present only very sparingly in the atmosphere, from water, and from the mineral salts of the soil. While we rely partly upon animal food (meat, milk, and eggs), this does not alter the fact of our absolute dependence upon the green plants, which in turn owe their growth to the translated energy of the sun. It is amusing to note the apparent travesty upon our human life which can be read into the contrasted conduct of green plants and of animals. The plants are conserving, while the animals are spendthrift. Plants create and distribute wealth. They seem like the thrifty and industrious members of society upon whose charity others less competent depend. One is reminded irresistibly of the parent at home and the son at college. If the father does not literally subsist upon a diet of carbon dioxid and water that the son may have protein and alcohol, the approach to a parallel is too close for complacent attention.

The Body and the Diet.—Turning now to the definite problems of human nutrition, let us consider the respective make-up of the body and the diet. There must evidently be a degree of similarity between them, inasmuch as the one has been built from the other. Similar compounds are met with in both, but, as we shall find, in quite unlike proportions. The body is mainly water. Water makes up about two-thirds of the total weight and forms even a larger percentage of the most active tissues. No material reduction of its quantity can be tolerated. Even after death from thirst the amount is surprisingly little diminished. In the diet also water occupies the first place. It is likely to constitute fully five-sixths of the daily income. Its most obvious services are in connection with the absorption of food in solution and the removal of dissolved wastes. By its evaporation from the skin and the breathing passages it helps to keep the body temperature from rising above its normal level.

Second to water among the substances which compose the body we find the group of bewilderingly complex compounds known as the *proteins.* A protein always yields the five elements—carbon, oxygen, nitrogen, hydrogen, and sulphur[1]—when subjected to analysis. Some members of the group contain phosphorus also. Merely to mention these constituent elements is to give no proper conception of the intricate manner in which they must evidently be combined. To appreciate this we need to consider the very long list of cleavage products, in themselves rather complex, which can be obtained by the decomposition of protein from a single source. The physiologic chemist is somewhat in the position of a person

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[1] The elements occur in proteins in about the following percentages: C 53, O 22, N 16, H 7, S 1 per cent. Phosphorus when present amounts to 1 per cent. more or less. It is quite impossible to convey an adequate impression of the complex fashion in which the five or six elements are combined. Many years ago the following formula was suggested for hemoglobin, the red protein of the blood, which is exceptional in containing iron:

$$C_{758}H_{1203}O_{228}N_{195}FeS_3.$$

It is not seriously maintained that these large numbers are precisely correct, but the order of their magnitude is probably typical.

who sees the various parts of a watch—the wheels, springs, jewels, etc.—lying loose upon the table of the watchmaker. He may gain a fair notion of the intricacy of the watch, though he may be very far from knowing how the parts were related in the time-piece. We do well to use the plural number in speaking of the proteins, for all recent work tends to emphasize the distinctive molecular pattern which characterizes each form and makes it differ definitely from every other. "There is one flesh of men and another of beasts and another of fishes and another of birds." This is excellent and altogether modern chemical biology. The presence of the element nitrogen in the proteins distinguishes them sharply from the other prominent compounds in both the body and its daily income. Nitrogen makes up about 16 per cent. of protein, and the value of this figure in calculations will be apparent later. It has been said that the proteins are second only to water in their abundance in the body. This is not true of the diet unless we have to do with a carnivorous animal. Among the herbivora, and almost always among men, the second place in the list of supplies is occupied by the *carbohydrates*.

Third in quantity among the constituents of the body we find in most individuals the *mineral compounds*. These would not make so large a proportion if it were not for the skeleton. Bone is a tissue in which salts of lime are abundantly present. But in all the other tissues and in the fluids too we find a variety of salts, and it is well established that their presence is not accidental, but a matter of moment. Sodium, potassium, calcium, and magnesium at least, perhaps other bases also, must be kept in certain balanced relations if the life processes are to go on. The acids represented are chiefly hydrochloric, phosphoric, and carbonic. Sodium chlorid, the one salt which we take pains to add to our food, is the one most abundant in blood and lymph. Potassium rather than sodium compounds predominate in the cells.

Next in amount to the salts in the body of average build, and not uncommonly exceeding them, are the *fats*.[1] The word "fat" is used sometimes in a chemical and sometimes in an anatomic sense. In the first case it denotes a compound of carbon, hydrogen, and oxygen, having a formula of a certain type. In the other usage the meaning is "adipose tissue," a form of connective tissue rich in such compounds. Fats have familiar physical characters. They are not soluble in water or to any great extent in the fluids of the body. They pass from solid to liquid form at moderate temperatures; the fats of the human body are regarded as in a fluid state when under the influence of its warmth. No other common physiologic compounds have so much latent energy awaiting release by oxidation. Fats are more plentiful in apparently lean individuals than might be judged. A considerable store of adipose tissue is to be found in any condition short of imminent starvation.

It has been said above that *carbohydrates* usually have the leading place among the solid matters of the diet. This is owing to the large proportion of vegetable foods generally consumed. In the animal body the occurrence of carbohydrate is rather scant, and it is one of the chief problems of the physiologist to account for the daily disappearance of a great quantity of these compounds in the economy of the organism. The reader may already foresee what we shall later explain in detail, that this disappearance of carbohydrate is due in part to the fact that it is the fuel most constantly called upon to evolve energy, and in part to the ease with which the tissues transform to fat a surplus of these substances. Under the head of carbohydrates we distinguish the starches and the sugars.

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[1] Fats are compounds which can be resolved into glycerin and organic acids. Those of chief interest in nutrition are the glycerids of palmitic, stearic, and oleic acids. The first mentioned has a composition indicated by the formula $C_3H_5(OOCH_{31}C_{15})_3$. The others are nearly related. The three common fats differ in their melting-points and in other respects. They are mingled in definite proportions to form the body fat of each animal species.

Starches[1] are of high molecular complexity, imperfectly soluble, and tasteless. Sugars are cleavage products of starches or, if they occur apart from previously existing starches, closely resemble such cleavage products. They are of definite and moderate molecular weight, they are soluble, crystallizable, and sweet. They contain the same elements which are found in fats—carbon, hydrogen, and oxygen—but the percentage composition is wholly different and the structure of the molecule also. While the carbohydrates are energetic, their fuel value is less than half that of fats.

We have now named this list of substances as uniting to form the body—water, proteins, mineral matter, fats, and carbohydrates—the order suggesting their relative abundance. We have said that in the diet water also takes the first place, but that carbohydrates ordinarily take the second. Either proteins or fats may stand third among the constituents of the diet. Often the amounts of the two are found to be about equal. A possible diet comprises 100 grams of protein, 100 grams of fat, and 250 grams of carbohydrate, illustrating this equality. The mineral matter in the ration is not likely to exceed 20 grams a day. Both the body and its income, of course, contain in small amounts substances which do not fall into any of the classes named. Such miscellaneous organic compounds are conveniently grouped as *extractives*. Many of them are nitrogenous and represent disintegration products of proteins. Reference to their significance will be made from time to time.

At the very outset the double service of food to the

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[1] The three elements in starch are present in proportions represented by the formula $C_6H_{10}O_5$. But the number of atoms in the molecule is not correctly indicated by this formula; it requires to be multiplied throughout by an unknown, but considerable number. Sugars are of two common classes: the disaccharids, with the formula $C_{12}H_{22}O_{11}$, and the monosaccharids or hexoses, with the formula $C_6H_{12}O_6$. Cane-sugar, malt-sugar, and milk-sugar are disaccharids. The hexoses of direct interest in nutrition are glucose (also called dextrose), fructose (or levulose), and galactose (a derivative of milk-sugar).

organism was indicated. It represents both building material and fuel. If we liken the living body to a power-house, we see clearly how both kinds of supplies are required. Coal is the most bulky supply of the power-plant and the one on which its operation most immediately depends. But there must also be new parts to replace those which wear out. The up-keep of the building calls for new wood-work, for paint, etc. A certain difficulty is encountered in the attempt to show parallel conditions in the case of the body because the separation of the two functions is here much less sharp. Protein food, on the whole, has a peculiar title to be regarded as building material, but it is also an entirely available fuel. It is as if planks and beams designed primarily to repair the structure of the power-house were fed into its furnaces. The suggested comparison must not be pressed too far, for it conveys an impression of wanton destructiveness which we cannot assume to be just in the case of the organism. There are some minor supplies brought into the power-house which are not fuels nor precisely materials for repair. The oil is an example. Some of the extractives of the diet occupy an analogous position, being neither sources of energy nor of construction, but nevertheless favorably affecting the course of events. This comes near to our conception of a *drug* in relation to the processes of life.

CHAPTER III

THE NATURE AND THE MEANS OF DIGESTION

It has been said that one of the results of the specialization of cells is the loss of the primitive power to receive and utilize all kinds of food. The blood brings to the tissues of the body food of certain standard forms, and it is only these which can be used. The attempt to add various soluble foods to the blood by direct injection into the circulation has shown that in most cases such foods are offered in vain to the living cells. Milk introduced in this way is not a practical means of nutrition. Cane-sugar added in measured amounts to the blood is excreted promptly and in almost undiminished quantity by the kidneys. Thus it becomes clear that foods introduced directly into the blood are frequently treated like waste products, while the same foods after transformation in the alimentary canal are entirely acceptable to the body cells. The function of the alimentary canal is to work over the many foreign forms of nutriment into a few forms of the native type. From day to day the diet may be of quite variable character, but its variations hardly show themselves in the composition of the blood.

The term *digestion* is usually applied to those changes in the food-stuffs which precede absorption. To cover subsequent changes we use the word *metabolism.*

One of the more evident characteristics of digestion is that it is a refining process. It effects a separation of the useful and the useless portions of the ration. This is a very conspicuous fact with the herbivora, whose food contains much woody material from which the available nutriment must be laboriously extracted. With mankind, especially under modern conditions, a great part of this work of separation is accomplished in the preparation of food, both industrial and domestic. In this way the task of the digestive organs is lightened, and, as we are often told, overeating is made easy. Some foods are quite devoid of residues when successfully digested and absorbed.

The early writers, having little knowledge of chemistry, were naturally led to make much of the mechanical reduction of food in the alimentary tract. Mastication subdivides the food, and it was held that the later operations, especially those of the stomach, were essentially further grindings of a similar sort. Such mechanical processes as do occur continue to be of interest, but they are now seen to be preliminary to actual digestion. Moreover, we shall see that it is easy to assume that they are of a more positive nature than is really the case. The human stomach is not a mill, though the gizzard of a bird may be fairly described by that word.

In the eighteenth century the emphasis passed from mechanical factors to the process of dissolving the food. Solution is plainly one of the features of digestion, but it is a somewhat superficial one. Of course, it is natural to believe that solid food must become liquid before it can penetrate the intestinal wall, but mere solubility, as we have already seen, is not a guarantee of fitness for the use of the cells. Freely soluble foods like cane-sugar and milk-sugar require to undergo digestive changes just as definite as those carried out in the case of fats or coagulated proteins. It is often stated that the object of digestion is to produce diffusible substances. This statement is inadequate, for diffusibility like solubility does not in itself determine the utility of a food. The sugars mentioned above are sufficiently diffusible, and the changes which they undergo before absorption serve a more fundamental purpose than the mere hastening of their passage through the lining of the intestine.

In the light of modern chemical knowledge we can be somewhat specific in regard to the molecular aspects of the digestive processes. They are probably always *cleavages*, large molecules giving rise to smaller. When the original molecule is of extraordinary size, as with proteins and starches, these cleavages have a serial character and a number of intermediate products must accordingly be formed. That is to say, the earlier products are in turn subjected to digestion. Such cleavages are generally, if not always, *hydrolytic*, that is, water enters into the reaction and its elements are found combined in the products. For the simpler instances of digestion, as in the case of fats and of the disaccharids,[1] we can write precise chemical equations. We cannot do this with the same accuracy for the starches, and we are still farther from being able to express the exact manner in which the protein molecule undergoes hydrolysis. Yet we have sufficient evidence that the digestion is generally of a uniform type.

Some constituents of the diet need no digestion. This is the case with the mineral salts, so far as they are absorbed, with the simple sugars (monosaccharids), and with alcohol. It is hardly necessary to say that water is also ready for reception into the body fluids. The numerous extractives are for the most part absorbed in the form in which they are eaten. A diet entirely predigested seems not to be practicable. If one were prepared it would have to contain advanced decomposition products of the proteins, which are bitter to the taste, and an amount of sugar which would be cloying and subject to fermentation.

Digestion is anticipated to some extent by changes in our food which precede its actual arrival in the canal. The ripening of fruits and vegetables, as well as the corresponding processes in meat, illustrate this point. The influence of cooking is not so constantly of a sort to initiate digestion, yet in many instances it is so. For

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[1] The following equation illustrates the hydrolysis of a disaccharid:

$$C_{12}H_{22}O_{11} + H_2O = 2C_6H_{12}O_6.$$

This means that one molecule of malt-sugar, reacting with one molecule of water, gives rise to two molecules of glucose.

example, when meat is boiled the common variety of connective tissue in it is converted to gelatin. This change is a typical hydrolysis, and if it were not executed in advance it would be an early task of the gastric juice. When cooking is attended by considerable drying of the food it is less likely to count definitely toward digestion. Most proteins are coagulated by heat, and this change to solid form seems opposed to the general course of events in the alimentary system. The action of microscopic organisms upon food substances is in line more or less with normal digestion; the maturing of cheese is an example. But bacterial action may depart so far from the normal decomposition as to generate products of strongly poisonous properties, the so-called *ptomains* being among them.

The Means of Digestion.—Hydrolytic cleavages closely resembling those of animal digestion may be caused to occur in various ways. Boiling food-stuffs with acids accomplishes this. So does treatment with alkalis. Similar results follow the application of superheated steam. But the striking fact is that such changes as are brought about in the laboratory by violent reagents, high temperatures, or both in conjunction, are caused to take place in the stomach and the intestine by bland juices acting at the mild temperature of the body. The changes effected by these juices are often modified by the simultaneous activity of bacteria, but the presence of the latter is to be regarded as accidental and non-essential.

The power to digest foods has been known for a long time to reside in the secretions which enter the alimentary tract. It was at first necessarily estimated simply by observing the progressive solution of solid food. The intimate nature of the process has become appreciated more recently. Comparison of the juices from different sources shows that they are individual and specific to the extent that each one, as a rule, acts upon certain classes of food and not on all. There is sufficient evidence for the belief that when a juice digests two or more classes of food-stuffs it contains separate and distinct reagents for the performance of each line of work. We do not know the precise chemical nature of the active bodies, "digestive principles" as they were formerly called, but we know a great deal about the conditions of their working.

When a digestive secretion has a single well-marked effect upon one sort of food material we say that it contains an *enzyme*. We are thus naming a body which we know chiefly by its power to promote a certain chemical reaction. It is not many years since an able writer protested against this confident reference to a *substance* where it is a *property* rather than a compound which we are observing. It will be admitted that it is doubtful whether anyone has ever seen that which is an enzyme and nothing else. What we see and handle are solutions possessing characteristic powers or dry preparations capable of furnishing such solutions. But it has seemed altogether reasonable to connect the property with a substance and we shall continue to do so. Acting on this basis, we say of a juice which hydrolyzes starch that it contains a *diastatic enzyme*, and of one that acts in a parallel fashion on proteins that it contains a *proteolytic enzyme*. When the action is upon fats we call the enzyme *lipolytic*, or, using the substantive, we call it a *lipase*. It is unfortunate that there is much confusion at present in the use of such terms; there are a great many more in use than there need be. The simplest plan is, perhaps, to fall back upon our Saxon and speak of enzymes as starch-splitting, protein-splitting, sugar-splitting, and fat-splitting. We shall take pains, however, in our detailed discussion to introduce various equivalent terms. We shall find especially that enzymes are often named with reference to their sources as well as to their powers.

Enzymes are similar in many respects to the catalyzers of inorganic chemistry. Their presence accelerates reactions which in their absence might not be appreciable. We do not think of them as contributing either material or energy to the process. They suggest the oil in a machine which lessens the resistance of its parts to the driving force.

The enzyme in a digesting mixture is not forcibly compelling the molecules to disintegrate, but it is removing some hindrance to their spontaneous rearrangement. It is not definitely used up in this service. Accordingly, it follows that a limited quantity of a digestive juice, of course, containing a still more limited quantity of enzyme, may be responsible for an amount of digestion practically unlimited. Unlimited time would be demanded for such a demonstration. (This form of statement should be qualified. Enzymes are somewhat unstable and liable to deteriorate.)

When a process of hydrolysis takes place under the influence of an enzyme and in a glass vessel, there must be a rising percentage of the products and a declining percentage of the initial substance as the reaction goes on. The velocity of the transformation is found to diminish and at last it seems entirely arrested. A mixture now exists which contains the first and the last members of the chemical system in proportions which have become constant. It is an instance of chemical equilibrium. The halting of the reaction does not mean that the enzyme is exhausted. If any means can be devised by which the accumulated end-products can be removed the hydrolysis will be continued. It was specified above that the trial should be made in a glass vessel. The reader will quickly recognize the important difference between such a container, from which nothing can escape, and the alimentary canal, from which active absorption processes withdraw the products of digestion. A clear field is thus provided for the continuance to substantial completion of the reactions which the enzymes are promoting. The contrast between laboratory conditions and those which prevail in the body did not escape the acute mind of Spallanzani, who was a pioneer among students of these matters. As early as 1777 he recorded that the solution of meat by gastric juice could be greatly facilitated by letting the digestive fluid fall drop by drop upon the food and to trickle away, bearing the dissolved products.

Enzymes are exceedingly sensitive to varying degrees of acidity and alkalinity in the medium. Most of them do not keep their efficacy if the solution is far from the neutral point. But they are somewhat individual in this as in other properties, the acid which is highly favorable for gastric digestion, for example, being quite prohibitive of salivary action. They are all destroyed when in solution by temperatures somewhat short of boiling. Cold suspends their activity, but does not prevent its return upon warming. They are most effective at a temperature not far from that of the blood, though in general a few degrees higher. These relations between the enzymes and temperature are much like those established in the case of the simpler living forms. Having this in mind, one easily adopts the common practice of speaking of the *killing* of enzymes by heat. It must not be forgotten that this is a figurative expression. We are not justified in thinking of enzymes as living. Living organisms when they grow and multiply in a nutrient medium may decompose it much as suitably assorted enzymes would do, and, in fact, the organisms in question are probably producing their own enzymes for the purpose. Formerly such living things as the yeasts and the bacteria were described as "organized ferments," and the detached enzymes, incapable of self-multiplication, were called "unorganized ferments." These terms are not much used at the present time. Enzymes are assumed to be products of living cells and may be very characteristic fragments of the cell's fabric, but they are not independently living.

The digestive changes to which we pay most attention are those which occur in the cavity of the alimentary canal, and which can be observed to take place also when the same mixtures are placed in the flasks and test-tubes of the laboratory. But we must not overlook the probable fact that similar changes are constantly occurring within the boundaries of every active cell. *Intracellular digestion*, presumably made possible by intracellular enzymes, obviously takes place when a protozoan cell engulfs a solid food particle, and is probably just as definite a process when a muscle-fiber of the human body nourishes itself at the expense of the surrounding lymph. We owe to the German chemist, Abderhalden, the clear exposition of this second digestion, which is an essential feature of the life-processes of the higher animals. We shall recur to the subject in treating of protein metabolism.

While the great majority of enzymes are hydrolytic and favor reactions of the class which we have been discussing, it must be added that there are other enzymes associated with other orders of chemical change. Enzymes which promote oxidations are believed to play a most important part in the activities of the tissues. When reactions are hydrolytic they proceed with but little evolution or absorption of heat. When they are oxidative the release of energy is a most characteristic attendant condition.

CHAPTER IV

THE WORK OF MUSCLES AND GLANDS

We cannot enter upon a description of the alimentary canal and its activities until we have devoted some space to the physiology of *contraction* and *secretion*. Movement is the most familiar manifestation of animal life. When visible to the naked eye it is the expression of the shortening of elongated units—cells or fibers—associated to form contractile tissues. In the human body there are three principal kinds of these tissues. The obvious external movements of the limbs and the features, the act of breathing, etc., are produced by what we call the skeletal muscles. Contractile tissue of another order forms the walls of the heart and furnishes the power for its beating. A third kind occurs in the walls of the alimentary tract, in the blood-vessels, and elsewhere.

The term *skeletal* applied to a type of contractile tissue implies relationship to the bones. It is easy to see that external movements are made effective through the connection of the muscles which produce them with bones acting as levers. In some instances the term is a misnomer, for there are some small muscles histologically like the rest which do not act upon bones. This is clearly the case with the ring-like band which surrounds the mouth and by its contraction puckers the lips as in whistling. The large and conspicuous muscles are attached, usually at both ends, to the bones. We can generally observe that one end is more freely movable than the other. The comparatively fixed end is called the *origin* of the muscle, the end more subject to movement is its *insertion*.

What is called a skeletal muscle is a bundle in which we can distinguish an active and a passive part. There are the true contractile elements and there is the *connective tissue.* The inactive substance forms a sheath enclosing the rest and also partitions which subdivide the interior. The arrangement is familiar in the cross-section of a piece of meat. The subdivision which is apparent to the unaided eye is repeated on a microscopic scale until the finest meshes of the connective tissue enclose the hair-like individual fibers of the muscle. Each of these slender fibers is a miniature muscle in principle. The function of the connective tissue is often overlooked. While this part of the muscle is entirely passive in character, and scarcely to be considered alive excepting for a certain power of renewal after injury, it is quite necessary to the act of contraction. It may fairly be said to constitute a harness through which all the numberless, minute contractile elements are enabled to unite their efforts. As the end of a muscle is approached the connective tissue increases in quantity at the expense of the typical contractile material. In most cases there is an extension of the muscle consisting of connective tissue only, and in a dense form, which attaches the whole to the bone. This is the *tendon.* It may be a long tough cord or it may form a wide thin sheet. A muscle deprived of its connective tissue would be simply a mass of unattached living fibers which might slip about among themselves, but which could not apply their combined tension to accomplish any external effect.

The fiber of skeletal muscle is a modified cell. Its length is exceptionally great for its width, perhaps a thousand times as great. When it shortens it conforms to the general principle laid down in Chapter I, that is, it does not diminish in volume, but only in surface and, therefore, in length. How the chemical process which underlies the forcible shortening is made to contribute energy to carry it out has proved one of the most difficult problems of physiology. It cannot be dealt with here. But the fact is to be emphasized that we are in the presence of a mechanism somewhat like the steam-engine, inasmuch as it produces motion and does physical work at the cost of fuel destroyed. The resemblance goes farther than this, for both with the engine and with the muscle the accomplishment of a measured amount of work is attended by seemingly wasteful evolution of heat. An engine is considered economical if it turns 15 per cent. of the energy resident in its fuel into horsepower. Muscles sometimes do better than this, but much of the time they are even less efficient. It is fair to point out that the heat set free as an accompaniment of muscle contraction is often of value to the animal. In our own case the temperature of the body must be kept above that of its usual surroundings. By far the largest part of the heat devoted to this maintenance of a relatively high body temperature is produced in connection with muscular activity. Muscles are thus seen to be organs of heat production as well as organs to carry out movements. When the external temperature is high or the degree of muscular contraction is greatly above the average, the heat evolved does become distinctly an embarrassment to the organism.

The source of the energy displayed in muscular activity is chiefly the disruption of carbohydrate molecules. Sugar appears to be the preferred fuel of the muscular machine, though other foods are known to be available also. When sugar is completely oxidized the only end-products are carbon dioxid and water, the same substances which would be formed by the literal burning of the sugar with an adequate supply of oxygen. These waste-products are very readily removed from the muscle, when its situation is normal, by the circulating blood. The carbon dioxid will almost immediately escape from the blood when it passes through the lungs. The water becomes part of the large total volume which is always passing into and out of the body, and may leave by all the main channels of excretion—the respiratory passages, the kidneys, and the skin. It will be noted that the quantity of water leaving the body is constantly in excess of the income. Ordinarily the body excretes all the water which it receives plus the water which arises within it by oxidation.

A distinction must be borne in mind between the compounds which for the most part make up the muscle and those substances which it is generally found to use as sources of energy. The muscle is mainly composed of proteins. But, as just stated, it is most apt to destroy carbohydrates when at work. One is reminded of the fact that a steam-engine is composed chiefly of steel, but burns coal as its fuel. The comparison is somewhat faulty, however, for it suggests a more radical difference between structure and fuel than we can safely infer for the muscle. Under some conditions muscular work may involve some destruction of protein material.

All that has been said of contraction up to this time applies equally to all three classes of muscle. Nevertheless each type is adapted to its particular work by peculiar properties. Skeletal muscle is capable of quick shortening and prompt relaxation. A contraction may occur and the return to an extended condition be accomplished in one-tenth of a second. The trained finger of a pianist may strike a key ten times in a second. Such movements are in strong contrast with those executed by the form of muscle found in the viscera. The contractions of the stomach develop very slowly, are maintained for some time, and are correspondingly slow in fading out. Of course, it is true that skeletal muscles may also make prolonged contractions, as in keeping the body erect, carrying a suit-case, and in countless other instances. Experimental study has shown that such contractions as these are really compounded of successive brief twitches occurring too rapidly to permit relaxation. In view of this the possibility of having prolonged contractions in skeletal muscle does not invalidate the statement that it is essentially a quick-acting tissue.

Muscle and Nerve.—The conception that muscular activity is due to the nervous system is probably sufficiently familiar. Every skeletal muscle has its own strand of nerve-fibers placing it in connection with the brain or the spinal cord and under their control. If its connection is severed it becomes paralyzed and remains inactive, unless special local means, like electricity, are employed to excite it. Ordinarily we are justified in saying that skeletal muscle is *not automatic,* meaning that every movement which it makes is an indication of a previous act, or, as we say, a *discharge* on the part of the nervous system.

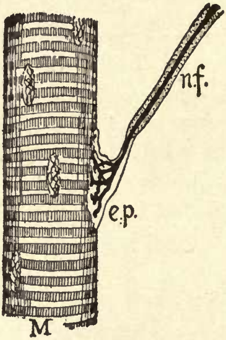

Fig. 4.—The above represents somewhat diagrammatically a very small fraction of the length of a fiber of skeletal muscle. To include the entire element with the length proportional to the width we should have to extend this drawing to a length of several yards. The fiber is cylindric and enclosed by a more definite membrane than is usual with animal cells. The cross-marking is not a feature of this membrane, but stands for a peculiar organization of the protoplasm inside. Nuclei are seen here and there near the surface. The segment shown is supposed to be the particular one about in the middle of the fiber within which falls the connection with the nervous system. A nerve-fiber (*n.f.*) is seen making a junction with the muscle-fiber (*M*) through the so-called end-plate (*e.p.*).

In somewhat sharp contrast is the behavior of the muscle composing the heart and of the form which is found in the viscera. These two kinds of contractile tissue are described as *automatic,* in the sense that they show a tendency to rhythmic contraction and relaxation even when deprived of their nervous connections. The automatic property of the heart is the cause of its beating.

In varying degrees the different portions of the alimentary canal exhibit the same power, not ceasing to shorten and to extend when observed entirely outside the body of the animal. While we emphasize this remarkable tendency to rhythmic activity, we must hasten to add that tissues showing such capacities are nevertheless subject to some nervous control. Thus the heart beats primarily because of the peculiar nature of its own substance, but variations of rate and strength are constantly occurring as a result of the influence of the nervous system. In this connection it must be pointed out that such influence is not necessarily so applied as to excite increased activity, but may be *inhibitory*, that is, reducing the rate and force of the spontaneous contractions. A large place is now given to the inhibitory functions of the nervous system, and we shall meet with other examples of the restraint which it imposes upon various organs. A little reflection makes us realize that much of the highest work of the brain must be in the line of inhibition. A man is distinguished by the acts from which he refrains quite as much as by those which he performs.

Muscular Tone.—It will be well before we go farther to make clear what is meant by tone (tonus, tonicity) in connection with the behavior of contractile tissues. Muscle is said to exhibit tone when it is not completely relaxed. Tone is thus a mild, sustained contraction. It seems rarely to be absent altogether, but may vary much in degree. Tone in the skeletal muscles gives them a certain firmness and maintains a slight, steady pull upon their tendons. This is not likely to result in actual movement, because these muscles usually fall into antagonized groups, one of which opposes another. A heightened tone in the muscles of the arm may not change its position, since the force tending to bend it may be offset by an equal tension adapted to straighten it. Changes of tone in the walls of the hollow viscera, as the stomach, have a much more evident effect, since they alter the size of the cavity. One must discriminate carefully between stretch-ing and tone change in such a case. A non-living, elastic sac may be distended by increasing its contents, but will react with a pressure proportional to the distention. A living organ which adapts itself to increased contents by a diminution of tone may exert no more pressure when full than when nearly empty. This principle is well illustrated by the urinary bladder. At one time this organ may have a capacity of a pint, and again its cavity may be nearly obliterated, but there is no strict correspondence between its size and the internal pressure. Indeed, a strong degree of tone and a high pressure may exist when the bladder is quite small.

Glands and Secretion.—We have taken time and space to deal with the elements of muscular activity, and we must also give a place to another type of tissue and to its work. Some appreciation of the physiology of glands is as much a prerequisite of the study of the alimentary process as is a knowledge of the mechanism of contraction. Everyone understands that the nervous system throws the skeletal muscles into their orderly activity, but the fact that the secretions of the body are often produced under nervous influences is not so familiar. Yet we do not have to look far for suggestive examples. The flow of tears as an accompaniment of an emotional experience is clear evidence that the small organs above the eyeballs which elaborate the tears are in connection with the brain and responsive to its changing conditions. A like relationship can be demonstrated for the glands that produce saliva and for those which secrete sweat. Secretion and contraction are two manifestations of metabolism which are alike regulated by the nervous system. In fact, it is doubtful whether we have any other expression of the working of the nerve-centers than these two, the phenomena of consciousness being set aside for the present.

What, then, is a gland? The word is used sometimes to designate a large organ like the liver, the pancreas, or a kidney. Sometimes it is used with reference to a microscopic affair like an individual sweat-gland or one of the minute pits in the inner surface of the stomach or the intestine. The fundamental structure is the same in both classes. The microscopic gland is a depression of a cellular surface—a pocket, one might say—out of which when it is active the secretion wells. The cells which bound its cavity are the producers of the secretion, and are in turn dependent for renewal upon the lymph which underlies them and the blood which is flowing close by. A superficial view would suggest that such a gland is a filtering device adapted for straining off certain portions of the blood. This is, however, an entirely inadequate con-

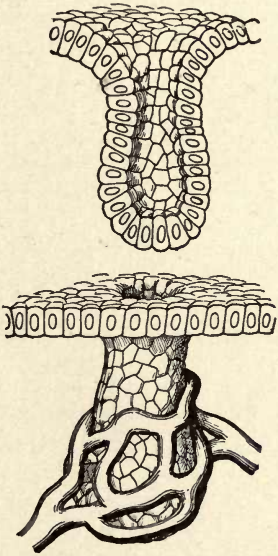

Fig. 5.—The principle of glandular structure. In the upper figure a simple microscopic gland is supposed to be laid open by a section along its vertical axis. The cells are seen to surround a recess into which they discharge their secretion. Below, the same structure is shown in its entirety, and in addition the encircling blood-vessels which contribute to make good the losses suffered by the secreting cells.

ception. Most secretions contain substances which were not present in the blood at all, and which must, therefore, have been elaborated by the cells of the gland. When we remember that the same blood flows through all the glands we cannot fail to be impressed by the variety of the products which are made from the same raw material—products as unlike as milk and bile, urine and saliva.

A compound gland, like the pancreas, is an aggregate of numberless units, which are individually like the simple microscopic glands. Within the meshes of an abundant supporting tissue which is shot through with blood-vessels are these small pockets walled around with the characteristic cells of the gland. These ultimate recesses are called *alveoli* or *acini*. Each has a way open through which its liquid product may move toward an outlet. Usually there is a single main *duct* formed by the union of all the fine passages from the alveoli and bearing their combined contributions. A compound gland may have more than one duct. Glandular secretions may be discharged directly upon the surface of the skin, as in the case of the sweat, or they may enter cavities, as happens with the gastric juice, the pancreatic juice, and the secretion of the intestinal lining. The bile and the urine are two secretions which accumulate temporarily in special containers, the gall-bladder and the urinary bladder respectively, before they reach their final destination.

Internal Secretions.—It may not be premature to add at this point that any organ may yield some peculiar product of its own life process to the lymph or to the blood as well as to the cavities of the hollow viscera and to the exterior of the body. A product of this kind which merges with the circulating medium instead of appearing distinct and separate from it is called an *internal secretion*. One may maintain that every organ has such a secretion, for inasmuch as each has its unique chemical composition and its distinctive metabolism, it must give to the blood compounds which no other organ duplicates. As stated before, the actual make-up of the blood is the resultant of the action of all the tissues upon it. But we shall find that internal secretion is a function much more clearly attributable to certain organs than to others and most evident in connection with a few small structures like the thyroid and the adrenal, to which later reference must be made. To have an internal secretion an organ need not be a typical gland. No duct will be required to carry such materials as its cells turn over to the blood-stream. In some cases organs believed to work along these lines are spoken of as *ductless glands*. A word recently introduced as an equivalent of the term "internal secretion" should be given. It is the word "hormone," meaning a chemical messenger, a very convenient and suggestive expression.

Absorption and Secretion.—Gland-cells have been said to draw upon the blood or the lymph for their raw material and to manufacture their secretions therefrom. In this process something enters the deeper boundary of the cell layer and in a more or less transformed state it is later discharged from the exposed surface. It is helpful to compare this operation with what takes place in the intestine when the products of the digestive cleavage are being removed to the circulation. When absorption is going on it is the exposed ends of the cells which receive dissolved substances and their deeper borders which are discharging to the fluids that underlie them. Such a process has been well called "reversed secretion," and there is the same possibility of an extensive making over of the transferred material in this case as in the other. In other words, the digestive products which are last detected in the intestine are not necessarily those which will be dealt out to the blood by the cells of the absorbing membrane. Both secretion and absorption are phenomena which can be completely carried out only by *living* cells. Each is probably promoted by a definite application of energy on the part of the cells concerned. In either case it is possible that there may be some transfer of material through the clefts *between* the cells as well as through the cell bodies.

CHAPTER V

REFLEX ACTION

In the previous chapter it was pointed out that all the work done by the skeletal muscles is in response to the discharges of the central nervous system. For the other types of muscle—the cardiac and the visceral—it was shown that there is an inherent tendency to rhythmic activity, but that over these tissues also the nervous system exercises a regulation. Finally, it was stated that the glands likewise are subject to central government, although not to the same degree in all cases. We must now proceed to consider how the nerve-centers are themselves prompted to throw muscles and glands into action.

As we observe the body at work we cannot fail to be impressed with the timeliness of its adjustments. It is constantly meeting with emergencies and adapting itself to new conditions. If we are inclined to attribute all these quick adaptations to intelligent choice of courses to be pursued we shall find that we cannot long defend such an explanation of the facts as they occur. We cannot pretend that we think of each inequality of the pavement as we cross the street, or of each individual in the crowd through which we make our way. The balancing of our bodies, standing or walking, is not a matter about which we are given to deliberating. These things seem to take care of themselves. It is such adjustments which " seem to take care of themselves " that are called *reflex actions.* A reflex is an adaptive change to meet some new external condition brought about through the agency of the central nervous system. We may or may not notice the occurrence of a reflex. If consciousness is at all involved, it is incidental and not causal. Often the conscious effort is rather to prevent the reflex from taking place, as is apt to be true when we sneeze. Of some reflexes we are quite unlikely to be aware; this is the case with the narrowing of the pupil in response to increase of light.

Let us now go into some detail and analyze carefully the reflex process. We have seen that the primary cause is an external change of some sort, the word "external" meaning outside the central nervous system and not necessarily outside the body. The change which is at the root of the reflex is usually referred to as an external stimulus. It would be easy to give a long list of examples. A foreign particle comes in contact with the larynx; its contact is the stimulus which develops the coughing reflex. Slight drying of the exposed surface of the eyeball is a common cause of the winking reflex. Irritation of the lining of the stomach is the most frequent of the many possible stimuli through which vomiting can be excited.

External stimuli would fail of any extended effect if it were not for the nervous connections of the parts affected. In the last chapter the nervous system was spoken of as sending its impulses out to muscles and glands. But its work is twofold. It not only acts, but it is acted upon. Its fibers fall into two classes, those which are concerned with transmission of effects *outward* from the brain and the spinal cord, and those having the opposite function, the carrying *inward* of impulses started by external causes. The first class of conductors are usually called *motor;* the second, *sensory*. Both terms are open to objection, as a little consideration will show. The effects which the nervous system produces in the tissues of the body are not solely movements. The word "motor," then, is not inclusive enough. It is better to substitute the word *efferent*,[1] which means simply centrifugal, and which implies nothing whatever about the nature of the responses evoked. Efferent fibers may be motor, that is, exciting contraction, but they may also inhibit contraction, and

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[1] *Efferre*, to bear away.

when they end in connection with the cells of glands they may be *secretory*. Probably also they may inhibit secretion.

Just as we have found the word "motor" inadequate and have agreed to replace it by "efferent," so the word "sensory" does not properly indicate the whole service of the fibers which bear impulses toward the brain and cord. *Sensory* implies "productive of sensation," and we cannot assign such a property to all the two million fibers which assail the centers with their communications. In the great majority of cases we do not feel any consequences of their activity. The term *afferent* is free from this objection and is the logical complement of *efferent*. If one hastens to ask what is the significance of afferent fibers which do not arouse sensation, the answer is simple and definite: They produce reflexes.

If the first element in the reflex process is the application of an external stimulus, it is now clear that the next element is the *afferent transmission* of the impulses. What these impulses are cannot be discussed. It should be recalled that they are not fluid pulses nor electric currents in the usual sense of the expression. They represent energy of some kind in rapid, but not immeasurably rapid, motion. They pass along the nerves at rates in excess of 100 feet in a second, so that the longest paths in the human body are traversed almost instantaneously. The time used in such transits might be quite appreciable if we could observe it closely in a whale.

When the afferent impulses reach the central nervous system the third event in the development of the reflex act occurs. This is localized in the brain or the spinal cord, and we may speak of it as "a central process" without committing ourselves as to its exact character. What we actually observe is that the arrival of the afferent impulses is followed by the appearance of efferent ones. It is not necessary to decide whether these efferent impulses are the same currents which just entered the intricate fabric of the central organ and which have found a path open through its mazes which has led them out again. That is one way of picturing the phenomenon. According to the older and more familiar view the impulses which come out are not those which went in, but a new set generated by an energetic metabolic process, a *discharge* on the part of cells in the brain or the cord. If this is the true conception the afferent impusles serve to "touch off" irritable nervous elements, much as these elements in their turn may touch off muscle-fibers or gland-cells.

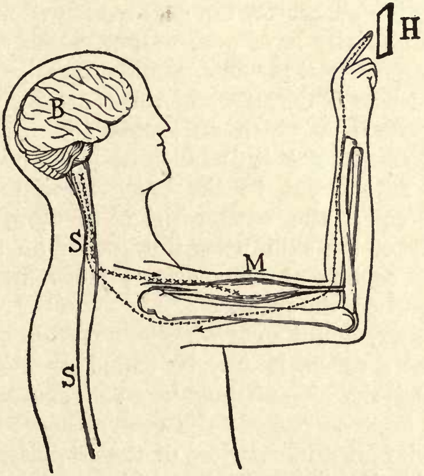

Fig. 6.—The principle of reflex action. The subject touches a hot object (*H*). Afferent nerve-impulses travel the route marked by dots and dashes to the spinal cord (*S*). Efferent impulses return promptly along the route marked by little crosses to the muscle (*M*), which co-operates with others not shown to withdraw the finger from the stimulating surface. The situation of the co-ordinating center is left undetermined, whether in the brain or the cord.

The fourth step in the evolution of the reflex is the *efferent transmission.* This may be said always to be more voluminous than the afferent flow which went before. Impulses go out by many channels, where but few were engaged in bringing them in. A great characteristic of the "central process" is the spreading of the initial stimulation, so that there seems to be no proportion between the cause and the response. The number of nerve-fibers which can be excited by the slender proboscis of a mosquito as it pierces the skin of a sleeper must be very small. The reflex movement which results may involve a very large share of his skeletal muscles.

The fifth and final occurrence completing the reflex is the reaction on the part of the muscles or the gland-tissue in which the efferent fibers end. As already indicated, this may be a movement, an outpouring of secretion, or it may have a negative character, the suppression of movements that would naturally have occurred, or possibly the withholding of some secretion which would otherwise have been discharged. The illustrations of reflex action most often chosen are those in which an immediate, even abrupt, response is seen. Yet it is quite easy to find examples of gradual adjustment to the new external condition. Changes of color, the outward sign of changes in the blood-supply of the skin, when they occur on account of warming or cooling of the surface, are reflexes of this prolonged and gentle order.

If there is any doubt as to whether a certain action is to be classed as a reflex, it may be tested according to the foregoing analysis. There must be an assignable stimulus, external at least as regards the central nervous system, there must be an afferent flow of the impulses resulting from the stimulation, a process within the bounds of the central axis, a return flow of impulses in multiplied volume, and the action itself. The more one thinks of the common course of events, the larger the number of actions which he finds he can place in this class. It becomes appropriate to ask what kinds of bodily activity are outside this department. To this question it can be replied that *automatic* actions, such as the beating of the heart, are to be distinguished from reflexes. The nervous system is not required to maintain the heart-beat. There are cases also in which the chemical composition of the blood reaching the centers modifies their behavior and causes them to send out certain impulses. Such cases do not fit our description of the reflex, since in them the stimulation is applied centrally and no afferent nervous mechanism is needed. Our breathing movements are determined to a great extent by such chemical conditions, but it is a fact that reflex disturbances of the breathing are so prevalent that it is often difficult to give just recognition to the two factors.

We are accustomed to contrast sharply actions which are reflex with those which we regard as strictly voluntary or deliberate. The distinction is a convenient one and not generally productive of confusion, but sometimes it becomes quite difficult to draw the line. It may be urged that all our conscious, intentional acts are performed in answer to external conditions which have risen to make an occasion for such new adjustments. So it might be argued that the writing of a word from a copy should be considered a reflex in which the retinal image of the copy furnished the external stimulus. Such images printed upon the retina of the trained pianist by the notes that are before him cause his fingers to drop upon the corresponding keys of the instrument. It may be claimed that this is a reflex action. Without denying the force of such reasoning, we shall do well to restrict the term to the class of responses for which we are quite sure that attention is unnecessary, and usually to those for which we have an inborn or at least a very early developed capacity. When we ask ourselves whether any act is really other than the result of external circumstances affecting an organism with its own past history registered in its structure, we find, almost with a shock, that we are face to face with philosophic and ethical problems, responsibility and free will. Most of us like to believe that a place is to be reserved for a type of action, even though it may be rare and slight, which is not externally caused.

The great difficulty encountered by the beginner in physiology lies in the attempt to realize the inevitable character of reflexes and their structural basis. He finds it hard not to read conscious purpose into acts which so constantly prove advantageous to the individual. When a frog adroitly catches a fly it is natural to assume a desire and a design on the part of the frog. Scientific analysis nevertheless makes it appear far more probable that the fly is entrapped because the frog is a mechanical device adapted to do this thing over and over again. The eye receives the flitting shadow of the insect, the stimulus excites the brain, and the well-directed fling of the tongue follows. The reflex is not done away with when the part of the brain most likely to stand in relation to consciousness has been destroyed. We have to remember that much of the service of the eye is subconscious, as when it makes us turn aside from obstacles in our path. It is in this way that the eyes of the somnambulist assist in guiding his movements. Conscious attention is no more essential to such a use of the eyes in the waking than in the abnormal sleeping state. In fact, close attention to the balancing of the body is quite as likely to derange as to promote the reflex adjustment.

Central Resistance.—Reflexes are not obtainable with the same ease at all times. We express this fact by saying that there are variations of resistance in the central nervous system. If reflexes are hard to bring about, we say that the resistance is high; if they occur with unusual freedom and seem disproportionate to the exciting stimuli, we say that the resistance is low. Narcotics and anesthetics are said to raise the resistance, and their effect can be gaged by observing the degree of difficulty with which certain reflexes can be produced, or whether, indeed, they can be produced at all. Drugs of an opposite order, the true stimulants, make it easy to call out most reflexes. When one is distinctly under the influence of coffee, a noise may cause one to start, with a sharp contraction of many muscles. The auditory stimulus has an undue effect, and it is natural to assume that the conditions in the brain and cord are uncommonly favorable to the penetration and to the multiplication of nervous impulses. In poisoning by strychnin such an extension of conduction may exist that some trifling cause may precipitate a terrific and exhaust-ing convulsion. Clearly, then, a certain degree of central resistance is the most favorable condition for the activities of life. Any increase will tend to prevent needed adaptations to external changes, and any great decrease will make the reflex responses exaggerated, disorderly, and ill suited to their object. There is reason to suppose that the more frequently occurring reflexes become easier of production through a lowering of resistance in their particular pathways. This brings us close to the subject of habit formation.

Our emphasis has been constantly upon the advantage derived by the animal (or by man) from the possession of reflex capacities. When the environment is the accustomed one and the changes taking place are such as the species has often experienced, we find that almost every reflex is obviously beneficial. The reactions are such as maintain bodily equilibrium, secure nutriment, evade or defeat enemies, resist changes of temperature, all making for self-preservation. But it must be noted that an unintelligent mechanism will act amiss in any environment which is sufficiently unlike the accustomed one. It will hardly be claimed that the reflexes exhibited by the novice on first going to sea help him in the struggle for existence. A number of reflex effects can be thought of which can scarcely be of value. Sneezing when going out into bright sunlight is one of these. Hiccups following immoderate laughter do not seem to be of any service, nor does laughter itself when induced by tickling. These instances, which on the whole have little importance, are mentioned simply to enforce the contention that the reflex mechanism, however refined, is not directed in its routine performances by intelligence. Its structure determines its conduct. The finger laid upon hot iron is twitched away before the situation is reasoned out, in fact, before pain is felt. Central connections exist which make the movement sure to occur. If we could rearrange those central connections we can conceive of a luckless subject who would not remove his finger from the stove, but would stand violently coughing while the injury proceeded.

CHAPTER VI

THE ALIMENTARY CANAL

THE single-celled animal digests its food within its own protoplasm, sometimes holding it for a while in a temporary cavity filled with fluid, the so-called food vacuole. In such intracellular cavities true digestive secretions containing enzymes are doubtless at work. It is probable that single-celled forms may also secrete enzymes to the exterior and so modify food material which is near-by, but not yet enclosed. This appears to be the case with bacteria when they dissolve the solid gelatin in which they are growing.

Among many-celled animals digestion of this second type, that is, external to the cells, becomes more conspicuous. Their bodies are so formed as to contain spaces in which food may undergo digestion and from which the hydrolyzed products may be absorbed. In the sea-anemone a round opening or mouth leads to a cavity which is very large in proportion to the size of the animal. This primitive alimentary tract has no other opening. In the earthworm, a somewhat more highly developed form, a straight canal in the axis of the body leads from a mouth near the anterior end to an anus at the posterior. However much the alimentary systems of the higher animals may be elaborated, each still represents a more or less winding passage between a mouth through which food is received and a vent or anus for the discharge of residues and excretions. The canal may be greatly lengthened through coiling. Some sections may be widened and others narrowed; the walls in some places may be thick and elsewhere thin. Local differentiation of this kind causes us to distinguish in the human subject the familiar divisions of the tract, as the esophagus, the stomach, the small and the large intestines. The lengthening of the system, it should be noted, does not merely increase its capacity, but multiplies the surface available for the processes of absorption.

A few anatomic expressions may well be defined at this time. *Anterior*, as we shall use the word, means toward the head; *posterior*, away from the head. *Dorsal* means toward the back; *ventral*, toward the front. Right and left have their ordinary use. (In most figures, the subject being viewed from in front, right and left are reversed.) Reference must often be made to the *body cavities*. These

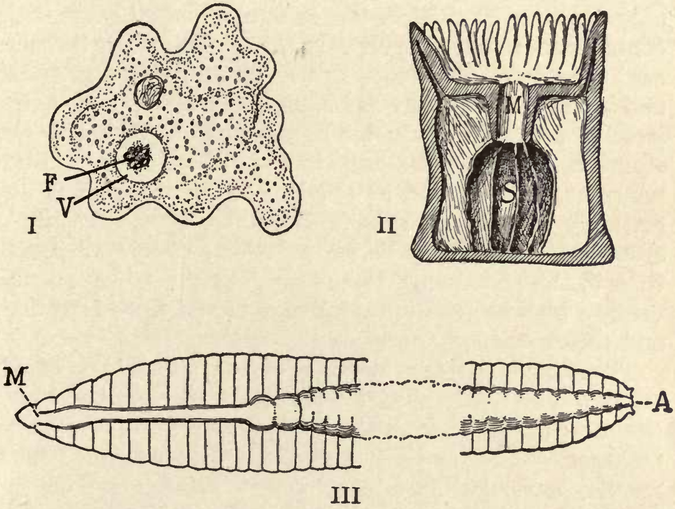

Fig. 7.—I represents a protozoan cell—an ameba—which has enclosed a particle available for food (F). The particle occupies the center of a clear space or vacuole (V). Undoubtedly it is surrounded by a fluid having digestive powers. II is a diagrammatic section through the familiar sea-anemone. There is a relatively huge digestive cavity (S) with a single opening to the exterior (M). III suggests the type of alimentary system found in the earthworm and in higher animals. Two openings exist, the mouth (M), definitely devoted to the reception of food, and the anus (A), used exclusively for the discharge of wastes.

are the thoracic cavity above the diaphragm and within the cage of the ribs, the abdominal cavity below the diaphragm, and the much smaller pelvic cavity bounded by the bones of the hip girdle. When we speak of these as cavities we do not mean that they contain any air-filled space. They are completely filled by the organs which they enclose plus a small quantity of fluid. Hence they are only potential cavities in life, becoming actual when their contents are removed in course of dissection. The thoracic cavity contains the lungs, nearly surrounding the heart, and is traversed by the esophagus. The abdominal cavity is filled almost entirely by the organs of digestion—the stomach, the small and large intestines, the liver, and the pancreas. The spleen at the left of the stomach is less certainly connected in its functions with the alimentary system. The kidneys lie in the dorsal body wall rather than in the abdomen. In the small pelvic cavity are the urinary bladder, the terminal part of the large intestine, and the reproductive organs.

The *mouth*, the first division of the alimentary canal, scarcely calls for detailed description. Above, a bony partition separates it from the intricate spaces of the nasal passages. At the back this "roof" is prolonged as a mobile, muscular curtain—the soft palate. Below the edge of the soft palate a region is reached which is common to the alimentary and respiratory systems. This segment of the canal is known as the *pharynx*, though the term is extended also to the space behind the soft palate, which is above the normal course of food. The teeth and the tongue with its wonderful muscular development are sufficiently obvious. Ducts from the *salivary glands* open into the mouth. We are rarely conscious of the situation of these openings, though in the dentist's chair we may notice the rapid flow of saliva from one which is opposite the upper molars. This is the place of entrance of the secretion of the *parotid gland*, situated before and below the ear, the gland usually affected in mumps. Under the tongue and within the sweep of the lower jaw-bone there

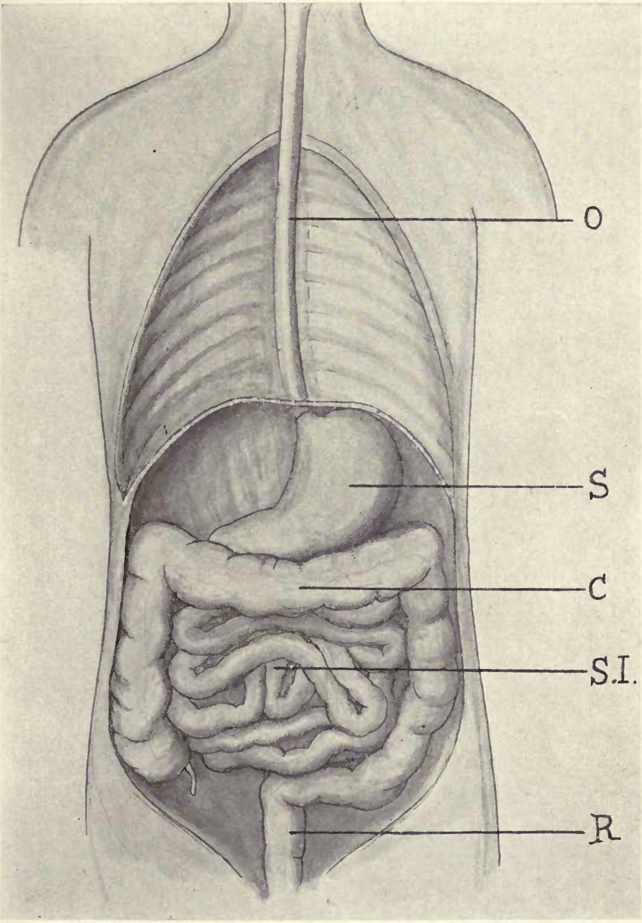

Fig. 8.—The human alimentary canal shown diagrammatically: *O* is the esophagus; *S* is the stomach; *S.I.* suggests the small intestine; *C* is the colon (see Fig. 14); *R* is the rectum. The connection between the stomach and the small intestine occurs behind the transverse colon, which also hides the pancreas.

are, on either side, two other glands, the *submaxillary* and the *sublingual*, with ducts opening in the floor of the mouth.

Below the root of the tongue there is a leaf-like projection, the epiglottis, which juts backward and guards the entrance to the *larynx*. Through the larynx a way is open to the trachea and the lungs. At this point, therefore, the courses taken by the food and by the breath part company. From here the esophagus extends through the neck and the thorax, lying at first behind the trachea, and lower down passing back of the heart. Perforating the diaphragm slightly to the left of the midline it opens into the stomach.

The stomach is the most expanded part of the alimentary canal. Its position is higher up than is generally assumed, so that it is well within the embrace of the lower ribs on the left side. It has a capacity varying greatly with the degree of its distention and with its variations of tone. After a full meal it may contain more than a quart. The form of the stomach also changes considerably from time to time, but we distinguish a large, rounded portion toward the left and a more conical region tapering off toward the right and joining the small intestine. The opening from the esophagus into the stomach is called the *cardia*, and that from the stomach to the small intestine is the *pylorus*. The pylorus is a trifle to the right of the midline. The upper border from the cardia to the pylorus is the "lesser curvature" of the stomach; a line drawn from the cardia around the convex left-hand side and thence along the lower margin to the pylorus is said to follow the "greater curvature."

Leading away from the pylorus the small intestine describes a short turn, within which is the *pancreas*. This first curve is called the *duodenum*. The remainder of the small intestine is a slender tube almost 20 feet in length, coiled upon itself in a confusing manner. Two divisions are recognized, the *jejunum*, continuous with the duodenum and the *ileum*, extending onward to join the large intestine. No sharp line of demarcation exists between these sections, but the latter is regarded as constituting somewhat more than half the whole. The ileum finally arrives at a point not far from the crest of the right hip-bone and there enters the large intestine.

The large intestine is so called from its diameter, which is two or three times that of the small. It is quite as often called the *colon*. Beginning with a small rounded pouch, the *cecum*, it may be followed upward on the right side of the body to the level of the lower ribs. This part is the ascending colon. From here it bends sharply to the left and crosses the full width of the abdominal cavity. This horizontal segment is known as the transverse colon and lies close to the ventral body wall. Thus it passes in front of the duodenum and is in practical contact with the

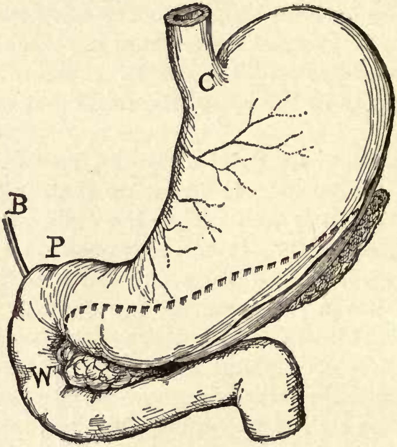

Fig. 10.—The stomach with the pancreas and duodenum: *C* is placed at the cardiac opening of the stomach, while *P* is at the pylorus. A dotted line is used to complete the form of the pancreas, which discharges to the intestine near *W*. The shape of the stomach is of one moderately filled; with further distention the lower border of the organ would sag and the pylorus would cease to be the lowest point. *B* is the common bile-duct, which reaches the intestine behind at the same point at which the pancreas delivers its secretion.

stomach. At the left side of the body and near the spleen the descending colon begins. Its course is downward and backward, so that it passes behind the coils of the small intestine. Following the dorsal boundary of the cavity around to the middle line, the colon forms the short, curved region called the sigmoid flexure. The remaining section is the *rectum*, situated directly in front of the lower extremity of the spinal column within the pelvis and terminating at the anus.

Almost everywhere the lining of the alimentary canal is pitted with microscopic glands. Those in the stomach furnish the gastric juice; those in the intestine, the intestinal juice. Besides these small glands and the salivary glands already mentioned, there are the pancreas and the liver, contributing secretions to the cavity of the digestive tract. The pancreas has been said to lie in the turn of the duodenum. It is thus under the pyloric portion of the stomach and behind the transverse colon. Its main duct discharges into the small intestine about 3 inches below the pylorus. A second, but very small, duct opens close by. The liver, which is the largest gland in the body, is fitted to the concave under surface of the diaphragm and is mainly to the right of the midplane. It is cleft into several lobes, from which ducts converge and unite as they approach the duodenum. A single duct is finally formed and it enters the intestine at the same point as the chief pancreatic duct. The arrangement serves to blend the two secretions, and is somewhat suggestive of the devices used with bath-tubs for mingling hot and cold water.

The liver produces bile, and its channel of discharge to the duodenum is accordingly known as the bile-duct. This duct has a side branch which leads to a contractile sac embedded in the under surface of the liver, this reservoir being the gall-bladder. Bile, as it flows down from the liver, may either find its way directly to the intestine or it may turn aside into the gall-bladder. The course taken will depend on the contraction and relaxation of the muscular walls of the ducts. Active contraction of the gall-bladder when it is full may send a considerable amount of bile at one time into the intestine. The relation of the gall-bladder to the liver is like that of the urinary bladder to the kidneys, at least to the extent that its existence makes possible a continuous production of the secretion with an intermittent emptying. It has been shown, however, that the bile is concentrated and otherwise modified during its stay in the gall-bladder. The urine does not change its character distinctly while it is in storage.

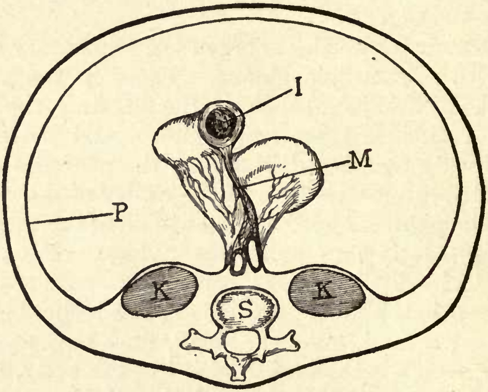

Fig. 11.—This is an entirely schematic section across the human body in the mid-abdominal region: *S* indicates the spine; *K*, the kidneys; *P* is the peritoneum, the lining of the abdominal wall. It is prolonged from the back to form the mesentery (*M*), which extends to and around the loop of intestine (*I*). The large unoccupied space shown does not really exist, for successive portions of the alimentary canal together with other organs completely fill the cavity.

When the abdominal wall of an animal is cut through and laid back from the organs within, one's first impression is that the viscera are lying unattached in the cavity. They are, in fact, not adherent to the ventral or lateral portions of the wall. But if we take a loop of the small intestine at random and attempt to lift it from its resting-place, we find it attached to the middle of the back by a tough, transparent membrane, the *mesentery*. In the mesentery can be seen blood-vessels, lymphatics, and nerves. This suspending sheet thus serves not merely for mechanical support, but also establishes connection between the intestine and the circulatory and nervous systems. The student is apt to find it hard to visualize the mesentery in its actual form; he is to imagine a membrane which at one edge extends to the entire length of the small intestine and to much of the large, while its other edge is condensed to be inserted into the space of a few inches before the spinal column. What results from these conditions has been described as "a ruffle or flounce." Although the mesentery is thin it is really a doubled sheet enveloping the intestine. This will be made clear by the diagram, which also shows how the mesentery is continuous with the exquisitely smooth, lustrous lining of the abdominal cavity, to which is given the name of *peritoneum*. Dissection of a small animal will give a comprehension of these anatomic facts which can scarcely be gained by reading.

The stomach has a supporting membrane attached to it along its lesser curvature and uniting it to the liver, which is, in turn, anchored to the dorsal body wall. This membrane is, in effect, a mesentery for the stomach, but is called the lesser omentum. An extension of similar tissue hangs from the greater curvature like an apron over the intestinal coils and is called the great omentum. It may become a ponderous appendage from the fat which it sometimes accumulates. The continuation of the mesentery over the external surface of the intestine and the identical covering of the stomach form for these organs what is spoken of as their *serous coat*.

The Finer Structure of the Alimentary Organs.—We have said that the internal surface of the stomach and of both intestines is provided with glands. The inner layer of the wall of the canal in which these glands occur is called the mucous coat or mucous membrane. This is in reference to the fact that its exposed cells produce the slimy substance, mucus, more familiarly associated with nasal discharges. It probably acts as a lubricant in the digestive tract and also protects the lining cells from harsh contacts, both physical and chemical. The mucous membrane is depressed to form the recesses of the glands, and in the small intestine is raised into the microscopic prominences referred to as *villi*. Underlying it blood-vessels and nerve-fibers run thickly.

Between the mucous layer and the serous coat on the outside of the intestine there is a development of muscle of the order described in a previous chapter as characteristic of most internal organs, that is to say, slow acting, more or less automatic, and much given to tone changes. In the small intestine there are two distinct muscular coats: the inner and thicker has its fibers at right angles to the axis of the canal, while the outer has them set parallel to this axis. The inner coat is hence spoken of as circular and the outer as longitudinal. There is no doubt of the superior prominence of the circular coat in the production of intestinal movements. In the stomach the muscular organization is less simple and there are oblique elements in addition to those which can be classed as circular and longitudinal. The colon has the circular coat, but instead of a complete covering of longitudinal muscle it has three bands of contractile tissue extending along its wall.

At any point along the course of the intestine temporary closure may be effected by the contraction of the circular muscle. But there are certain places where such closure is far more frequent or, indeed, the usual condition. Where the esophagus joins the stomach an irritable band, the cardiac sphincter, is much of the time firmly contracted. There is, similarly, a pyloric sphincter guarding the opening between the stomach and the duodenum. Where the ileum enters the cecum a valve exists which is adapted to prevent the reflux of material from the colon to the small intestine. This, the ileocecal valve, is probably reinforced in its mechanical action by muscular support. Finally, the short anal canal is closed by an inner sphincter which is essentially a thickening of its own wall, and an external one composed of skeletal muscle.

CHAPTER VII

THE MOUTH—SWALLOWING; SALIVARY DIGESTION

Mastication.—The hygienic importance of thorough mastication is undoubted, but there is little occasion for any extended analysis of a process so obvious. It is to be observed that the lower jaw does not have merely an up-and-down movement, but that it glides backward and forward and has some lateral play at the same time. The teeth, therefore, do not simply chop the food, but rub and grind it. In the work of mechanical reduction a larger part is borne by the tongue than is commonly recognized. The little member seems to be everywhere at once, thrusting food between the teeth, withdrawing it again, bruising and rasping it against the roof of the mouth. While this action is going on an intimate mixture with the saliva is accomplished. We must now proceed to a discussion of this the first of the digestive secretions.

Mention has been made of the three pairs of glands which supply the saliva. Their united product is estimated to reach an amount of about 3 pints a day, equalling the volume of the urine. If one finds it hard to credit such a statement, attention may be called to the copious character of the flow which is noted when one is interrupted at the moment of taking food. There is little secretion apart from eating unless it is excited by chewing sundry things. At mealtime a large part of what is swallowed is saliva, and the proportion must be greatly raised by the practice of prolonged mastication, so-called Fletcherism. The formation of saliva is to be regarded as a reflex in which the primary stimulation is furnished by food in the mouth acting upon the endings of nerves excitable by its chemical ingredients and by its temperature more than by its mere contact. We have to do with something more than the typical reflex, however, because it is a familiar fact that the appeal to consciousness has much influence upon the flow of saliva. The "watering of the mouth" at the approach of acceptable food is a hard phenomenon to classify. It is a reflex, but it is one which would not occur in an unconscious subject. For such actions the term *psychoreflex* is often used.

The saliva is a bland fluid which one would hardly suppose to be endowed with active powers of digestion. In some animals it does not have any apparent chemical action. Still, it has valuable properties which we shall do well to recognize. Whether it is a digestive juice or not, its physical effect is useful in mastication, since it softens the food, makes it cohere into the pellets which are prepared for swallowing, and later lubricates their transit to the stomach. Moreover, it has a defensive use, protecting the mouth from injury when food or fluid is taken too hot or when some corrosive liquid calls for dilution. As it issues fresh from the glands it is slightly alkaline in reaction. If it stagnates for a long time in the by-places of the mouth, as happens during sleep, and if it contains at the same time traces of carbohydrate food in solution, bacterial fermentation may make it acid and the effect upon the teeth may be injurious. The value of an alkaline mouth-wash, like milk of magnesia, used at bedtime is evident.

Human saliva contains various salts. Attention need be called only to its lime compounds, which are always deposited more or less upon the back surfaces of the teeth, a process which reminds one of the formation of stalactites and stalagmites in caverns. The hard crust that results is the tartar. It is not very unlike the original substance of the teeth in its chemical composition, and its occurrence might seem to indicate a mode of making good the wearing away of the teeth. Unfortunately we cannot regard it in this favorable light, for the lime salts are always contaminated with food particles and bacteria. The deposit should be removed by the dentist at regular intervals.

The three glands furnish slightly different varieties of saliva. *Mucin*, the essential compound in mucus, is present in the secretion of the two lower glands and not in that of the parotid. It gives to the saliva from the submaxillary and sublingual glands a ropy, mucilaginous character, which, of course, becomes more apparent when evaporation has concentrated the solution. This is illustrated when the mouth is dried by rapid breathing during exercise and becomes furred with the residue of salivary mucin. This constituent of the saliva probably makes it superior to water as an agent for molding the food into pellets. The most interesting property of the secretion, its power to hydrolyze starch, may be discussed to more advantage after we have followed the food to the stomach. Clearly, there is not time enough for much digestive change in the mouth of a person of average habits.

Swallowing.—The transfer to the stomach is a more complex matter than is likely to be realized. It involves an interruption of breathing and the protection of the nasal passages and the larynx against the intrusion of food. The first purpose is effected by the swinging back of the soft palate against the back of the pharynx. The second is accomplished by the drawing forward of the larynx toward the chin, a movement which can be plainly felt. By it the larynx is tucked under the root of the tongue and overlaid by the epiglottis. The same motion serves to widen the upper part of the esophagus, which is not usually appreciably open. With the parts in this position the bolus of food is crowded back from its original seat upon the tongue and urged through the pharynx by the successive contraction of the bands of muscle which surround it. As soon as it is fairly within the esophagus the soft palate is lowered, the larynx is allowed to emerge from its covert, and the breathing can be resumed. Such quick and well-ordered adjustments give evidence of co-ordinated reflex action, the contact of the food morsel with one spot after another furnishing the requisite stimuli. We cannot go through the series of movements unless there is at least a little saliva to be swallowed, and we cannot arrest the march of events when it is once begun.

The contractile tissue in the upper part of the esophagus is of a skeletal variety. Lower down this gives place to typical visceral muscle. Hence it is not strange to find that the advance of the bolus becomes progressively slower as it descends. The movement which is here taking place

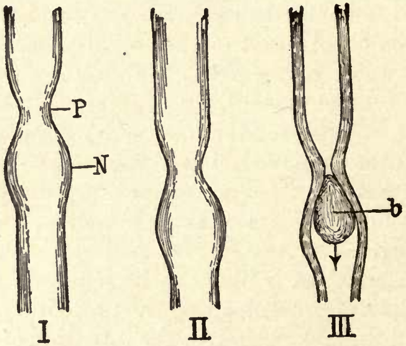

Fig. 12.—An exaggerated representation of peristalsis. I and II are successive views of the same portion of the alimentary tube: *P* is the zone of contraction shifting downward and always preceded by the zone of unusual relaxation (*N*). III is an imaginary section through II, showing the food bolus (*b*) slipping along in advance of the contracting region, its advance being facilitated by the relaxation below.

is what is known as a *peristalsis*, and it is highly important that its principle should be understood. The most obvious feature is a ring of contraction setting in above the enclosed pellet, causing it to slide onward, and following it down by involving in succession each level of the tube. The mechanical application can be simply illustrated by propelling a glass bead through a soft-rubber tube by pinching repeatedly behind it with thumb and finger. A strict analysis of what occurs in the esophagus obliges us to recognize that the process is not so simple as it first appears.

There seem to be two phases in what is called the peristaltic wave. The eye detects chiefly the traveling contraction, but this is apparently preceded by a zone of unusual relaxation, a region of inhibition.

The peristaltic wave which is necessary for the propulsion of solid food does not seem to be required to send liquid to the stomach. A swallow of water is shot swiftly from the mouth to the cardiac sphincter and arrives there distinctly in advance of the plodding peristalsis. When one drinks a glass of water, the swallows following in rapid succession, a single peristaltic wave ends the series. Of course, when fluid is carried up-grade in the esophagus, as when a horse is drinking from a pool at his feet, active peristalsis is as necessary as though solid food were being moved, and one may plainly see the passing of each swallow along the extended neck. We shall find that the small intestine exhibits movements which are approximately the same in principle as those of the esophagus, but far slower and usually less energetic.

Salivary Digestion.—Within the stomach the accumulated food with a large admixture of saliva lies for some time with little motion. Here then salivary digestion must take place. The statement has been made that in some animals the saliva has only mechanical and protective functions. More frequently, however, it has the power to hydrolyze starch, forming malt-sugar as the chief end-product. This seems to justify the assumption that an enzyme is present, and it is variously named *ptyalin, salivary amylase,* or *salivary diastase.* Such an enzyme probably plays an important part in the digestive processes of ruminants, animals which chew the cud. Human saliva acts upon starch with surprising energy. A simple demonstration of the fact may be had by holding a bread-crumb in the mouth longer than is habitual, when it will gradually develop a mildly sweet taste.

The prevailing opinion in regard to the amount of digestion accomplished by the saliva in man has undergone a change during the last few years. It is allowed a larger place than was formerly granted to it. The enzyme is extremely sensitive to acid. Inasmuch as the gastric juice is decidedly acid, it used to be claimed that salivary digestion could not proceed in the stomach. But it has come to be recognized that when a large mass of food is introduced into the stomach within a short time the gastric juice penetrates it rather slowly. A few minutes after the completion of a meal we may picture the stomach-contents as being acidified near the surface, the acid slowly making its way inward, but having a neutral or even alkaline central portion. Salivary digestion will be continued in the steadily diminishing region not yet reached by the acid, and will cease only when the gastric secretion from one wall of the stomach meets that from the other. Any rotation of the contents would probably bring about an earlier distribution of the acid and arrest of starch digestion. No such rotation seems normally to occur. A factor which operates to postpone the destruction of ptyalin is the power of the proteins of the diet to engage hydrochloric acid in combination. Since proteins are almost always present, the gastric glands must secrete acid enough to satisfy their capacity before there can be the excess of strictly free acid which will put an end to salivary digestion.

If the mixed food is quite acid at the outset, it is hard to see how there can be any hydrolysis of starch brought about by the saliva. Yet we constantly eat acid fruits before our breakfast cereal and notice no ill effects. Starch which escapes digestion at this stage is destined to be acted upon by the pancreatic juice, and the final result may be entirely satisfactory. Still it is reasonable to assume that the greater the work done by the saliva, the lighter will be the task remaining for the other secretions and the greater the probability of its complete accomplishment. The power of saliva to convert raw starch to sugar is almost incomparably smaller than its capacity to digest starch which has been cooked. Raw starch exists in very dense grains which have to be dissolved from the surface inward. Cooking, especially boiling, utterly destroys these grains, and permits a reaction between the enzyme and the separated molecules of the carbohydrate.

The change from starch to sugar seems not to be effected by a single reaction, but by stages. Physiologic chemists have studied extensively the numerous intermediate bodies which have a fugitive existence in the process. Most of these are covered by the term *dextrins.* It is sufficient for our present purpose to regard them as carbohydrates, simpler in their molecular structure than the original starch, but complex as compared with the familiar sugars. We have said that the chief product of salivary hydrolysis is malt-sugar or *maltose.* This is one of several sugars classed as disaccharids. It can be hydrolyzed further to form *dextrose* (or *glucose*), a sugar of the simplest type, and one which is ready to be absorbed and to minister to the living tissues. Some dextrose is said to be formed in prolonged salivary digestion, but the cleavage lags when the maltose stage has been reached.

CHAPTER VIII

THE MOVEMENTS OF THE STOMACH

It will be recalled (Chapter VI) that the stomach consists of a main rounded portion from which a much smaller conical segment extends to the right to join the duodenum at the pylorus. The larger part is called the *fundus*, the tapering region is the *antrum*. The muscular coats of the antrum are somewhat thicker than those of the fundus and show an especially conspicuous development of the circular elements. There is no such contrast between the two parts of the human stomach as between the thin-walled crop and massive gizzard of the bird, but there is a faint suggestion of an analogous difference. The fundus is, indeed, primarily a place for the storage of food; the antrum, while not a crushing mechanism, has distinctly greater motor properties.

The antrum is considered to be set off from the fundus by the so-called *transverse band*. This is an irritable ring of the circular muscle which is often contracted enough to indent the outline of the stomach at this point, and which may occasionally create a temporary division of the gastric cavity into two parts. It has been called the sphincter of the antrum, but it cannot fairly be compared with the cardiac and the pyloric sphincters, since these are habitually closed, while closure at the transverse band is rare.

Regulation of the Cardiac Sphincter.—Food and drink entering the stomach pass the cardiac sphincter. The guardian muscle is usually more or less contracted. It relaxes upon the arrival of the peristaltic wave in the esophagus. If it is recalled that the peristalsis consists of a wave of inhibition running before a contraction, it is

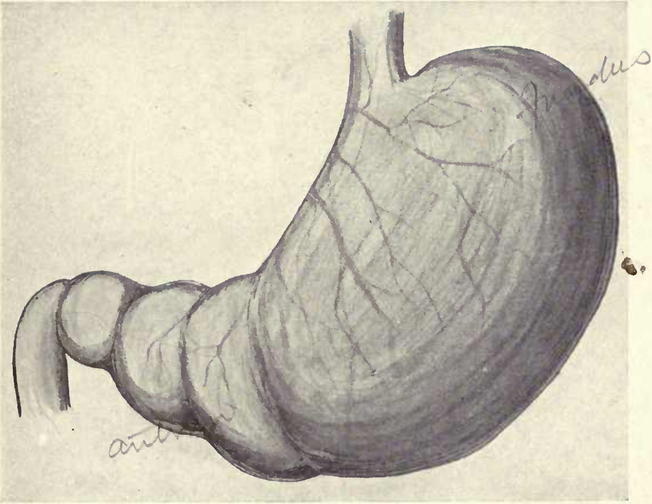

Fig. 13.—To suggest the probable appearance of the distended and active human stomach. Three marked waves of contraction are seen in the antral region. These are to be conceived of as passing onward toward the pylorus.

easy to see how the cardia may be opened at the moment when its muscular walls fall under the influence of the phase of relaxation. Closure will follow immediately, as the second or positive part of the peristalsis involves the sphincter. Attention has been called to the fact that liquids may outrun a pursuing peristalsis and arrive several seconds in advance of it at the cardiac opening. Under such circumstances it is said that the fluid remains at the bottom of the esophagus until overtaken by the wave, when the relaxation occurs which permits it to pass into the stomach. A person drinking with ill-advised haste may have the disagreeable experience of filling the esophagus enough to produce a painful distention. Relief comes abruptly when the peristalsis has made its way to the cardiac sphincter and secured an entrance for the liquid.

While this has been the generally accepted description of the facts, it has been shown recently that the cardia is not always so firmly contracted. Observations by *x*-ray methods, to be described presently, have shown that for some time after a meal there may be a reflux from the stomach of a cat into the esophagus. Each escape of food evokes a local peristaltic wave which returns it to the stomach. Such an incident does not entail any movement of the throat muscles and is probably subconscious. As the period of digestion continues the sphincter becomes more tightly set and no longer allows any such return of stomach-contents. The increased tension has a simple explanation, which, like many another point about the stomach, we owe to W. B. Cannon. He has shown that the tension is developed in response to the rise of acidity in the liquid just within the cardia. Since the acid appears normally after each filling of the stomach, we have here an automatic provision for the establishment of the requisite guard over this opening. The influence of the nervous system seems capable of nullifying the local effect of acid, since the sphincter may be relaxed to permit vomiting at times when the gastric contents are excessively acid.

The Fundus.—An important service of the stomach is to store food in relatively large quantities at mealtimes and to deliver it gradually to the intestine. A person who has been deprived of the stomach, or of most of it, by surgery is made aware of this when he finds it impossible to eat "a square meal," and is compelled to take small portions of food at short intervals. He is then serving his intestines somewhat as they are normally treated by the stomach. Storage is not the sole function of the stomach, but we do well to emphasize it. The fundus accommodates itself to its contents by tone changes, relaxing when food is being swallowed and afterward exerting a steady, moderate pressure which insures the filling of the antrum after every discharge at the pylorus. A lack of this tonic reaction may be a cause of serious disorders.

The earlier writers often claimed that there is a definite and regular overturning of the contents of the fundus. In the light of more recent observations this does not seem to be usual. A German investigator fed to a rat three courses of food of contrasted colors. The animal was then killed and frozen. A section made through the hardened mass within the stomach showed distinct stratification. The food first taken was in the antrum and the lower part of the fundus, the second instalment was above the first, and the third was just under the cardia. It seems hardly probable that entirely liquid food could remain thus stratified when one considers the extent to which the stomach is subjected to the influence of bodily movements.

***x*-Ray Studies of the Stomach.**—While much can be learned of the behavior of the stomach through experiments involving its exposure by surgical procedures, the ideal method is clearly one which leaves the animal in its normal condition. Such a method became available when the *x*-ray was first turned to account to observe visceral movements. The image of any part of the body projected by means of the *x*-ray shows the bones in clear contrast with the softer parts, but scarcely outlines the organs. If, however, any harmless substance opaque to the *x*-ray is introduced into the contents of the alimentary canal, it becomes possible to recognize the situation of this substance so long as it remains sufficiently concentrated. More than this, if the cavity is well filled its outline is, of course, identical with that of the included material. The *x*-ray picture will then show the changing contour of the organ in silhouette. The compounds most used to secure opacity to the *x*-ray are the salts of bismuth, generally the subnitrate or the subcarbonate.

The most numerous experiments of this sort are those of Cannon, and the cat has been the favorite subject. When the animal has had a full meal of bread-crumbs and milk with the bismuth salt evenly mixed in the mass the *x*-ray shows the entire form of the stomach. The fundus has an even outline and preserves it unchanged from hour to hour, except that a very gradual contraction takes place. The antrum is traversed by deep but slow-moving peristaltic waves, which originate near the transverse band and pass to the pylorus. The tendency of such waves must be to force successive portions of the food into the intestine, but in the great majority of cases the waves bear down upon a tightly closed pyloric sphincter. The only possible result is then an eddying movement, the contents advancing only to rebound from what is, for the time, a blind pouch. This favors the reduction of the larger morsels and helps to secure at length the formation of the smooth, creamy "chyme." But it is probable that most people have an exaggerated notion of the mechanical powers of the stomach.

The waves which pass over the antrum arise in the cat with strange regularity at intervals of ten seconds. Each wave takes about half a minute to make its way to the pylorus, so there are commonly three creases to be seen, all shifting with a motion of clock-like slowness toward the outlet. During the prolonged period required for the emptying of the stomach of the cat—eight hours or more—it is evident that the total number of the waves may be over two thousand. When the pyloric sphincter momentarily relaxes, under influences to be discussed presently, the peristalsis of the antrum naturally drives more or less of its contents into the duodenum.

Nervous Control of the Gastric Movements.—Muscular elements of the order found in the stomach have been said to have an automatic property. We have insisted, however, that this fact does not exclude the influence of the central nervous system. There is abundant evidence so far as the stomach is concerned that the musculature of the organ is played upon by efferent impulses. If it is separated from the central nervous system many of its reactions take place in a nearly normal manner, but we cannot assume that its adjustments are as well timed and decisive as they were before. Laboratory trials show that the impulses which are sent to the stomach may either accentuate or abate its spontaneous movements. In other words, they may either excite or inhibit the contractile elements.

Of the two types of nervous control, the inhibitory seems to be of particular significance. Complete arrest of the peristalsis of the antrum may be brought about. This happens in the cat when the animal is enraged or terrified, and, indeed, when it seems merely to be restless. Cannon has again and again seen the peristaltic notches fading away from the *x*-ray profile of the antrum when the animal has wearied of being kept under restraint, and is manifesting its feeling by switching its tail and struggling. He has seen the regular activity resumed when the cat has been pacified. Similar facts have been demonstrated for the rabbit. Since we generally believe that the higher the grade of an animal's development, the more extensive the command of the nervous system over its organs, we have every reason to think that unpleasant emotions may be accompanied in man also by inhibition of the gastric movements. We shall have occasion to enlarge upon this matter in connection with the Hygiene of Nutrition.

The Pyloric Sphincter.—The regulation of the escape of the stomach-contents to the intestine has long been a subject of interest. Nearly eighty years ago William Beaumont published his observations upon the stomach of Alexis St. Martin, a young Canadian trapper, who had suffered a gunshot wound in the left side, in consequence of which he had a permanent gastric fistula. The impression which went abroad from this celebrated case has seemed to convey to the less scientific writers the idea that the pylorus has a power almost akin to intelligent inspection whereby it permits the passage of certain portions of the chyme and refuses egress to other portions. This notion recalls amusingly the teaching of Van Helmont, in the seventeenth century, that the soul of man resides in the pylorus. It cannot be said that all the conditions affecting the discharge from the stomach are entirely clear, but much progress has been made in this direction.

The sphincter is influenced both by the physical consistency and by the chemical reaction of the gastric contents. The contact of coarse, angular particles with the adjacent mucous membrane seems to reinforce its contraction, so that such material tends to be kept longer in the stomach. A more important factor with this sphincter, as with the cardiac, is the acidity of the chyme. It was stated above that when the stomach-contents becomes distinctly acidified, the tone of the cardiac sphincter is increased. The acid in this case is acting upon the lining *below* the irritable ring. Comparison of the two sphincters shows it to be a principle applicable to both—that acid acting immediately above favors their relaxation, while acid below causes them to tighten. If this is the main factor in regulating the pylorus, the first opening will occur when the acidity in the antrum has reached a certain point. The next peristaltic wave will transfer a little chyme to the duodenum. At this instant there will be acid material both above and below the sphincter. The action from below appears to predominate, so that closure will be established and maintained until the acid in the duodenum is either neutralized or removed somewhat from the pylorus. When the stimulation from below is no longer effective the acid above will cause a second gaping of the sphincter, followed as before by prompt and decisive contraction. A more efficient mechanism to insure gradual delivery to the intestine without distending it locally can scarcely be conceived. When the latest portions of a meal are leaving the stomach, the first which went out may have reached the colon, and intermediate fractions may be undergoing digestion in numerous loops of the intervening small intestine.

Our meals are usually of a mixed character, including proteins, fats, and carbohydrates. For purposes of experiment single food-stuffs may be fed to an animal and the rate of departure from the stomach noted for each. The *x*-ray has been employed for this purpose. Carbohydrates have a striking tendency to escape rapidly to the intestine. The discharge of proteins and of fats is relatively much delayed. We must be content with stating the fact without undertaking to discuss its somewhat complex causes.

Vomiting.—The occasional expulsion of the stomach-contents through the cardia and esophagus is accomplished as the result of a reflex movement in which the chief muscles involved are not the coats of the stomach, but the contractile tissue of the diaphragm and abdominal wall. When these contract simultaneously a high pressure is thrown upon the stomach. Such a pressure may accompany the act of straining or bracing the body for lifting, but does not ordinarily result in vomiting, it would appear, because of the resistance offered by the cardiac sphincter. In the crisis of nausea, however, convulsive movements of this kind take place with inhibition of the sphincter. With the passage open, each application of intense pressure to the stomach may drive a portion of its contents to the exterior. The palate meanwhile has assumed the same position as for swallowing; the larynx is drawn forward and is shielded by the root of the tongue, which is depressed and grooved. At every descent of the diaphragm the capacity of the thorax is increased, and as no air is permitted to enter the lungs the esophagus is dilated.

During the act of vomiting the fundus is said to contract steadily upon its diminishing contents. This is not a movement powerful enough to secure the emptying of the stomach, but adapts it to be gripped effectively by the muscles of the body wall. The transverse band is at the same time strongly contracted and the antrum has a very small volume. The pyloric sphincter is said to be closed, but it is a familiar fact that bile from the duodenum may be pressed backward into the stomach under the stress of violent vomiting. Profuse salivation precedes and accompanies the act. Such a reflex has a manifest value when it serves to remove from the stomach material which might prove poisonous. It occurs, however, under many circumstances when it seems not to have any advantageous result. Its apparent uselessness in seasickness has already been alluded to. It appears equally illogical when, in pregnancy, it is excited by irritation of the pelvic nerves.

CHAPTER IX

GASTRIC SECRETION AND DIGESTION

It was in the eighteenth century that the chemical factors in digestion were first clearly separated from the mechanical. The accounts which have been preserved of the experiments of Réaumur (1752) and of Spallanzani (1777) are of extraordinary interest. An entertaining summary is to be found in Foster's "Lectures on the History of Physiology," Chapter VIII. These ingenious investigators were the first to show that digestive changes may be caused to take place outside the body and in the absence of any mechanical process whatever. They obtained small quantities of gastric juice from various animals, mixed it with food in flasks and test-tubes, and watched for signs of alteration. Spallanzani, in particular, succeeded in bringing about considerable solution of his samples.

From that time to the present studies of digestion have continued. Where the pioneers were forced to be content with observing the dissolving of solid food, their successors are drawing inferences regarding the transformations of unseen molecules. A deeper insight into the meanings of digestion became possible as the new science of organic chemistry was swiftly advanced by the researches of Wöhler, Berzelius, and Liebig. As was pointed out in Chapter III, it is the molecular change which is significant and not the physical. Experiments in which material is introduced into the alimentary canals of animals and later withdrawn for analysis are constantly compared with trials in which the digestion takes place throughout in the thermostats of the laboratory.

The stomach is popularly supposed to have a very large share in the total work of digestion. It cannot, however, be claimed that it is indispensable to man. It forms, as already indicated, a convenient place of deposit for food and a gradual feeder of the small intestine, but it is meanwhile the seat of preliminary digestive changes which greatly facilitate the further advance of the process. Attention has been called to the fact that salivary digestion is continued for a time in the almost stationary contents of the fundus. When this is stopped by the penetration of the acid gastric juice it is superseded by a new type of digestion in which the proteins are the food-stuffs acted upon. The gastric hydrolysis of proteins is generally referred to as peptic digestion. Before we discuss it in detail we must consider the nature and the circumstances of formation of the gastric juice.

This secretion is the product of the numerous, relatively simple glands with which the mucous coat of the stomach is provided. Beaumont has vividly described the appearance presented by the lining of St. Martin's stomach directly after a meal. The surface, usually of a pale gray, flushed deeply, and the gastric juice welled up in glistening beads from the invisible mouths of the glands. Its manner of breaking out resembled the rising of perspiration from the pores of the skin. The empty stomach may have a well-marked film of mucus upon its walls, but its active secretion is limpid and free flowing. The volume which the human stomach produces in twenty-four hours is apparently very large; if we have a right to judge from what is known of the dog, it may be 3 or 4 quarts. A dog, being carnivorous, probably secretes a disproportionate quantity, and our estimate for man should very likely be reduced.

The Acid of the Gastric Juice.—Repeated reference has been made to the acidity of the stomach-contents. The early investigators were surprised and puzzled when they were forced to recognize that the acid in question is largely free hydrochloric. When we consider that this acid cannot be made industrially except by decomposing a chlorid with the still stronger and more corrosive sulphuric acid and in an earthen container, we can appreciate their feeling. For here is what we call a strong mineral acid proceeding from delicate living cells and from fluids of neutral reaction. The formation of hydrochloric acid by the cells of the gastric glands has become much more intelligible in the light of modern chemical teachings. The current theories cannot be presented here. It is evident that when the elements of an acid are withdrawn from a neutral fluid it must, theoretically at least, be rendered alkaline. We have a capital illustration of the refinement of the mechanism by which the body preserves uniform internal conditions in the fact that when gastric juice is being secreted, the urine, usually acid to common indicators, becomes alkaline. Thus the normal chemical equilibrium of the blood is maintained sacred from disturbance. The juice secreted into the antrum is said not to be acid.

Mention has been made of some ways in which the acid of the stomach modifies local conditions. We have seen that it gradually checks salivary digestion. It is the most important controlling factor for the two sphincters. Other features of its action must now be presented. Among these is its distinct antiseptic infleunce. Spallanzani noticed that pieces of meat undergoing digestion in gastric juice passed into solution without putrefying. Similar pieces kept for an equal time in water had radically spoiled. This was a significant observation at the time, because digestion and putrefaction had been regarded by many as identical. We know now that putrefactive decomposition of protein is due to the influence of swarming micro-organisms, and that hydrochloric acid in the concentration usual in the gastric juice restrains the development of such forms.

The average strength of the acid in man is given as 0.2 to 0.3 per cent. Such a concentration by no means suffices to sterilize the stomach-contents, but in all probability it destroys many kinds of bacteria, including some which might become the cause of disease. Others it undoubtedly weakens, so that they multiply less rapidly when the chyme passes on to the small intestine, where the conditions for bacterial growth are more favorable. It is not surprising to find that the species of organisms which thrive most in the stomach are those which themselves produce acid. The "sour stomach" commonly referred to is a stomach in which the generation of lactic acid from sugars is actively taking place. This is a process very like the familiar souring of milk. Indeed, milk is one source of such acid fermentation in the stomach. Excessive acidity, whether due to the native juice or to the activity of bacteria, may be a cause of discomfort and a hindrance to digestion. Cannon has lately shown that acidity above a certain degree delays the departure of food from the stomach, and this is easily comprehensible when it is recalled that after each brief relaxation the pylorus remains closed until the acid which has just passed has been neutralized or dispersed. Acidity within limits is a necessary condition of gastric digestion, and this will be discussed later.

The Secretion of the Gastric Juice.—The glands of the empty stomach seem to be quite inactive. The natural supposition that they begin to secrete when food comes in contact with the mucous membrane is not borne out by the results of experiments. It is most important to note that the juice may start somewhat in advance of the arrival of food. The stomach as well as the mouth may be said to water at the contemplation of a meal. Abundant evidence of this fact has been furnished by the extraordinary experiments of the Russian physiologist Pawlow upon dogs. When a permanent opening has been made to the interior of a dog's stomach a little gastric juice may issue when the dog is merely shown food which he likes.

That it is unnecessary to have actual contact with the stomach wall is still better shown in the case now to be described. A dog having a gastric fistula is subjected to a second operation, by which the esophagus is severed and the portion connected with the pharynx made to open through the skin of the neck. Whatever is swallowed by the dog is now returned to the exterior. The pleasure of eating is not impaired. To maintain nutrition suitable food may be introduced directly into the stomach. When the dog chews and swallows a meal he is quaintly said to have a "Scheinfütterung"—a fictitious feeding. This proceeding is accompanied by a steady flow of the secretion from the gastric fistula.

The secretion obtained under circumstances like the above is called the psychic secretion. This term serves to emphasize the fact that a mental element is a necessary incident of the reaction. The conditions governing gastric secretion seem to be quite parallel with those which regulate the movements of the stomach, and their importance in hygiene is equally evident. There are a number of individuals who have in various ways lost the power to swallow food, commonly because of the closure of the esophagus. Their lives are preserved by feeding through gastric fistulas established by surgery. These unfortunates find it to their advantage to attend to the idea of eating, and to taste and chew portions of their food at the time when it is being introduced into their stomachs.

After a brief period of fictitious feeding the flow of gastric juice into the stomach of a dog may continue for two or three hours. In view of this we must conclude that, however important the mental state may be for the initiation of the process, it need not be its accompaniment throughout. We cannot pretend that a meal receives our constant attention during any such interval. Nevertheless we are hardly likely to overestimate the necessity of securing a normal start. If the initial circumstances are not favorable the secretion may be long delayed or even lacking.

Now that we have reserved a due place for the psychic element, we must pass on to consider the other factors which modify the activity of the glands of the stomach. Much has been learned from the surprising operations of Pawlow and others, who have succeeded in dividing the stomach of the dog into two parts without robbing either of its connection with the circulatory and nervous systems. When the dog has recovered from the immediate effects it may be said to have two stomachs. Either or both may communicate with the exterior by a fistula, while one still retains its normal relations with the esophagus and small intestine. This arrangement makes it possible to place food in one stomach and to obtain and measure the unmixed juice secreted into the other. The evidence goes to show that when the glands in the lining of one sac are active there is corresponding activity on the part of those in the other.

A most significant fact is at once noted when such a dog is under observation. There are kinds of food, perfectly appropriate for the animal's nutrition, which may lie in the stomach without exciting any flow of the juice. This is said to be true of bread, white of egg, starch, and some sugars. The same articles of diet would be met by an abundant gastric secretion if they had been eaten with enjoyment by the hungry dog. It makes a radical difference, then, whether these materials enter the stomach through the mouth and attract the favorable notice of the animal, or whether they are slipped through a fistula, a proceeding which would probably not be recognized by him as a mode of feeding.

On the other hand, there are some things which do cause an outbreak of gastric juice by their mere presence in the stomach and in the absence of any psychic factor. To a somewhat limited extent this is the case with water, though only, it appears, when there is enough of it to distend the stomach slightly. The best-known excitant of the secretion is meat, and the property is said to belong to the *extractives* or minor substances in this food, and not to the proteins of which it is chiefly composed. Meat causes a considerable flow of the juice, but there is a much longer initial delay than when the psychic element has its normal place. In fact, the total quantity produced when meat is introduced into a dog's stomach without attracting his attention is decidedly less than when it is eaten in the natural way, and when the psychic and chemical agencies are combined.

It is unfortunate that our knowledge of this matter has been drawn so largely from a carnivorous animal. Meat might be expected to stimulate the stomach of the dog more surely than other foods. How far the secretion may be elicited by placing other compounds in the stomach is imperfectly known. Milk is credited with some power to call it forth, but its superiority to water seems doubtful. Alcohol is said to have a positive action of the same kind.

It is claimed that the dextrins, the intermediate bodies produced in salivary digestion of starch, have the property of starting the gastric flow. If this is true it is interesting as establishing a connecting link between the two successive processes, and making it apparent how one may tend to insure the setting in of the other in due time. A link of this sort exists between gastric digestion and pancreatic secretion, as we shall have occasion to point out. The condiments, such as pepper and spices, have a reputation for stimulating the discharge of gastric juice, and undoubtedly do so when they favorably affect the flavor of the food. They are known to increase the blood flow in the lining of the stomach, which would perhaps help to continue the secretion process when once under way, but whether they can actually initiate it apart from their psychic effect remains uncertain.

When gastric secretion is well started there is provision for its maintenance as long as the stomach contains food. It appears that some of the early products of digestion act after the manner of the extractive substances of meat and excite the glands to continued activity. The acid itself has been found to be absorbed by the cells lining the antrum and to set in motion a train of events leading to the same result. This form of stimulation will evidently cease only with the departure of the last portions of the acid chyme. The flow of gastric juice is retarded by fats and by alkaline mixtures.

Digestion in the Stomach.—The gastric juice is usually said to contain two enzymes. Recent work indicates the presence of a third. The two familiar ones are *pepsin* and *rennin*. The third is the gastric *lipase*. Certain writers have questioned whether we ought to speak of pepsin and rennin as distinct individuals, suggesting rather that there is in the secretion a single body having two sets of properties. We need not enter into such a discussion; we shall for the present continue the convenient usage of speaking of pepsin and rennin as two substances.

Rennin.—The fact that extracts of the stomach wall cause the curdling or coagulation of milk has been known from very early times. Such extracts, usually derived from the stomach of the calf, have long been in use in the manufacture of cheese. Rennet is the industrial term for an extract with this property; rennin is the scientific term for the supposed enzyme contained in it. Cheese curd consists of the bulk of the protein of milk which has undergone an obscure chemical change and has passed into an insoluble form. From a physical standpoint this is an anomaly among the digestive processes. We look to see solids becoming liquids, while in this curious instance a liquid becomes a solid. No very convincing explanation of this occurrence has been offered. It may be suggested that it prevents an unduly rapid passage to the small intestine, but so far as we know the mechanism of the pylorus is entirely competent, even for liquid food. The curd when formed has to undergo solution like any other solid.

The action of rennin becomes the more enigmatic when it is noted that it is found in the stomachs of animals which do not have milk in their normal diets. Milk is curdled by extracts of various organs other than the digestive glands and by some vegetable juices. In the human stomach a very firm curd may be formed when a large quantity of cows' milk is taken at one time. The dense mass may be slow to digest. Human milk is said never to set into such a tenacious coagulum, and this is natural, since, regarded as a solution of proteins, it is much more dilute than the milk of the cow.

Peptic Digestion.—The chief enzyme of the gastric juice is the one commonly called pepsin. Its relations with the acid of the stomach are so close that many writers urge that we should speak rather of "pepsin-hydrochloric acid," the term suggesting the existence of a compound of the two which is responsible for the action on the food. The power to digest proteins is manifested only with an acid reaction, and is permanently lost when the mixture is made distinctly alkaline. The conditions which permit peptic digestion to take place are, therefore, precisely those which exclude the action of the saliva.

When protein in solid form, such as boiled white of egg, is subjected to the influence of gastric juice the pieces swell and become softened. Later they are dissolved. When the trial is made with protein which is originally in solution, such as unboiled white of egg, there is no visible evidence of change. But there are physical and chemical tests which can be employed to show that digestion is as definite a change in this case as in the other. An early manifestation of this fact is the loss of the property of coagulation on heating. Later there are indications that the molecules are undergoing cleavage. At each successive stage there is a gain in the power of diffusion, a reduction of viscosity, and a diminution in the number of precipitants which can be employed to throw the protein out of solution.

Physiologic chemists have studied minutely the characteristics of the hydrolytic products during the advance of peptic digestion. They have attempted to identify numerous compounds, each of which has a transient existence and is then itself hydrolyzed. For our present purposes it would be unprofitable to dwell upon such questions of detail. Certain of the earlier cleavage products are included under the general name of *proteoses* or *albumoses;* others, arising later and of a simpler character, are called *peptones.* Roughly speaking, there is a parallel between salivary and peptic digestion. In either case, molecules of great size—

of starch and protein respectively—are subdivided progressively, first with the formation of somewhat complex bodies—dextrins and proteoses—later to form maltose in the first instance and peptones in the second. The correspondence is imperfect in several ways; for example, maltose is a single substance, while there appear to be a number of peptones. It will be remembered that maltose itself is slowly transformed by long-continued action of saliva. Quite similarly, the gastric juice will in time effect a further digestion of the peptones, but this advanced digestion seems normally to be postponed until the intestine is reached.

Gastric Lipase.—Down to a recent time it was held that fat underwent no true digestion in the stomach. It was recognized that some forms of fat, butter, for example, must be melted, and that the fat in the adipose tissue of meat might be released from the enclosing cells when their protein portion was dissolved. These, however, are mere physical changes. Attentive study has brought out the fact that there is, after all, some hydrolysis of fat in the stomach, though it is probably slight. An enzyme with this action is accordingly assumed and is spoken of as *gastric lipase.* It is only the most finely divided (emulsified) fats which seem to be appreciably affected. The products of this decomposition as well as of the later fat digestion in the intestine are *glycerin* and free *fatty acids.*

Summary.—The material passing the pylorus is comparatively dilute and normally free from coarse particles. It is acid in reaction, both the native hydrochloric acid and the acids formed by fermentation contributing. Much of the food is as yet practically undigested. On the other hand, some progress has been made in the transformation of cooked starch into sugar. The proteins are partially peptonized. If milk has formed a part of the diet, it will have been curdled and redissolved. Fats may have been liquefied and scattered, but are not likely to have been extensively hydrolyzed. On the whole, gastric digestion may fairly be described as preliminary in character.

CHAPTER X

THE SMALL INTESTINE: ITS MOVEMENTS, SECRETIONS, AND DIGESTIVE PROCESSES

THE intestinal content is propelled on its winding way by peristaltic movements. These are similar in their mechanical principle to the waves of muscular contraction passing down the esophagus in the act of swallowing. They are, however, much slower and gentler in character. As a rule they do not run an uninterrupted course from the pylorus to the ileocecal valve, though such a phenomenon is an occasional possibility. More commonly a wave will travel a limited distance and then fade out, leaving the material which it was moving to rest for a time in some depending loop. If this is true, the progress of the food is intermittent; *x*-ray observations upon human subjects have led to the estimate that it takes four or five hours for the passage through the whole length of the small intestine. This time may be assumed to vary widely with the individual and the diet. Reduced to an average rate the data quoted above give us about one inch per minute.

Intestinal peristalsis, like the movements of the stomach, is governed mainly by local mechanisms. Yet in this case as in the other the central nervous system may exert an influence tending to accelerate or to suppress the activity of the muscular coats. The second or inhibitory action is the more marked. A question much discussed is whether the direction of peristalsis in the small intestine is at all subject to reversal. The sum of the evidence at present supports the view that such a reversal (antiperistalsis) is possible, but only under conditions which are clearly abnormal. Ordinarily it is plain that the intestine is distinctly specialized to act in one way rather than the other.

Not all the muscular contractions exhibited by the small intestine have a progressive character. Frequently a loop which contains food will become creased at short intervals by rings of constriction which do not shift their position, but remain stationary for a time. The internal effect is to create a series of small pouches holding separate portions of the chyme. After this condition has persisted for a time the regions originally contracted become relaxed, and new contractions set in at points midway between them. Under the influence of such movements the food is constantly shifted about and subdivided, but it is not driven steadily in one direction. This "marking time" on the part of the small intestine is referred to as *rhythmic segmentation.* Inasmuch as it serves to alter the contact relations between the intestinal contents and the lining, it probably favors absorption. Some writers have made much of the effect which these contractions may be assumed to have upon the flow of blood and lymph in the walls of the canal. When pressure is applied at brief intervals to tissue containing these fluids the result may be described as a massaging action, hastening the circulation and crowding out some of the lymph. This again must tend to promote the absorption process.

A longitudinal movement of individual loops is often described. Two neighboring turns of the intestine may be seen to glide the one upon the other, coming to rest after slipping a short distance, and presently reversing the direction of their travel. This form of activity cannot definitely further the progress of the contents, but when it affects segments enclosing liquid material we may suppose that the food and juices are tilted about and brought into relation with the largest possible area of absorbing surface.

The Secretions Entering the Small Intestine.—In Chapter VI it was stated that this part of the canal receives the contributions of the liver and the pancreas, as well as of the microscopic glands in its own mucous membrane. The bile and the pancreatic juice, it will be remembered, enter just below the pylorus. The intestinal juice is produced by all parts of the extensive lining, but more abundantly in the upper than in the lower segments. The three secretions have some characters in common. They are all alkaline in reaction, owing to the presence in them of sodium carbonate. This confers upon them in a considerable degree the power to neutralize acids. As the acid chyme from the stomach meets the alkaline secretions in the duodenum there must be more or less carbonic acid gas evolved. This may be helpful to the digestive process, since the tendency will be to lighten the texture of the food particles, much as dough is lightened by the agency of yeast.

It is not merely the acid from the stomach which may be combated by the alkali of the juices below; there are two other sources of acid to be taken into account. One of these is found in the bacterial fermentation, chiefly of sugars, which goes on in the intestine. The second is the entirely normal formation of free acids occurring in the course of fat digestion. So far as the first class of acids are neutralized the products are mainly lactates and butyrates; the fatty acids may be converted into *soaps*. There is no guarantee of an exact proportionality between the acids and the alkali, and it is impossible to say which will be in excess in a particular part of the canal. Generally, however, the resulting reaction of the mixture is not far from the neutral point.

The united volume of the three secretions is held to be very large, but any estimate tends to mislead, since throughout the length of the intestine we have the withdrawal of water keeping pace approximately with its inflow. In a certain section selected for observation the bulk of the contents may show little change during a long period, and yet there may have been profuse secretion entirely disguised by counterbalancing absorption. In this consideration we see indicated an important service shared by all the digestive secretions, that of supplying liberal quantities of water to act as the solvent and carrier of food-stuffs destined for absorption. If absorption were to continue without compensatory secretion, a final stage might be reached in which the cavity of the intestine would be drained of all fluid, while the walls would be crusted with a dry residue suggestive of boiler scale.

The Pancreatic Juice.—In considering the causes of gastric secretion the importance of the central nervous system called for emphasis. This is not true to the same extent of the government of the pancreas, though here also it is held that the nervous system plays a part. A chemical means of control is better known. As has been hinted before, there is an intimate relation between the gastric activity and the later awakening of the pancreas from its usual state of repose. The arrival of acid from the stomach in the duodenum causes a timely outflow of pancreatic juice.

This might be supposed to be an instance of reflex action, like the production of saliva when acid is taken into the mouth. It has been shown, however, that it has another explanation. The acid, striking into the lining membrane of the duodenum, initiates a series of reactions which have been studied in detail, and which lead at last to the formation of a substance of quite definite chemical properties called *secretin*. This finds its way into the circulation, and, like a drug, is swept far and wide. It stimulates the pancreas to produce its secretion, augments the formation of bile by the liver, and probably excites the glands in the wall of the intestine to greater activity. In the light of these facts it becomes clear that a vigorous gastric digestion with the strongly acid chyme which results goes far to insure a normal intestinal process.

The pancreatic juice in man is an abundant secretion—a pint or more daily—and, in marked contrast with the saliva and the gastric juice, it has relations with all three principal classes of food-stuffs. It contains an enzyme which some have thought to be identical with the ptyalin of the saliva, but generally called *amylopsin* or *pancreatic amylase*. Thus the progress of starch digestion, interrupted for a time in the stomach, is now renewed. The slight acidity which may exist in the intestine is not likely to prevent this type of digestion from going on to completion.

Beside acting on starches, the pancreatic juice continues and greatly accelerates the hydrolysis of fats which has been barely begun in the stomach. The enzyme concerned is called *steapsin* in the older books, but by more recent writers *lipase*. The immediate products are glycerin and fatty acids. A secondary formation of soaps is a possibility already indicated. When an oil undergoes digestion it breaks up at an early stage into microscopic drops and is said to be emulsified. This subdivision clearly multiplies the surface of contact between the food and the digestive juice, and has an effect corresponding to that of mastication upon solids. It is, therefore, most helpful to digestion, but it is not to be confused with digestion itself.

The statement is commonly made that the pancreatic juice continues the work of pepsin upon proteins by virtue of an enzyme called *trypsin*. While this is approximately true, it calls for a certain qualification. If the juice is carefully collected as it comes from the main duct of the pancreas without being allowed to mingle with other secretions or even to touch the lining of the intestine, it is reported that it is usually incapable of hydrolyzing proteins. This power it gains in a striking degree when it has been mixed with ever so little of the intestinal juice, the *succus entericus*, as it is sometimes called. The interaction of the two secretions is described as resulting in the "activating" of the pancreatic juice. The natural inference is that the inactive fluid contains in solution a body, not yet deserving the name of enzyme, but ready to become one by a quick transformation. An inactive antecedent body of this kind is termed a *zymogen;* in this specific instance, *trypsinogen*. Acting on the assumption that there is a definite substance in the intestinal juice capable of changing trypsinogen to trypsin, physiologists have given the name of *enterokinase* to the agent concerned.

Tryptic digestion differs in characteristic ways from the

kinase
activates

peptic process which has been described. Acid which is essential to digestion in the stomach is antagonistic to the pancreatic type. Trypsin does its work best in a nearly neutral mixture. In the normal course of events it acts upon material already partly hydrolyzed, but it has the power to carry through all its stages the digestion of native protein. If the food is a solid, mere inspection reveals a difference between peptic and tryptic solution. In the former case there is marked swelling, as previously stated; in the latter there is progressive corrosion, a shredding or honeycombing of the specimen.

When chemical methods are employed in the study of tryptic digestion, it is found to run a course roughly parallel with that of the gastric digestion of proteins. Corresponding intermediate bodies—proteoses—are described in both instances, though it is said that some stages in the tryptic process are passed so rapidly as to seem almost to be omitted. What distinguishes the pancreatic proteolysis most radically from the peptic is the facility with which the peptones are broken down into still simpler bodies. We have made the statement that these late cleavages take place only very slowly under the influence of gastric juice. So it becomes clear that trypsin is distinctly adapted to follow after pepsin in the accomplishment of protein digestion.

Peptones are compounds which are simple by comparison with standard proteins, but which are still too complex to be given precise chemical formulas. When they are hydrolyzed, most of the products come within the knowledge of the organic chemist so definitely that their molecular structure can be confidently expressed. To the student it must be admitted that such formulas do not appear simple, but if he is disposed to resent the use of the word he is to reflect that these molecules stand in some such relation to the original protein complex as the bits of the mosaic bear to the whole design. It is with some such an idea that the Germans have called them *Bausteine*, that is, the building-stones, from which a new architecture can be constructed. The simplest products of the tryptic process are conveniently called amino-acids.

The Intestinal Juice.—This copious secretion was formerly regarded as having little to do with digestion. The present disposition is to credit it with a very considerable share. When the pancreatic juice is prevented from entering the intestine it remains possible to keep up the nutrition of the animal, and one must conclude that the intestinal juice is successfully preparing more than one kind of food for absorption. Samples of the secretion have often been obtained from loops of the intestine disconnected from the remainder of the canal. Different workers give varying accounts of its properties.

The feature of its digestive action concerning which there is the most general agreement is the hydrolysis of the more complex sugars, the disaccharids. Of these sugars, three are commonly present, and there appear to be three enzymes adapted to act upon them. Maltose arises principally from the salivary and pancreatic digestion of starch. It is hydrolyzed to dextrose (glucose) by an enzyme, which is best called *maltase.* Lactose, or milk-sugar, is similarly converted into equal parts of dextrose, and the less familiar sugar galactose by the enzyme *lactase.* Saccharose, or cane-sugar, gives rise to dextrose, and a sugar of different properties, levulose (fructose), under the influence of the enzyme, *invertase.*

When an extract is prepared from the thoroughly minced lining of the small intestine it can be shown to have the power to cause proteoses and peptones to undergo hydrolysis, though it is said not to act upon the original unmodified protein. This is equivalent to saying that such an extract can parallel the later work of trypsin, though lacking its power to initiate digestion. The enzyme implied has been named *erepsin.* It is regarded as an open question whether this enzyme normally enters the cavity of the intestine or does its work within the confines of the cells from which it can be extracted. We may conceive that when an animal is deprived of its pancreatic secretion it is still able to digest proteins, pepsin beginning the digestion and carrying it to a stage at which the products are susceptible to the action of erepsin. The presence of enterokinase in the intestinal juice has just been noted.

The Bile.—The secretion of the liver cannot be regarded in the same light as the digestive juices mentioned heretofore. It is not secreted merely after meals, but is always flowing through the ducts which converge from the several lobes of the liver. It is not necessarily entering the intestine at all times, since the gall-bladder provides a place for its temporary storage, as described in Chapter VI. While the production of bile never ceases, it does show an acceleration during the digestive periods, and this is believed to be in response to the stimulating effect of secretin.

Bile attracted the attention of physicians in very early times, its bright color and intensely bitter taste giving it a certain distinction. It entered largely into ancient theories of disease and of medicine. We have traces of these facts in the root-meaning of such words as bilious, choleric, and melancholy. In popular estimation bile is a poison arising now and then in the system and causing digestive disturbances. Patient study has shown that the bile is a complex mixture, and that it numbers among its constituents some which are waste-products and others which have a favorable effect upon the progress of digestion and absorption. It stands, therefore, in a position intermediate between that of the gastric juice, which is formed solely to advance digestion, and that of the urine, which is composed of material useless to the body.

The pigments of the bile are counted as waste substances. A red one predominates in carnivorous animals. The bile of the herbivora is green, as is also the case with human bile. These pigments show in their chemical nature a close relationship with the red coloring-matter of the blood, the important compound *hemoglobin*. All the evidence goes to show that the bile-pigments are modified fractions of the great hemoglobin molecule, and that their abundance is an indication of the amount of destruction suffered by the red corpuscles of the blood. These pigments are relatively insoluble and are not always successfully carried to the intestine by the bile. When they deposit in solid form in the gall-bladder they contribute to the formation of "gallstones," aggregations in which another waste-product, the waxy *cholesterin*, may be included. The pigments are usually more or less altered by bacterial action in the course of their journey through the canal, and eventually become the chief coloring-matter of the feces.

The bitter taste of bile is due to two organic salts of high molecular weight. These seem to have a totally different significance from that of the pigments and cholesterin. They are not lost to the body, but are absorbed from the lower part of the small intestine and are presumably secreted again and again. This phenomenon has been spoken of as the "circulation of the bile-salts." The withholding of these bodies from the alimentary tract tends to derange digestion and, in particular, to diminish the absorption of fats. When bile is tested by itself it shows only the feeblest digestive powers, yet pancreatic digestion is greatly promoted by its presence, and it may be likewise an ally of the intestinal juice.

Light is thrown on the properties of the bile by observing the condition of jaundice. This disorder is commonly caused by the more or less general plugging of the bile-ducts with mucus. The secretion cannot make its escape from the liver in the normal way and some of it enters the circulation. Bile-pigments make their appearance in the white of the eye and in the skin. The urinary pigment, which is always closely related to the pigments of the bile, is much increased. The ill feeling which usually attends the condition may be due in part to the mildly poisonous effect of the abnormally retained bile constituents. It is likely to be aggravated by indigestion. The bile-salts are lacking and the capacity to digest the food and promptly absorb the end-products is greatly reduced. Bacterial action in the intestine may become pronounced. This last fact has suggested that the bile may be an antiseptic. It cannot be shown to have anything like a universal action of this kind, but it is very probable that it has a selective one, favoring one type of organism and restraining another. Even though it had no such influence, the intestinal bacteria might be expected to multiply in its absence, for the simple fact of delayed absorption would suffice to bring this about. Our best defense against excessive fermentation and putrefaction is in the early and complete removal of the food from the sphere of action of micro-organisms.

Summary.—The secretions flowing into the small intestine supply enzymes in sufficient number and variety to accomplish the digestion of all common foods. The transformation of starch to maltose begun in the stomach is completed by the pancreatic amylase. The resolution of proteins into the simple structural units from which their molecules are built is carried out under the influence of trypsin and perhaps of erepsin. The last-named enzyme is supposed by many to work upon the tryptic products as they pass through the lining cells on their way to the blood. Fats are hydrolyzed by the pancreatic lipase, with the formation of glycerin and fatty acids, the latter being in some measure converted to soaps. The disaccharids are changed to monosaccharids, a work attributed to the intestinal juice. Fermentation caused by bacteria has been taking place along with the strictly normal processes. The most evident products are organic acids, which may or may not be fully neutralized by the alkaline secretions.

Protection Against Self-digestion.—There has been much discussion of the fact that the proteolytic enzymes in the digestive tract do not ordinarily attack its mucous membrane. They may do so after death and when the tissues are in an abnormal condition, as in case of gastric ulcer, the juices may strongly antagonize the healing process. It is often asserted that there is a definite chemical difference between the proteins of living and of lifeless matter. A recent explanation of the resistance which living cells offer to digestion is based on the apparent fact that such cells form bodies which have the capacity to neutralize enzymes in fixed proportions. The name of *anti-enzymes* has been applied to such protective substances.

CHAPTER XI

THE LARGE INTESTINE

THE material passing into the colon is dilute and much reduced in volume as compared with the chyme passing out of the stomach. In the lower part of the small intestine the absorption of water more than counterbalances the secretion, hence the shrinkage of the contents. But since the end-products of digestion are being absorbed also, there is no tendency toward extreme concentration. In the large intestine there is but little secretion, and the continuation of the absorption of water reduces the contents at last to a nearly solid consistency.

The colon appears to be of very unequal value to animals of different classes. In the carnivora the work of digestion and absorption is so nearly finished by the small intestine that very little remains to be done. The small quantity of matter having a potential food value may be accompanied into the large intestine by enzymes, which may there carry further their digestive action. Such food, however, is likely to be a negligible amount, and the digestive powers of the mixture at this point are unreliable. In the herbivora, the food being bulky and refractory, a considerable portion may arrive undigested in the colon. These animals have very capacious ceca, in which great masses of contents seem to be held for long intervals. The digestion occurring there may be partly effected by the native secretions, but it is believed to be largely the work of bacteria.

The average human being resembles the carnivorous type rather than the other. Numerous cases have been observed in which no use was made of the colon, and it was never difficult to maintain nutrition. When the large intestine is no longer traversed the discharges are watery and rather voluminous, but they contain only small percentages

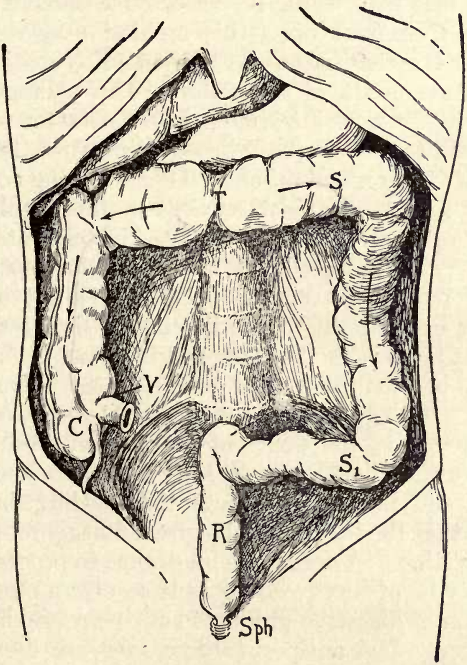

Fig. 14.—The colon with special reference to its movements: *T* is placed near the seat of frequent sustained or tonic contraction. From here backward to the cecum (*C*) antiperistalsis is of common occurrence, but this segment is swept also by occasional waves in the opposite direction; *V* indicates the position of the ileocecal valve, which prevents reflux to the small intestine under the influence of antiperistalsis; beyond *T* the infrequent movements which take place have always a progressive character; *S* and S_1 are regions often found to contain stationary contents; *K* is the kink referred to in the text; *R* is the rectum, and *Sph* is the double sphincter at the anus.

of valuable nutriment. The fluid escaping from the end of the small intestine or the beginning of the large is described as entirely inoffensive, which indicates that putrefactive decomposition of protein is usually confined to the colon. Protein putrefaction is nowadays held accountable for many ailments, and from this view has arisen the common teaching that man would be better off without a large intestine. Comment upon this opinion may well be reserved for the chapter on the Hygiene of Nutrition.

The Movements of the Colon.—The average rate of progress in the large intestine is low. A factor tending to make it so has recently been brought to notice through the studies of Cannon and others. The ascending colon has a property not duplicated elsewhere in the canal, that of habitual antiperistalsis. As repeated instalments pass the ileocecal valve the cecum is filled and the accumulating contents reach higher and higher levels, but instead of thrusting onward this gathering mass, the circular muscular coat most of the time urges it backward. The result is said to be much like what is seen in the antrum of the stomach, although here the direction of the movement is reversed, that is, the waves of contraction press the mixture downward into a pouch, from which the only escape is by an eddying reflux through the crawling ring. It is assumed that the ileocecal valve prevents any return to the small intestine. A deliberate hindrance to progress at this point may be of service so far as it secures a more perfect absorption of digestive products and the retrieving of surplus water. The antiperistaltic waves are described as starting from a zone in the transverse colon near the midline of the body.

From time to time contractions sweep over the ascending colon in what we should call the normal direction, and send onward more or less of its contents. Beyond the midpoint referred to above those movements which occur are invariably progressive, but are separated by long periods of repose. If we adopt a recent estimate we can make the following general statement: The foremost portion of a meal, that which was first to pass the pylorus and the ileocecal valve, may be expected to be near the spleen at the end of the ninth hour. When defecation occurs all the colon beyond this point may be freed of its contents. If this happens once in twenty-four hours the age of the food residues discharged will evidently vary from thirty-three hours, for the matter longest retained, down to nine hours, in the case of that which barely came within the section evacuated. There must be extremely wide departures from these figures in individual subjects.

The descending colon is reported to be found empty, as a rule, when observed with the *x*-ray. This is taken to mean that it is an irritable segment which is stimulated to advance all that enters it to the sigmoid flexure without delay. The sigmoid flexure, on the contrary, permits a relatively large accumulation before it is excited to contract. This region of the colon is interesting from a biologic standpoint, because it seems to be an adaptation to the erect position of the body. Quadrupeds hold the large intestine, roughly speaking, in a horizontal plane, and with them the effect of gravity on the contents is immaterial. These animals have no sigmoid flexure, the descending colon inclining toward the midline, and joining the rectum without the S-shaped connection. When the erect position is assumed there will naturally be a tendency on the part of the fecal material to settle toward the anus. The development of the sigmoid in the apes and in man provides a place of lodgment for the burden and spares the rectum from a constant distention.

The sharp bend between the sigmoid and the rectum, amounting almost to a kink, such as one may see in a rubber tube that has been doubled, is not easily passed by the feces. It is only when the quantity has become considerable that a vigorous peristalsis overcomes the resistance and fills the rectum. Here for the first time the pressure arouses distinct sensations. If defecation is postponed the tone of the rectum may be lowered and these sensations cease to be felt. If the occasion favors, the anal sphincters are inhibited and the rectum is emptied by its own peristalsis, reinforced by external pressure developed through contractions of the abdominal muscles and the diaphragm.

The action of the skeletal muscles at this time resembles that in vomiting, but is, of course, much more largely voluntary and more sustained in character.

The Feces.—Two classes of material may be mingled in the contents of the colon: the residues of the diet and the excretions of the alimentary tract including its glands. The proportion existing between these two is a variable one. Physiologists have lately come to regard the food residues in the feces, under average conditions, as forming a less prominent element than was formerly supposed. A correspondingly increased importance is assumed by the excretions. The feces passed during long fasting are evidently made up exclusively of bodies of the second class. Such feces, while small in amount, may have practically the same composition as those formed upon a moderate and digestible diet. This suggests that the increased quantity which results from eating does not imply a greater residue so much as a greater production of secretions along the active canal. A mass very much like normal feces may gather in an isolated loop of the intestine to which no food is admitted. Among the substances originating from the tract rather than from the food are the modified bile-pigments, cholesterin or its derivatives, mucus, and detached cells.

Bacteria, living and dead, intimately mixed with the numerous products of their own life activity, are prominent in the bowel discharges. These organisms can in one sense be said to have their origin in the diet, since that was the source of the primary seeding or infection. From another point of view they are largely developed at the expense of the body itself, for they have multiplied in the intestine and may have lived in part upon its secretions as well as upon the food. The gases of the colon are due to them.

True food residues include the indigestible matter of the diet and some undigested food—normally but little of the latter. Absorption is strikingly efficient with most subjects and reasonable diets. Not more than 5 per cent. of most foods goes to waste. The principal indigestible component is the *cellulose* of vegetable tissues. When it is abundant, as in a diet containing coarse, woody matter, such as is eaten by the rabbit, the feces are given an immense bulk. The same result is secured in a measure when man adopts a ration in which fruits and vegetables enter freely. Much cellulose is an impediment to complete digestion and absorption of the proteins and carbohydrates which it envelops, but the foods in which it occurs are cheap and the waste involved does not open an economic question of moment. Some bacterial decomposition of cellulose is said to take place in the colon and may be of slight advantage to us, not that we profit by the products of such fermentation, but that a freer exposure of proteins and starch may be insured.

Most writers have held that a moderate amount of indigestible material is a desirable feature of the diet. This teaching was emphasized by the celebrated Sylvester Graham early in the last century. Lowell has referred to him as an "apostle of bran." Later authorities have not recommended such wholesale loading of the tract with husks and fibers, but an admixture of such elements has been generally advocated. The favorable effects include the well-recognized stimulation of peristalsis and probably a better distribution of food along the canal. The indigestible fraction of the food has been spoken of as ballast and also by the expressive name of "roughage."

Under abnormal circumstances the loss of valuable food through the stools may become extensive. This will be the case when absorption is interfered with either by an acceleration of peristalsis or in other ways. Different cathartics bring this about in a varying manner, some by hastening the rate of propulsion, and others, especially the salines, giving the intestinal contents a concentration and a chemical character which forbids absorption. A mild disturbance of this nature is more apt to result in a waste of fats and fatty acids than of other forms of food.

Rectal Feeding.—While the large intestine of man is not called upon in normal conditions to absorb much nutriment, it has a marked reserve power to do so. This is often of the greatest value in sickness, when it may be possible to tide over a critical time and to keep up a measure of strength by introducing suitable foods into the colon. Fluid mixtures used in this way must be of low osmotic pressure, a fact which, unfortunately, rules out the sugars excepting in small amounts. Milk and eggs are much employed. Experience has shown that the body makes a partial use of the proteins offered, even though they have not undergone digestion. The results are better when artificial digestion has been brought about in advance. So far as we know there is no flow of efficient digestive secretions in response to the introduction of food through the rectum. It is believed that nutritive enemata may in part at least enter the region of prevailing antiperistalsis, and that this must favor their long retention and better utilization. Stimulants may be given through the large intestine and water to allay thirst.

CHAPTER XII

THE BLOOD

The intestinal lining is a barrier between the mixture of food and secretions within the canal and the blood which flows through the neighboring vessels. The main problem to be dealt with in treating of absorption is the transfer of portions of the intestinal contents to the blood. We shall find that a certain fraction of the incoming nutriment is carried for a time in the lymph, but this is destined before long to blend with the main current of the circulation. It will be for our advantage to become somewhat familiar with the make-up and service of the blood before we discuss the entrance into it of the products of digestion.

Blood is a carrier. Regarding it as such, we can conveniently subdivide its functions according to the classes of material which it conveys. Most people will think of it as, first of all, the bearer of food to the tissues. This is, indeed, a matter of prime importance. The food is added to the blood mainly as it flows through the capillaries of the wall of the alimentary canal, and taken from it by the various parts of the living body in proportions corresponding with the degree of the local activity. The largest tax is that levied by the skeletal muscles. An unfailing supply of oxygen is a need even more urgent from moment to moment than the presentation of food. Oxygen is added to the blood in the lungs, and is withdrawn from it as it makes its round through the body, the quantity consumed in different organs being an even better measure of their individual metabolism than is their appropriation of food. Where oxygen is taken from the blood, carbon dioxid is returned to it. This indicates that the blood is a bearer of wastes. The excess of carbon dioxid makes its escape during the next transit of the blood through the lungs. Other waste substances are gathered by the blood as it flows near the active cells. The major part of these is destined for excretion by the kidneys, and these organs receive so large a share of blood that the entire volume must come under their influence within a short space of time. A minor fraction of the waste finds an outlet in the bile, the sweat, and through the intestinal wall.

It has already been pointed out that every organ has a chemical constitution and a metabolism peculiar to itself. Therefore each organ must make certain demands upon the blood not exactly duplicated elsewhere. What is more important, each organ gives rise to products unlike those formed by any other part. In a number of cases these products can be shown to have far-reaching effects. Their existence has been mentioned in Chapter IV. Recognizing the large part which they play in the economy of the organism, we may state at this point that an essential service of the blood is the transportation of internal secretions.

Another function of the blood, and one often overlooked, is that of equalizing the temperature of different regions. One is reminded of the arrangement of a heating system in a house where a fire burns in a furnace and a circulation of air, hot water, or steam disperses the heat through the rooms above. Interruption of this circulation will allow the upper stories of the house to cool off, while the basement is overheated. In the living body heat production is a function of all active tissues. The ancients believed that it was the particular duty of the heart. This organ is, in fact, distinguished for its rapid evolution of energy, but it must be remembered that it is of small bulk. A much larger share of the aggregate heat production is borne by the skeletal muscles. These are supplemented to some extent by the liver and the other great glands of the body. Blood passing through a tissue which is undergoing lively metabolism will have a higher temperature as it leaves than it had when it entered. As it flows on it will communicate some of this surplus heat to resting structures in which little or no heat production is going on. This is the case with the connective tissues and with the skin.

At the surface the blood loses heat, at least under all conditions which can be called normal. The cooler blood then returns to the large vessels, merges with the heated blood from the muscles and glands, and brings the temperature of the mixture to an average which seldom varies materially. The means by which this standard temperature is maintained will be discussed at length in a later chapter. It will be well to point out even at this time that the skin is subject to considerable changes of temperature, and that our sense of being warm or cold depends entirely on the condition prevailing at the surface. If we turn again to our illustration of a house heated by a "circulation" of hot air or water, we shall recognize that here, as in the living body, there is a constant escape of heat to the environment. The temperature of a pane of glass in a window of the house will be influenced both by the internal and the external state of affairs. The glass may be warmed as hot air is wafted against it from within or cooled by a gust from without. So the skin may be warmed by a waxing of the blood-current close beneath it or chilled by a passing draft.

Blood may be described as a red fluid, but inspection with the microscope shows at a glance that its redness is not due to a coloring-matter in solution and uniformly distributed, but to the presence of minute solid bodies in suspension. These are the *red corpuscles.* The liquid in which they are swept about is the *plasma.* The corpuscles make up something less than one-half the total volume. In view of this, it is surprising that the blood can have such a free-flowing character and find its way through the capillaries so readily. One would anticipate that such a mingling of solid particles with fluid would result in the formation of a highly viscid mass. That the actual condition is so different must be due to the absolute smoothness and the great pliability of the corpuscles.

The Red Corpuscles.—The individual corpuscle is usually seen in the form of a disk slightly hollowed on its surfaces. It is about five times as wide as it is thick. A very slight unbalanced pressure acting from one side will convert it into a saucer- or even a cup-shaped form. It is remarkably elastic, and springs back into its original shape as soon as there is no longer a force acting to distort it. Most cells of the body are variable in outline and in size, but one red corpuscle is as much like another as though all had been made in the same mold. The diameter does not vary perceptibly from $\frac{1}{3200}$ inch. This is the figure for human blood; there is a standard size of corpuscle for each animal species.

The red corpuscles are often spoken of as cells, but their claim to rank as such is questionable. Regarding them from an anatomic standpoint, they lack a feature which is reckoned an essential of the cell; namely, the nucleus. On the physiologic side there is no good reason for supposing them to be alive. The fairest view, probably, is to look upon each red corpuscle as a modified and, in a sense, degenerate cell. A single substance has come to constitute a very large percentage of its make-up. This is the peculiar, iron-containing protein, *hemoglobin*. We shall not be far wrong if we consider the corpuscle to be a packet of hemoglobin moving passively at the mercy of the current. Its function is clear and definite. Hemoglobin has the property of combining with oxygen whenever the gas is freely present in the surrounding medium. It has also the property of releasing this oxygen when it comes into a situation where there is a relative scarcity of the element.

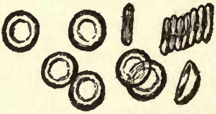

Fig. 15.—Red blood-corpuscles. Several are shown in different positions. The hollow centers are evident. In one case two corpuscles are overlapped to show that they are transparent. They tend to run into piles, as shown at the right. A saucer-shaped form is represented.

The hemoglobin of the blood, as can be seen from what has been said, is ever passing from one state to another, as it alternately adds oxygen to itself and parts with it. Evidently it can be described as existing in two varieties: a form fully charged with detachable oxygen (oxyhemoglobin), and a form from which this loosely engaged oxygen has been removed (reduced hemoglobin). The first is the prevailing variety in *arterial* blood fresh from the lungs, and it gives to such blood a bright scarlet color. The *venous* blood, returning from the tissues, still contains a goodly proportion of oxyhemoglobin, but mingled with it there is now a variable amount of the reduced compound. Reduced hemoglobin is of a dark color, and venous blood, in consequence, inclines toward a purple. The sharply contrasting red and blue so commonly used in diagrams to distinguish arteries from veins greatly exaggerate the actual difference.

The red corpuscle, it will now be clear, is a bearer of oxygen. A service like this must be dependent on the extent of surface exposed for the absorption and the discharge of the gas. The disk is obviously more efficient than a sphere would be, for it has more surface in proportion to its mass. Small corpuscles likewise must be quicker to load and to unload than large ones, and this helps us to understand why the largest corpuscles in nature are not found in large animals, but in those like the frog and the fish, which do not have a very intense metabolism. There is an additional reason why small corpuscles are better fitted to meet the demand for a great oxygen supply: the capillaries must be of a size to admit the corpuscles, and an animal with large corpuscles cannot have the closely woven capillary net which becomes a possibility when the diameter of the corpuscles is reduced and which brings the oxygen into closer relations with the cells which require it.

The red corpuscles originate, generally speaking, by the transformation of cells in an unexpected locality. This is the so-called "red marrow" which fills the small spaces that abound in the enlarged extremities of the long bones. Here there is always going on a progressive change in the composition of the cells, in course of which hemoglobin replaces most of their original substance. The cell nuclei are eventually lost and the newly formed corpuscles detach themselves and drift away in the blood-stream. Their hollow centers strongly suggest the deficiency due to the loss of the nuclei. It is an interesting fact that when recovery is taking place after hemorrhage, red corpuscles containing nuclei are often to be found in samples of the blood. This makes it seem as though in meeting the emergency corpuscles in an incomplete stage of their development had been pressed into service.

The first glance at a specimen of blood under the microscope leaves the impression that the corpuscles are all of one unvarying type. Closer observation shows here and there among the host of colored elements bodies of another order, the white or colorless corpuscles. There is but one of these to 500 or 1000 red. The white corpuscles are not flattened, but more nearly spheric. They are, however, of no fixed form, and many of them have the property of ameboid movement. This is good evidence that they are to be considered living, and it can be shown further that they have nuclei and conform to our conception of complete cells. Much that is of interest is known of them, and the relation which they bear to the checking of bacterial infection is of the utmost importance. We shall not enter upon a discussion of this fascinating subject.

The Plasma.—Aside from the transportation of oxygen, all the chief functions of the blood could apparently be fulfilled by the plasma. The standard foods of the tissues are here. So also in much smaller amounts are the non-gaseous wastes. Carbon dioxid, the most abundant of all waste-products, is carried jointly by the plasma and the corpuscles. It is evident that we must expect a solution meeting such manifold requirements to be of a highly complex nature. This is eminently the case.

More than nine-tenths of the plasma is water. The proportion is little increased by drinking and little reduced by thirst. Its constancy is secured by kidney activity coupled with rapid exchanges of fluid which take place between the blood and the lymph and tissues. When a great draft is made upon the water of the blood, as is the case in profuse sweating, the volume is restored by taking in water from outside the vessels, and this may mean a marked loss of body weight. The blood itself is not likely to share appreciably in such a loss. Its total volume in the adult of average build has been variously estimated at from 3 to 5 quarts. The earlier calculations led to the higher figures; 4 quarts (8 pounds or $\frac{1}{16}$ of the weight) is a reasonable standard for us to adopt.

Among the substances in the plasma which can be classed under the general head of foods, proteins take the first place. They form about four-fifths of the total solids. This high proportion does not correspond at all with the make-up of an average diet, in which, as we have seen, proteins take the second or even the third place. It is usual to distinguish three varieties of protein in the plasma, serum-albumin, serum-globulin, and fibrinogen, but indications are multiplying which support the belief that the actual number of proteins with clearly individual characters is much greater. Our knowledge of these bodies, their mode of origin, place of formation, and the particular value of each one in the system, is in a highly unsatisfactory state.

Carbohydrates, which occupy the leading position in the rations ordinarily chosen by civilized man, are very scantily represented in the plasma. The principal one present is the monosaccharid, dextrose, known also as glucose, or grape-sugar. The percentage of dextrose figured for the whole blood is between 0.1 and 0.2. This means from 1 to 2 grams of sugar in a liter of blood, and limits the total amount in circulation to 10 grams at most. Such a quantity seems insignificant when it is remembered that 100 grams of sugar may easily be formed in the digestion of a moderate meal. The sugar is not readily increased by free feeding of carbohydrates, nor does it noticeably diminish during long fasting. The explanation of this singular constancy will be given later.

Fat, or its derivatives, is found in the plasma in a proportion of a similar order to that of sugar. It is much more subject to variation, rising notably after a meal in which there was much fat. Plasma obtained from a dog at such a time exhibit the phenomenon of developing a true cream, the fat gathering at the surface. During starvation the blood is not necessarily poor in fat, since it is likely to be engaged in carrying this form of food from places of storage—the adipose tissue—to the muscles and elsewhere to be oxidized.

Those compounds in the plasma which we can confidently designate as waste-products occur only in the smallest quantities. Carbon dioxid is, of course, an exception, being very abundant. Among the non-gaseous wastes destined to be dealt with by the kidneys, *urea* is the only one which is easily detected. This is the compound in which seven-eighths of the nitrogen is carried from the body. The fact that the waste substances are kept down to such a low level in the blood is evidence of the remarkable efficiency of the kidneys and the supplementary organs of excretion. It is also a reminder of how rapid and copious is the circulation. No portion of the blood can long escape passage through the glands which have this striking power to hold it to a standard composition.

If the mixed solids from a sample of plasma are incinerated, we have left a small mass of ash or mineral matter amounting to about 1 per cent. of the whole blood. By far the largest component is sodium chlorid, the chief salt of the diet, and the only one which we deliberately add to our food. Other bases represented are potassium, calcium, and magnesium. Besides chlorids, we find carbonates and phosphates, the former having greatly involved relations with the carbon dioxid of the blood. To the list which has been given might be added many minor constituents, some of which are judged to be present because of certain properties displayed by the blood rather than because they can be chemically identified. Illustrations of such are afforded by the internal secretions, enzymes, and the immune bodies. Individual peculiarities of metabolism, susceptibility, and resistance must depend on substances of this obscure class.

Coagulation.—Blood when shed shows the familiar property of clotting. This is a most valuable quality, since it provides for the automatic checking of ordinary bleeding and also forms a protective shield, the scab, beneath which the healing process may go on. The importance of coagulability is emphasized by the rather frequent observation of cases in which it is lacking, and in which serious or even fatal hemorrhages follow trifling injuries. The essence of the process is a chemical change affecting one of the minor proteins of the plasma in such a way that it passes into a solid form and cements together the red corpuscles. The original protein is the one already named as fibrinogen. The modified form after coagulation is called *fibrin*. The actual amount of fibrin is extremely small (perhaps 2 to 4 parts in 1000 of blood), but it is not difficult, when we consider its gummy character, to understand how it can convert a liquid medium into a stiff jelly by knitting together the suspended corpuscles.

The entirely natural impression that coagulation is the result of exposure to the air is erroneous. The matter has been the subject of the most painstaking studies, of which we can give only the briefest summary. The formation of fibrin is an instance of enzyme action, and forcibly recalls the curdling of milk in the stomach under the influence of rennin. The resemblance is not complete in every respect, but is still suggestive. If we are to assume that an enzyme exists in the blood at the time of clotting and not before, we must establish its origin. Reducing the facts to the barest essentials, we may make the following statement: normal blood contains in great numbers minute and extremely perishable bodies known as the blood-plates. These are much smaller than the red corpuscles. When

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the surroundings are normal, as is presumably the case within the vessels, they keep their integrity, or at least do not disintegrate *en masse*. When they are brought in contact with foreign surfaces they do undergo prompt decomposition and, of course, their constituent material is dissolved in the plasma. Something derived from the blood-plates sets in motion the series of chemical reactions which leads at last to the perfecting of an enzyme, *thrombin*, capable of transforming the soluble fibrinogen into the insoluble fibrin.

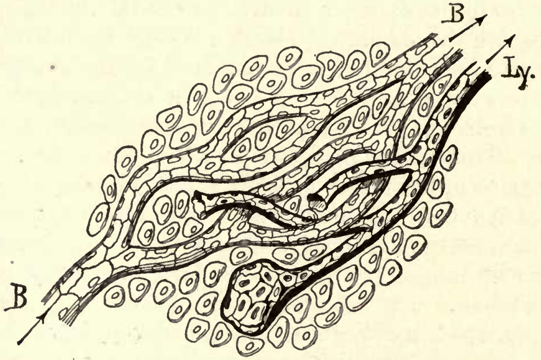


Fig. 16.—The origin of the lymphatics. This is an extension of Fig. 3. The course of the blood among the cells is shown as before (*B–B*). A detail of the lymphatic system is added (*Ly.*). The drawing is severely conventional. Two branches of the lymphatic are represented as beginning with open mouths so situated as to receive the surplus fluid directly from the interstices of the tissue. A third is connected with a blind sac. There is at present some disagreement as to which is the more typical mode of origin.

Lymph.—This term is usually made to stand for the fluid outside the blood-vessels. Used in this way, it includes the liquid filling the microscopic intervals between neighboring cells, the larger spaces which often occur in the loosely woven connective tissues, and also the contents of an inconspicuous system of tubular channels known as lymphatics. A recent writer, Starling, has suggested that a distinction should be made between the fluid in the lymphatics and that which is not enclosed in vessels of any sort. He would restrict the term lymph to the first application, and would speak of the other as tissue-fluid. This usage appears highly desirable, but is not as yet widely current.

Lymph, in the sense of tissue-fluid, cannot be collected for analysis. Considering the delicacy of the capillary wall and the probable freedom with which exchanges take place through it, there is reason to believe that this fluid must closely resemble the blood-plasma. When a tissue is the seat of an active metabolism the income and outgo of its cells must tend to alter the composition of the adjacent lymph and to make it less like the plasma. The general effect will be to reduce the oxygen to a low level, to raise the carbon dioxid content correspondingly, to consume a fraction of the organic food, and to add miscellaneous waste-products. The lymph which can be obtained by cutting one of the larger lymphatics of the body has these characters. This lymph may not be precisely like the mixture which exists in close contact with the living cells, but it is probable that the differences are not great. According to a view formerly universal and still held by many, lymph can work its way from any interstice of an organ into the branches of the lymphatics, and so to larger vessels of the same class. Many believe, however, that there is a definite separation between the unwalled spaces of the tissues and the interior of the true lymphatic system. If this is the correct conception, we have good reason to differentiate lymph from tissue-fluid. We may adopt either view provisionally without being seriously misled. Lymph contains white corpuscles and blood-plates. Since it has in it some fibrinogen it may coagulate, but owing to the absence of red corpuscles the clot is frail and tremulous.

CHAPTER XIII

THE CIRCULATION

We must postpone still further our account of the absorption of the products of digestion until we shall have made clear the general course followed by the circulating blood. We have quoted the estimate that the body contains 8 or 10 pounds of blood. At a given moment about one-fourth of this may be assumed to be in the thorax (the heart, the lungs, and the great blood-vessels), a fourth in the skeletal muscles, a fourth in the liver, and the remaining fourth elsewhere. The ceaseless movement of this large volume of liquid is maintained by the beating of the heart.

This organ consists of two halves, right and left, completely separated, so far as their cavities are concerned, by a middle partition. Regarded as a mass of muscle, the heart is single; considered as a pump, it is double. Each half is, in a literal sense, a force-pump. Each side shows us two communicating chambers, an auricle above and a ventricle below. The auricles *receive* the blood, which the corresponding ventricles will shortly *discharge.* The vessels leading to the auricles are called veins; those which convey the blood from the ventricles are called arteries. The auricles have thin walls, while the ventricles are fitted for their task by heavy muscular development. The left ventricle has much more power than its fellow, and the necessity for this will soon be evident.

A single great artery, the aorta, springs from the left ventricle. Its branches reach all parts of the body. Subdividing repeatedly, they introduce the blood at last into the *capillaries,* the innumerable vessels of the smallest order through whose exquisitely thin walls take place the exchanges with the lymph already described. The word "capillary" means hair-like, but the description falls far short of indicating the actual slenderness of these microscopic tubes. They are so narrow that the corpuscles pass through them practically in single file. The capillaries are short and soon unite to form the smallest veins. These lead the blood back toward the heart, joining as they go to form larger and less numerous channels, until at the last there are but two great veins. These enter the right auricle, one from above and one from below. The sweep of the blood from the left ventricle through the body

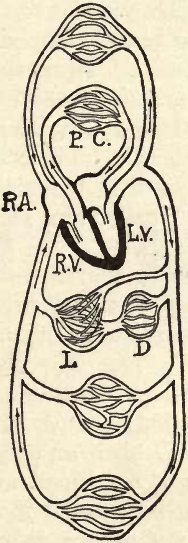


Fig. 17.—In this diagram, as is usual in such cases, right and left are reversed. This is as though the observer were looking at another subject. The short pulmonary path is to be traced from the right ventricle to the left auricle (*P. C.*). Alternative routes are suggested for the passage of the blood through the greater circulation from the left ventricle to the right auricle. The blood which traverses the digestive tract (*D*) passes through a second set of capillaries in the liver (*L*) before it can return to the heart. Note that the liver has in addition a separate arterial supply of blood.

at large and back to the right auricle is called the *systemic* circulation.

From the right auricle the blood descends to the ventricle of the same side, and is sent forth again, this time through the vessel known as the pulmonary artery. This immediately forks into branches which plunge into the two lungs. The smaller pulmonary arteries lead to rich capillary networks which are wrapped around the numberless air-sacs of the lungs. Here the corpuscles are recharged with oxygen and the carbon dioxid of the blood is reduced to a standard amount. Pulmonary veins return the blood to the left auricle. The relatively short journey of the blood from the right ventricle to the left auricle by way of the lungs is called the *pulmonary* or lesser circulation.

It is necessary to call attention to the fact that the adjectives "arterial" and "venous" are not used in a sense which exactly corresponds with the meanings of the nouns "artery" and "vein." The adjectives have a chemical significance; the nouns, an anatomic one. Arterial blood is blood fully oxygenated; venous blood is blood more or less deficient in oxygen. But an artery, as has been said, is merely a vessel carrying blood away from the heart. The blood within will be arterial if we are observing the systemic circulation, and venous if it is in the pulmonary. So the systemic veins are filled with venous blood, while the pulmonary veins carry that which has just been brought up to the arterial standard through coming into relation with the air in the lungs.

From what was stated above with respect to the distribution of the blood, it is evident that less than one-fourth of the whole volume is in the pulmonary circulation at one time, but the student must be cautioned against the conclusion that the pulmonary circuit is traversed by less blood than passes through the systemic pathways. The quantities passing along the two routes are inevitably equal, for it is, after all, the same blood which runs through each in turn. If a chain is traveling over two wheels, as shown in the diagram (Fig. 18), the links pass the two in equal numbers, and yet there are constantly more links on their way from *L* to *R* than from *R* to *L*.

When we speak of a heart-beat we mean a co-ordinated contraction of the heart's peculiar muscle. The phenomenon includes two phases: a brief and not forcible contraction of the auricles followed by a longer and much more powerful closing in of the ventricles upon their cavities. The ventricular contraction is the essential factor in propelling the blood. Valves between the auricles and the ventricles permit the latter to fill during their period of relaxation, and forbid the backward flow from the ventricles when they are emptying themselves. Other valves at the commencement of the aorta and the pulmonary artery allow blood to pass out during each contraction of the ventricles, but not to return from either artery into the heart when the resting phase ensues. The action of the two sets of valves is precisely on the principle of the two which make a syringe-bulb an effective force-pump. The right and left halves of the heart act practically at the same time.

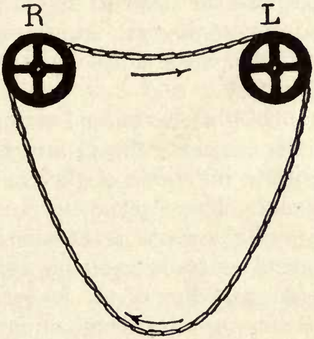


Fig. 18.—For explanation of figure see text.

Either ventricle when full may contain 5 or 6 fluidounces of blood. As it contracts it reduces its capacity and discharges blood in like measure. At the conclusion of the active period it may have nearly obliterated its cavity, or the effort may fail while there is still considerable blood within. Estimating an average output from one ventricle to be about 4 ounces, or 100 c.c., it is apparent that forty beats will suffice to discharge from one side of the heart an amount of blood equivalent to the entire quantity of circulation (40 x 100 = 4000 c.c., or 4 liters). In other words, it will require less than one minute for all the blood to pass successively through both sides of the heart. When this statement is made it should be remembered that certain routes in the systemic circuit are many times longer than others (compare the path to and from the feet with that to and from the esophagus), and some corpuscles may revisit the heart two or three times while others are making one prolonged journey.

It would be out of place to enter here upon a discussion of the value of the auricles. From a mechanical point of view they contribute but little of the energy required for driving the blood. They serve to accommodate the gathering volume of blood which the veins bring in during the rather prolonged contraction of the ventricles, and they secure a more efficient filling of the lower chambers of the heart. While their muscular development is slight, their automatic power is peculiarly marked, and it is a fair statement that the ventricle, under normal conditions, is stimulated to perform each beat by an influence radiating to it from the auricle. If there is an interruption of certain strands of tissue which normally unite the two, they cease to maintain the same rhythm, the auricle continuing at the accustomed rate, while the ventricle beats much less frequently. When the heart is dying the last signs of pulsation are in the auricles.

The Portal Circulation.—In our general description of the course followed by the blood on its way through the body it was stated that when it has passed through a set of capillaries it is gathered up into veins to be returned to the right auricle. An important departure from this order is now to be indicated. The blood which has traversed the small vessels of the digestive tract (including the stomach, both intestines, the pancreas, and the spleen) would be expected to make its way back to the heart through branches of the systemic veins. The actual arrangement is as follows: A large vessel receives all the blood from this region and carries it into the liver, where a second set of capillaries is entered. When these unite it is to form short veins discharging into the chief vein of the body, just below the diaphragm and practically within the boundaries of the liver. The channel leading from the organs of digestion to the liver occupies a unique position. Inasmuch as it is formed from a capillary system it seems to be a vein, but since it also supplies a capillary system it may be contended that it is an artery. Its structure favors the view that it is a vein and it is so called. The vessels which gather the blood from the digestive tract and distribute it inside the liver are said to form the portal system; the chief conductor described above is called the portal vein. An important consequence of this arrangement is that the absorbed products of digestion, so far as they are in the blood rather than the lymph, are brought under the influence of the liver before they go elsewhere.

The question will naturally be raised whether the liver is supplied exclusively with venous blood. Provision is made for a supplementary supply through what is known as the hepatic artery, a vessel which is an offshoot of the general arterial system, and which, of course, introduces into the liver blood rich in oxygen. An analogous condition may be noted in the lungs, where the main currents are the venous streams coming from the right side of the heart, but where there are also interwoven in the tissue much smaller vessels which take their rise in the arterial tree springing from the left ventricle.

The problems of the circulation fall into two classes: There are those which are purely physical and which can be approximately reproduced and more or less successfully studied in lifeless models. There are also those which have to do with the behavior of the organs concerned when they are viewed as living structures. Under the first class are included the facts of blood-pressure, velocity of flow, the resistance overcome, etc. The interpretation of such data is almost a science in itself and is known as hemodynamics. Among the questions of the second sort are the mysterious automaticity of the heart and the nervous government of the quantity and the distribution of blood flow. These difficult matters may well be left to be briefly dealt with toward the end of the book, when the general work of the central nervous system will be presented. We must, however, devote some space at this time to the fundamentals of hemodynamics.

The Character of the Blood Flow in Vessels of Different Classes.—When an artery is cut the blood escapes in a forcible jet which may spring to a distance of several feet. The stream is not steady, but mounts and declines in a rhythm corresponding with the heart-beat. A good deal of pressure must be applied to restrain the bleeding. If a vein is severed the flow of blood is rapid and copious, but easily repressed. It is uniform so far as can be judged. These observations lead to the conclusion that the blood in the arteries is under a high average pressure, with large fluctuations from moment to moment. The pressure in the veins is evidently very low.

The diminution of pressure between the arteries and the veins can be simply explained. When the blood is started on its course through the systemic circulation the high pressure which it exerts against the elastic wall may be regarded as a measure of the energy which the ventricle has impressed upon it. When it draws near the right side of the heart, the goal of its journey, its abated pressure is the sign that the initial energy has been spent. How has it been consumed? There is but one possible answer: It has been transformed into heat in overcoming the friction encountered in the vessels. Analogous conditions can be demonstrated for any tubular system through which liquid is driven. In the mains which carry a city water-supply from a pumping-station to distant points there is a similar decline in pressure along each line as it is followed farther from the fountain head. (The assumption is made that we have to do with pipes which are on the same level throughout.)

In any such system the cutting down of the pressure will be abrupt at any point on the route where there is an unusual impediment to the flow. This is the case in the body where the blood-steam is so extensively subdivided to enter the smallest vessels. Subdivision of channel means multiplied surface for friction. Thus there occurs a radical drop in pressure between the smallest arteries in which we can measure it and the veins of similar size. The highest pressure developed anywhere must be in the left ventricle when it is discharging the blood, for it is then to be regarded as the starting-point of the circulation. The lowest pressure which is ever registered is probably in the same ventricle when it is beginning to fill, for now it is the terminus of one of the two circuits.

The swelling of the arteries which promptly follows each ventricular contraction is what we recognize as the pulse. It is the sign of a newly introduced portion of blood distributing itself in the vessels. We have said that the veins show no such rhythmic enlargement. We have, therefore, to account for the conversion of the intermittent flow in the arteries into the constant flow in the veins. The principal factor concerned is the marked elasticity of the arterial trunks. It will be helpful to refer to the artificial devices which serve the same purpose in connection with force-pumps. A familiar one is the air-chamber. This is a large container communicating with the outflow-pipe. Whenever a stroke of the pump drives water along this pipe a certain share proceeds directly toward the outlet, while another fraction turns aside into the air-chamber. During the return stroke when no water is issuing from the pump barrel the air which a moment before underwent compression in the chamber tends to regain its original volume, and in so doing forces water through the lateral branch and thence along the main pipe. The intermittent delivery through the valve is transformed more or less successfully into a continuous flow through the remote outlet.

The neutralizing of intermittency in the blood system is referable to the same principle, but the elastic compensator is not to be found as a single localized feature; it is discovered in the universal capacity of the arteries to stretch and to regain their former size. At the beginning of the aorta or of the pulmonary artery we have complete intermittency, the blood alternately forging ahead and halting. But each portion of blood ejected from the heart finds room for itself partly by distending the arteries and not altogether by driving forward the blood which is before it. Hence, when the ventricles relax and the outpouring of blood ceases there is still an onward movement in the smaller and more distant arteries, because the larger ones, which were momentarily overdistended, are now contracting and sending along part of their accumulation. The farther we go from the heart the more largely the driving of the blood is to be attributed to the reaction of the stretched arterial walls and the more nearly uniform it becomes. This does not mean that the whole power keeping up the circulation is not to be sought in the heart-beat; it merely means that this energy may be stored temporarily by these elastic structures and rendered back again.

The facts we have been treating may be expressed in another way. The arterial tree forms a reservoir of considerable capacity. Within it is an amount of blood so large that the single contribution of the ventricle makes a rather small addition to it. The escape of the blood through the terminal twigs cannot cease while there is so much stored under a high pressure in the aorta and its branches. The heart may omit or "drop" a beat without noticeably diminishing the flow through the capillaries. A standstill will be reached only when the arteries have attained a degree of contraction such that the internal pressure is no higher than that in the veins. The homely illustration (Fig. 19) which accompanies this may be helpful. The pump delivers water intermittently to the leaky trough, keeping it filled to a level which is nearly constant, though fluctuating a little in the rhythm of the strokes. Meanwhile the escape of water through the cracks is all but uniform in its rate. One important difference between the pump and trough, on the one hand, and the circulatory system, on the other, lies in the fact that in the first case the driving force is gravity; in the second, it is the reaction of the enclosing elastic walls.

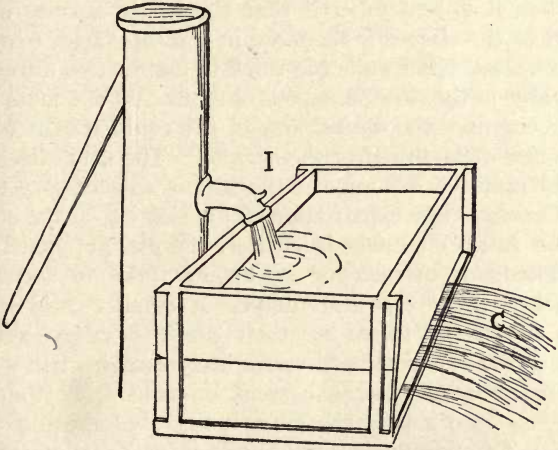


Fig. 19.—At *I* the discharge is in gushes with pauses between—the type of the expulsion of blood from the heart At *C* the escape through the cracks is at a practically constant rate; this is true of the blood flow through the capillaries.

A set of facts which it is well to separate in one's thought as completely as possible from considerations of pressure is the body of data respecting the linear velocity of the blood. By this is meant the rate of advance of the average corpuscle. In any vessel the stream runs more swiftly in the central axis and lags along the walls. The velocity in the arteries rises and falls as does the pressure, but, on the whole, is relatively high. The aorta is passed at a speed of at least a foot in a second. The veins also are traversed at a high velocity, though the figures are somewhat lower than for the arteries. The movement in the capillaries is in sharp contrast to that in both arteries and veins, being exceedingly slow, perhaps $\frac{1}{25}$ inch in a second. It appears that a corpuscle may take as long to go through a capillary link which would scarcely span the breadth of a pin-head as to travel from the heart to the brain.

When it is remembered that the actual service of the blood to the tissues is rendered in the capillaries (since all other vessels have walls too thick to permit free diffusion), the value of the slow passage is obvious. At the same time, one recognizes the desirability of the rapid transit to and from this department of the system. The heart itself and all the main vessels may be thought of as accessory to the capillaries. The explanation of the slowing of the stream in the small channels is entirely simple, yet often misapprehended. Whenever an artery forks to form two branches, these are individually of smaller cross-section than the parent stem, but their *combined* cross-section is greater. The result is the same that is seen when a river widens or deepens—the current slackens. If the river broadens into a lake the current may become imperceptible, yet we know that the water is still setting forward toward the outlet.

Are we then to believe that the capillary system is many times wider than the aorta or the great veins? There is no escape from this conclusion: their number is so vast that, despite their infinitesimal size as single conveyors of the blood, collectively they form the broadest division of the entire path. If they fail to suggest a lake, an analogy may be found in the tangled swamp in which a stream loses itself, breaking into many sluggish arms, from which at last the waters converge to resume a rapid course over a narrow bed. The acceleration noticed as the veins are followed toward the heart is merely a sign that as their number grows less their combined cross-section also contracts.

The Movement of the Lymph.—Just as we find veins returning from every part of the body, we can make out, though with much greater difficulty, small vessels bringing lymph in the same general direction, that is, toward the thorax. Like the veins, they unite as they draw near the heart, and the great majority eventually contribute to a trunk known as the *thoracic duct.* This springs from the union of many branches in the abdominal cavity, pierces the diaphragm, and can be traced upward in front of the spinal column until it empties into a great vein which is bringing the blood from the left shoulder toward the right auricle. A comparatively insignificant group of lymphatics centers at an outlet in the corresponding position on the right.

The onward movement of the lymph in its channels is parallel with that of the venous blood, but is incomparably slower. It is sometimes almost entirely arrested. In the last chapter it was stated that we cannot confidently say whether the lymphatics drain all the microscopic spaces in the tissues or whether they rise in small definite enclosures. In either case they are bearing away a certain overflow of fluid and may be regarded as supplementing the service of the veins. As to the cause of the halting movement of their contents, the simplest statement that can be made is somewhat as follows: The formation of new lymph in all the organs crowds away the lymph previously in the beginnings of the lymphatics, and this is the central fact to be considered. The energy required is derived partly from the heart, since liquid may be forced out of the capillaries by its transmitted pressure, and partly from other sources too obscure to be discussed. The lymph is generally referred to as a carrier of waste, but a partial exception must be made in favor of the lymph coming from the intestinal area during digestion. This lymph may contain absorbed food, principally fat. It was in the mesentery that lymphatics distended with milky liquid were first seen. They were called *lacteals* because of their appearance, and this term is still used in a local sense.

CHAPTER XIV

THE ABSORPTION OF THE FOOD-STUFFS

If two unlike solutions are separated by a membrane, such as a sheet of parchment or some artificial substitute, they will usually tend to equalize both in composition and concentration. When, for example, potassium chlorid and sodium chlorid solutions are placed on opposite sides of such a partition, each salt proves its ability to pass through the barrier, and in the course of time there will be uniform mixtures in both compartments. This is said to show that the salts are *diffusible* and that the membrane is *permeable.* Different membranes are permeable in very different degrees, and the freedom with which various salts pass through a particular membrane is also far from constant. Some substances may appear freely soluble and may go readily through ordinary filters, but may hardly diffuse at all. This, as a rule, is the case with the proteins. If a mixture of unboiled white of egg and sodium chlorid is on one side of a membrane and the other side is washed with running water, nearly all the salt will escape, leaving the protein practically undiminished. The process by which diffusible salts are encouraged to separate themselves from substances which cannot accompany them through the membrane into the water beyond it is called *dialysis.*

The products of digestion are, in general, much more diffusible than the food-stuffs from which they are derived. Starch, even when boiled for a long time, does not make its way through ordinary membranes; the sugars do so with relative ease. Fats are not even soluble in water; soaps and glycerin are diffusible compounds. Peptones arising from the hydrolysis of proteins have some power to penetrate membranes, and the simpler amino-acids pass still more freely. We might picture the situation in the intestine somewhat as follows: The blood flows steadily beneath a rather complex cellular wall, the other surface of which is bathed by the mixed products of digestion and the digestive secretions. Peptones and amino-acids, sugars, soaps, and glycerin, being formed in relative abundance in the intestine, diffuse into the blood, which contains little of these bodies. If the blood were to stand still the small volume in direct relation with the absorbing surface would accumulate digestive products until it held them in the same concentration in which they exist in the canal. Then a state of equilibrium would be established and no further transfer to the blood would occur.

Detailed observation shows that the facts of absorption cannot be expressed in this simple manner. It has already been hinted that large allowance must be made in such a case for the fact that the membrane under examination is alive. Its cells may discharge material at one surface quite unlike that which they receive at the other. They probably have a considerable metabolism. This means that energy is set free within their borders and a share of it may be applied to the moving of the absorbed food. We have previously called attention to the parallelism between secretion and absorption.

Before we can go further with this discussion something must be said concerning the place of absorption and the minute anatomy of the structures involved. There is a measure of absorption from the stomach. Until rather recently this organ was not credited with any marked powers of this kind, unless it were in the case of *alcohol.* This is a highly diffusible compound and its prompt entrance into the circulation is noteworthy. When one says of a glass of wine, "This goes to my head," the statement is literally true. The alcohol strikes through the walls of the stomach at once and is borne to all parts of the body, including the brain. On the other hand, water is not at all freely absorbed when it is taken into an empty stomach. It is known to pass the pylorus in practically unchanged volume. Some poisons produce no positive effects while in the stomach, but exert their action promptly when they pass to the small intestine.

As regards the sugars and the products of peptic digestion, it is now believed that there is a considerable absorption of these substances from the stomach. They disappear most rapidly when they are present in high concentration, and the process is promoted by condiments which increase the blood flow under the gastric mucous membrane. When all reasonable allowance is made for the part played by the stomach in absorption, the fact remains undisputed that the major part of the work is done below the pylorus. Furthermore, since, as has been said, there is usually little valuable material left to be recovered by the colon, it becomes evident that the small intestine is of central importance.

A striking peculiarity of the small intestine is the extension of its internal surface. This is effected, first, by the numerous cross-folds which cut into its cavity, and, second, by the microscopic projections which stud its lining. These are the *villi*. An individual villus may be described as a minute finger-shaped process. It rises above the general surface in a contrast to the glands, which sink below; the villus is a peg, as the gland is a pit. Obviously the existence of the villi increases many times over the number of cells in contact with the intestinal contents. These cells are described as columnar; they are prisms standing side by side, with their larger surfaces in contact and their smaller ends presented to the interior of the intestine and to the loose internal tissue of the villi. A certain share of absorption may take place through the crevices between the cells, but the main transfer of material seems to be through their own protoplasmic bodies.

The interior of a villus is filled by a confusing assortment of cells, some of which have been thought to be contractile. There are probably intervals between these cells containing lymph, and near the central axis of the villus is a rather definite *lymphatic* channel. It is a small branch of the general lymphatic system and opens one way, by which food can pass from the seat of absorption to the veins in the thorax, there to mingle with the blood. Between the exposed cells of the villus and the lymphatic at its core is interposed a net of capillaries carrying blood which has come from the neighboring aorta, and which will flow through the liver before it returns to the heart. It may be said at once that, of the two possible routes for absorption, the portal system is the more important.

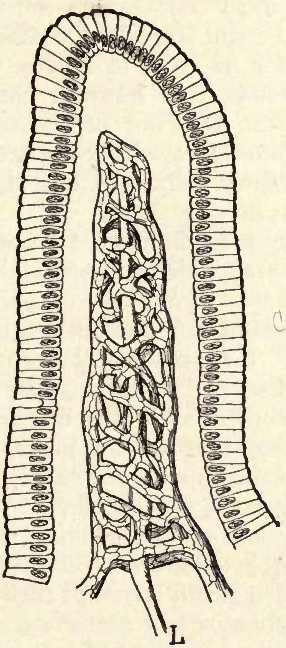
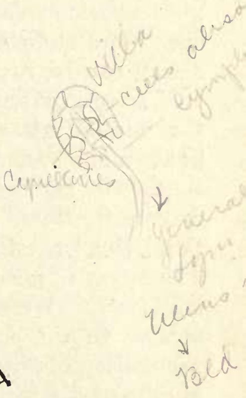


Fig. 20.—This is a conventionalized drawing to show the essentials in the structure of a villus. The lining cells of the intestine are shown as in section. Within is seen a tangle of capillaries, and at the very core of the villus a lymphatic (*L*). The loose tissue, which in reality exists inside the villus, has been ignored for the sake of simplicity.



The statement has been made that the cells lining the intestine do not act in a way that can be imitated by lifeless models. The fact is covered by the expression that they exercise selective powers. Too much might easily be inferred from this phrase; there is the same danger which was pointed out in connection with the pyloric sphincter, the inclination to credit the cells with something more like intelligence than it is right to assume for them. It is reasonable to believe that however complex and unexpected may be the behavior of the cells concerned, a mechanistic explanation would be apparent if our knowledge were sufficiently full. What is meant by selective action can be readily illustrated.

If a comparison is made in the laboratory to determine the relative rates at which glucose and magnesium sulphate make their way through an ordinary membrane, the sugar will lag behind the salt, although both pass with relative freedom. If a mixture of the two is introduced into the living intestine the impression is totally different. The sugar is absorbed, while the magnesium sulphate is kept back. We say that the mucous membrane is impermeable to this salt, though we can hardly picture the peculiarity of structure which makes it so. A salt which is refused absorption by the intestinal wall will act as a laxative, for it will hold back from absorption a large quantity of water and this will be swept through by the peristalsis. An investigator has called attention to the fact that all the common precipitants of calcium are denied passage into the blood, and may, therefore, be reckoned as cathartics. These include, beside the sulphates, the phosphates, the citrates, and the tartrates.

Again and again we find as we pursue the subject that laboratory tests give us little indication of what may be expected of the intestine as an absorbing mechanism. Some substances usually held to be indiffusible pass into the circulation with comparative readiness. Even egg-albumen, a protein of enormous molecule, may enter the blood. This was recently proved by the observation that after eating a number of raw eggs the albumin may be found in the urine. It evidently reaches the capillaries to some extent before it can be hydrolyzed by the digestive enzymes, even at a time when these are presumably present and active. The application of mild poisons to the lining of the intestine causes it to behave much more like the typical indifferent membrane. Thus a weak solution of sodium fluorid (which does not visibly disorganize the cells) wipes out the selective properties which have been instanced. This makes it seem the more probable that the normal processes require the application of energy, and that accordingly they cannot continue after the death of the cells.

A mosaic surface formed of cells, each one of which is a living body, is far from comparable with a homogeneous partition. Even if we leave out of account the crevices between the cells which may bear a part in absorption, as already noted, we must consider the individual cell to be an elaborate structure. Its surface layer is undoubtedly different in its chemical nature from its interior. There is good reason to believe that the exposed border differs entirely from the end which abuts on the connective tissue. A result of this complex organization is the existence of a property that might be called "polarity," that is, a capacity to act in one direction rather than the other. A somewhat ponderous expression for the same idea is found in the phrase "irreciprocal permeability." This means specialization for absorption, and strongly suggests that if the cells could be reversed in their relation to the interior of the intestine they would begin to absorb from the lymph and secrete into the canal. Gland-cells may be said to have irreciprocal permeability in this reversed sense.

The departure of the intestinal lining from the behavior of a common membrane is still more obvious when we note that absorption may be accompanied by chemical transformation. The food-stuffs which leave the interior of the canal do not of necessity reappear in the circulation in the same form. Two possibilities exist: either the process of digestive cleavage may be continued during the passage through the wall, or a recombining of the products of digestion may be accomplished. The first action is thought to occur to some extent when the peptones formed in the cleavage of proteins are moving toward the blood. It will be recalled that the enzyme erepsin, having the power to decompose peptones still farther, is obtainable from these cells, and it is quite possible that its action is intracellular.

The opposite property, that of synthesizing, is illustrated by the behavior of the products of fat digestion. We have seen that the pancreatic enzyme hydrolyzes fats, with the formation of fatty acids and glycerin as the first result of the cleavage, and that the fatty acid may be changed to soaps, though we do not know how extensively they undergo this second change. It follows that it is these bodies which disappear from the intestine, but they are not to be found at all freely in the contents of the lymphatics. In their place we have neutral fat evidently reconstructed during the transfer. Microscopic study of the cells through which the material has been passing shows that the border adjoining the cavity of the intestine is without fat droplets, but that these occur deeper down, increasing in size toward the other border. The appearance strongly indicates that some compounds other than neutral fats entered the cells and underwent a transformation while progressing through the protoplasm.

CHAPTER XV

THE METABOLISM OF FATS AND CARBOHYDRATES

It was pointed out early in our treatment of the subject that foods serve a twofold purpose: to some extent they are built into the body as relatively permanent parts of its structure, while in a much larger degree they are steadily oxidized, yielding their energy to maintain its activities. The proportion between the two divisions of the supply cannot be constant. Clearly, the fraction of the diet devoted to construction must be larger in childhood than in adult life. There may be other periods during which the constructive work is notably prominent, for example, recovery from illness or from fasting, pregnancy, and perhaps athletic training. Apart from these times we must assume that the actual building of tissue is a very small item. In other words, the living matter of the body is comparatively stable and needs only slight though perfectly definite contributions to insure its up-keep from day to day.

The food-stuffs entering the circulation may be destined for immediate destruction or for storage. Throughout long terms of our lives a fair balance is preserved between the income and the consumption of these compounds. If we receive in one day certain quantities of proteins, fats, and carbohydrates, and there is evidence of an exactly equal decomposition of the three classes of material, we cannot say with precision whether the oxidation affected the particular food eaten or corresponding matter stored previously, but in either case the condition of the system at the beginning and at the end of the twenty-four hours is the same. We must now proceed to discuss the possibilities of transformation and retention of the different food-stuffs, and we shall find that the story is most simple in the case of the fats.

Fat Metabolism.—Broadly speaking, we can say that fat never becomes anything else until it is decomposed with release of energy. This statement may be too sweeping to cover all the conditions which may arise in disease, but it is substantially true in health. We have traced the fat from the walls of the intestine into the lymphatics. From the smaller branches it must find its way to the thoracic duct, and through this vessel it goes to merge with the general blood-stream. In the blood, the lymph, and the tissues at large fat is present in a small percentage. We must now give attention to the special provision made for the storage of fat in what is called *adipose tissue.*

The word "fat" is used in two senses. In its strict chemical meaning it describes a certain type of compound, and it is this usage which we have thus far employed. But when we speak of the fat of meat we include something more. We mean a form of connective tissue in which the cells hold a large accumulation of fat in the chemical sense. Under the microscope this tissue is seen to be composed of a fibrous network holding within its meshes these distended cells. The fat which they contain is in drops of such a size that the protoplasmic portion of each cell seems a mere envelope, while the nucleus is crowded to one side. So it happens that while the fat is really an inclusion, it forms a very large percentage of the whole mass. When a piece of adipose tissue is subjected to the action of gastric juice the fibers and protein of the cells are rapidly digested, and the actual fat, being liberated, rises to the top and floats as a clear layer of oil.

Of course, the amount of adipose tissue varies widely with the individual. Still it is more abundant in subjects of spare build than is usually supposed. The hollow shafts of the long bones, such as those of the arms and legs, contain what is called the white marrow. This is typical adipose tissue. A large deposit is to be found at the back of the abdominal cavity, where it closes round the upper parts of the kidneys. Flakes of it occur in the mesentery and on the surface of the heart. It is developed in the deep eye-sockets. In subjects better nourished there will be more or less of this tissue widely distributed over the body occupying a position between the skin and the underlying muscles—the so-called subcutaneous fat. This may be indefinitely increased in the obese. Another characteristic of obesity is the gathering of adipose tissue in the great omentum, the sheet of membrane hanging from the lower border of the stomach. When much fat is present in this situation the ventral wall of the body has a double burden, one layer of this reserve material outside and a second within the abdominal muscles.

We shall postpone to a later time any discussion of the factors which influence the accumulation of fat in the system. A point previously made is to be insisted upon, that the fat of the body is not derived solely, nor, indeed, chiefly, from the fat of the food. We shall presently consider to what extent it is formed from the other food-stuffs. Whether there is a great or only a moderate amount, it will serve to maintain the activities of the muscles during periods of insufficient feeding or absolute fasting. When an animal has died from starvation but little fat can be found in its tissues. The reduction of the fat presumably present at the beginning of inanition has been estimated to have reached 97 per cent. of the supply when death finally supervenes. The power to endure starvation is naturally greater for an animal or a man having a large initial store.

For each species the body fat has a nearly constant character. There is a certain ratio maintained between the several fatty acids, and, as a result of this, a definite melting-point. There cannot be such a diversity here, as is the case with the proteins of different animals, but there is a similar appearance of individuality. Accordingly, when one animal preys upon another of a different species and is nourished at the expense of its victim, it does not store precisely the form of fat which it has eaten, but modifies it to conform to its own standard. The making over is a still more marked phenomenon when a vegetable oil is eaten and transformed into animal fat.

The Metabolism of Carbohydrates.—The sugar of the blood is usually called dextrose or glucose. As a matter of fact, it cannot be strictly correct to speak of a single sugar in the plasma, for there are probably three at least. Glucose, however, is undoubtedly the principal one, and so far as we know the possible services to the body are practically the same for all. Reference has already been made to the fact that the quantity of sugar in the blood is small, but singularly constant. It is now time to explain how this constancy is maintained.

It has been stated that the body contains relatively little carbohydrate in spite of its large supply. When it is considered that the entire volume of blood contains less than 10 grams of sugar, though the amount absorbed after a single meal may be as much as 100 grams, it appears strange that there should be, as a rule, no significant increase in the percentage circulating during the period of digestion. The solution of this problem was achieved in great measure by the French physiologist Bernard, near the middle of the last century. Knowing that the incoming sugar passes to the liver, he anticipated that this organ might have the power to take the surplus from the passing stream and store it temporarily in some form.

Glycogen.—Investigation showed that there could be obtained from the liver of a well-fed animal (rabbit) considerable quantities of a carbohydrate resembling starch. This substance is called glycogen. Its presence within the cells of the liver can be demonstrated in microscopic preparations. Its molecule is of unknown size, and it is capable of undergoing digestion in the same manner as vegetable starch with the formation of sugar. The amount may be strikingly large, reaching, in the rabbit, one-fourth the total weight of the liver, deducting the weight of the blood usually contained in it. In the human liver it does not attain to such a high percentage, but may still equal something like 10 per cent. of the net weight of the organ.

This means that a full-sized liver may hold 150 grams of glycogen.

Bernard's interpretation of his discovery was somewhat as follows: The liver is the carbohydrate bank of the body. Like any bank, it is subject by turns to deposit and withdrawal. Its hoard is increasing when much sugar is arriving from the intestine, for it is then diverting the surplus from the blood of the portal circulation. The change by which sugar is made into glycogen is clearly just the reverse of the digestive process, a dehydration and a condensation to form larger molecules as contrasted with the familiar hydrolytic cleavage. The liver cells seem to be stimulated to make this change by the rise of the percentage of sugar in the portal blood. When absorption ceases it may be assumed that the sugar of the blood in general sinks slightly in amount. This condition appears to cause a reversal of the prevailing reaction in the liver, the stored glycogen is gradually transformed to sugar, and this passes out to renew the supply in the circulation. The approximate constancy of the sugar in the blood is thus accounted for in the main by the power which the liver possesses to remove or return it, according to the shifting conditions.

The making of glycogen from sugars occurs only during life. The converse change from glycogen to sugar takes place freely after death, and is doubtless due to an enzyme. It might be anticipated that a comparatively short period of fasting would suffice to exhaust the glycogen of the liver. As a matter of fact, there is a large reduction in the first day, but the removal then proceeds slowly and is scarcely ever completed. The disappearance is greatly hastened by muscular activity, most effectually by the intense convulsions produced by strychnin-poisoning. For human subjects it has been shown that glycogen is consumed rapidly under the influence of iced baths. (How we are able to judge of the abundance or scarcity of glycogen in living men will be explained in another connection.)

For some time after Bernard first called attention to the "glycogenic function" of the liver, the fact that glycogen is deposited also in the skeletal muscles was overlooked. In these tissues it does not reach any such percentage as may be found in the liver, but inasmuch as the muscles form nearly half the entire mass of the body, a small percentage means a large aggregate. Collectively, the muscles have commonly been estimated to hold an amount equal to that in the liver, and there is a growing impression that they contain even more. The total glycogen in the system may probably be as much as 400 grams, or nearly a pound. The question which now calls for consideration concerns the importance of maintaining such a strict constancy in the sugar-content of the blood.

Some light is thrown on this matter when we observe the result of artificial increase of sugar concentration. This may be brought about by injecting sugar solution into the blood-vessels. If this is done freely there is excessive lymph-formation and other evidence of deranged conditions in the circulatory system. A symptom to which especial attention must be called is the appearance of sugar in the urine under such circumstances. The kidneys are so organized that any distinct rise of sugar in the blood leads to the excretion of the excess. Thus the composition of the blood is restored to the standard, while potential food is lost to the tissues. Such a waste of sugar is less likely to follow abundant feeding of foods rich in it than to occur after the experimental procedure just described, but it may nevertheless result from the selection of peculiar diets. It is then called *alimentary glycosuria*. This escape of surplus sugar is not to be confused with diabetes. Alimentary glycosuria is induced somewhat readily by eating sugar, but hardly ever by eating starch. The differing reaction is presumably explained by the fact that sugar requires a brief digestive treatment and is then rapidly absorbed. Starch, on the other hand, has to pass through serial stages of digestion, and the absorption of the resulting sugar is extended over a longer period. In the first case we may suppose that the inrush of sugar overwhelms the liver, which is unable to arrest all of it. That which goes by raises the sugar content of the blood above the level at which it begins to pass into the urine.

If for any reason much of the glycogen in the liver or the muscles is quickly resolved into sugar the blood must be affected quite as though the added sugar had come from the intestine. Glycosuria will ensue. Certain changes in the circulation are known to cause such a flooding of the system with sugar and the appearance of a part of it in the urine. A most interesting instance of such glycosuria is that following an experience of strong emotion. It seems that one of the results of the disturbance in the central nervous system is the conversion of a large amount of glycogen into dextrose. With acute insight a physiologist has pointed out that this release of sugar is a helpful reaction under the circumstances. The occasion of emotion is usually an occasion for strenuous action, perhaps for flight or for giving battle, and the muscles may be reinforced by the increased supply of their preferred fuel brought to them.

The regulating action of the liver and the muscles upon the carbohydrate distribution may be paralleled, in part at least, by an analogy. Let us compare the active tissues to a mill turned by the waters of a stream. The water-supply to the mill is to be compared with the sugar-supply to the cells which derive their energy from it. A meal is to the body as a storm is to the mill-stream—it adds to the volume of the power-producing element. The dam by the mill is like the kidney in its relation to the accumulated store; if the water rises above the crest of the dam it flows over and passes on down the stream without having contributed its energy to the turning of the machinery; if the sugar rises above a certain level it begins to escape, with its potency for work lost to the organism. Moreover, the capacity of the liver and the muscles to hold back carbohydrate suggests the function of a broad mill-pond. The larger the pond above the dam the more successfully the irregularities due to alternating rain and drought will be offset and the less likely will be a wasteful overflow when a storm follows a term of low water. The conversion of an intermittent supply into a constant one is the function of the mill-pond, and it is equally the service of the tissues holding glycogen.

While a relatively sudden rise of sugar in the circulation may produce glycosuria, a slight chronic excess over the normal may have an entirely different effect. If the diet is supplying day by day a little more carbohydrate than the body is oxidizing, the surplus may be transformed to fat. The opinion that starchy and saccharin foods are fattening has scientific support as well as common observation in its favor. Glycogen formation is limited and we may suppose that fat-building takes place when the glycogen reserve is at its maximum and still more sugar is offering. An important advance was made in physiologic knowledge when Liebig called attention to the fact that a cow's milk contains an amount of fat utterly out of proportion to the scanty supply furnished by the food of the animal. It had been believed that no such transformation could be accomplished by animal tissues, and that all fat found in the body or in the secretions must have been received as fat. Liebig fell into error when he stated that the milk-fat had been made solely from proteins and not at all from carbohydrates, but he had taken a notable step in recognizing the possibility of changing one food-stuff into another. Quantitative experiments soon showed that carbohydrates must be given a very prominent place among fat-forming materials.

The steps through which sugar is transformed into fat are little understood. A comparison of the composition of the two makes it evident that a great deal of oxygen has to be removed in the reactions. This element is never set free in animal metabolism; in the present instance it is separated in the form of carbon dioxid. This is not merely a theoretic consideration, but a condition which can be demonstrated by experiments upon an animal rapidly gaining fat. A wood-chuck, for example, when it is eating voraciously of starchy food and gaining steadily in fat, breathes out more carbon dioxid than can be accounted for by the oxygen consumed. The excess is a by-product of the process in which sugar with its high percentage of oxygen is made over into fat with a much lower percentage.[1]

Recourse may be had once more to analogy. Bernard compared the liver to a bank, but we may extend the comparison to the whole body. The products of digestion are the daily deposits; the oxidations stand for the daily payments. The bank will have a convenient cash balance on hand from which to meet current demands. This is the function of glycogen. The cash in the bank will be but a small fraction of its total resources, and its variations from hour to hour will signify but little as regards the stability of the institution. So the glycogen of the body is a small reserve and may vary by 50 per cent. within twenty-four hours. The body-fat, like the securities held by the bank, is a large accumulation and less subject to change. If for some time the deposits are in excess of the withdrawals, the officials of the bank will, of course, make new investments. The parallel is clear: the body receiving more carbohydrate than it is expending will not allow it to go on increasing in the liver and muscles, but will begin to convert it to fat. Unhappily, the correspondence fails at one point: a bank which is subject to a "run" may sell its bonds and other holdings that it may have cash to pay its depositors. The obvious suggestion is that the fat of the body will be reconverted to sugar when there are demands to be met and no incoming food. This is not known to occur; the oxidation of fat during starvation appears to proceed without any such previous change.

Using another metaphor, though still a financial one, it

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[1] Without assuming that the process is fully understood, French authorities have suggested that the principles involved may be shown in the following equation:

$$13(C_6H_{12}O_6) = C_{55}H_{104}O_6 + 23(CO_2) + 26(H_2O).$$

(Shäfer, "Text-book of Physiology," vol. i, p. 933.)

may be said that the glycogen is like a checking account which a man uses to pay his routine expenses, drawing upon it often and recruiting it at longer intervals. Such an account is sometimes nearly wiped out and then at one stroke largely increased. The fat of the body is like a savings bank deposit, gathered slowly, drawn upon only in emergencies, and, it may be added, gaining by compound interest in many cases.

Two facts readily suggest themselves which may be used to explain the low limit of glycogen storage. For one thing, its physical properties would probably make a high percentage of it undesirable. In the second place, there is a distinct economy in substituting fat for glycogen because fat represents more energy in proportion to its mass. An individual who carries 20 pounds of adipose tissue may wish to be rid of a part of it, but if he were compelled to bear a load of glycogen equivalent in energy his burden would amount to about 45 pounds.

The Pancreas and Carbohydrate Metabolism.—We have repeatedly compared the carbohydrate of the body to money. Just as it is the eventual function of money to be spent, so it is the destiny of carbohydrate to be oxidized that its latent energy may be turned to account. This oxidation takes place chiefly in the muscles, to some extent, doubtless, in the glands, the gray matter of the nervous system, and the absorbing cells of the intestine. The intensity of the local process will in every case be proportional to the heat and other forms of energy developed. Considering the wide distribution of this purposeful destruction of sugar it is surprising to find it all dependent upon an obscure action of the pancreas.

This organ has been dwelt upon previously as a most important contributor of digestive juice to the intestine. It would be anticipated that the removal of the pancreas from an animal would be followed by defects of digestion and assimilation. This is probably justified by the results of a trial, but the effect upon digestion is overshadowed by a consequence hardly to be foreseen. This is the almost complete loss on the animal's part of the power to oxidize dextrose. In other words, a process not occurring in the pancreas at all, but in the tissues at large, is arrested by the removal of this gland. What is the natural explanation of this condition? Evidently that something proceeds from the pancreas through the circulation to other parts of the body, without which the cells in general are incapable of decomposing the sugar.

This imperfectly known product of the pancreas is an example of what has been referred to as a hormone. One is tempted to think of it as an enzyme, but it cannot be accurately described by this word. If it were a typical enzyme we might expect it to cause the destruction of sugar in solutions to which it has been added. No marked disappearance of sugar occurs when the experiment is made. In view of this it is wiser not to commit ourselves as to the precise character of the body in question. The fact seems to be that neither the pancreatic extract by itself nor an extract of muscle will particularly promote the oxidation of sugar, but that a combination of the two is necessary.

Diabetes.—If, owing to a lack of the pancreatic hormone, the ability to utilize sugar is lost, the continued absorption of carbohydrate will raise the percentage in the blood, with the result which always ensues under this condition. The kidneys will steadily excrete the surplus sugar. Unlike alimentary glycosuria, this overflow of sugar will not be limited to times of free feeding with carbohydrates, but will attend the ingestion of the most moderate amounts. (As a matter of fact, sugar will still be excreted when carbohydrates are excluded from the diet and in fasting. The explanation of this fact must be deferred to the next chapter.) The difficulty of keeping up nutrition when the cells can make no use of glucose will be evident in a measure even at this point, and we shall find additional reasons later.

Whether human diabetes is necessarily associated with some disorder of the pancreas cannot be stated with certainty. It is known to be so in an increasing number of the cases studied. Often when the pancreas shows no defect to the naked eye, some abnormality is revealed by the microscope. Assuming that the trouble centers in the lack of the hormone, physicians have frequently undertaken to treat diabetes by administering preparations of pancreatic tissue or extracts. The results have been generally disappointing, though a solitary case recently reported showed marked improvement for a time. The peculiarity of the subject in this instance was an uncommon capacity for eating nearly raw meat. This made it possible for him to be fed incredible quantities of pancreatic tissue (sweetbreads) from calves. The helpful treatment was interrupted when, after an attack of indigestion, he found himself unable to eat any more sweetbreads. To say that he could not do so to save his life is to express the literal truth, for he fell into a rapid decline and soon died.

CHAPTER XVI

NITROGENOUS METABOLISM

Our knowledge of the history of the products of protein digestion has been much extended in the past few years, but there are still many uncertain passages. Any account which can be given must be held subject to revision. Nevertheless the course of nitrogenous metabolism, in its broader aspects, is tolerably clear. The present interpretation is most easily appreciated when earlier conceptions have been briefly reviewed.

Not long ago it was held that the earlier products of tryptic digestion were promptly absorbed, and that the formation of the late products, the amino-acids, was rather an accidental and, possibly, an unfortunate occurrence. It was believed that the simplest bodies could not serve all the purposes of nutrition. Such compounds were known to arise in the laboratory experiments, but their formation in the intestine under strictly normal conditions was questioned. The opinion prevailed also that the peptones which disappeared from the canal were reconstructed at the time of absorption and represented thereafter by the protein of the blood. The old impression that but little in the line of synthesis could be expected of the animal tissues was distinctly influential.

About 1901 it was shown that a dog can be nourished when the nitrogenous food which it receives is in the form of the most advanced products of tryptic hydrolysis. A quantity of lean meat had been digesting with pancreatic juice for a period of months. The resulting mixture contained only bodies of a simpler order than the ones on which nutrition had hitherto been supposed to depend. Food so prepared is not attractive, but it can maintain an animal in fair condition. Physiologists accepted the evidence and granted that the proteins of the organism could be synthesized—sometimes at least—from amino-acids. Shortly after this change in our conceptions the discovery of erepsin was announced. It was recognized that the existence of this enzyme made it more probable that digestion should normally run its full course rather than it should be terminated at an early stage by the intervention of the absorbing cells. It became apparent that even though the material leaving the intestine might have the relatively complex character which we associate with the peptone stage of digestion, the products delivered to the interior of the villi by the cells might have undergone further cleavage. The ability of the animal to turn to account such simple bodies in synthesizing its own proteins became clear.

In the chapter on Intestinal Digestion (Chapter X) the statement was made that the various amino-acids have been called the "building-stones" of metabolism. In the course of digestion they are separated, and after absorption or during the very act of absorption, they are to some extent assembled again. Many facts bearing upon this process have been brought to our attention by the recent studies of physiologic chemists concerning the constitution of protein molecules. All that has been done of late in this direction has served to emphasize the variety of individual structure comprehended under the term protein. When such compounds from various sources are subjected to decomposition, either by digestion or by other means, the assortment of amino-acids obtained differs with the particular protein under investigation.

Some, which one is tempted to regard as perfect proteins, yield the full list of amino-acids as at present known. Others, seemingly defective when judged by this rather arbitrary standard, fail to yield certain members of the series. This variation has an important bearing on matters of nutrition. It can no longer be maintained that all substances characterized as proteins are equivalent in their power to minister to growth and repair. Among an increasing number of defective proteins now recognized gelatin is the best known. Its behavior in the system calls for exposition.

Gelatin.—This familiar compound belongs to the ill-defined group often spoken of as the albuminoids. These may fairly be regarded as proteins which have undergone a more or less definite degeneration both in function and in chemical structure. They are found as intercellular substance in the connective tissues and also in the dead and dry surface layer of the skin. They make the chief substance of the hair and nails. Gelatin itself is derived by boiling certain varieties of connective tissue, including bone and tendon. It gives nearly average percentages of the five elements present in ordinary proteins. When this fact was discovered in the early days of organic chemistry it was urged that gelatin must have a value in nutrition quite equal to that of any nitrogenous food.

Trials were made on a large scale in the pauper institutions of France. It was found very definitely that the free use of gelatin led to indigestion and that it soon became repugnant to the subjects, however hungry they might be. These effects were later found to be correlated with inadequacy to maintain the weight and strength of animals. An animal cannot be said to be perfectly nourished if it is losing more of any element day by day than it is receiving. This is eminently true of the nitrogen in the income and the outgo. "Nitrogenous equilibrium," expressing the equality of the two, is a phrase we shall use freely. Now nitrogenous equilibrium cannot be established by feeding gelatin in place of all other protein, no matter how skilfully the experiment is conducted.

For many years the insufficiency of gelatin to make good the losses from the tissues remained a mystery. It has been amply explained by the findings of chemists in our own time. Gelatin yields most of the building-stones required for the new construction, but it does not furnish them all. Therefore it is impossible to make blood-proteins or the proteins of the living cells from its cleavage products. It is useless to increase the *quantity* of the amino-acids if the *variety* is not great enough to supply the details of the molecular pattern to be wrought. What is true of gelatin is true of a number of proteins from vegetable sources. They do not give all the groupings needed in the constitution of the more elaborate animal protoplasm.

In some cases a single protein may be adequate for nutrition, supplying a complete assortment of amino-acids. But it will be seen that successful nutrition is more certainly to be secured by using proteins from various foods. This is our practice, save in the important case of the milk-fed infant. Milk actually contains proteins of more than one order, so that the exclusive use of this food does not narrow the selection of building units so greatly as might be supposed. The chief protein of milk contains the element phosphorus and is perhaps of somewhat unusual complexity.

In an introductory chapter the protein molecule was likened to a watch with its many dissimilar parts associated in the one possible way to secure a desired result. One or more of these parts might be missing without their absence being apparent to the untrained person as he looked into the works. He could nevertheless observe the fact that the watch would not go. This is quite parallel with our progress toward an understanding of the failure of gelatin and other proteins to serve all purposes in nutrition. Just as the watch-maker, with his special knowledge, easily detects what is wanting, so the physiologic chemist is now able to say with much accuracy what particular amino-acids are lacking in his feeding experiments. As the defective watch may be made serviceable by the addition of certain bits of mechanism, so in a measure an insufficient diet may be made adequate when extra amino-acids are supplied.

It is necessary now to approach a subject of some difficulty. We must attempt to show why a given quantity of protein fed—say 100 grams—cannot contribute an equal quantity to the protein supply of the body. When protein of one kind undergoes complete hydrolysis and protein of a new kind is to be made from the resulting cleavage products, certain of the building-stones will be needlessly plentiful, while others will be relatively scarce. We have seen that if a single one of these structural units is not furnished, there is complete failure to synthesize the new compound. Similarly, if the second body is to contain a large percentage of an amino-acid which is but scantily represented in the first, the possible formation is definitely limited. The principle is easily illustrated. Suppose that in a club of 100 members there are 25 Democrats. It is desired to elect for purposes of debate the largest possible body, consisting of Democrats and Republicans in equal numbers. Evidently, this body will comprise 25 men of each party. There will be 50 men unrelated to the new organization. We may change the comparison: A house is pulled down and another is to be erected from the timbers. If the second house is of an architecture entirely unlike that of the first, there will be many unavailable pieces to discard and the new building will be smaller than the old. It is not at all unlikely that the misfit fragments of building material will go into the cellar of the new house, later to be used as fuel. This is just what the body does with the misfit amino-acids. So far as they do not find place in the mosaic which is put together they serve as producers of energy.

Again, a better analogy suggests itself: The structure of a molecule of food-protein, previously compared with that of a watch or a house, may be likened to the type set up to print a page. The letters, some of which occur frequently and some rarely, stand for the amino-acids. The type is allowed to fall apart, the symbol of digestion. It is to be set up again to print different matter. If the language and vocabulary are much as at first, it may be possible to compose nearly a whole page before the lack of some letter brings the proceeding to a standstill. But some shrinkage will be inevitable and when the type-setting has to halt there will be some unused letters. The shrinkage will be much greater if the second page is to be printed in a language other than the original. Suppose, for example, the type used in English composition is next devoted to German. The resulting difficulty is readily foreseen—the letter *z* is uncommon in English, but frequent in German. Hardly a line can be perfectly set up before this letter will be vainly sought. Almost the whole collection of type will be useless for composing. This is analogous to the attempt to minister to animal growth with some isolated vegetable protein of exceptional constitution. Offering the cleavage products of gelatin to the cells is like giving the compositor incomplete fonts of type. He cannot set up connected matter if some of the letters are not to be found.

It seems natural to assume that the closer the structural resemblance between the proteins digested and those to be synthesized, the more economically the making over can be accomplished. It is permissible to infer that nutrition can be subserved by a smaller quantity of proteins when they are derived from animal sources than when they are of vegetable origin. One cannot, however, use this as a strong argument against vegetarianism. The quantity of proteins which one takes when following the dictates of the appetite is apparently so liberal that all constructive requirements are easily met, even though the difference between the composition of the food-proteins and those of the body is a wide one. Too rigorous logic applied in this connection might lead to the recommending of cannibalism.

Our knowledge of the place and the manner of protein synthesis is incomplete. The cells which line the intestine and receive the digestive products are generally held to bear a large part in the work. The fact that these cells contain erepsin, an enzyme capable of breaking down the more complex nitrogenous bodies, does not exclude the possibility that dehydrations and condensations may still take place within them. The enzyme may be modified under some conditions so as to be inactive. It is even conceivable that it may facilitate the combining of the building-stones. Some enzymes, like other catalysts, may favor the progress of reactions either in one direction or the reverse, according to the proportions of the substances present at the moment.

It is not easy to estimate the extent of protein synthesis which normally takes place. Of course, it is more prominent during growth than during adult life. The present impression is to the effect that only a very small fraction of the usual protein income is thus used. Most people can materially reduce the quantity of protein in the diet and still remain in nitrogenous equilibrium. When the lowest level at which this is possible has been attained it is still true, as we have just pointed out, that the amount of new protein constructed is but a fraction of that supplied. It is, therefore, certain that under average conditions by far the larger part of the nitrogenous food eaten never exists in the form of proteins after absorption. We must now consider the destiny and value of the uncombined building-stones.

The surplus amino-acids, either free or in simple combinations, are borne away from the intestine in the portal blood. Accordingly, these digestive products, like the sugars, are brought under the influence of the liver-cells. They undergo a transformation in this organ—and very probably elsewhere—which has important consequences. This is the process described as "deaminization." To deaminize an amino-acid is to remove from it the group to which it owes its name, the radicle NH_2. One of the products of this reaction will be non-nitrogenous, the other will contain nitrogen in a greatly increased percentage. We cannot claim to know all the steps which are gone through in this connection, and we shall not discuss those which are known. We shall emphasize simply the final results.

The chief nitrogenous compound which issues from the series of reactions occurring in the liver is *urea.* This is apparently of no further use in the system. It is destined to circulate until it shall find its way into the urine. The efficiency of the kidneys is so remarkable and the whole blood volume is carried through them at such short intervals that the percentage of urea in normal blood is kept very low. Urea seems to be a most convenient form for nitrogen elimination; it is highly soluble and diffusible, inert, and, comparatively speaking, non-poisonous. If a man eats 100 grams of protein in twenty-four hours he will excrete some 30 grams of urea, an amount which represents about seven-eighths of the total nitrogen passing into and out of the body. This urea is not all made by the liver, but a large share of it proceeds from the deaminizing activities of this organ.

What, then, is the principal non-nitrogenous compound produced from the amino-acids in the liver? There seems to be no doubt that it is *dextrose*. Evidence in support of this belief has been derived from the study of diabetes. Whether this condition is experimentally induced or develops spontaneously, it is found that, if the case is one of full severity, sugar excretion goes on even when no carbohydrate is fed, and, indeed, throughout long periods of fasting. This sugar might be assumed to have come from the fat of the body, but it can be more surely attributed to the protein which is being decomposed. The following consideration shows this: the nitrogen and the sugar in the urine of the fasting diabetic patient maintain a singularly constant ratio; 1 gram of nitrogen is accompanied by 3.6 grams of dextrose. They rise and fall together. This seems to prove that the two must have a common source, which can only be protein. Again, the feeding of amino-acids to the diabetic increases his loss of sugar; the feeding of fat does not have this effect. A simple calculation shows that 100 grams of protein fed may give rise within the body to about 57 grams of sugar. The seriousness of diabetes will now be better appreciated than has been possible up to this time. The organism loses not merely the support normally secured from the chief carbohydrates of the diet, but, in great part, that ordinarily furnished by protein food.

From all this it appears that much of the protein which we eat serves only to supply the tissues with carbohydrate. The impression is likely to be that this is a roundabout and not an economical way to provide sugar, which might have been taken as such at the outset. The facts may fairly be employed to support the modern teaching that excess of protein is to be avoided, but we have already shown the necessity for allowing more than is actually to be reconstructed after the digestive dismembering. Recognizing as inevitable the discarding of amino-acids, we can see the desirability of having them made to furnish a simple standard food like sugar, valuable for its store of energy. The possibility of glycogen formation from protein naturally follows. The glycogen of carnivorous animals presumably has such an origin. The maintenance of the sugar of the blood during long fasting is also ascribed to the disintegrating protein of the tissues. Given dextrose in such quantities, the production of fat from protein becomes at least theoretically possible. Broadly speaking, we may claim for protein that it can do all that any form of organic food can do for the system. Yet this does not impair the statement, equally to be recognized, that carbohydrates and fats should form much the larger part of the income.

After the constructive requirement has been met, all additional protein seems to entail unprofitable labor on the part of the liver in deaminizing the cleavage products, the presence of various substances of a possibly detrimental nature in the circulation, and an activity on the part of the kidneys which may amount to an abuse of these important excretory organs. There is this general contrast between the behavior of proteins and non-proteins in the body: the former give rise to rather complex waste-products imposing a task upon the liver and kidneys; the latter are oxidized cleanly to carbon dioxid and water, two compounds which are eliminated with ease. A fuller discussion of these facts will be undertaken in the chapter on The Hygiene of Nutrition (Chapter XXII).

Folin, of the Harvard Medical School, has classified the facts of protein metabolism in a particularly clear and helpful form. He distinguishes two lines of transformation, the *endogenous* and the *exogenous*. Under the head of endogenous metabolism he traces the various steps in the history of those building-stones which are erected into the proteins of the blood and other tissues. The narrative is continued in the account of the rather gradual and steady crumbling which such tissue-proteins undergo. What is loosely called the wear and tear of the cells gives rise to definite end-products, one of which Folin holds to be of particular value in estimating the extent of such decomposition. This is the substance *creatinin*, which accompanies urea out of the body and which is far less subject to fluctuation. The urea excreted rises and falls with the protein ration, but the creatinin is not markedly responsive to dietetic variations. It is believed, therefore, that endogenous metabolism, a necessary feature of animal life, is relatively independent of feeding, at least while nutrition is satisfactory.

Exogenous metabolism is an expression to cover all the reactions affecting the uncombined amino-acids. Hence it includes the formation of urea, dextrose, and whatever substances may be formed from the nitrogenous cleavage products in the liver. It may be extended to take in the secondary production of glycogen or of fat from surplus sugar originating in this way. In contrast with endogenous metabolism its amount varies widely. With a low protein diet the exogenous changes will be but a fraction of what they will become with abundant protein. One may be tempted to conclude that in fasting the metabolism will be wholly endogenous. The insight of a German writer has served to show us that this is not so. We have spoken at length of the assembling of amino-acids fresh from the intestine to form the standard proteins of the blood. Now there are differences of constitution between the blood-proteins and those of the various organs much as there are between these same blood-proteins and those of the food. When a particular tissue, muscle, for example, is to be nourished at the expense of the blood (or the lymph), a true local digestion is necessary, and once more there must be the selecting and rejecting of amino-acids. Those not available may reach the liver and be deaminized there quite as if they had come from the seat of the original digestion.

Note.—The outlines of nitrogenous metabolism given in this chapter follow closely Abderhalden's presentation of the subject. It is impossible to predict how far the prevailing views may be modified as the result of work now in progress. Mendel's researches seem tending to support the belief that more remodeling of the amino-acids can be carried on than has been generally supposed. A recent suggestion of his must be considered. The food which lies in the intestine is not used solely by the animal, but serves also to nourish swarms of bacteria. These are plants and are known to possess well-marked synthetic powers. It is certain that the multiplying bacteria construct new proteins from the nitrogenous cleavage products placed at their disposal. The proteins thus formed may be radically different in molecular pattern from any in the diet. Great numbers of these intestinal bacteria are always perishing, and when they die they must yield their substance to the digestive juices for resolution into its component groupings. Thus there may be a hidden supply of amino-acids to the system which is more or less independent of the ration which the experimenter has furnished.

Another possible divergence from the account given above must be indicated. As we have pictured the succession of events, the amino-acids used for synthesis have been combined to form the characteristic and abundant proteins of the blood, these to be locally digested and made to supply the necessary building units to the various tissues. But the impression seems to be gaining in favor that amino-acids uncombined may escape the influence of the liver, and be taken to all parts of the body and offered in free condition to organs which may require them. If this is the usual procedure the suggestion is that the blood proteins form a rather stable reserve mass of food material not much subject to depletion and renewal under ordinary conditions of feeding. In starvation we know that the proteins of certain organs are used to keep up the nutrition of others more essential to survival. It would be interesting to know whether such transferred material is carried in the form of amino-acids or organized temporarily into proteins of the type found in the plasma. But there is no part of physiologic chemistry where our knowledge is so much at fault as just this section.

A SUMMARY OF METABOLISM

Fats are hydrolyzed in the alimentary canal to fatty acids and glycerin. To an uncertain extent there is soap formation. These products are largely recombined to form fat during the passage through the lining cells of the intestine. Fat is stored chiefly in adipose tissue. Its eventual service is to be oxidized to carbon dioxid and water with release of its energy.

Carbohydrates enter the circulation in the form of simple sugars, mainly glucose. There is little sugar in the blood at any one time. Much is dehydrated by the cells of the liver and muscles to make glycogen, subject to reconversion to sugar when required. A surplus may be converted to fat. The possibility of the converse change from fat to sugar is generally held to be unproved. The final value of carbohydrate is like that of fat; its energy is set free through the respiratory oxidation, and the end-products again are carbon dioxid and water. The internal secretion of the pancreas is necessary to bring about this destruction.

Proteins are hydrolyzed to simple compounds (amino-acids or combinations of these), and these are used for the synthesis of the new proteins—of types peculiar to the species—which can be utilized for growth or repair. A large surplus of uncombined amino-acids is usual; these are dealt with by the liver, and the best-known resulting products are urea—destined to be excreted—and glucose, for which all the possibilities exist that have been mentioned above. The amount of wasting suffered by nitrogenous tissues as a part of their life process is believed to to be indicated by the extent to which the product creatinin is eliminated. All proteins yield sulphur compounds among their decomposition products. Some yield phosphorus compounds also, and it is these proteins which give rise to much of the uric acid which often tends to be retained and to cause trouble.

CHAPTER XVII

THE REMOVAL OF THE END-PRODUCTS OF METABOLISM

THE statement has repeatedly been made in varying form that the bulk of the food is taken for the sake of its potential energy. Either at once or after storage it is oxidized, and the energy turned to account for temperature maintenance and for the performance of muscular work. The main products are carbon dioxid and water. These are likewise the chief products formed when familiar fuels are burned outside the body. Wood, coal, and gas yield the two in great quantity and only small amounts of other compounds. Hence the primary problems of excretion concern the manner of elimination of carbon dioxid and water.

The water leaving the body during twenty-four hours may be 2 or 3 kilograms. The carbon dioxid discharged in the same period is not often in excess of 1 kilogram. Nevertheless, we say that carbon dioxid is the leading waste-product of animal life. This is justified by the consideration that by far the larger part of the water which we measure is merely water previously received in the same state. To this large volume the tissues have added a moderate quantity of water—say 250 grams—which is a true metabolic product. This has been formed by the oxidation of compounds containing hydrogen. The water output of the body is inevitably greater in the long run than the water income. This fact may be disguised on single days by water retention.

Carbon Dioxid Elimination.—Respiration has been defined as the process within the living cells in course of which complex organic molecules are decomposed and more or less completely oxidized. Carbon dioxid is the most conspicuous product. The respiratory exchanges occur in the different tissues in a measure corresponding with the extent to which they severally evolve energy. The skeletal muscles lead in amount of respiration (and of carbon dioxid set free), both because of their great mass and their activity. The glands, especially the liver and the kidneys, contribute largely to the total. So does the heart. Other tissues have a minor part in the general respiration. Some which are passive and stable, like cartilage, can have but little.

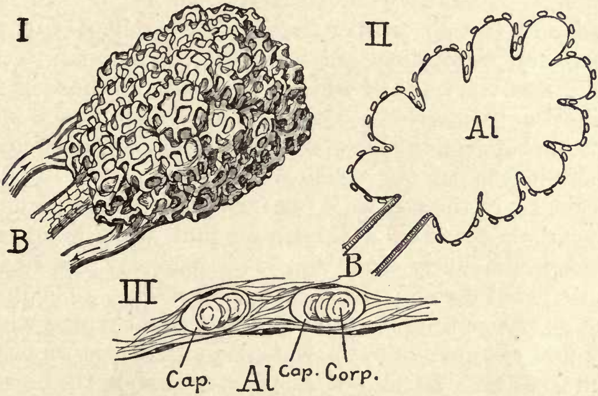

Fig. 21.—I is intended to suggest the form of an air-sac of the lung overlaid with a network of capillaries belonging to the pulmonary system. II is an imaginary section through such an air-sac. *B* in both I and II is the minute bronchial tube through which the air is renewed. III is a bit of detail from II, still more enlarged, showing two capillaries (*Cap.*) conveying corpuscles (*Corp.*). The air is close by (*Al*), yet two partitions intervene, the capillary wall and the wall of the air-sac.

The carbon dioxid formed by the cells is first transferred to the lymph. The concentration of the gas in the lymph leads to its passage into the blood. A gas will always pass from a higher to a lower concentration when the two solutions are placed in communication. The delicate capillary wall between the lymph and the passing blood offers practically no impediment to the movement. It will be remembered that the blood which enters upon the very short journey through the capillaries is arterial; that which enters the minute veins only a fraction of an inch away is reckoned venous. It has parted with a large share of its oxygen and has received carbon dioxid. It is swept on without significant change to the right side of the heart and thence to the lungs. The development of these organs is such as to multiply the surface of contact between the blood and the air within them. The capillaries of the pulmonary circulation are wrapped about innumerable elastic sacs, the walls of which are as thin as those of the capillaries themselves. There is, accordingly, a double partition between the blood and the air, but it is of a nature to permit free gaseous exchange.

If the air in the sacs were not renewed it would accumulate carbon dioxid in increasing amount, while its oxygen would progressively diminish. This tendency is normally counteracted through the effects of breathing. The lungs have no power to move of themselves; the changes which they undergo are due to the widening and the return of the thoracic walls. This is not the place to analyze the breathing movements. The muscles employed are of the skeletal order. Being so, they are not automatic, and it follows that every breath taken is the expression of a separate and distinct act on the part of the central nervous system. Each time the chest is made larger the air presses in along the breathing passages to fill the space created for it in the host of widened sacs. The return of the chest walls to their first position reduces the capacity of the sacs, and air is pressed out along the same channels by which it entered. The action is that of a pair of bellows not provided with the usual inlet valve.

It is not to be conceived that we empty and refill the air spaces of the lungs with each breath. We usually expel something like one-fifth or one-sixth of the air contained and replace that fraction with fresh air. When allowance is made for the rather long and capacious passages between the air-sacs and the nostrils the impression that out breathing is rather ineffective becomes strengthened. To offset this idea we must remember that the movements occur fifteen or eighteen times a minute, providing thus for at least two fairly complete renewals of the whole volume of air within that time. Still it is a fact that when the breathing is rarely deepened beyond the constant habit, some portions of the lungs, notably their upper extremities, are but little subject to extension and contraction. By the deepest possible breathing we can increase the proportion of the air removed and replaced to perhaps three-fourths of the total at a single movement. A quiet breath, unmodified by the influence of attention, muscular activity, or any other temporary condition, is said to amount to about 500 c.c. (30 cubic inches or 1 pint). Reckoning sixteen breaths in a minute, this will mean 8 liters of air breathed in that interval, about 500 in an hour, or 12,000 in a day. Fresh air has but a small content (0.03 to 0.04 per cent.) of carbon dioxid. The air expired has 4 per cent., more or less; 4 per cent. of 12,000 liters is 480 liters, a fair average volume to represent the daily output of this gas. This quantity, changed from volume to weight with correction for temperature, is about 800 grams.

The air to which the blood is exposed in the lungs is at least as rich in carbon dioxid as that which we breathe out. Coming into relation with air of such a composition the blood by no means frees itself of its large carbon dioxid content. It carries on to the left side of the heart and so to the general arterial system some five-sixths of the carbon dioxid which it contained when it entered the lungs. The actual amount in venous blood is in the neighborhood of 45 in 100 c.c. of blood. As much as 38 c.c. in 100 will usually remain in blood which is counted arterial and which carries a maximum of oxygen. Carbon dioxid does not interfere with the capacity of the blood to carry oxygen, and the converse is equally true. It may be well to state that the color of blood varies with the extent to which the corpuscles are charged with oxygen and is independent of the carbon dioxid present.

While there is no question of the propriety of calling carbon dioxid a waste-product, it does not follow that the system would be benefited by its complete removal. How far this is from being the case has been shown by the important experiments of Yandell Henderson. He has demonstrated that any considerable lowering of the carbon dioxid below the high standard noted above as characteristic of arterial blood results in marked prostration, often involving the suspension of breathing and perhaps resulting fatally. The inference is that a certain concentration of carbon dioxid is a desirable source of stimulation to the nervous system and especially to the respiratory center. The intimate connection between this gas and breathing is manifest when its percentage in the blood is ever so little increased. A noteworthy deepening of the respiration promptly results. Since this is true it is not strange that a reduction of the carbon dioxid should cause inhibition of the breathing movements.

Water Elimination.—Water leaves the body by all the possible excretory routes. Statements regarding the proportion taking this or that course can have but little value, so great is the variation under different circumstances. If we exclude the effects of exercise and of unusual temperatures we may expect to find somewhat more than half the whole amount to be removed by the kidneys. The daily volume of the urine is customarily set down at 1200 to 1500 c.c. The remaining excretion of water will be almost wholly accounted for by the perspiration and by evaporation from the breathing passages. Of these two, the former is commonly more considerable. Some loss of water will occur in the feces, but normally this is not to be compared with the quantities discharged in the three ways just mentioned.

When the external temperature is high the water passes in increased amounts through the skin and the perspiration may greatly exceed the urine. The urinary secretion

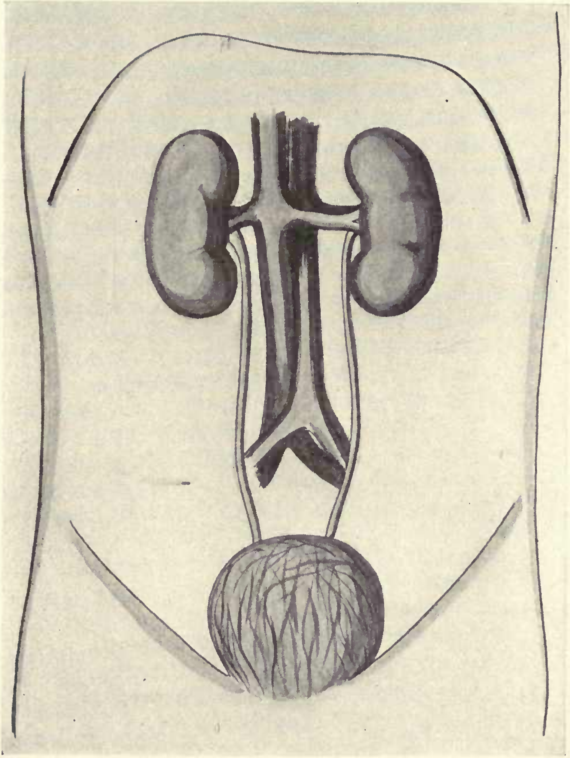

Fig. 22.—The kidneys and the urinary bladder. The two kidneys are shown within an outline which suggests the body cavity. Their advantageous connections with the chief artery and vein of the system are indicated. Below is the bladder reached by the two ureters. These vessels enter the bladder low down and behind—not at the level, where they disappear from the figure.

may shrink somewhat or may be kept near the standard as a result of the water drinking which is stimulated. The output of water from the skin during the hot weather and also during muscular activity does not serve primarily as a vehicle of waste, but rather as a means of ridding the body of heat. This matter will be discussed at length at another time. The evaporation from the respiratory tract probably varies less widely than the perspiration. The body seems bound to saturate all the air that is breathed, so that this loss increases with the volume of breathing and is greater when the air is dry than when it is humid.

The Kidneys and the Urine.—The chief significance of the kidneys is their function of excreting the distinctive products of protein metabolism. A secondary service is the disposal of inorganic salts. The two glands are placed to the right and left of the spinal column at the level of the lower ribs. Each kidney receives a large short artery from the aorta which passes between them. Each returns a large vein, not to the portal system, but to the chief venous trunk of the body. The kidneys, in consequence of this arrangement, constitute short cuts or "shunts" in the circulation, and are perfused by an exceptionally large quantity of blood. No portion of the blood can long escape their influence. The urine discharged by the many tubular units of the kidneys is conveyed through the ureters, contractile vessels which lead to the bladder. This is a saccular organ capable of accommodating much urine when dilated, and of contracting again to nearly complete expulsion of its contents. Its walls of muscle (the same type found in the alimentary canal) are obviously under nervous control and much subject to reflexes.

Urine of average composition is a complex solution containing some 3 or 4 per cent. of dissolved solids. The leading substance is urea, the chief nitrogenous waste of the system, and the index, according to Folin, of the exogenous metabolism. Its origin has been discussed. Evidently the duty of the kidney is less to manufacture urea than to select and remove from the blood the urea originating in the liver and elsewhere. Second in abundance among the urinary constituents we ordinarily find the mineral salts. The quantity of these depends in a large measure upon the amount in the diet, and as sodium chlorid is the one taken most freely, so it will generally be the principal inorganic compound in the urine. The chlorids of the mixture are accompanied by phosphates and sulphates. These are not to any extent salts which have been eaten, but, like the urea, they represent modified fragments of protein molecules. The phosphates come from a limited class of proteins, largely from those of the cell-nuclei; the sulphates arise from all proteins.

The minor ingredients of the urine are very numerous. Those of most interest are the bodies which carry the nitrogenous waste over and above that handled as urea. To one unfamiliar with organic chemistry a list of their names can have little meaning. The substance creatinin, already mentioned, is provisionally regarded as indicative of the rate of true endogenous metabolism, the inevitable gradual wasting of the nitrogenous tissues. Another compound which has attracted much attention on account of its apparent relation to several pathologic conditions is uric acid. A certain amount of this is produced during fasting and is not increased by the taking of many kinds of food. The addition to the diet of meats leads to a larger formation of uric acid. A maximum quantity is elaborated when glandular tissues, such as liver, kidneys, and sweetbreads, are eaten. These articles contain an exceptional proportion of nuclear material rich in the proteins just referred to as sources of phosphates. The same proteins are evidently uric-acid formers. The chief peculiarity of uric acid is its slight solubility, which renders its complete excretion difficult and uncertain. Retention of this crystalline substance has been held accountable for the painful symptoms of gout and of a good deal that goes by the inclusive name of rheumatism.

We have by no means exhausted the list of normal urinary constituents, but the student must be referred to other sources for details. The most commonly occurring compounds of an abnormal character are sugar and albumin. The significance of the sugar should be clear in the light of what has been said. Its transient appearance as a result of free consumption does not indicate a diseased condition, but only dietetic indiscretion. Continuous elimination shows that the body has not the usual power to oxidize its sugar. The kidneys are not generally at fault; the defect is in the metabolism of the pancreas or elsewhere. An abundant escape of albumin (presumably drawing upon the protein mass of the blood) is commonly due to a disordered condition of the kidneys. It takes place, for example, in Bright's disease.

Urine when freshly secreted is ordinarily acid to litmus. It may be alkaline when much vegetable food is eaten, and becomes so on standing in any case. The change is due to a bacterial fermentation whereby urea is transformed into ammonium carbonate. An ammoniacal odor develops in connection with this alteration and the liquid is likely to become turbid. The deposition of a sediment under such conditions is no cause for anxiety. It has often been represented by unscrupulous quacks to be a serious symptom. The urine of the herbivora, which is normally alkaline, becomes acid when the animals are fasting, and it may be pointed out that they are then carnivorous—living upon their own flesh and fat.

How much urine is secreted depends largely on the quantity of water taken, so far at least as this is in excess of the perspiration. Kidney activity is stimulated by almost any dissolved substance foreign to the standard composition of the blood. The nitrates, for example, are absorbed rather freely from the intestine and afterward removed by the kidneys in a large volume of water. They, therefore, belong to the class of bodies known as diuretics. The active principle of coffee and tea has the same action. In securing their own elimination such compounds may promote the excretion of others. Diuretics bring about their effect partly through modifying the circulation, and partly, it is believed, through direct influence upon the kidney cells. As regards the first mode of working, it may be said that the kidney is readily responsive to increased blood-flow, especially if it is attended with high arterial pressure. Difficulties with the heart, if they entail retarded circulation and lowered pressure, frequently lead to deficient output.

Other Factors in Excretion.—The lungs and the kidneys perform so large a share in the disposal of metabolic waste as to leave relatively little of the work undone. The feces, however, include small quantities of miscellaneous excretions, and it is assumed that the precise part borne by the intestine and the liver (in the separation of bile) could not be taken by the kidneys. The modified bile-pigments and cholesterin of the feces illustrate this specific action. The share of the skin in the removal of waste is popularly overestimated. The belief that "the pores must be kept open" lest poisons gather in the system is so fruitful of wholesome practices that one is reluctant to question it. Candor requires, however, that the physiologist repudiate the moral in the story of the Italian boy, who died because the surface of his body had been sealed with gold paint for a few hours. If the case is authentic, he must have died because of the character of the application and not from toxic products of his own evolving. Volunteers have submitted to have the skin shellacked and have not suffered any other ill effects than sensitiveness to heat and cold.

Perspiration is almost purely a mineral solution and the salts it carries could doubtless be cared for by the kidneys. When made profuse by severe exercise, it contains in small amounts some of the organic constituents of the urine, but its highest possible rating as a vehicle of nitrogen excretion is not impressive. The same may be said of the assistance rendered by the skin to the lungs. Carbon dioxid passes from the skin in measurable quantities when there is abundant perspiration, but the largest loss which can occur in this way seems insignificant when compared with the discharge from the lungs.

CHAPTER XVIII

THE ESTIMATION OF METABOLISM

It is about fifty years since the first well-equipped laboratory for the quantitative study of human nutrition was opened in Munich. Before that time much had been accomplished in the analysis of foods, the measurement of rations, and the examination of urine, but no satisfactory knowledge of the general metabolism could be had until means should be devised to entrap and measure the gaseous outgo of the body. This difficult task was accomplished by the construction of the first *respiration chamber*, now one of several in various centers of scientific research.

In the long run there must be a correspondence between the food and the metabolism, the income and the outgo, but on a single day there is no necessary agreement between them. This is radically demonstrated on a day of fasting, when the income is *nil* and the outgo is considerable. It is to the excreta that we attend, therefore, when we wish to judge to what extent various materials have been broken down in the body. Studies of the food may be valuable, but in our first discussion we shall limit ourselves to the simple case of the subject without income. A great deal can be learned about the metabolism by determining two chemical elements—the carbon and the nitrogen of the waste-products. Other facts can be ascertained when the quantity of oxygen consumed is noted. Water excretion is frequently measured also.

Nitrogen Elimination.—The fact is already familiar that the nitrogen leaving the system is found almost wholly in the urine. An additional fraction is in the feces. Concerning this latter item it will be remembered that we cannot easily say how largely it is a residue signifying incomplete absorption and how far it is a true waste-product. If feces are discharged during long fasting the nitrogen contained must be the body's own contribution. On the whole, the fecal nitrogen is nowadays regarded as an excretion unless it is clearly excessive. The nitrogen of the perspiration can usually be ignored.

When we assume all the nitrogen eliminated to have come from the decomposition of proteins, a certain error always exists, but it is not great enough to be considered in the present elementary treatment of the subject. Nitrogen constitutes about 16 per cent. of protein. Accordingly, the excretion of 16 grams is taken to stand for the destruction of 100 grams of protein. This is not far from an average amount when the diet is freely chosen. In the opinion of an increasing number of authorities it is higher than it should be for the best nutritional condition. To arrive at an estimate of the protein metabolized we multiply the quantity of nitrogen in the outgo by 6.25 (an operation which is equivalent to dividing by 16 to find 1 per cent. and multiplying by 100 to obtain the total). This was a familiar procedure before the erection of respiration chambers made possible a complete survey of the metabolism.

Carbon Elimination.—A subject excreting 16 grams of nitrogen may be expected to excrete something like 200 or 250 grams of carbon in the same period. This will be in the respiratory carbon dioxid so largely as to make the urinary and fecal carbon appear insignificant. Figures from an actual experiment are:

In the respiration	208	grams.
In the urine	6	“
In the feces	11	“
Total	225	“

This carbon may have been furnished by all three types of body substance—the proteins, fats, and carbohydrates—in numberless possible combinations. The amount of protein decomposition has already been fixed at 100 grams.

Such an amount of protein must have yielded in its falling apart a quantity of carbon represented by the percentage of that element in the compound. The actual percentage is about 53, so that in this instance 53 grams of the 225 may be ascribed to protein as a source. The remaining carbon, 172 grams, must have been derived from non-nitrogenous material. How far it has come from fat and how far from carbohydrate we cannot exactly determine without additional data.

It is of value to know all the circumstances of such a trial. If the twenty-four hours under consideration is the first fasting day and the diet of the day before has been the ordinary one, we may assume that the subject entered upon the experimental period with a fair stock of glycogen. This will be used rather freely at the outset, but more and more slowly as the hours pass. Carbohydrate, accordingly, contributes largely to the support of the organism during the first day of abstinence, and thereafter bears but a very small part. To say that the glycogen of the body is used up in a single day of fasting would not be correct; the fact is rather that the rate of consumption diminishes sharply. In proportion to this diminution in the use of carbohydrate the fat is called upon increasingly. For any day of hunger after the first it is substantially true that the individual is living on protein and fat.

Let us continue the discussion of our numerical illustration with the added statement that the day is the second rather than the first in a fast. The 172 grams of carbon from non-protein material may now be attributed to fat. The percentage of carbon in fat is about 77. A simple calculation (dividing by 77 and multiplying by 100, or, what is the same thing, multiplying our first quantity by 1.3) gives 223.6 grams of fat as the amount destroyed in the body during twenty-four hours. The total metabolism is then 100 grams of protein and 223.6 grams of fat. It is not safe to conclude from this that the loss of weight will prove to be just equal to the sum of the two items. It may be found to be either more or less, the result depending chiefly on the relation of the income and outgo of water.

Could there be conditions under which all the non-protein carbon could confidently be assigned to carbohydrate sources? Not in the fasting state nor commonly on a mixed diet. The case might be approximated by giving ample rations with minimal fat and maximal carbohydrate for days together. This is nearly equivalent to the nutrition of the herbivora. If our supposed human subject yielded the amounts of carbon and nitrogen already quoted while adequately fed upon protein and carbohydrate, we should not be much in error in assuming that the carbon from non-protein had been evolved from starches and sugars metabolized. Carbon forms about 40 per cent. of carbohydrate, and, if we reckon according to the same principle as before, we find that 172 grams of carbon could have come from 430 grams of carbohydrate, more or less. Under more ordinary conditions of feeding —and on the first day of a fast—both carbohydrate and fat would share with protein the sustaining of the body's activities.

The Respiratory Quotient.—The modern respiration chamber is a small room with impervious walls and carefully controlled ventilation. The carbon dioxid of the air drawn off is either determined directly or estimated from measured samples bearing a known relation to the total volume. In chambers of the best type the oxygen consumption is also ascertained. If we know both the carbon dioxid production and the oxygen absorption we can, of course, compute the ratio between the two. The value of this ratio, based on the volumes and not the weights of the two gases, is known as the respiratory quotient. It is figured by dividing the volume of carbon dioxid by the volume of oxygen. So determined it has most of the time the character of a proper fraction, or, rendered as a decimal, it is less than one. This is a way of saying that the carbon dioxid discharged is generally less than the oxygen which has disappeared in the exchange.

Every molecule of carbon dioxid holds combined the equivalent of a molecule of oxygen. It follows that if all the oxygen were devoted to the formation of carbon dioxid the two volumes would be equal and the ratio between them would be unity. The failure of a part of the oxygen to reappear as carbon dioxid indicates that it has been combined in some other way. It has actually gone to form the second great respiratory product, the water of the metabolism. The interest which physiologists feel in the respiratory quotient springs from the fact that it varies with the prevailing employment of one kind of material or another in the general oxidation which is going on. The decimal value of the ratio is elevated in proportion to the prominence of carbohydrate in the process. It is lowest when fat is bearing a principal part. Since, at the beginning of a fast, carbohydrate is called upon to meet the requirement, while its place is taken by fat a few hours later, the respiratory quotient will show a decline which marks with exactness the shifting of the current.

It would not be easy to show how the respiratory quotient can be made the basis of equations which determine how much fat and how much carbohydrate are broken down to give a certain output of carbon dioxid. Suffice it to say that the possibility exists and is highly fruitful of results in the quantitative studies of nutrition laboratories. The meaning of the respiratory quotient is sometimes altered by temporary conditions. Perhaps the most interesting of these is the peculiar increase in carbon dioxid outgo exhibited by an animal which is rapidly fattening on a diet rich in carbohydrates. Such an animal may show for days together a respiratory quotient in excess of unity, that is, it produces carbon dioxid not accounted for by the observed oxygen intake. This extra carbon dioxid is explained satisfactorily as having come from the carbohydrate undergoing transformation to fat. (See also Chapter XV, page 143.)

Equilibrium.—Our nearly uniform weight, maintained for periods of years, suggests that income and outgo are often nicely balanced. Complete equilibrium demands strict equality between the income and outgo of water, of mineral matter, of nitrogen, and of carbon. The realization of these conditions is not likely, though it is often closely approached. Partial equilibrium, that is, equality between intake and output for one class of compounds with inequality for another, is more common. The most frequent striking of a balance is between the nitrogen of the food and that of the excreta. Nitrogenous equilibrium is the rule rather than the exception. The tendency of the body to establish this correspondence, in spite of wide variations in the diet, was noted long ago. It was said that the organism refused to store protein when supplied with large amounts of this kind of food. This is true in the narrow sense that the body does not add freely to the adult measure of its living tissues when offered extra protein. Yet, as we have seen, the return of all the nitrogen fed does not of necessity mean that the body has retained no part of the protein supplied to it. The chief reason why there is such a marked disposition to make the output of nitrogen equal the income is found in the fact that all the amino-acids beyond the small quantity used for protein synthesis are deaminized. So long as this is the case, raising the nitrogen of the food must result merely in adding to the urea excreted. The non-nitrogenous residues may find more or less permanent lodgment in the tissues in the form of glycogen or fat.

Nitrogen retention is to be expected during growth when the protein syntheses are more extensive than the endogenous decomposition. The recovery from illness or from a fast is another instance when the body protein must definitely increase. This is really only a special case of growth. Change of climate or the pursuit of athletic training may encourage some degree of protein storage. And without seriously qualifying what has just been said it may be stated that abundant nitrogenous food may have the same effect, but the nitrogen retention secured by forced feeding is always limited to a very small fraction of the protein given.

The roughly maintained equilibrium, which is, after all, a striking example of the adjustments of the organism, is to be traced to the singular reliability of the appetite. This is the agent which prompts so surely to the taking of extra food when one exchanges an inactive life for one of bodily activity. The most radical changes in the total metabolism are unlikely to lead to lasting variations in body weight beyond slight gains and losses, which, by the way, are often the reverse of what was anticipated. Exercise, which is supported by large oxidation, may even result in some increase of weight, showing that the appetite has rather more than met the precise need of the body.

Carbon Retention.—When a quantitative comparison is made between the compounds in the diet and those excreted it is not infrequently found that carbon is being stored, though the nitrogen of income and outgo may be balanced. What can be inferred as to the nature of the substance added to the tissues? Just as in the previous case where we desired to interpret the meaning of the carbon loss during fasting, we have to consider the respective share taken by carbohydrate and by fat. As before, it is important to know the condition of the subject prior to the trial. If the day is the first of feeding after a fast there will be some recruiting of the glycogen in the body, and a part of the carbon retention may be attributed to a gain of this material. Otherwise, when carbon is stored in the midst of a period of liberal feeding, the probability is that fat rather than carbohydrate has been deposited.

Applying the same factors as in the earlier instance, we multiply the retained carbon by 1.3 if the circumstances point to its having been held as fat. An excess of 10 grams of carbon in the income over the outgo would be assumed to indicate the addition of 13 grams of fat to the supply in the body. An amount of this magnitude would not show itself decisively in the weight, being easily disguised by the temporary gain or loss of water that might occur at the same time.

CHAPTER XIX

THE ENERGY OF THE METABOLISM

THE initial statement in this book—that living things are transformers of matter and energy—is a text to which we have closely adhered. In recent chapters the emphasis has been placed upon transformations of matter. We shall now pass on to speak of the energy evolved by animals and particularly by the human body. The fundamental facts are presumably clear. The energy of the income is potential in the complex molecules of the food. It is released in the oxidative decomposition processes of life and made kinetic. It appears chiefly—often solely—in the form of heat. Measurements of the heat production of living organisms are generally to be accepted as indicative of the total energy production. Certain exceptions to the rule will soon be noted.

Fuel Values.—Since energy can be transmuted from one form to another it is possible to make the units which stand primarily for one kind do duty for all. It is our constant practice to use the units of heat to measure all the energy of metabolism. The unit which we shall employ is the large *Calorie,* approximately defined as the amount of energy required to raise the temperature of 1 kilogram of water one centigrade degree. The large Calorie is invariably distinguished from the small by the capital C. The small calorie is $\frac{1}{1000}$ of the large; no further reference to it will be made. When a combustible organic substance of a standard composition is completely oxidized a definite quantity of heat is evolved. The heat produced by oxidizing 1 gram of any compound is its *fuel value.*

The highest fuel value recorded is that of hydrogen, about 34 Cal. This is the amount of heat produced when a gram of hydrogen gas (11 liters) is oxidized to water. One gram of carbon oxidized to carbon dioxid gives nearly 8 Cal. These two illustrations do not bear directly on our physiologic inquiry, for the body does not use the free elements for oxidation, but their compounds. It is, therefore, of more interest to turn to the fuel values of carbohydrates, fats, alcohol, and proteins, since these are the actual sources of heat and kindred energy. The calorific value of a compound is not precisely that of the carbon and the hydrogen contained in it and not yet bonded to oxygen, although some early work of a useful kind was based upon that assumption. It is to be noted that the oxygen in the physiologic compounds reduces their potency; the less they contain the more largely they will consist of elements subject to oxidation. This is the main reason why fats have fuel values greatly in excess of those of carbohydrates. A gram of fat contains nearly twice as much carbon as a gram of sugar. It also contains much hydrogen with unsatisfied affinities for oxygen.

The actual heat production observed when a gram of starch is burned is a trifle more than 4 Cal. Sugars, which are slightly richer in oxygen than starch is, have a little lower fuel value. The figure (4 Cal.) is fairly representative of carbohydrates as a class. The oxidation of 1 gram of fat liberates about 9.3 Cal., or 2¼ times as much as starch. A gram of grain alcohol fully oxidized gives an intermediate quantity, about 7 Cal. All these non-nitrogenous compounds are made to yield the same simple products, namely, carbon dioxid and water, whether they are destroyed by literal burning outside the body or by the metabolic processes. We shall see shortly that the energy which is found to be set free in their oxidation can be proved to be equal in the two cases.

Protein stands somewhat apart in its behavior. A gram of dried protein burned in oxygen gives nearly 6 Cal. But some of the products generated in such a laboratory test are not those which the body forms from protein and excretes. Urea, for example, is not found after the actual burning of protein. Urea itself has a certain capacity for oxidation and a low but distinct fuel value, something like 2.5 Cal. per gram. The residual fuel value in urea is a sign that some portion of the energy latent in protein is constantly lost to the animal economy. Bacteria may profit by it, but it seems not to be available for the higher living forms. There are certain products other than urea which remain after the decomposition of protein molecules and which likewise represent unused energy. Some of these minor products accompany the urea in the urine, while others are mingled with the feces. To make accurate allowance for the energy lost with these incompletely oxidized compounds is a difficult matter. The estimate arrived at credits to a gram of protein 4 Cal. or a little more. It is a coincidence with very convenient results that this is almost exactly the same as the figure for carbohydrate.

The Total Daily Metabolism.—The widest limits between which the metabolism of an adult may vary may be set down as 1000 and 10,000 Cal. per day. The lowest level will be approached when there is complete rest and protection from cold during the twenty-four hours. The maximum will be reached, if ever, when a large, powerful man performs the heaviest muscular work while under observation. The food taken on a single day influences the result less than would be anticipated. (As already pointed out, the appetite follows the metabolism rather than precedes it.) High protein feeding has an effect which will be discussed later.

Of course, the average for an individual will generally fluctuate much less than is suggested above. It will rarely fall below 1500 or rise above 3000 under the conditions of city life. Until recently it would have appeared reasonable to fix upon 2400 as a mean. This value has lately come to be regarded as higher than the actual energy output of most people. Perhaps 2000 may be adopted as an ordinary amount. For sixteen hours of waking we may allow 100 Cal. per hour, and for eight hours of sleep

60 per hour, an estimate adding up to 2080. It will be suggestive if we consider how much of a single food-stuff would be required to furnish a total of this order.

Two thousand Calories could be obtained by the oxidation of about 500 grams of starch or sugar. The meeting of the energy requirement is not the only qualification to be demanded of a day's dietary. A ration of pure sugar is obviously not to be recommended, though the consumption of candy to such an extent may be entirely possible for some subjects. The quantity of fat needed to afford the same heat value will be in the vicinity of 216 grams. One can hardly conceive of eating clear fat to this amount. Making a similar calculation for alcohol, we find that a little less than 300 grams of this compound will theoretically meet the need. A palpable absurdity is apparent. While the attempt to use alcohol exclusively as a fuel for the body would evidently be disastrous, it is interesting to consider that a lamp burning 300 grams of absolute alcohol in a day would equal a human being as a source of energy. The flame would be a very small one and the comparison gives one a feeling of dissatisfaction and disappointment.

Since protein is nearly equivalent to carbohydrate as a source of energy, the theoretic ration of protein would be the same as that of sugar, namely, 500 grams. The practical impossibility of eating so much protein is evident when it is remembered that protein is acceptable only when softened and expanded with liberal quantities of water. Lean meat, which is not strictly a straight protein food, but which approaches that composition, is three-fourths water. White of egg, in which the solid portion is almost all protein, is seven-eighths water. The attempt to dry such material and so to reduce it to the smallest bulk produces a mass resembling hardened glue or shellac. To subsist on the proteins of meat alone, the fat having been removed, one would be compelled to eat some five pounds daily. Travelers have described certain peoples as living almost wholly on meat or fish, but this does not mean a pure protein diet, the fat undoubtedly figuring largely.

The Eskimos necessarily eat but little carbohydrate, for they can obtain no vegetable food of importance; it seems plain, however, that they have increased both fat and protein consumption and not protein alone.

The foregoing suggestions make clear the inconveniences and the unhygienic aspect of any attempt to live on a single type of food. It is a fact, furthermore, that one could not under any conditions continue indefinitely to eat only non-nitrogenous food. Protein metabolism never ceases and a certain nitrogenous income must be provided. We cannot, therefore, judge the fitness of a diet solely by its heat value. It must measure up to a reasonable standard in this respect, but it must also include a suitable proportion of protein. Another criterion, not so commonly insisted upon, is that a sufficient quantity and variety of mineral compounds shall be supplied. Of course, these scientific characterizations of the diet are inadequate unless attention is paid also to attractiveness and digestibility.

When a subject freely chooses his food, unprejudiced by chemical knowledge, he is apt to make use of all three classes of food-stuffs to a considerable extent. Carbohydrate will usually amount to more than half the total solids of the ration, while protein and fat show a curious tendency to be taken in nearly equal weights. An example of such a selection, perhaps the one most frequently quoted, is the following:

Protein	100 grams	(410 Calories).
Fat	100 "	930 "
Carbohydrate	250 "	1025 "
		2365 "

Of late years, observation having been extended to large numbers of people, it has become evident that Americans of student and professional classes rarely choose to eat as much as 100 grams of protein.

Calorimetry.—We have been speaking of the amounts of heat set free in the oxidation of various food materials, and of the energy liberated by animals and men as an accompaniment of their metabolism. The determination of such data requires the use of calorimeters. These are of various forms, but have the same underlying principle. In case a food sample is to be burned it is enclosed in a small chamber, preferably in an atmosphere of oxygen, and its combustion is initiated by means of an electric spark. The heat is imparted to a large mass of water surrounding the chamber and can then be estimated by the elevation of temperature observed in this water. This is an elementary and somewhat sweeping statement; numerous corrections would be necessary in practice.

One of the earliest attempts to gage the heat production of an animal consisted in confining it within a chamber having double walls and ice between. The amount of ice melted could thus be made the basis for the estimate desired. The employment of a water calorimeter evidently does away with the unnatural chilling which must have been entailed in this primitive trial. The large and costly calorimeters in modern laboratories for the study of human nutrition are of the water type. No adequate idea of the difficulty involved in such work is likely to be grasped by reading this condensed presentation. Ventilation must be maintained and allowance made for the warming of the circulating air. The evaporation of water must be accurately measured, for if this were ignored a great deal of heat produced in the metabolism would escape measurement. (In the evaporation of 1 kilogram of water heat to the amount of 536.5 Cal. will be made latent.) Changes in the body temperature cannot be overlooked. If, for example, a human subject equivalent in heat capacity to 50 kilograms of water should experience a rise of temperature amounting to 0.5° C. during an experiment, 25 Cal. would have been retained in his body. If, instead, there were a fall of 0.5 degrees there would have been a discharge of 25 Cal., and the observed heat output would have been greater than that due to the current metabolism.

Now the question may be asked whether we can be sure that the observed heat production (corrected for body temperature changes and supplemented by the heat loss through evaporation) is a just representation of the total energy set free. May there not be other forms of energy than heat? What are the facts concerning muscular work? We cannot say positively that no energy eludes the calorimeter, but the impression is constantly being confirmed that any such escape must be insignificant. As to the energy of movement it can be shown that under most conditions this will eventuate in heat. This is an important matter and deserves to be carefully illustrated.

Let us take for an example the case of the heart. This organ does a great deal of work in forcing the blood through the vessels. Does this work appear as heat so as to be arrested and recorded by the calorimeter? There is no doubt that it does. The conversion is effected as the resistance to the blood-flow is encountered and overcome. The heart produces some heat within itself, and some additional heat due to its metabolism is made to appear in all parts of the body. Wherever the blood is driven there is friction, which is a means of transforming the energy of motion into heat. The same statement applies to the breathing movements. Work is done, in the physical sense of the term, each time the ribs are lifted, but with their return to the expiratory position this work is reconverted into heat. So, too, all ordinary forms of exercise may be shown to result in heat production.

Nevertheless it is possible to devise conditions under which a part of the metabolic energy will not be given to the calorimeter. Suppose, for example, that the subject within the apparatus is employed in taking books from the floor and placing them upon shelves. As long as he pursues this form of activity a share of his evolved energy will become potential and be lost to direct observation. It may be said to exist as "energy of position" in the mass which he has elevated. In other words, it has been stored. If, after a day of this labor, he should occupy himself in removing the books from the shelves and laying them upon the floor, he would be giving to the calorimeter more heat than that actually produced as a result of his metabolism. When the books had all been returned to the original level the sum of the calories for the two periods would justly represent the energy production of his body. One could conceive of two calorimeters placed side by side, in one of which a man might turn a crank operating a shaft which should pass into the second chamber and there revolve a wheel against the resistance of a brake. Most of his energy would be registered by the first calorimeter, but a fair proportion of it, standing for most of his muscular work, would be apparent in the second.

Direct and Indirect Calorimetry.—We have said elsewhere that the proof of the validity of the principle of the conservation of energy for living things was a great achievement of the nineteenth century physiologists. The method of this proof may now be outlined. We have just seen that the total energy production of animals, including man, may be satisfactorily measured in calorimeters, provided that the amount of evaporation is known and any changes of body temperature considered. This procedure is *direct calorimetry*. Now, of course, it is possible, during the same period to collect the excreta and to determine the character and the amount of the metabolism according to the principles explained in the last chapter. Knowing the metabolism—so many grams of protein, of fat, and of glycogen destroyed—we may credit to each of these its respective fuel value and calculate the number of calories which could theoretically result from just such oxidation. We may then compare the energy as determined from the living organism and the energy which should have been liberated in the formation of the measured wastes.

To make the matter plain, we may refer once more to the case on which the numerical estimation of metabolism was previously based. The subject was credited with a metabolism of 100 grams of protein and 223.6 grams of fat. (This, it may be recalled, is the usual assumption when the day is one of fasting and does not closely follow carbohydrate feeding.) The apparent heat value of the calculated metabolism will be as follows:

100 grams of protein at 4.1 calories = 410 Calories.
223.6 grams of fat at 9.3 " = 2079 "
Total................ 2489 "

This bit of reckoning is an instance of *indirect calorimetry*. It is found in practice that direct and indirect calorimetry lead to results so nearly identical as to make it certain that the discrepancy between them is accidental. The two figures differ in modern work by less than 1 per cent.

The correspondence between the observed and the calculated calories means this: that the animal displays no powers of movement or heat production which cannot be referred to the oxidation of organic compounds in its body, and so eventually to the stores of chemical energy in its food. It is an engine, a transformer, and not a creator of energy. A glimpse of this conception came within the vision of the brilliant Count Rumford more than one hundred years ago. He had become convinced that heat must be a form of energy rather than a substance. His conclusions had been drawn in part from the observation that there seemed to be no limit to the quantity of heat obtainable from small masses of metal in the process of drilling. With a flash of insight he looked at the horse which was walking in a circle to move the drill, and queried whether the heat in the iron turnings might not be a derivative of the muscular work of the animal, and whether the same energy had not in some sense pre-existed in the food given to it. The verification of his induction was long deferred, but has at length been made entirely conclusive. The credit for this demonstration is shared by many workers, but most conspicuously by Rubner, in Germany, and Atwater, in this country.

Let us return once more to our quantitative illustration. If the day of the experiment had been one of ample feeding instead of fasting, and the diet had consisted of protein and carbohydrate, the metabolism might have been held to have involved these materials rather than protein and fat. The supposition has already been entertained and may now be made a basis for indirect calorimetry. From p. 180 we copy the amounts of protein and carbohydrate, multiplying by 4.1, the value common to both:

100 grams protein	410	Calories.
430 " carbohydrate	1763	"
Total	2173	"

Comparing this sum with the 2489 Cal. previously determined, we see that for a given production of carbon dioxid the evolution of heat will be greatest when fat is the exclusive non-protein source, and least when the metabolism is as nearly as possible on a carbohydrate footing. The difference is some 15 per cent.

If both carbohydrate and fat had participated in the decomposition underlying the observed excretion, the heat of the metabolism might have had any value intermediate between 2173 and 2489 Cal. The figure obtained by direct calorimetry might in such a case of mixed metabolism be used to determine the part borne by carbohydrate and fat respectively. How this could be done, roughly at least, may be shown here. Suppose the total heat production to be 2300 Cal. (The data regarding excreta are still assumed to be as before, 16 grams of nitrogen and 225 grams of carbon.) We can first deduct from 2300 the 410 Cal. necessarily assigned to the protein metabolism. The remainder, 1890 Cal., stands for the heat released in the oxidation of glycogen and fat. We can now write simultaneous equations as below:

Let $x =$ the carbon from fat.
$y =$ " " carbohydrate.
Then $x + y = 172$ (carbon from non-protein sources, page 171).
Also $1.3 \times 9.3x + 2.5y \times 4.1 = 1890$ (remembering that by multiplying the carbon in fat by 1.3 we obtain the fat represented, and that by multiplying this result in turn by 9.3 we get the calories. The case of the carbohydrate is parallel).

Solving the equations we obtain the following (decimals disregarded):

$x = 69$	90	grams of fat,	heat value,	837	Calories.
$y = 103$	227	“ carbohydrate,	“ “	1054	“
				1891	“

Thus we see that when the character of the metabolism is known we can quite accurately predict the associated heat production (indirect calorimetry), and when the heat production and the excreta are known we can deduce equations to find the relative shares of fat and carbohydrate in the general decomposition.

CHAPTER XX

THE FACTORS WHICH MODIFY METABOLISM

THE circumstances which radically affect the quantity and kind of decomposition going on in the body must already be evident. There can be no hesitation in placing first among these conditions muscular activity. Minimal metabolism attends the most nearly complete state of rest which can be secured. It is somewhat lower during sleep than during a like period of lying awake, doubtless because the waking subject cannot so successfully abolish muscular contraction. When one is sleeping metabolism obviously continues in certain of the breathing muscles and the beating heart. We cannot doubt that it proceeds also in the glands, the muscular coats of the alimentary canal, the nerve-centers, and many other localities. The lowest rate at which the metabolism of a healthy adult is likely to go on during sleep is in the vicinity of 50 Cal. per hour.

Very moderate activity suffices to double this rate of heat production. More vigorous exercise raises the figure in many cases to 200 or 300 Cal. per hour, while we have records of as much as 600 Cal. per hour. This strikingly high level was reached by a professional bicycle rider exerting himself to the utmost upon a stationary bicycle inside a calorimeter. The total for a day observed upon an athlete working to the limit of endurance may reach 9000 Cal. Changes so extreme as these could hardly fail to attract early attention. Lavoisier in the eighteenth century noticed that exercise led to increased consumption of oxygen. Everyday experience of the heating and the "winding" effect of activity would lead to the clear impression of heightened metabolism.

When it had become plain that muscular contractions must involve increased destruction of material, the question arose as to the nature of the substance sacrificed. Chemical teaching in the middle of the nineteenth century was dominated by the influence of Liebig. It was his view that the performance of muscular work could be supported only by the consumption of protein. The impression was a natural one, since muscle is so largely composed of protein. He recognized that carbohydrates and fats were oxidized in the respiratory process, but held that heat alone and not movement resulted from their metabolism. The distinction which Liebig attempted to draw between the service of protein and non-protein material was destined to be wiped out in consequence of a certain memorable trial. The reference is to the so-called "Faulhorn experiment" of Fick and Wislicenus.

By the year 1860 the conception of the convertibility of energy from one form to another had become familiar. A valuable datum, the mechanical equivalent of heat, had become available. (One calorie is equal to the energy consumed in raising 426.5 kilograms 1 meter.) The fuel values of a number of substances were known. Two young scientists, Fick and Wislicenus, conceived a project for testing the prevailing belief in the unique service of protein as the support of muscular activity. They knew that the nitrogen of the urine would afford the approximate measure of the protein undergoing destruction in a given interval. If a known amount of work were done it would be possible to find out whether the protein consumed in the same time would account for all of it.

They ascended the Faulhorn, a mountain rising 1956 meters above the lake at its foot. In reaching the top each experimenter must have done an amount of work represented by the product of his weight by the vertical height attained. (Much additional work must have been done also—by the heart, the breathing muscles, and in the execution of other movements—for which no credit is given in the calculation.) The figured work, therefore, was a minimum quantity. For Fick it was 129,096 kilogrammeters; for Wislicenus, a heavier man, it was 148,656. The investigators collected their urine while on the path and for some hours after completing the ascent. They ate only non-nitrogenous food, that the excretion might not be increased merely as a result of diet. The nitrogen found in the urine indicated in each case the destruction of between 30 and 40 grams of protein. The highest theoretic contribution which such a quantity of protein could have made to the work done would have been only half the known total, and, of course, a smaller part of the actual performance. The inference could not be escaped; something other than protein had been used as a source of muscular energy.

The figures obtained by Fick and Wislicenus have been revised and corrected by critics in view of later discoveries, but their chief significance has never been modified. At the time of this celebrated experiment the respiration apparatus at Munich had not been built. As soon as this plant was in operation under the direction of Voit and Pettenkofer it became possible to learn much more about the effects of exercise upon metabolism. It was soon established that instead of being the sole fuel employed to furnish muscular energy, protein is not even the principal one. The nitrogen excretion of a man on a mixed diet does not increase notably in a period of work as compared with what it is during rest. On the other hand, his output of carbon dioxid, like the calories, is a reliable index of the degree of his activity. The contracting muscles evidently employ non-nitrogenous material for oxidation when the usual conditions of supply are maintained.

The question which naturally follows is as to whether carbohydrate or fat is the preferred fuel. This cannot be discussed at length, but it seems fair to say that both may be used to good purpose and with nearly equal economy. The herbivorous animals may be assumed to work most of the time at the expense of carbohydrate oxidized. The carnivora use much more fat, though it is to be borne in mind that the large quantities of protein which they consume are a source of sugar within the body. Gram for gram, it must be remembered, sugar and fat are not equivalent. One gram of fat has the energy of approximately 2¼ grams of carbohydrate. Quantities of the two foodstuffs which are in this proportion (and hence equal in fuel value) are said to be isodynamic. The principle may be illustrated as follows: 50 grams of fat is withdrawn from a day's ration and 113 grams of starch substituted. A simple computation will show that the heat value of the diet has neither been increased nor diminished. The calories lost through the removal of the fat are 465, while those introduced with the starch are practically the same. Of course, the possibility of such substitutions is much limited by considerations of palatability and individual variations of digestive power.

The fact that carbohydrate and fat are freely used to yield energy for muscular movement does not exclude protein from such service. A carnivorous animal can be kept for a long time strong and active upon a diet composed almost wholly of protein. Yet it remains possible that carbohydrate is the chosen fuel during feeding of this kind. When enough protein is given to secure nitrogen equilibrium and to furnish energy to the full extent needed for the work done, the uncombined amino-acids must give rise to abundant sugar, and it may well be that this is the chief factor in the muscular metabolism. An engine is made of iron and steel, but its regular fuel is coal; a muscle is made essentially of protein, but protein is not its usual fuel. Protein food must be needed in definite amounts for the original development of muscles and also for the increase in their substance under conditions of training. It is not clear that any considerable supply is needed for their best working when the desired level of development has been reached. This distinction between *growth* and *operation* has important bearings upon theories of hygiene.

Mental States and Metabolism.—After hearing of the striking correspondence between the degree of muscular work and the extent of metabolism, one is disposed to ask what are the facts regarding mental work. When it is said that mental states have no distinct influence, apart from that which is secondary to the changes in tissue activity which may attend them, a feeling akin to disappointment is often manifested. Yet a little reflection will convince one that positive effects are scarcely to be expected. The central nervous system, important as it is, constitutes, after all, only 3 or 4 per cent. of the body. Most of its substance is stable and relatively passive in its nature. If its really active cells were to double their average metabolism the addition to the heat production and carbon dioxid elimination of the subject would not be significant in the totals observed. A slight change in the state of the muscles would suffice to offset and disguise it.

An emotional experience is much more than a cerebral phenomenon. In times of excitement the skeletal muscles are played upon by the nervous system and metabolism in consequence may be largely increased. But this is not the direct result of the brain process; it is merely a special case of muscular activity. An emotion, pleasurable or the reverse, is a kind of exercise and often one of marked intensity. This is recognizable in the increased heart action, in the quickened breathing, and in the contractions which bring about characteristic attitudes and expressions.

Mental application of a kind which can be more or less successfully separated from these muscular accompaniments cannot be shown positively to affect the metabolism. A short time ago a trial was made at Middletown, Connecticut, in which a group of students in Wesleyan University took *bona-fide* examinations in a respiration chamber which was at the same time a calorimeter. Each man took his turn, spending three hours over his paper and experiencing the usual anxiety and strain attendant on such a proceeding. On other days each subject spent a like period in the chamber engaged in copying printed matter. Thus it was possible to compare in about twenty cases the metabolism of a period of brain work with the metabolism during a time in which similar muscular movements were made, but in the absence of conscious effort. There was no distinct difference.

Brain cells undoubtedly have peculiar metabolic products and make demands upon the blood for supplies of a somewhat different order from those required by any other tissues. But their distinguishing wastes can hardly be recognized when mingled with the outgo from so many other organs, and it is equally difficult to discover just what they appropriate for their nutrition. The notion that certain articles of diet are brain "foods" rests on very unsafe assumptions. The popular association of phosphorus with the brain and its activity has no more justification than could be claimed for sulphur or any element present in the proteins.

From what has been said it will be evident that the diet must be increased for the support of muscular work, but that no more food is needed for the student occupied with his books than for the same man at leisure. The chances are that his leisure days will be spent in less sedentary fashion than his days of application, and that his appetite will lead to a larger consumption in his so-called resting time.

Feeding and Metabolism.—What can be said at this time about the influence of food upon metabolism must be in the nature of a summary of points already made. Any effect which food may have is generally so much less in degree than the effect of activity as to be readily concealed by changes in the exercise taken. Thus, while it is broadly correct to say that a fasting man metabolizes less material than a man who has abundant food, the relation will be reversed if the starving subject is compelled to work more actively than his fellow. An animal which is denied food is economical in its metabolism, but the economy is secured chiefly through its marked tendency to be quiet. When the influence of muscular activity is eliminated as far as possible we can discover some suggestive facts with reference to the varying properties of the different food-stuffs.

Suppose that a man remains for two days in a calorimeter, the first being a day of fasting and the second a day of feeding. His occupation on the two days is made as nearly identical as may be. We will assume that the metabolism of the first day is found to be 2000 Calories. The food value of the ration allowed for the second day may be also 2000 Calories. It can be predicted that the metabolism will rise somewhat in consequence of the taking of food, but the increase will not be striking. The new total will perhaps be something like 2300 Calories. A far greater increment would have resulted from the prescribing of moderate muscular work. The precise extent of the advance will be conditioned largely upon the make-up of the diet. If protein is given quite freely the stimulation of the metabolism will be decidedly more evident than if the food furnished is almost wholly non-nitrogenous. Protein is said to exert a *specific dynamic effect* upon the decomposition processes of the body.

The divergence between protein and other types of food in the matter of increasing the metabolism has been carefully estimated by Rubner. He has given us some helpful figures. If the fasting heat production of an animal is represented by the number 100, the requirement will not be exactly met by a supply of any food having this value, but must be met by larger supplies. Carbohydrate is the most economical of the three kinds; a fasting metabolism of 100 Calories may be compensated and equilibrium of income and outgo established by giving 106 Calories in the form of starch or sugar. (The quantity must be that actually assimilated, not merely what is swallowed.) In other words, feeding an animal for one day on carbohydrate exclusively, and liberally enough to make the energy given equal that evolved, may be expected to raise its metabolism some 6 per cent. above the previous fasting level.

With fat there is a slightly more positive effect in the same direction. If fat is given to an animal after an interval of fasting the metabolism responds by rising more than in the first case. Instead of the 6 per cent. increase about 14 per cent. is to be anticipated. Hence, to insure equality of income and outgo from the energy standpoint 114 Calories must be furnished in the form of fat to correspond with a fasting production of 100 Calories. The specific dynamic effect of protein is much more decisive. If pure protein is the only food the metabolism may increase by as much as 40 per cent. over the fasting standard. The selection of much protein at a meal will be followed, during the next few hours, by a definite rise in heat production which may be a really wasteful operation. A quantity of heat may be generated entirely apart from the performance of muscular movements and have to be removed as a useless excess.

Foods rich in protein have the name of being "heating," and here as in many another instance the popular impression has been supported by scientific findings. We can see that the eating of much meat in warm weather must add to the discomfort of the eater. The effect is something like the opening of a furnace draft when the house is already too hot for the pleasure of its tenant. A distinction must be made between the heating influence of protein and the high fuel value of fat. It is true that fat, gram for gram, can liberate more energy in the body than can protein. But it is less likely to be destroyed when there is no useful application to be made of its energy content.

Age and Sex as Influencing Metabolism.—Young and growing individuals whether human or otherwise have relatively more heat production than is the case with adults. Thus an infant weighing 10 kilograms (22 pounds) may be expected to have a metabolism of 600 or 700 Calories. That is to say, that with a weight only one-sixth or one-seventh of that of a grown man, it has a heat production one-third or one-fourth as great. It has been shown, however, that if the metabolism of both the infant and the adult is calculated for the surface of the body there is a reasonable proportionality between them. The area of the skin of an average man is something less than 2 square meters. The minimum metabolism may be said to be in the vicinity of 1000 Calories per square meter.

The smaller the body, if it is of a certain standard shape, the larger its surface in proportion to the weight. This is an important biologic principle. Mathematically stated it runs as follows: If two animals of similar build are compared with reference to a given dimension, such as length, their weights will vary as the cube and their surfaces as the square of this measurement. That is, if one animal is twice as long as another it will weigh eight times as much and have four times the surface. Since the body loses heat in proportion to the extension of its surface it is not strange that this is the determining factor for the metabolism. It is surprising nevertheless that animals as unlike as man, mouse, and fowl should evolve heat in nearly equal quantities for a unit of superficial area.

Broadly speaking, it may be said that men have a greater metabolism than women. When the larger average stature of men is taken into consideration the difference is diminished, but does not wholly disappear. We must recognize that when a man and a woman are equal in weight there are still characteristic features of organization which modify the comparison. Of these the most evident is the greater prominence of subcutaneous adipose tissue in the female figure. When allowance is made for this inactive material, it is plain that for equal weights the woman has less truly living substance to be the seat of metabolism. Her skeletal muscles in particular are very unlikely to make as large a mass as those of a man who weighs the same. The adipose tissue may have a secondary effect also. While its presence means that the metabolism is confined to a more limited system in the woman than in the man, it tends at the same time to economize her heat loss and so to lessen the need of internal oxidation. Such a conception will be more readily entertained when attention shall have been given to the subject matter of the next chapter.

CHAPTER XXI

THE MAINTENANCE OF THE BODY TEMPERATURE

All animals are producers of heat, and must, therefore, maintain temperatures above those of their surroundings unless the evaporation of water more than compensates for the heat of metabolism. We speak, however, of warm-blooded and cold-blooded animals as though some were far more liberal than others in their calorific output. This is actually the case. But a better distinction between the two classes may be found in the fact that some animals allow themselves to be warmed and cooled readily, while others keep near to a constant standard of internal temperature. We call a frog a cold-blooded animal, but what we really mean is that it accepts for its own the temperature of its environment. On a very hot day the frog may be as warm as a man; in winter the frog is chilled through and through, while the tissues of a human being everywhere save at the surface are kept at the same temperature as in summer.

Animals which have a fixed standard to which they adhere under all ordinary conditions are spoken of as *homothermous*. This trait is shared by birds and mammals. Our interest, of course, centers in man's remarkable capacity to keep his deeper tissues at the same level in spite of radical external changes and equally sweeping changes in his own metabolism. The means by which this result is attained differ somewhat with different animals of the homothermous order. We shall confine our attention almost entirely to the human problem.

The common clinical thermometer bears the mark "Normal" opposite the point on its scale corresponding to

98.6° F. (In all the following discussion the familiar Fahrenheit system will be used.) The standard just quoted is for the mouth. The body temperature is often estimated by placing the thermometer elsewhere, as in the armpit or the rectum. The rectal temperature is the most reliable, and is usually higher by half a degree, or a little more, than that of the mouth. It is clear that the temperature of the skin cannot be a constant one; it is affected both by the external conditions and by the variations of blood-flow in the superficial vessels.

There are small but distinct changes of body temperature during each day. The lowest figures are noted early in the morning before one has become active and when the sense of prostration is apt to be overpowering. A gentle upgrade is maintained until the maximum is reached in the late afternoon or early evening. The average extent of the rise is about 1° F. It coincides suggestively with the temperamental change, which is to be observed from a prosaic and literal frame of mind to a condition of emotional instability. Compared with the morning, the evening is a feverish period. When there is actual fever the diurnal ascent of the temperature often adds considerably to the restlessness and discomfort of the patient as night approaches.

After we have made allowance for such irregularities it remains true that the approximate constancy of the temperature is one of the most wonderful facts which the physiologist has to explain. Uniformity of temperature implies equality of heat production and heat loss. Our task, then, is to show how this equality is continued in the face of variable factors tending to disturb it. Artificial contrivances for keeping constant temperatures in certain chambers may be considered with advantage before we attempt to analyze a mechanism so much more intricate than they. There are two principles on which incubators or thermostats may be operated: (1) The heat given to the system may be increased or diminished to keep pace with the heat lost; (2) a constant supply of heat may be provided and adjustments made to favor its escape or to conserve it, according as the tendency is toward a rise or fall in temperature.

The first principle is illustrated by those thermostats in which gas flames are automatically caused to rise when the apparatus begins to cool off and are cut down when it begins to be warmed above the intended level. The second way of securing the same result is exemplified by the common incubator used for hatching eggs, in which the heat is furnished by a lamp kept burning at the same height at all times, while a ventilator, opening and closing, dissipates or retains the heat as required. In the living body we can recognize the working of both these principles, but it is rather surprising to find how much is accomplished by the second without the aid of the first. In other words, the constant internal temperature is maintained much of the time by the promotion or the retarding of heat loss without any appeal to the tissues for metabolic support.

Our practice of adapting our clothing to the season and to in-door and out-door life is an extension of the means which the organism itself employs for the same purpose. Extra clothing hinders the escape of heat from the body and makes possible the maintenance of the normal state with no increase of oxidation in spite of some degree of external cold. A race of naked savages must certainly vary the amount of their metabolism much more positively from summer to winter than we do with the habits of our civilization. Animals may enjoy the protection of heavier coats in cold weather, and they show, moreover, an instinct to assume those positions that reduce to a minimum their surface exposure.

To explain in detail how changing circumstances are met, let us imagine a man placed successively in atmospheres of different temperatures. We will begin with a room at 68° F., a condition which we regard as agreeable and which we aim to produce when artificial heating is in use. If our subject has spent an hour in this room he has very likely had a metabolism of 100 Calories, and he has in the same time discharged by radiation, conduction, and evaporation a similar amount of heat. His blood is some 30 degrees warmer than the air around him. Let him now take his place in a room where the thermometer stands at 84° F. Suppose him to remain for an hour in this disagreeably warm apartment. His temperature will be found to rise but little, perhaps not at all. Yet the change has reduced the difference between his own temperature and that of his surroundings from about 30 degrees to about 15. The tendency of his environment to withdraw heat from his body must have been halved. What, then, has happened? Has his metabolism fallen to 50 Calories or has there been a readjustment to facilitate the removal of the full 100 Calories? The latter is found to be the case.

The withdrawal of heat from the body is favored by two reflex changes. One of these consists in an increase in the amount of blood flowing through the skin and thus exposed to the cooling influence of the outside air. The other is seen in the breaking out of perspiration. The evaporation of the water thus brought to the surface cools the skin and the blood beneath it. The blood then mingles with that which has been passing through the deeper tissues and the rising temperature is checked. It is well to insist just here that the appearance of the skin gives little indication of the rate at which the sweat is being secreted. So long as evaporation keeps up with the arrival of the water at the pores there will be no visible moisture. We notice the perspiration most when it is failing to accomplish its object, that is, when it accumulates instead of being vaporized. The evaporation of water from the respiratory passages is, of course, one means of removing heat, but with human beings this is not a quantity which increases with external warming. It does enter into the adaptive reaction in the case of animals which pant.

Let us now transfer our subject to the unusual temperature of 105° F. The radiation and conduction effects will now be reversed; the blood will tend to be warmed rather than cooled as it approaches the surface. The metabolism will continue unabated. The body is thus exposed to warming from without, while it does not cease to heat itself from within. How can it escape a steady rise of its internal temperature leading to prostration and death? Benjamin Franklin answered this question when he pointed out that the sole resource of the organism in such a situation must be its power to evaporate water. To dispose of 100 Calories in an hour by evaporation alone demands the secretion of about 200 grams of water in the same time, an amount which can readily be produced.

When the air is warm the humidity has much to do with human power to endure the condition. If there is full saturation and a temperature as high as that of the blood the heat of metabolism will be pent in the body and heat-stroke is inevitable if there is not a prompt relief; 100 Calories added to the average human body in an hour will raise its temperature by nearly 4° F. A second hour of such an upgrade could hardly be survived. Men may live and work for several hours on a stretch in dry air with the temperature around them as high as 130° F., but they cannot be active in saturated air at 90° F. The first of these conditions is realized in the stoke-holds of ocean steamers; the second, in certain deep mines. Everyone knows that the most trying weather we have to put up with is not that which makes the record for the mercury, but those days which are less warm, but which we describe as muggy or sticky. We are acceding to a correct instinct when we are relaxed and indolent under such circumstances.

We may now return to the starting-point and submit our imaginary victim to temperatures lower than 68° F. If he is taken to a room where the thermometer is at 60° F. he will probably feel chilly. We are affected more by a slight change in the vicinity of 65° F. than in any other part of the scale. The fact is, apparently, that when the external temperature is cut down from 68° to 60° F. the skin temperature, on which our sensation depends, is reduced by a good deal more than 8 degrees. This is due to the reduction in the volume of blood in the cutaneous vessels. It is the expression of the endeavor of the organism to economize to the utmost its outgo of heat. Discomfort is permitted to develop as an incident of the adaptation. The metabolism still remains about as it has been throughout the series of trials.

If the room temperature is now lowered decidedly and no wraps are provided the body can no longer maintain itself by mere economy of heat loss. It must shift from the method of the incubator with a constant flame and an adjustable ventilator to the other form of regulation—that of the thermostat with variable flame. That is to say, the metabolism must be stimulated. A sign of this rallying on the part of the heat-producing tissues is seen in the onset of shivering. This is obviously a form of muscular exercise, and as such is attended with increase of metabolism. When we resist the impulse to shiver, as we sometimes do, we merely adopt another kind of contractile activity with its accompanying contribution of heat to the body. If we analyze the experience of being cold we find that we can recognize a disposition to muscular tenseness, while it is familiar enough that when the cold is severe we cannot keep from moving briskly and so supplying the necessary heat. It is desirable to reiterate that the muscles are not merely organs of movement, but our main reliance for heat production. Cold weather generally means large metabolism, but the connection is indirect; the increase is only a special case of the rise always associated with exercise. So, too, the increase of appetite which is usual in winter is secondary to the greater use of the muscles.

Humidity makes for discomfort in cold as well as in warm weather. It seems at first unreasonable to say that moisture can make us more sensitive to heat in summer and also to cold in winter, yet this is true. The climate of our Atlantic coast is notorious for the "penetrating" character of its cold, and this in spite of the fact that the thermometer does not fall so low as it does a short distance inland. The paradox is easily explained. We have said that high humidity in hot weather interferes with our comfort and efficiency by hindering free evaporation. In winter it has no such influence, because even though the cold air is fully saturated it ceases to be so when it has been warmed by contact with the skin. Evaporation can, therefore, never be retarded seriously by moisture in cool air. What we notice in cold weather is the increased conducting power of air containing water vapor. Damp air may fairly be said to partake of the nature of the water that is in it; water feels colder to the hand than does air of the same temperature because it abstracts the heat more rapidly. Similarly, moist cold air takes heat more rapidly than does dry cold air. This property is present just as surely in warm humid air, but it can affect us only when there is a wide difference in temperature between the skin and the surroundings.

Temperature Maintenance During Exercise.—We have been discussing the ways in which the human body guards itself against changes of temperature which tend to impress themselves upon it from the outside. Another question is in regard to how it escapes the tendency to overheat itself when, during exercise, its metabolism is doubled, trebled, or even more strikingly augmented. Reflection shows that it employs the two reflexes on which it relies for defense against the heat of the warm room, namely, increased surface blood-flow and increased perspiration. These are rendered more efficient by the hastened circulation, a condition not produced in any great degree by external heat without the activity.

A supplementary factor exists in the deepened breathing which takes heat from the system, both in the act of warming the respired air and in the process of saturating it. Still another factor can be recognized in the fanning effect of the movements of parts of the body or of the body as a whole. A man running brings the exposed portions of his skin constantly into contact with fresh volumes of air and slips away from the air which he has just warmed and saturated. The cooling of his blood is in this way considerably facilitated. If he is not progressing through space, but carrying on his activities in one place—for example, in sawing wood—his arms and trunk still make short excursions and exchange old air for new. A breeze makes a considerable difference with the heat output of a man's body.

Fever.—When the body temperature is found to rise above its normal level and to persist at an elevation which brings many ill consequences upon the subject, what shall we name as the cause of the disorder? Shall we say that the metabolism is excessive? Studies made upon fever patients show that their nitrogenous metabolism is often surprisingly high, an indication of rapid destruction of the tissues, but the total heat production is not impressively large. We shall more nearly express the facts if we say that there is interference with heat loss. Frequently we can see evidence of a withholding of the perspiration. Perhaps it is best to say that the central fact in fever is the setting up of a false standard by the nervous system to which for a time there is an adherence as strict as that obtaining in health for the normal one. This perverted action of the nervous system is brought about by the poisons in the circulation at such times. Transient fever may be brought on by very severe exercise; it is experienced by men who run Marathon races. In these cases the controlling centers are probably acting in the normal way, but cannot secure the complete removal of the extraordinary quantities of heat which are produced.

Summary.—The maintenance of a nearly uniform body temperature is the result of a balance between heat evolved and heat dissipated. So long as the external conditions are not such as to cause shivering, muscular tension, or instinctive activity of some other form the organism regulates its temperature almost wholly by making adjustments to promote or to restrict the loss of heat. The wearing of clothing adapted to the season makes it possible to minimize the demands made upon the muscles for extra heat. Decidedly low temperatures and exceptional exposure can be withstood only by calling upon the contractile tissues for an increased heat production.

CHAPTER XXII

THE HYGIENE OF NUTRITION

It is convenient to make a division under this general heading between those factors not directly connected with the diet, which none the less deserve consideration, and those which do concern the choice of food. Probably too little attention is paid to the fact that disorders of digestion and nutrition frequently arise when the food eaten is above criticism, both as to quantity and kind.

Nervous Conditions Affecting Digestion.—Enough has already been said to make it plain that the processes occurring in the alimentary canal are greatly subject to influences radiating from the brain. It is especially striking that both the movements of the stomach and the secretion of the gastric juice may be inhibited as a result of disturbing circumstances. Intestinal movements may be modified in similar fashion. Emphasis has been placed on the dependence of the whole digestive process upon a good start. This can hardly be too strongly enforced. The good start can scarcely be secured if the mental state of the subject is not favorable to the enjoyment of his meal.

Cannon has collected various instances of the suspension of digestion in consequence of disagreeable experiences, and it would be easy for almost anyone to add to his list. He tells us, for example, of the case of a woman whose stomach was emptied under the direction of a specialist in order to ascertain the degree of digestion undergone by a prescribed breakfast. The dinner of the night before was recovered and was found almost unaltered. Inquiry led to the discovery that the woman had passed a night of intense agitation as the result of misconduct on the part of her husband. People who are seasick some hours after a meal often vomit undigested food. Apprehension of being sick has probably inhibited the gastric activities.

Just as a single occasion of painful emotion may lead to a passing digestive disturbance, so continued mental depression, worry, or grief may permanently impair the working of the tract and undermine the vigor and capacity of the sufferer. Homesickness is not to be regarded lightly as a cause of malnutrition. Companionship is a powerful promoter of assimilation. The attractive serving of food, a pleasant room, and good ventilation are of high importance. The lack of all these, so commonly faced by the lonely student or the young man making a start in a strange city, may be to some extent counteracted by the cultivation of optimism and the mental discipline which makes it possible to detach one's self from sordid surroundings. Alcohol works to the same end, but is a perilous resource under these circumstances.

Children are very often the victims of sharp attacks of indigestion. Their sicknesses, which are accepted with little surprise in many families, are almost always held to be due to injudicious eating. While this is a reasonable belief in many cases, it may be asked whether emotional causes of indigestion in children are considered as much as they should be. How common it is to see children made to cry while at the table by ill-timed rebukes. The quick temper and thoughtlessness of parents destroys the happiness of many a meal. Granting that instruction in table-manners ought to be given at suitable times, one may still protest against the downright rudeness of elders toward children when it is shown in the infliction of ridicule and humiliation. Consideration of others' feelings is the finest element in deportment.

Moreover, it is probably fair to claim that children may be injured by being forced to eat food which they dislike. The aversions of early life are singularly strong. What passes for a foolish whim may be an instinctive loathing. There is an element of hypocrisy in the attitude of parents who are selecting precisely what they please to eat, while compelling little children to swallow food which repels. To oblige a child to finish a plateful of food against its inclination may be crass brutality. Of course, children cannot be humored in the selection of eccentric diets, but they need not be made to eat when they would rather go hungry. There is little likelihood that they will refuse the staple articles.

Unhappiness may give rise to digestive difficulties which do not disappear with the removal of the first cause. It is not hard to show how this may be. Suppose that the power to digest and absorb food is lessened by central inhibitions. A consequence is likely to be the accumulation of unabsorbed organic material in the colon and perhaps higher up as well. Bacterial decomposition will be fostered. Some of the products of such a process may be sufficiently like the normal products of enzyme action to play a part in nutrition, but others will probably prove distinctly detrimental. With the entrance into the circulation of such bodies there is originated what is known as *auto-intoxication.*

Long ago it was recognized that the reception into the system of bacterial products might be a cause of general ill health, of headache, and of somnolence. Within a few years the impression has gained ground that poisons from the colon have a much larger and more definite share in the development of disease. Much that goes by the name of rheumatism appears traceable to this source. Some of the toxic compounds seem to have the property of dissolving the red corpuscles of the blood, leading thus to anemia and the serious crippling of the energies which accompanies it. Nervous symptoms are among the most frequent nowadays referred to this condition, seemingly so remote from the brain.

Physicians apply the term "vicious cycle" to a set of conditions in which the establishment of one tends to accentuate the others, and these, in their turn, add to the intensity of the first. We can see how a vicious cycle may become operative in the case of a person whose digestive abilities have been once reduced by mental depression. Auto-intoxication may be induced and one of the clearest results is a further depression of spirits. In this way a lasting injury may be done and the indigestion which began as the effect of temporary unhappiness may be perpetuated in spite of the return of favorable circumstances. Auto-intoxication may come from errors of diet as well as from emotional causes, and a further discussion of it will be postponed.

Physical fatigue as well as mental may interfere with the progress of digestion. It is well that the appetite usually flags in times of exhaustion, so that one is in a measure insured against the tendency to overtax weakened organs. But when the fatigue is habitual there is an unfortunate dilemma; the body must have abundant food to support the heavy labor and it is not well able to care for the food eaten. Loss of weight is common when a man is so situated. Deprivation of sleep emphasizes this state of affairs, and by dulling both the appetite and the digestive capacity it proves for many people the surest means of reducing adipose tissue.

Other possible causes of indigestion may be mentioned briefly. Taking cold is one of these. While the congestion and inflammation which so often follow exposure to drafts and dampness are most frequently centered in the mucous membranes of the nose and throat, a corresponding involvement of the alimentary canal is not rare. Diarrheal attacks are common in the spring and fall when the weather changes are erratic. They are probably to be classed as intestinal "colds." Another source of alimentary trouble is to be found in uncorrected defects of vision. While headaches are the most persistent symptoms of astigmatism and other ocular imperfections, indigestion is not uncommon, and its disappearance when glasses are worn seems sometimes almost magical.

Quantity of Food.—Is overeating the prevalent error of the race? Is undereating easily possible? These are questions which call for open-minded treatment and regarding which it is hard to exclude personal bias. A writer's love for the pleasures of the table, or his ascetic superiority to them, must tincture his expressed views. The present author once committed himself to the statement that overeating is the rule with men and the exception with women. A pupil—a girl—rendered the teaching in her examination as follows: "Women rarely overeat, men do constantly, and are, as a result, bulky and stupid." The assertion, though radical, is exceedingly well worth considering.

The claim is often made that the average practice of mankind must be the expression of a correct biologic instinct. Against this it is urged that our own generation may inherit appetites which were adapted to spur our ancestors to find food when the quest was difficult. Such appetites may be false guides when no effort is required to obtain the means of satisfaction. Variety of food may lead to overconsumption. Modern conditions make it possible to have many kinds of food and interesting contrasts of flavor which encourage eating for sensuous gratification. The primitive diet was monotonous and unseasoned.

Economic factors are tending to lessen the individual ration, and a great mass of published instruction influences people in the same direction. It is probable that the American breakfast is a much less substantial meal today than it was twenty years ago. The use of fruit has increased and food of greater fuel value has been displaced. Odd patent cereals, small quantities of which exhaust the appetite, have been widely substituted for the reliable oatmeal. Meat and potato are not demanded. Lighter lunches at noon are the rule, and though the late dinner may be a heavier meal than the old-time supper, the day's ration seems to have definitely diminished. This is particularly true of protein. The choice of 100 grams of nitrogenous food, an amount once described as average, is now found to be exceptional. If any one of the three main classes of food-stuffs is used more freely than formerly, it is the carbohydrate group.

Protests against overeating and the advocacy of few and simple foods have been heard from time to time all along the course of history. More than one recent commentator on these movements has cited the story of the captive Israelites in Babylon. The four young men who excelled all other members of the king's household were those who had substituted a diet of cereals for the meat and wine that were urged upon them. They were the prototypes of Sylvester Graham and Horace Fletcher. The general teaching that less food should be eaten is very often coupled with an approach to vegetarianism, if not its downright adoption.

An earlier reference has been made to Graham. He was a gifted and well-educated New Englander, born in 1794 and dying in 1851. Fitted for the ministry, he employed his great talents as a public speaker, chiefly in the temperance cause and in support of his dietetic doctrines. His "Lectures on the Science of Human Life," published in 1839, constitute an impressive work. He had a large following, and is said to have injured the trade of the butchers in some localities to such an extent that he was in danger of mob violence at their hands. Aside from his extreme recommendation of the inclusion of husks and bran with food, he taught practically what we are continually hearing at the present time: that the diet should be limited in quantity and variety, that it should be unstimulating, and that it ought to be eaten "slowly and cheerfully."

In our own day we have become used to the claim that most men would attain to better health and greater efficiency if they would reduce their rations by 25 per cent. or more. Conditions of life which were formerly held to warrant individual allowances of 2500 or 3000 Calories are now said to be met by the supply of 2000 or even of 1800 Calories. The most authoritative statements to this effect have come from the physiologists of the Sheffield Scientific

School. In a more popular form the same ideas have been attractively presented by Mr. Fletcher.

The experience and the principles of this gentleman are somewhat familiar to the American public. By his practice of protracted mastication he contrives to satisfy the appetite while taking an exceptionally small amount of food. Salivary digestion is favored and the mechanical subdivision of the food is carried to an extreme point. Remarkably complete digestion and absorption follow. By faithfully pursuing this system Mr. Fletcher has vastly bettered his general health, and is a rare example of muscular and mental power for a man above sixty years of age. He is a vigorous pedestrian and mountain-climber and holds surprising records for endurance tests in the gymnasium.

The chief gain observed in his case, as in others which are more or less parallel, is the acquiring of immunity to fatigue, both muscular and central. It is not claimed that the sparing diet confers great strength for momentary efforts—"explosive strength," as the term goes—but that moderate muscular contractions may be repeated many times with far less discomfort than before. The inference appears to be that the subject who eats more than is best has in his circulation and his tissues by-products which act like the muscular waste which is normally responsible for fatigue. According to this conception he is never really fresh for his task, but is obliged to start with a handicap. When he reduces his diet the cells and fluids of his body free themselves of these by-products and he realizes a capacity quite unguessed in the past.

The same assumption explains the fact mentioned by Mr. Fletcher, that the hours of sleep can be reduced decidedly when the diet is cut down. It would seem as though a part of our sleep might often be due to avoidable auto-intoxication. If one can shorten his nightly sleep without feeling the worse for it this is an important gain. The small ration decreases the contents of the colon in two ways: First, the food residues themselves are minimal, and, second, the secretions of the digestive tract are less voluminous when there is only a light task for them to perform. Well-marked constipation is established, the Fletcherite having only one or two evacuations in a week, but the material retained is apparently innocuous.

Many of the ills referable to auto-intoxication often disappear when the practice of prolonged chewing is followed. This could be explained as resulting from the limitation of colon accumulations, but seems in part to proceed from the strange fact that under the system the consumption of protein invariably shrinks even more than in proportion to the general restriction of the food. This occurs when the subjects are guided entirely by instinct and have no theories in regard to the matter. Indifference to meat or even an antipathy to it may be developed.

One does not have to look far to see examples of the practical working of the Fletcher system, though the persons who illustrate it may have no associations with the name. Middle-aged and elderly housewives are to be found in large numbers who are slow and frugal eaters, who care little for meat, who are constipated, and who are marvels of endurance in the execution of their hard tasks. They sleep lightly and rise early—habits diagnostic of Fletcherism. They live to great ages, restlessly active to the last. They show the strong points of the regimen; do they display any drawbacks attributable to it?

It is certainly possible to undereat. There can be no reasonable doubt that the condition of the very poor would be bettered if they could have more food, even though it were of no finer quality than that to which they are accustomed. Crichton-Browne, an English writer, has acutely pointed out that the allowance of the poorest classes comes near to the ideal of the New Haven School, and that it is also almost identical with the "punishment diet" of British prisons. It may well be that a diet which is successful in connection with the best housing conditions and a life abounding in stimuli to the intellect and the feelings may not support cheerfulness and vigor in those whose surroundings are wretched. Underfeeding produces gloom and moroseness unless other circumstances are more influential and oppose it.

Previous experience is something to be considered when seeking to judge whether an individual ought to reduce his food-supply. If he has lived in luxury and under every temptation to indulgence, if he is overweight as a result of his habits, short of breath and drowsy, he can probably profit by the expedient. If he has been restrained from satisfying his appetite by sheer poverty or by voluntary sacrifices, if he is thin, sensitive to cold, and subject to insomnia, it is quite likely that an increase of food will make him stronger and more energetic. Undereating is often coupled with indigestion in such a way that it is impossible to say which is the cause and which the effect. Within wide limits the digestive glands accommodate themselves to the tax levied upon them, providing adequate amounts of their juices for large or small meals. Low diet, therefore, may weaken the adaptibility of the organs it is designed to spare.

Benedict, of the Carnegie Nutrition Laboratory, has proved himself an exceedingly shrewd critic of those writers who go to extreme lengths in their championship of reduced feeding. He has shown that when the food supply is very small the absorption is often less complete than with a more liberal income, a clear sign that the digestive system is not in such good working order as it might be with more to do. Professor Chittenden, the foremost advocate of careful restriction, agrees with his critic to this extent at least: he believes that an occasional banquet is a valuable means of testing the canal to see whether it has retained the reserve power which it is desirable to have. Many people of the economical type characterized just now have lost the faculty of enjoying a large meal and cannot easily increase their income when the physician recommends it.

The Peculiarities of Protein.—While the advice to limit all forms of food is constantly heard, it is the use of much protein which is most vigorously condemned. The decisive effect of a large protein allowance upon the metabolism—an effect in the direction of a seemingly useless increase—has been mentioned. Other peculiar properties call for discussion. We may conveniently distinguish the influences proceeding from an excess of protein in the intestine from those which are associated with an excess of nitrogenous metabolism. In regard to the first it may be said that protein far more than the non-nitrogenous foods is capable of generating toxic substances and so of becoming a cause of true auto-intoxication. An unabsorbed surplus of protein is, therefore, to be avoided.

If, however, the absorption is as complete as can be desired, reasons can still be given for keeping the protein income of the body relatively low and depending largely upon carbohydrates and fats in preference to nitrogenous food. Emphasis has been placed elsewhere on the simplicity of the normal oxidation products formed from sugar and fats in contrast to the numerous and rather complex bodies which arise from the working over of the protein derivatives. Carbon dioxid and water are disposed of by the healthy system with apparent ease. The nitrogenous wastes require preliminary treatment by the liver and perhaps by other organs, and must then be removed from the blood by the kidneys. The principal one, urea, is not commonly a source of trouble, but the minor attendants, such as uric acid, are viewed with disfavor.

One is naturally led to the opinion that high protein feeding must lay a burden upon the liver and the kidneys, but it is probably just to assume that what is a severe tax for one person may not be so for another. The native efficiency of these organs is doubtless as variable as many other inherited qualities. Nitrogenous by- or end-products, whether having their origin in the decompositions within the colon or in the metabolism, are presumably responsible for the premature fatigue of which we have spoken. An additional injury which may be laid to their charge must now be considered. This is the production in later life of arteriosclerosis.

The saying is current among physicians that "a man is as old as his arteries." It is certainly a fact that the stiffening of these vessels is a chief cause of malnutrition and waning power in the tissues of the aged. If arteriosclerosis sets in prematurely, other features of a senile decline may be expected. Metchnikoff has sought to establish a connection between the overconsumption of proteins and early loss of elasticity and adaptability in the human circulatory apparatus. Such a connection has long been granted to hold for alcohol We seem brought to admit that this serious impairment of efficiency may spring from intemperance in eating as well as in drinking.

The postponement of old age by frugality in feeding seems in a measure possible. Yet we must remember that self-denial in this respect may defeat its own end, since it may too greatly weaken the digestive capacity. An alternative to low diet, it has been suggested, may be found in the deliberate regulation of the bacterial conditions in the intestine. The claim is made, and seemingly with good reason, that a harmless type of fermentation may be encouraged with the result that the undesirable decomposition may be prevented. This is the theory underlying the various modes of sour-milk treatment so much in vogue during the last five years. Lactic acid in moderate amounts appears to be quite devoid of danger to one's health. Its presence in the canal is hostile to the development of the organisms, which cause radical putrefaction of the proteins and definite auto-intoxication. A dominant acid fermentation may be secured either by the taking of sour milk (kephir, koumiss, matzoon, etc.) or by swallowing from time to time cultures of the lactic organisms, together with sugar for them to work on.

The comparative harmlessness of even extreme constipation when associated with sparing feeding and active absorption has been granted. Such inaction of the intestine when it accompanies more liberal indulgence in food must be unfortunate and must favor some phases of auto-intoxication. Many people resort periodically to the use of cathartics when they feel slightly "under the weather," and enjoy a buoyant recovery of energy and ambition when the disturbance is over. It is natural to interpret such an experience as showing, first, the existence of a source of poisoning, and, second, its successful removal. The wise man, however, will not be satisfied with knowing a way out of such disorders; he will aim to prevent their recurrence. The habit of depending upon laxatives instead of general hygiene is to be deplored. Irrigation of the colon to relieve from auto-intoxication is often resorted to as a part of medical treatment with good effects, but is not to be advised so long as attention to diet and exercise can be made to serve the need.

Obesity.—The accumulation of adipose tissue in burdensome and disfiguring deposits is regarded as mirth-provoking, but should be viewed with due appreciation of its seriousness. In the light of what has gone before, there is no escape from the conclusion that during the period of increasing weight the diet must have been in excess of the requirement. Yet when a person has once become notably stout he is often observed to be a light eater. It is likely to be found that he cannot reduce his allowance of food without feeling quite uncomfortable. Various means may be resorted to in the attempt to abate the unwelcome condition, but frequently without success. Thus outdoor exercise, which, of course, increases the metabolism and should destroy the body-fat, may stimulate the appetite to an extent which fully corresponds with the oxidation, and so defeats its own purpose.

The gathering of adipose tissue under the skin has an effect somewhat like that of extra clothing. It is an obstacle to heat loss and makes it possible for the possessor to maintain himself with less expenditure of fuel. Hence, when the protecting layer is once established it becomes more and more easy to add to it. Its absence from the lean subject makes him a more prodigal dispenser of heat to his environment and he must presumably consume more food to secure an equilibrium. It is, therefore, much harder to begin the deposit than to nurture it when it exists. A fat man is like a house with double windows—the arrangement will save coal.

Reduction of adipose tissue by fasting is possible, but not popular. Several other methods have been tried. The Banting system, formerly much in vogue, consisted essentially in a diet containing a maximum of protein. It was held that such a diet would keep the muscles and glands from losing substance, while not promoting the formation of fat. We have seen, however, that fat formation from protein is at least theoretically possible. The success of the Banting treatment probably depended upon two factors: first, foods rich in protein are satiating, and an unconscious cutting down of income is therefore likely; second, the specific dynamic effect of so much protein would be expected to increase the metabolism. Restriction of water drinking is often recommended. Laxatives are sometimes used, presumably to hinder absorption. A procedure which seems rational is the selection of a rather bulky but not highly nutritious diet, including fruit and the coarser vegetables. By this means hunger can be fairly appeased, while the actual quantity of food entering the circulation is not sufficient to maintain carbon equilibrium.

CHAPTER XXIII

THE HYGIENE OF NUTRITION (Continued)

WATER; MEAT; SUGAR

Water.—There are particular foods which call for individual notice; one of these is water. The fact is already familiar that this compound so abundant in nature is also the largest item in the income of the human body. It is an essential part of all the tissues, and its percentage in their make-up cannot be materially reduced while life continues. It has been described before as an important vehicle of excretion, and we have seen that when it evaporates it often provides for the removal of heat, which would otherwise accumulate in the body to its hurt. When the discharge of water is unusually great the feeling of thirst is roused and dictates a renewal of the stored supply.

We can vary considerably our practice of water drinking. Hence this is a matter often dealt with by writers on hygiene. The common teaching is to the effect that one can hardly drink too much water unless it be at mealtimes. The beneficial results supposed to accrue from free drinking are assumed to include the avoidance of constipation and the promotion of the elimination of dissolved waste by the kidneys and possibly by the liver. There seem to be no reasons for doubting the soundness of these popular ideas. The drinking of a great deal of water is an excellent habit, and consumption of tea, coffee, and other beverages in which water is the principal constituent has this in its favor—it leads people to take much more water than they would otherwise.

It is probably correct to say that the duties of the kidneys are made lighter when we give them more water to excrete. This may be contrary to the general impression, for the temptation is to judge the work of a gland by the volume of its output. But in the light of facts which cannot be discussed here we are led to believe that concentration rather than sheer amount of secretion is what puts the tubules of the kidneys to the severest test. They act at the greatest disadvantage when required to excrete a maximum of solids in a minimum of water. The urine almost always has a concentration much higher than that of the blood from which it is derived, and it is fair to assume that the separation of the two fluids would be made easier if the difference of concentration could be lessened. Water drinking is the natural way to secure this result. "Water," says Osler, "is, after all, the great diuretic."

While teachers of hygiene are well agreed upon the value of water in liberal quantities as conducing to health, there has been much said against its free use with meals. We can hardly question the impression that many cases of indigestion have been benefited by the prohibition of water at the table. An approach to Fletcherism is favored when the saliva is not aided by swallows of water. Slower eating is likely, and slower eating may be expected to satisfy the appetite with a smaller actual intake. The idea that the digestive juices are seriously diluted by water taken with the food does not seem to be well founded. Laboratory experiments show that dilution of the fresh secretions is at least as likely to increase as to diminish their activity. It must be borne in mind that the dilution of a liquid containing a fixed amount of enzyme does not reduce the quantity of the enzyme, but only makes it act in a larger volume of the mixture.

Very cold water swallowed rapidly may chill the mucous membrane of the stomach and possibly retard the proggress of gastric secretion. Digestion itself may also be slowed if the contents of the stomach are cooled. But bacterial fermentation should apparently be delayed just as definitely as the normal hydrolysis, and we ought not to make too much of these possibilities. Very recently

Hawk, of the University of Illinois, has made a number of trials which are entirely favorable to the practice of drinking all the water that one chooses with meals. He has shown that the fecal nitrogen is lower when water is taken in large volume than when it is forbidden. This fact he holds to indicate more complete digestion and more thorough absorption. His subjects were in the best of health, and his results do not contradict those of physicians who have found the restriction of water beneficial in particular cases.

The opinion is commonly held that drinking much water favors increase of weight. To a limited extent such increase of weight may result from actual retention of water. We can see that a definite addition to the adipose tissue may proceed from the tendency to eat more food when water is taken freely. Perhaps the converse of this form of statement is more accurate; namely, that weight is lost when water is restricted and the quantity of solid food unconsciously diminished. Sometimes an erroneous inference may have been drawn from the fact that stout people drink a great deal of water. This is in part a consequence rather than a cause of their condition. Subcutaneous fat is a hindrance to the escape of heat from the body, and its presence during warm weather necessitates an unusual amount of perspiration. This, in turn, produces thirst.

Meat.—Much that is written tends to create the impression that meat is entirely unlike any other food. Its peculiarities are constantly exaggerated. When Erasmus Darwin excused himself from Lenten abstinence on the ground that "all flesh is grass" he perverted Scripture, but uttered a physiologic truth. Meat has two distinctive characters: it is very rich in proteins and in extractives. It is not any richer in protein than are peas and beans, but while these vegetables contain a large proportion of carbohydrates, lean meat contains these bodies very scantily. A diet of lean meat, therefore, comes near to being a straight protein diet. A plate of beans is equivalent in composition to a plate of meat and potato.

Vegetarianism has sometimes been advocated upon humanitarian grounds and sometimes because of its supposed favorable effect upon health. The idea that the destruction of animal life for human nutrition is morally wrong cannot be discussed here. It is true that not many people would kill animals for their own use if there were no other way to obtain meat. It is equally true that so many of the noblest and gentlest people that ever lived have enjoyed meat and fish that we cannot well credit the claim that flesh foods cause deterioration of character.

A diet containing much meat is naturally a high protein diet, and is, accordingly, subject to the drawbacks already mentioned in this connection. These have been seen to include an unprofitable spurring of the metabolism—more particularly objectionable in warm weather—and the menace of auto-intoxication. The typical proteins of meat are probably not better nor worse than other proteins in these relations. There is, however, greater, likelihood of overconsumption of proteins when meat is the source because of its very attractiveness. Men, especially those who spend money freely, are certainly prone to such indiscretions, while women set an example of temperance in this as in so many other practices. So far as the proteins eaten are destined to be reconstructed into those of the blood and tissues, it may be asserted that meat proteins are peculiarly well suited to the purpose. Their molecular correspondence with the pattern to be imitated is close. But the demand for amino-acids for this use seems to be small.

The real individuality of meat is owing to the presence in it of the secondary substance which we call extractives. These give it its odor and, in conjunction with mineral salts, its flavor. Their absolute amount is not large, but they are of much interest. They have been described by writers holding meat in disfavor as waste-products of animal life. The characterization seems broadly to be a justifiable one, though our disgust at the notion is not necessarily well founded. The extractives of meat certainly originated during the lifetime of the animal through the breaking down of its proteins, and were destined for ultimate excretion, either unchanged or after some alteration. It is hard to escape the conclusion that our pleasure in the taste of meat is due to compounds nearly akin to those of the urine.

Furthermore, it is plain that the opponents of meat are correct in making the point that when we receive these extractives we are simply adding to the duties of our own kidneys. When we eat 50 grams of protein in beans we have later to excrete about 8 grams of nitrogen in urea and other forms. When we eat 50 grams of protein in beefsteak we must subsequently excrete the same quantity of nitrogen plus that of the extractive bodies. The addition is not a large one, but it is partly in the form of uric acid and perhaps other bodies less tractable than urea. The advisability of limiting meat in rheumatism and related conditions has long been recognized.

While the extractives may be held to account for some of the possible ill effects of meat, they are also the source of its especial virtue. Palatability itself is of great hygienic worth, and these substances confer qualities which for most people cannot be equaled apart from meat. The promotion of gastric secretion in the normal subject and its establishment in the invalid are most surely secured by means of these same extractives. Aside from their favorable influence upon the stomach, they are probably mild stimulants in the same sense in which coffee and tea can be called so.

Some kinds of meat are well known to occasion indigestion. Pork and veal are particularly feared. While we may not know the reason why these foods so often disagree with people, it seems probable that texture is an important consideration. In both these meats the fiber is fine, and fat is intimately mingled with the lean. A close blending of fat with nitrogenous matter appears to give a fabric which it is hard to digest. The same principle is illustrated by fat-soaked fried foods. Under the cover of the fat thorough-going bacterial decomposition of the proteins may be accomplished with the final release of highly poisonous products. Attacks of acute indigestion resulting from this cause are much like the so-called ptomain-poisoning. But it is best to reserve the term for those cases in which the harmful bacterial change had taken place in the food before it was eaten.

Texture is an exceedingly weighty factor in determining the ease or difficulty of digestion for any food. It is this which makes the recognized difference between new and old bread and between the upper and the under crust of a pie. Osler has said, with his usual picturesqueness, that "pie north of Mason and Dixon's Line and hot bread south of it have done more harm than alcohol." Fats are best cared for when emulsified if liquid, and when of a flaky or crystalline character if solid. This last quality is realized in good bacon.

Sugar.—The reader will have noted that the starch, which is usually the most abundant compound in the daily income of man, is converted to a sugar before it is admitted to the circulation. The question arises why it is not equally well to eat sugar altogether in place of starch. This is the actual habit during the period of milk feeding in infancy. The enzymes that act upon starch are not freely furnished until some months after birth. In later life, however, starch comes to be the main reliance of the race. Experience has shown that cane-sugar is often productive of indigestion. Can we find definite reasons for the superiority of starch to sugar?

The fact has previously been mentioned that much sugar causes alimentary glycosuria, while this is never produced by the freest eating of starch. Here we have a clue to the difference between the two classes of carbohydrates. The glycosuria is not in itself a serious matter, but it shows that the solubility of sugar and the slight changes requisite for its digestion lead to its very rapid absorption. The digestion of starch is a more gradual and protracted process, and the resulting glucose is not formed so swiftly as to raise the concentration of the intestinal contents appreciably, nor delivered to the blood so abruptly as to increase markedly the percentage of sugar in circulation. It seems safe to assume that the storage of glycogen is effected more smoothly and easily after the ingestion of starch than after the taking at one time of a large quantity of sugar.

Highly soluble bodies of low or moderate molecular weight are said to confer on their concentrated solutions the property of high osmotic pressure. This is not the place to discuss what is meant by the expression. For practical purposes it can be said that concentrated solutions take water from tissues with which they may be brought in contact. Hence an irritant effect is to be expected. This is exemplified by the action of strong salt solutions in producing vomiting. Everyone who is fond of candy knows that it can be eaten until a point is reached at which an uneasy sensation of satiety verging on nausea is developed. This is relieved by drinking water, which, of course, lowers the concentration of the syrupy gastric contents and so lessens the irritation.

Cane-sugar is much sweeter than sugar of milk or the other sugars which arise in the course of digestion. It is, therefore, cloying and its free use may blunt the appetite for other foods. It is said also to be more disturbing to the stomach than the others. These two properties perhaps account sufficiently for the ill effects which are attributed to the increasing consumption of candy in this country. Still it is probable that the evils resulting have been much exaggerated. There is, however, no question that the constant eating of candy threatens to damage the teeth, and the indirect impairment of the digestive powers may be serious.

The relation between sugar and the decay of the teeth is apparently quite simple. Sugar is prone to ferment, a change brought about by bacteria which are inevitably present in the mouth. The chief product of such bacterial decomposition is lactic acid. This acid attacks the lime-salts of the teeth at points where the enamel has been chipped or worn away, or where it fails to meet the gum. The dissolving of the lime-salts leaves a soft and perishable organic structure which readily undergoes true decay. Every tiny deposit of sugar in the crevices of the teeth may soon become a focus of acid production and a center of disintegration. The popular impression that plain sugar is not so hurtful as sugar mingled with other substances in candy has this basis: pure sugar is so readily dissolved by the saliva that it is not likely to remain long clinging to the teeth. On the other hand, sugar which is mixed with fatty materials like chocolate may be sealed into crannies or retained under the edge of the gum with unfortunate effect. One who is bound to eat much candy should be willing to exercise unusual care to free the teeth from the remains, and may, in spite of his pains, have periodical days of reckoning at the dentist's.

Food Accessories.—It is perhaps unnecessary to enlarge upon the service of those compounds which are classed under this head. The double value of the extractives of meat which favor digestion both because of the flavors which they develop and because of their direct action upon the stomach wall has been sufficiently emphasized. The various condiments are believed to have a similar significance. So far as they season the food so as to make it more acceptable, they must evidently promote secretion. Their power to call forth the gastric juice by a purely local effect is not so well established, but they are known to increase the blood-flow in the mucous membrane, which must help to sustain the local activities.

Tea and Coffee.—These beverages owe what limited food value they have to the cream and sugar usually mixed with them. They give pleasure by their aroma, but they are given a peculiar position among articles of diet by the presence in them of the compound caffein, which is distinctly a drug. It is a stimulant to the heart, the kidneys, and the central nervous system. It is chemically related to uric acid, but is not known to yield this inconvenient waste-product in the human body. Individual susceptibility to the action of caffein varies greatly. Where one person notices little or no reaction after a cup of coffee, another is exhilarated to a marked degree and hours later may find himself lying sleepless with tense or trembling muscles, a dry, burning skin, and a mind feverishly active. Often it is found that a more protracted disturbance follows the taking of coffee with cream than is caused by black coffee.

It is too much to claim that the use of tea and coffee is altogether to be condemned. Many people, nevertheless, are better without them. For all who find themselves strongly stimulated it is the part of wisdom to limit the employment of these decoctions to real emergencies when uncommon demands are made upon the endurance and when for a time hygienic considerations have to be ignored. If young people will postpone the formation of the habit they will have one more resource when the pressure of mature life becomes severe.

Chocolate and its derivative, **cocoa,** may be regarded as having somewhat similar properties. There is a measure of drug action, though it is less pronounced than in the case of coffee. Here the active principle is theobromin, nearly related to caffein. Chocolate is more than a food accessory, being exceedingly nutritious. A chocolate habit is easily formed, but, aside from threatening damage to the teeth, it is comparatively innocent.

Mineral Salts.—These compounds have been referred to in an earlier chapter as forming an essential part of the tissues. Hence they must be supplied in sufficient quantity and variety during the period of growth. There is no real danger of failing to do this, though there are certain cases of malnutrition in which the central difficulty seems to be the lack of such constituents in the body of the child. The actual trouble is probably with the absorption rather than with the diet. Thus, in rickets there is an evident deficiency in the quantity of lime-salts incorporated into the developing skeleton, but it is not often true that there is any shortage in the amount offered in the food.

When the full stature is reached the need of a continued salt income is less marked, though there is reason to believe that the demand always exists. A certain loss in the urine and through the skin seems bound to occur, though the usual excretion of salts is far greater than the bare minimum, and appears to indicate a needless excess in the income. The salts of the diet have much to do with its palatability and so deserve a place with the organic condiments. An unusual quantity of saline matter may be supposed to impose a hard task upon the kidneys, and is known to aggravate any dropsical tendency that may be present.

Sodium chlorid is the one salt which we take pains to secure. We are inclined to think of it as a mere relish, but it has been shown that it has a deeper significance. The Austrian physiologist Bunge has found that it is sought both by animals and men whose food is largely or entirely vegetable. It is repugnant to those that are approximately carnivorous. Bunge points out that vegetable foods are generally rich in compounds of potassium and relatively deficient in those of sodium. He has demonstrated that when an excess of potassium salts is eaten the kidneys discharge the foreign material promptly, and in doing so let slip a good deal of the sodium chlorid from the blood. Accordingly, it is inevitable that the steady consumption of foods rich in potassium should create a demand for sodium. The seeking of common salt to meet the need is a singular illustration of the almost unerring working of instinct.

CHAPTER XXIV

ALCOHOL

Alcohol occupies a peculiar position among the constituents of the diet of mankind. A perfectly dispassionate estimate of its values and its drawbacks is arrived at with difficulty. Most discussions of the subject are frankly partisan and, therefore, partial. Alcohol affects the human system in many ways, and it is possible to select for emphasis either those aspects of its action which are detrimental or those which are favorable. In this way a writer may be entirely accurate in all his affirmations and yet fail to be just to a complex question because of what he leaves unsaid. One cannot properly approach such an analysis of the effects of alcohol without first learning the extent of its use the world over. In our own environment there is a feeling of hostility toward the intoxicant which would excite wonder in many countries enjoying an advanced civilization. Intemperance is deplored by thoughtful people everywhere, but the demand for total abstinence is sectional, though probably extending steadily.

The older literature abounds in the praise of wine. The Bible itself has many appreciative references to its potency as a comforter. It has also eloquent passages which condemn its abuse and records of abstinence on the part of certain sects or guilds among the Hebrews. No better physiologic distinction has ever been drawn than in the verse which places "wine which *maketh glad* the heart of man" in comparison with "bread which *strengtheneth* man's heart." To "make glad" is to minister to feeling, to "strengthen" is to confer power which can be demonstrated to an observer—an objective instead of a subjective result. We cannot point to many great men in the history of nations who have entirely avoided the use of alcohol.

Here in America there was little concerted protest against the use of alcoholic drinks until the nineteenth century. The Puritans, with all their restriction of recreation and self-indulgence, were singularly tolerant of hard cider and Jamaica rum. This laxity extended to all classes of society. About one hundred years ago Lyman Beecher described the immoderate drinking which was a feature of an ordination to the ministry in a Connecticut parsonage, host and guests being clergymen. Beecher himself became a vigorous leader of the movement for temperance, which was not until some years later an agitation for total abstinence.

Edward Everett Hale has told us in his "A New England Boyhood" of the common practice of serving wine at children's parties about the year 1830. He also tells us that when the "Franklin Medals" were annually awarded to Boston schoolboys, an entertainment and banquet was provided from which the youths departed in a tipsy condition. The utter impropriety of these proceedings shows us in an impressive manner how far we have moved from the standpoint of that age. The offenses of the time appear the more aggravated when we reflect that the liquors used were largely of the strongest type.

The world has long had one conspicuous example of consistent abstinence on the part of a great population. This is afforded by the Mahometan peoples. It is said that the Lascar sailors who visit our ports can be allowed shore leave with implicit confidence that they will return to the ship as sober as when they left it. A seaman who erred in this respect and was remonstrated with by his captain is reported to have excused himself on the ground that he had embraced Christianity.

Something will be said of alcohol under each of five heads. We shall proceed to consider it as a relish, a food, a drug, a cerebral alterative, and as a poison. While such a treatment is most convenient, it must be recognized that alcohol can scarcely exert a single influence unmixed with the others. One of the five aspects named may be particularly prominent for the moment, but traces at least of the others are to be looked for. It is this intricacy of action which makes it so hard to weigh the facts with equity. Another disturbing consideration is found in the very unequal susceptibility of different persons to the temporary effect of alcohol as well as to its habit-forming property.

Alcohol as a Relish.—It must be sufficiently clear from what has gone before that anything that adds to the zest and pleasure of a meal may be expected to promote digestion. The only exception to this rule may be looked for when the relish in some way interferes with the digestive process. Alcohol or, more correctly, alcoholic beverages may certainly be held to enhance the enjoyment of dining, and must, therefore, favor the digestion and absorption of food. It is often claimed in rebuttal that alcohol retards the action of enzymes. This is doubtless true of high concentrations, but no such mixtures can possibly be made to exist in the stomach. Rapid dilution by the juices and rapid absorption of the alcohol through the lining membrane combine to bring down its percentage to a level which cannot hinder the normal hydrolysis.

The appeal of wines and cocktails may be said to be due quite as much to the minor substances which they contain as to the alcohol. Pure dilute alcohol would not be attractive to many people. At the same time the extractives conferring flavor and fragrance do not seem to make a complete beverage when the alcohol is removed. With the frank admission that the finer alcoholic drinks may be promoters of digestion, we may fairly couple certain qualifying statements. First, such stimulation is unnecessary for those whose health is what it should be. Second, the employment of such means to spur the appetite leads readily to overeating. It is also to be observed that the use of alcoholic relishes gives no sanction to drinking apart from meals.

Alcohol in the stomach has the effect of increasing the local blood-flow, and it is well established that absorption is thereby promoted. Whether it takes its place with the extractives or meat as a chemical agent to excite gastric secretion is not so certain. It is hard to discriminate between the influence which it exercises through the central nervous system and that which it may exert upon the stomach wall in a more direct manner. The maximum favorable effect upon the digestion is produced by a small quantity of alcohol. Larger quantities are notoriously apt to nauseate and to precipitate disgraceful scenes, all too common in connection with elaborate banquets.

Alcohol as a Food.—There has been a great deal of opposition to the claim that alcohol can be reckoned a food. It has seemed to many of its antagonists that the admission weakens their position, but this is not necessarily the case. "To say that alcohol may be a food is not to deny that it is a dangerous one." Professor Atwater was roundly censured by leaders of the total abstinence movement for a publication which is really a powerful tract in favor of their position. He had said that alcohol might serve as a food, and all his earnest warnings against it were regarded as discounted. His experimental work on the subject is entirely conclusive.

The fact has been reiterated that the chief use of food is to undergo oxidation with release of energy. Alcohol in considerable amounts may be oxidized to carbon dioxid and water in the human system. When it is thus oxidized the heat value of each gram is about 7 Calories. There seems to be no provision for the retention of alcohol against a future time of need nor for its conversion into glycogen or fat. Its oxidation is bound to take place with little delay, and it is in this respect not so adaptable to the changing demands of the organism as is carbohydrate. Nevertheless we must grant that it may take its place in the diet as a substitute for other non-nitrogenous foods. Atwater's experiments, as well as many parallel studies, have made this evident.

A subject was brought into equilibrium on a ration without alcohol. It was then found possible to withdraw carbohydrates and fats to a certain extent and to replace with alcohol in isodynamic amounts without disturbing the equilibrium. The well-known fattening effect of moderate drinking may be explained as due in part to the whetting of appetite and in part to the sparing of carbohydrate and fat by the alcohol which is utilized in their stead. Fifty years ago the same fact was recognized by George Henry Lewes, in his interesting "Physiology of Common Life." He tells us how a convention of total abstainers once gathered in the city of Frankfort, in Germany, and how the cooks in the hotel in which the delegates lodged were put to it as never before to supply the pastry and pudding ordered by these unfamiliar patrons. The guests for whom the table had heretofore been set were accustomed to supply with alcohol a want which the teetotalers met with carbohydrate.

How far the substitution of alcohol for other non-nitrogenous foods may be carried has been much debated. If it is given too freely its oxidation is incomplete and, what is of more practical importance, the cerebral effect becomes prominent. To make the utmost use of alcohol as a nutrient it must be taken in small quantities and frequently. There seems to be a general agreement that from 50 to 75 grams of alcohol in twenty-four hours is about as much as can be allowed to an adult without untoward reactions. If we assume the larger amount to be permissible, it follows that alcohol may furnish as much as 500 calories, or about one-fifth of the day's total. The requirement may be translated into terms of various beverages: whisky, something less than ½ pint; sherry or port, 1 pint; champagne, 1 quart; beer, 2 quarts.

Meltzer has said that "alcohol in health is mostly a curse and in sickness mostly a blessing." Its peculiar merits in illness are connected with the fact of its appetizing character and with the circumstance that it requires no digestion. In this it resembles glucose. When alcohol is given to a patient no call is made upon the digestive glands. Hence it may be tolerated and absorbed when most foods would remain undigested. So far as it can be introduced into the circulation at such a time it becomes a source of heat and spares the dwindling stores of the system, but there is an obvious tendency on the part of physicians to restrict the use of alcohol in sickness. Statistics from representative hospitals show a marked shrinkage in the consumption of liquors during the last few years.

Alcohol as a Drug.—Certain properties of alcohol may be conveniently brought under this head, although no sharp line of demarcation can be drawn between these qualities and others to be dealt with later. The drug effect is obtainable from rather large single doses in contrast to the nutritive effect which was said above to be best secured by small amounts given at intervals. The most striking reaction of the system to alcohol in doses which may be regarded as having the drug effect is manifested by the circulatory apparatus. The taking of a glass or two of wine, especially on an empty stomach, will usually cause increased heart action and a flushing of the skin, accompanied by the subjective impression of warmth. This bringing of more blood to the surface of the body may be expected to lessen the volume of blood passing through the internal organs.

The chief value of alcohol as a drug is connected with this tendency to abate internal congestions. The central fact in the process which we call "taking cold" is an excess of blood in the mucous membranes. This may be continued for a time without ill consequences, but is always a menacing condition, lowering the local resistance to infection and so inviting disease. Alcohol has been much used to "break up" incipient colds and with very good success. Its influence upon the distribution of the blood is not unlike that of quinin and some other drugs; it is also similar to the action of hot applications to the skin.

The supposed warming power of alcohol needs critical examination. It is a fact not generally recognized that we have no reliable sensations indicative of the true body temperature. We realize only the surface conditions. A man who is out in the cold may produce a sense of comfort by taking alcohol, which will send more blood into the cutaneous vessels, but this pleasant glow is the sign that heat is passing from the body to its surroundings. It may be purchased at the cost of an expenditure which is imprudent. Arctic explorers seem well agreed that dependence on alcohol during exposure to intense cold is unwise, and that it is better to suffer a greater degree of discomfort than to rely upon its delusive support. This must be most distinctly the case when the hardships are to be borne for an indefinite period. It is more rational to give alcohol after exposure to wet and cold than during the trial. Afterward it may help to readjust the circulation and to ward off possible evil results.

Alcohol as a Cerebral Alterative.—After all, the main reason why humanity clings to alcohol and is with so much difficulty won over to abstinence, is found in its singular influence upon temperament. This is at the root of its social employment. The rather awkward term, "cerebral alterative," has been chosen to avoid the more familiar but questionable name of stimulant. Much discussion has been carried on concerning the right of alcohol to this designation. Stimulant and narcotic are opposing terms. Alcohol in large quantities is clearly a narcotic; whether it is invariably so is a subject of lively debate. It might be supposed that there would be no difficulty in deciding. Observation of men slightly affected by wine shows them to be animated and talkative; the natural verdict would be that they exemplify stimulation. Yet all the results of taking alcohol can be explained upon the theory that it is a narcotic. To show how this may be it is only necessary to point out that many operations of the nervous system are normally inhibitory in nature. When a reticent man becomes garrulous, it need not be inferred that he is stimulated in the best sense of the word; it may be more accurate to say that an agent which is essentially depressing in its influence has attacked first of all the inhibitory centers. Loss of self-consciousness is an obvious feature of the reaction, and loss of self-respect is reached by an easy transition.

A genuine stimulant should be an aid to application. Alcohol, on the contrary, is hostile to perseverance. Our word dissipation, which we use for intemperance, is a very suggestive one. Scattering rather than concentration is the essence of the mental state produced. A keen thinker has said that we tacitly contrast alcohol with coffee, a recognized stimulant, when we acknowledge the difference between the feelings with which we should view the use of one and the other by the engineer of a limited train. We instinctively feel that coffee will favor his unswerving attention to duty and that alcohol will make him less reliable. Alcohol in small quantities leads to inconsequence in thinking and is a handicap to any steady pursuit. On the other hand, the facile changes in the currents of mental life, the lightness and the unexpectedness of one's remarks, may promote social ease and the power to be entertaining. If alcohol is the foe of application it is also the foe of prosiness.

Too much emphasis can scarcely be brought to bear on the wide disparity between what a man thinks that alcohol does for him and what an impartial study shows that it really does. That "wine is a mocker" is a shrewd observation. The subjective impression is often of an exaltation of capacity which objective testing fails utterly to confirm. A subject does certain problems before taking a drink of whisky and comparable ones afterward. He says that the second task was done with greater speed and with a nonchalant confidence in his results. The watch says that he was slower, and checking up the work shows that the errors were more numerous. It is evident that his judgment of his own performances is unreliable. This is true also of manual operations. The recent tests made upon German type-setters have shown that speed and accuracy are both made to suffer when alcohol has been taken even in very limited amounts. Here, again, the subjects have an impression of their own superior accomplishment under alcohol, which turns out to be erroneous.

It has been freely admitted above that a little alcohol may promote sociability, but there can be no question that the reputation which alcohol possesses of bringing out the best wit and humor of which men are capable is largely unfounded. The reason is not far to seek. This reputation rests on the reports of men who were themselves influenced by the same agent which was working upon the nervous systems of the speakers to whom they were listening. Their reminiscences are to be taken with more than a grain of salt. The auditor who is "vinously exalted"—to use a phrase of Holmes—is an exceedingly lenient critic. He applauds with delight sallies which a neighbor, who has turned down his glass, perceives to be inane, if not in bad taste.

The justification of the social use of alcohol must be based on its power to produce this singular state of mind. It removes the consciousness of fatigue and the feeling of care. The attention is limited to the present moment and immediate interests. The faculty of discrimination is dulled, and with the consequent lowering of esthetic and intellectual ideals there comes a bland self-satisfaction and a naïve admiration of one's fellows. A vigorous writer has called this process "drugging for delectation." Can such an artifice be defended? It is most difficult to answer this question with entire justice to both sides. Perhaps it may be impossible to answer it in sweeping fashion for all men. One who is cynical and pessimistic by nature may really view his affairs more justly and judge his neighbors more equitably while under the influence of wine. This may be true of other temperaments, the neurasthenic, for instance. But the optimist—and may we not say the normal individual?—is not likely to be bettered by such an agent. Increased buoyancy and good humor in such subjects means silliness. If it is true, as is claimed, that gatherings of total abstainers are comparatively doleful, the lesson may be, not that alcohol is necessary to good fellowship, but rather that the average nervous system is below par. We doubt whether a man ought to rest content with any lower measure of health than that which will insure the social virtues without chemical aid.

With advancing age it may be unreasonable to demand so high a standard. As infirmities increase there must usually come a time when comfort rather than efficiency is to be sought. When it is clear that this time has arrived there is much to be said in favor of the more or less regular, moderate use of alcohol. It is a great anodyne. Granting this, we may also point out that the beneficent effect in age will be more surely obtained by those who have not exhausted the consolations of alcohol in earlier years.

Alcohol as a Poison.—It seems hardly necessary to enlarge upon the poisonous properties of alcohol. That these have been ridiculously exaggerated is obvious; that they are very real is equally clear. The spectacle of drunkenness and the shame and misery that attend it are too familiar. No one who begins to use alcohol can be quite sure that he will continue within bounds. The temperate lives of his relatives cannot be held to prove him secure. Susceptibility to the tendency to increase the indulgence is found again and again in young men of clean heredity and fine gifts. Hence the only absolute safety is in total abstinence. Yet the chances do not favor the ruin of the average man who adds alcohol to his diet.

Aside from the habit-forming property, it is becoming more and more widely recognized that alcohol often impairs the health of men who cannot be charged with intemperance. It predisposes to diseases of the heart, liver, and kidneys. It notoriously lessens the chance of survival when the user contracts pneumonia. It makes him an unfavorable subject for surgical operations. By hastening the development of arteriosclerosis it shortens the period of active and effective life. Insurance examiners are glad when they can record of an applicant that he is a total abstainer.

Enough has been said to show how various are the aspects of alcohol. It has been easy to treat them separately in the preceding paragraphs, but no such separation is possible in practice. The undoubted value of the alcoholic relish, its occasional merit as a significant part of the ration, and even its virtue as a drug cannot be utilized without some experience of its cerebral effect and the risk, not always remote, of forming a habit. The hygienic ideal to be striven for is a robustness of life which shall make alcohol superfluous as relish, food, or drug, and a cheerful, active mind which needs no artificial aid to keep it hopeful and sympathetic. The attainment may not be an easy task. Grief and worry and overwork may be added to an original depression of temperament, but the use of alcohol is never more unsafe than when sorrows are the excuse, and never so selfish and cowardly as when the motive is to shun responsibilities that ought to be faced. Men do not often see the sinister suggestion in the high spirits of one who has forgotten his cares for an evening by the most moderate indulgence. They fail to see that the banishment of the sense of pressing duties is the very characteristic of the drunkard when, developed to a logical extreme, it makes him indifferent to every obligation of conscience and of love.

CHAPTER XXV

INTERNAL SECRETION

In an early chapter of this book it was stated that there are two ways in which one organ of the body may exert an influence upon another. The more familiar and more studied method has been through the nervous connections which are maintained between all organs and the brain and cord. The existence of such ties provides for the possibility of reflex action. By this means any part of the organism may modify the behavior of any other part, not by affecting it directly, but by stimulating or inhibiting the centers which preside over the second organ. Some account of the work of the central nervous system is to be given hereafter. Before this is undertaken it is well to pay some attention to the other way in which co-ordination is promoted; namely, by the transfer of chemical products from place to place through the agency of the circulation.

This is the subject usually covered by the term internal secretion. The word hormone has been used elsewhere to denote an active substance generated in one place, but destined to take effect in another. The secretin produced in the walls of the upper part of the small intestine and carried thence to the pancreas and the other digestive glands to excite them to pour out their juices is an example. So also is the contribution made by the pancreas to the blood, which proves to be so important to the utilization of sugar. In this case it seems to be chiefly in the muscles that the hormone is valuable. Other instances of similar interaction can now be given, and there is reason to anticipate that the list of internal secretions will soon be made longer than it is at present.

There are several organs once regarded as insignificant which are now recognized as vital to the welfare of the whole system. Among these the *thyroid gland* has attracted particular interest. This is a small bilobed mass of tissue situated in front of the trachea below the larynx. It is one of several organs sometimes called ductless glands. The term is more appropriate in this case than in some others, since the microscope shows that the arrangement of the cells is distinctly glandular. They surround small recesses such as in typical glands would be in communication with an outlet or duct. Here, however, these cavities are blind. They are seen to contain a viscid material, the so-called colloid substance, which is evidently the product of the secreting cells. Since there is no channel leading to the exterior, the only possibility is that the distinctive secretion shall enter the circulation either directly or by way of the lymph.

The thyroid gland is frequently enlarged and then gives rise to the disfiguring swelling known as a goiter. Such enlargements are not necessarily attended with general disturbances of health, yet in many cases there are symptoms which can be referred to an excess of the active product. Palpitation, breathlessness, extreme nervousness, and marked loss of weight are likely to be observed. The same manifestations follow the giving of overdoses of thyroid extract. This has been employed for the correction of obesity, but it seems unwise to resort to a drug so powerful and far reaching in its action for the treatment of this condition.

Just as there may be too much of the thyroid material for the good of the subject, so there may be a serious deficiency. The relative failure of the gland to function as it should is the cause of a definite disease in human subjects, and its removal from dogs is followed by a decline if not by death. Young and growing animals are most seriously affected. All the facts which have been gathered support the belief that development and general well-being depend to a considerable extent on the normal functioning of the thyroid. Very recently it has been shown that what has been called the thyroid is, in reality, a compound structure. In addition to the type of tissue which forms the main mass of the organ in man, there are four nodules of a different sort, the parathyroids. These undoubtedly have a chemistry of their own and a distinctive relation to the economy of the body. For a statement of their peculiar importance reference must be had to larger works on physiology.

The full measure of the influence which radiates from the thyroid can be appreciated by considering the condition known as cretinism. This is the term used to describe the state of individuals in whom the thyroid has never performed its proper work. These subjects remain for years in a condition of arrested progress, both physical and mental. They are uncouth dwarfs with large heads, slack-walled abdomens, and feeble limbs. If they survive to the age of twenty or thirty they will scarcely have advanced beyond the stage reached at four or five. That the lack of the thyroid is actually responsible for these shocking cases is now abundantly proved. The demonstration is found in the happy circumstance that great improvement follows the judicious feeding of thyroid preparations to cretins. The material is obtained from calves or sheep. Its administration for a few months often results in transforming a repulsive cretin into a presentable child with a prospect of at least a moderate mental development.

In the dog it is possible to graft an extra thyroid into the abdominal cavity and then to remove the original gland, when the second organ will assume the functions necessary to the preservation of health. This was an important discovery, since it removed the ground for a prevalent opinion that the service of the thyroid was limited to the reflexes which it was supposed to originate. It had been thought that the gland affected the nutrition and general health by sending impulses along the nerves leading from it to the centers. A gland substituted for the native one and placed in a remote part of the body could not be in connection with the old afferent pathways, and whatever favorable effect it might have must be chemical in its origin.

There has been the same discussion as to whether the *reproductive organs* exercise their well-recognized influence on growth by nervous or by chemical means. The strange modifications of the type which are produced as a result of castration are familiar. The differences in build and temperament between the unruly bull and the tranquil ox illustrate the consequences. Such peculiarities might be referred to reflex changes due to the removal of sources of stimuli, but the present tendency is to regard them as due chiefly to the loss of active internal secretions. The case of the pancreas reminds us that an organ may well give rise simultaneously to products which are permanently separated from the blood and to others which return to it. Twenty years ago Brown-Séquard created a furore among people given to premature acceptance of extravagant claims when he announced that great rejuvenating virtues could be demonstrated to exist in the extracts of animal reproductive glands. His so-called "Elixir of Life" was a pulp formed from crushed testes of sheep. At some peril of infection he injected this unsterilized mixture under his skin and into the bodies of other aged volunteers. A certain degree of stimulation was noted, but it has usually been referred to suggestion.

Since animals and men are at their best physically and intellectually when the reproductive organs are active, the expectation entertained was not wholly unreasonable. Yet it was not to be supposed that their decline was responsible for all the losses incident to age. No extensive use of such extracts has followed the pioneer work of Brown-Séquard. The corresponding preparations from the female—ovarian extracts—have a better standing in modern medicine. Given after surgical removal of the ovaries they greatly relieve many of the symptoms which commonly annoy the patient.

The *adrenal bodies* are also numbered among the organs which help to maintain the system in normal working order. These are two inconspicuous structures placed one above each kidney. Their microscopic features are obscure and do not indicate a glandular organization. From the adrenal bodies can be obtained a powerful drug-like compound, adrenalin, which the living cells of these organs may be supposed to deliver continually to the passing blood. Its presence in the circulation is evidently a necessity. Destruction of the adrenals—which sometimes results from local tuberculosis—produces the singular fatal disturbance known as "Addison's bronze disease." An odd feature of this condition is the dark pigmentation of the skin, occurring sometimes uniformly and sometimes in patches. More important, however, is the steady loss of vigor affecting all the contractile tissues and leading to death.

Adrenalin injected into the blood-stream of an animal shows its most marked effect in the intense contraction of the small blood-vessels which is produced. This property has made the substance valuable to surgeons, since it can be used to check bleeding from cut surfaces. In like manner it can reduce congestion in inflamed tissues, for example, in a blood-shot eye. These artificial uses of adrenalin can all be connected with its natural service, which is largely in the direction of a reinforcement of contractility. Cannon has recently called attention to this fact in an unexpected and interesting relation.

He has proved by delicate tests that the blood of an animal receives additional adrenalin during a terrifying experience. For example, he has found the active compound increased in the blood of a cat which has been kept under restraint in the presence of a barking dog. Therefore it must be concluded that one of the many bodily accompaniments of an emotional outbreak is a stimulation of the adrenal bodies to unusual activity. The value of this reaction has just been made clear through the further researches of the same investigator. It appears that extra resistance to fatigue is conferred upon the skeletal muscles when adrenalin is sent to them. Thus, in an emergency that might call either for flight or conflict the animal is prepared for a maximum output of energy. We have here a scientific conception of the "strength of desperation."

The influence of other organs than those mentioned upon the welfare of the organism as a whole is constantly being studied. A great deal of attention is being given to the very small but distinctly compound structure, called the *hypophysis*, which is lodged beneath the brain in a hollow of one of the cranial bones. Its relation to the course of the metabolism is far from simple, but it seems to be clear that it is an indispensable contributor to the circulating medium. A much larger and more conspicuous affair, anatomically speaking, is the *thymus* of young animals, a mass of cells lying back of the breast-bone. It is the "neck sweetbread" of the market. Since it is prominent during growth the inference is natural that it ministers in some way to the process of development. It almost vanishes at maturity. It is not yet possible to make very definite statements about the thymus. Removal does not seriously hinder the progress of the growing animal.

Here and there in the body are firm kernels of tissue, spoken of as lymphatic glands or, better, as *lymph-nodes*. These may be regarded as producers of internal secretion. though it is probable that this description does not cover all their activities. They are found especially in the neck, the armpits, the groins, and in the mesentery. Wherever placed, each is set upon the route of the lymph as it comes from some region toward the chest. Thus the lymph-nodes of the neck must be passed by the lymph that has had its origin in the head, while those of the mesentery intercept that which has come from the intestine. Microscopic study shows that the lymph has to take a tortuous course among the cells of the nodes. Looked at from a mechanical standpoint these bodies are obstructions in the path. They are also suggestive of filters. Their own cells are continually becoming detached and drifting away in the lymph, a phenomenon which is a type of internal secretion made visible. They are believed to add substances in solution as well as cells to the passing fluid.

There is good ground for the view that the lymph-nodes are a defense against the spread of infection. When a boil exists upon the arm the nodes above the place where the bacteria are working so destructively are usually observed to be enlarged and tender. The lymph which is returning from the seat of the trouble is bearing the products of the suppuration, if not the infecting organisms themselves. Apparently this polluted lymph is more or less successfully disinfected before it is allowed to pass on into the thorax to merge with the blood in the veins. The lymph-nodes of the mesentery stand as outworks of the bodily fortifications against the entrance of microbic invaders from the intestine. When overpowered in their struggle the lymphatic glands themselves become foci of infection, as in the familiar form of tuberculosis known as scrofula.

One large organ, which from its anatomic relations has been called a ductless gland and which might be expected to have an internal secretion, has failed to give satisfactory evidence of such a function. This is the spleen, which is placed below the diaphragm to the left of the stomach. It remains an enigma to physiologists. Its blood-supply is large and its frequent changes of volume, contractions, and dilations alternating in a slow rhythm, give a strong suggestion of some well-marked action in progress. But it has never been shown that an animal is affected in any characteristic way by the loss of the spleen, provided the immediate effects of the severe operation are survived. Certain enzymes have been extracted from the tissue of the spleen, which may have to do with the metabolism of those peculiar proteins which yield uric acid. We may not be warranted in asserting that the spleen has no useful service to perform, but we can say that other organs appear to be able to make good its deficiency.

CHAPTER XXVI

THE NERVOUS SYSTEM

In the introductory chapter it was said in substance that the one word which most nearly covers the work of the nervous system is the word co-ordination. This statement arouses in one the impulse to protest that it leaves out of account the relations subsisting between the nervous system and the states of consciousness which are of the most immediate interest to us all. The physiologist, being human, sympathizes with such a protest, but he must continue to treat his material for the most part from an external point of observation. This is not for want of respect for the psychologic method; it is rather with frank recognition of the vastness of the realm in which that method is applicable. It is because he must defer to experts in that field that he will not enter upon it as an amateur.

Most readers need to be told with the utmost emphasis and with frequent reiteration that consciousness is the accompaniment of an excessively small share of the manifold reactions of the nervous system. In the words of President Hall, it is "a little candle burning in one room of the mind's museum." All that occurs from first to last in the life history of a fish or a frog can be explained as reflex adjustment, without the assumption of self-knowledge or conscious purpose on the part of the animal. That was a weird and fascinating picture which duBois Reymond once drew of a world precisely like our own, save that its inhabitants were unconscious. In such a world an artist without will or pleasure in his work might create a faultless statue because his inherited nervous mechanism and the existence of materials, tools, and a model, made the result inevitable.

In the previous discussion of reflex action (Chapter V) the conception was developed that the nervous system consists of pathways capable of transmitting energy in the form of "nerve-impulses" to and from its central portion. That central part is represented in the higher forms by the brain and the spinal cord. The afferent or incoming paths begin in localities where external influences or stimuli can be brought to bear. The nerve-endings which lie thus exposed are called "receptors." They may be simple terminal twigs or bulbs subject to stimulation by pressure or temperature. They may be connected with elaborate organs like the eye and the ear. The eye is a device for converting the energy of certain ether-waves into the impulses that traverse the optic nerve. The ear is, at least in part, a device for transforming the energy of certain air-waves into impulses that run along the auditory nerve.

The impulses which arrive within the brain or the cord may cause the immediate or delayed return flow of impulses along the efferent or centrifugal paths of the system. These lead in most cases to the contractile tissues which give objective expression to animal life. It must not be forgotten that the efferent branches of the nervous system extend also to various glands and may modify secretion as well as contraction. It will be recalled that efferent impulses may initiate the flow of tears, of the saliva, the gastric juice, and the adrenal principle. Other instances are almost equally clear.

In animals of all grades responses of the reflex type are the constant duty of the nervous equipment. Those forms which we regard as highest in the scale are distinguished by a second property, that of the modification of the responses as a result of individual experience. By this is meant the capacity for training, forming habits, or learning to profit by the past. It is what makes different members of the same species vary in their behavior. It is what makes an older member superior to a younger one in his powers of adjustment and maintenance. This is, of course, exemplified in the fullest degree by human beings. The prolonged period of growth and progress must indicate a plasticity in the arrangements of the nervous elements that is hardly ever entirely outlived.

Descartes in the seventeenth century grasped the two properties with his usual keenness. He pictured the reflex process with quaint symbolism, but with essential correctness. He likened a path of afferent transmission to a cord that is pulled. A valve is opened in the central organ and a fluid released to flow back along the nerve. Reaching a group of muscles this fluid wakes them to action. Descartes had used different analogies for the afferent and the efferent impulses, making one a mechanical twitch and the other a spurt of liquid; we now believe them to be nearly or quite identical in character. The same writer recognized the ability of the higher nervous systems to retain impressions, and likened the registration of a memory to the imprint of a seal upon wax.

Physiologically, the particular mark of the highly developed nervous axis is this capacity for recording individual and not merely racial experience. Anatomically, the advance in organization is signalized by an increasing predominance of the brain over the cord and of the "fore-brain" over the parts behind. A frog will carry out many complex reactions when the entire brain has been destroyed. That is to say that in the frog the cord is adequate for a great deal of reflex action. In a human paralytic whose injury has removed the lower half of the spinal cord from functional union with the brain, the reflexes which can be obtained from the lower extremities are few and slight. In other words, the cord in man has become less important as an organ for correlating afferent with efferent impulses and more important as the largest of all nerves, the highway to and from the brain. We shall now set forth in some detail certain of the adaptive changes which are constantly occurring through the mediation of the brain quite apart from attention or desire on the part of the subject.

This kind of subconscious control of organs is well illustrated in the case of the respiratory center. About a hundred years ago it was found by French workers that cutting across the nervous axis at the point where it leaves the skull—that is, where the brain passes into the cord—instantly stops the breathing. A similar cut a little higher up does not have this immediately fatal effect. It was inferred that the part of the brain next adjoining the cord must contain the special cells which stand in charge of the respiratory muscles. This section of the brain, just within the skull, is called the medulla. Later experiments have confirmed the early belief that the breathing is governed from this region. The muscles employed are not in themselves automatic. Every contraction which they make is referable to a metabolic change in the cells of the medulla. So there is a fundamental difference between the breathing movements and the beating of the heart. The former are due to central causes; the latter, to an innate quality of the contractile substance.

The respiratory center is frequently involved in reflex action. In fact, it is easy to convince one's self that hardly any considerable reflex occurs without some disturbance of the breathing as an incident. Any sort of shock will infallibly change the depth, regularity, or some other feature of the movements. Outcries following such shocks are merely respiratory reflexes, but the center is not prompted to each successive discharge by afferent impulses; it shows us the possibility of another means of regulation. This is through the influence upon the nerve-cells of the chemical composition of the blood and lymph in the vicinity. When exercise is taken the breathing is involuntarily deepened. The cause of this adjustment is found in the increase of carbon dioxid in the circulation. The center is remarkably sensitive to any rise in the percentage of this gas. Conversely, it is temporarily paralyzed by a reduction of the circulating carbon dioxid to an unusually low level. Variations of the oxygen of the blood affect its action surprisingly little.

An important work of the nervous system and one which is quite overlooked by the layman consists in the regulation of blood-flow. In our previous description of the plan of the circulation only its mechanical principles were discussed: the heart was spoken of as a force-pump and the vessels as elastic tubes. This is a proper presentation so far as it goes, but we must now proceed to show that the whole circulatory apparatus is living, and being so has the biologic characteristic of adaptation. The changes by which the ever-varying requirements of the body are met are of two kinds, changes in the force and frequency of the heart-beat and changes in the caliber of the small arteries and veins. The former are brought about by the *cardiac nerves;* the latter, by a department of the nervous mechanism which we call the *vasomotor system.*

It is a matter of familiar experience that the heart-rate is subject to striking variations. From an average of perhaps 65 per minute, when one is lying in comfortable relaxation, it can be driven to 150 or more, when one is hurrying up a grade. Such a change under the influence of muscular activity is evidently purposeful. The working tissues need a swifter current of blood to supply them with oxygen and to bear away their waste. The lungs must be visited at shorter intervals to keep normal the gaseous composition of the blood. Muscular activity is not to be supported by increased breathing alone; it is equally necessary that there shall be acceleration of the circulation. As the quick, deep breathing of one who is taking exercise bespeaks a governing center for the muscles employed, so the rapid beating of his heart suggests a central control of that organ.

Experimental proof of the central regulation of the heart is ample and detailed. Branches of the nervous system reach it from two distinct sources and are contrasted in their effect upon it. One set of fibers is said to be inhibitory, the other to have an accelerator action. The terms would seem to explain themselves. The inhibitory fibers restrain the heart much of the time from beating at the rate which it would exhibit if nervous regulation were entirely withdrawn. An exaggerated inhibitory influence may weaken its working to the point where the circulation becomes quite inadequate and faintness is produced. In laboratory trials actual arrest of the heart of a dog may be caused, though the beat is always resumed within a minute, so that death cannot be made to result. We ought not to lay much stress upon these extreme possibilities. It would be absurd to say that the function of the inhibitory cardiac nerves is to stop the heart; that could never be for the best good of the animal. We can say with more reason that their service is to economize the strength of the heart and to provide a reserve for emergencies. This has been described as a "brake action."

The accelerator nerves of the heart have a stimulating effect which extends to the vigor as well as to the rate of its beating. When we observe a specific increase of heart action we can hardly say whether it has been produced by positive accelerator influence or by the abatement of the habitual inhibitory control. It may, of course, represent the combined result of both. The government of organs by means of the balanced action of two opposing sets of nerves is repeatedly met with in the body. It can be demonstrated for the stomach and for other sections of the alimentary canal. A singular example is afforded by the nervous relations of the iris, the colored ring surrounding the black pupil of the eye. Stimulation of one nerve causes contraction of the pupil, while widening or dilatation follows the application of stimuli to an entirely different strand of fibers.

The heart may quicken the circulation by beating at a more rapid rate and with increased power, but it cannot send the blood to a particular part of the body at the expense of another part. The total blood-flow thus depends upon the heart acting under the balanced sway of inhibitory and accelerator nerves, but the distribution of blood, the favoring of organs which need it, is the work of the vasomotor system. The walls of the microscopic vessels, those which adjoin the capillaries in particular, are provided with muscular elements of the same general order as those which produce the movements of the digestive tract. These contractile elements are connected with the terminal branches of certain nerves. Hence the anatomic study of the tissues involved, even when unsupported by physiologic experiments, makes clear the possibility that the centers when acting reflexly or otherwise may influence the diameter of the blood-vessels and the volume of the circulation in any or all regions of the body.

Physiology reinforces anatomy at this point. For sixty years it has been certainly known that nervous regulation of the blood-flow is a fact. Much earlier than this the power was assumed to exist, "Ubi stimulus, ibi affluxus," they said, meaning that where there is activity there is an increase of blood. The paling and the flushing of the skin, occurring either in response to external changes of temperature or emotional conditions, are strongly suggestive of a central command of the vessels. This has been taken for granted in our own treatment of the matter of the maintenance of a normal body temperature. Much as the heart is reached by impulses which inhibit it and by others which spur it to a greater expenditure of energy, the small arteries and veins are subject to antagonistic influences. We speak of a vasoconstrictor effect when we mean a reinforcement of the existing tone, and we use the word vasodilator in the opposite sense, that is, to characterize changes in which the degree of contraction is lessened, with the result that the blood finds its way in greater quantity through the affected vessels.

The difference between the cardiac and the vasomotor factors in the control of the circulation can be made plain by means of an illustration borrowed from the laundry. Suppose that a supply-pipe runs along above a row of tubs and bears a faucet for each. Suppose, also, that there is a stop-cock on the pipe before it reaches the tubs. Finally, to make the correspondence closer, assume that the faucets can never be shut tight (for it is not likely that the blood-vessels can be). Now, by manipulating the cock (*H*) we can increase or diminish the outflow into all the tubs, but we cannot in this way hasten the filling of one more than another. This is obviously the type of cardiac regulation in the living system. The heart is appealed to when there is a general and widespread demand for more blood per unit of time, muscular activity being by far the most important occasion.

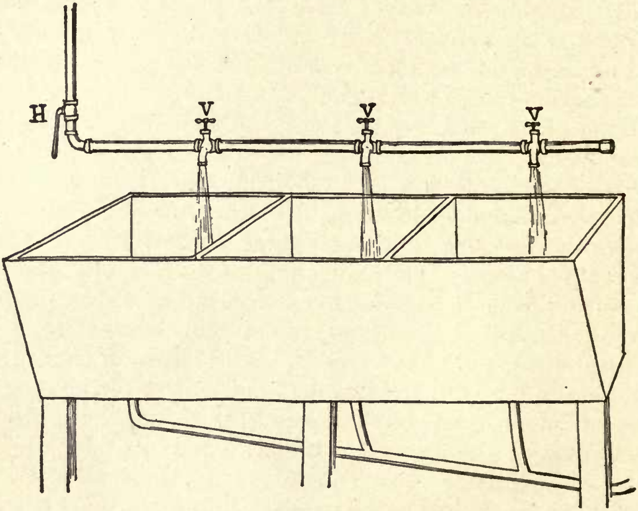

Fig. 23.—The supply to all the tubs is controlled at the "shut off" (*H*), while the share flowing into each compartment is regulated by its own faucet (*V*).

The faucets over the several tubs are the symbols of vasomotor equipment. By using them we can change the share of the total stream which shall enter any compartment. If our only desire is to fill one tub, we can open widely that faucet and close the others as far as possible. The vasomotor system actually operates in that way to the extent that a dilation in one large area seems often to be offset by a compensatory constriction in another. We count on this reciprocal relation in our medical and hygienic practice. For instance, we think that if we can encourage blood-flow at the surface we shall reduce it in the deeper parts. This is often an object, since congestions are important features of many disorders. We anticipate this balanced reaction when we make use of hot applications and when we give alcohol for a cold.

No one is likely to overestimate the services rendered by the vasomotor system. It has both a general and a local action. In the first sense it maintains a certain average state of contration in the arteries—the arterial tone—which keeps up to a desirable level the pressure in the arterial trunks. It is this pressure which guarantees the prompt and sufficient supply of blood wherever the paths are opened. The principle is the same that is observed in the mains distributing water through the streets of a city. The pressure must be great enough to keep up the supply on the high ground as well as the low. Leakage or wasteful use of water will lower the pressure and the failure will be noted first on the hills. An unusual dilation of many blood-vessels, such as probably accompanies an attack of indigestion where the abdominal organs are engorged, may lessen the pressure and the volume of blood passing through the brain with the consequence that there is faintness. Partial relief is found in lying down because the factor of gravity is eliminated and the head given an equal chance with the rest of the body.

We notice the failure of the vasomotor system to do its duty in cases like the above. We ought also to appreciate how remarkable it is that the adjustments usually occur with such smoothness and success. It is really a wonderful thing that we can rear up the elongated human form from a horizontal to a vertical position without entirely deranging the circulatory mechanism. That the blood does not distend the vessels below the heart and forsake those above must be due in a great measure to vasomotor correction. Doubtless, when one rises to his feet in the morning one is saved from falling in a faint by the promptness with which the arterial tone in the lower extremities is raised by the nervous system to fight back the threatened excess of blood. It is easy to see what would happen in a lifeless model under similar conditions.

While our vasomotor reactions are usually executed without our conscious attention, it has always to be borne in mind that close ties exist between the higher and the lower regions of the nervous fabric. Emotions register themselves in changes of blood-flow. The obedience of the vasomotor center to hypnotic suggestion is almost unlimited. It would appear that this division of the nervous system is the chief mediator in the correction of the many ills which unquestionably yield to Christian Science and kindred ministrations. A normal circulation goes far to insure normal nutrition and irritability in each part, and these states are the fundamentals of health. Furthermore, the feeling of health—which is not always the same thing as the possession of health—must depend, in the absence of more positive sensations, on the character of the cerebral circulation. Assuming the blood to be chemically normal a moderate change in the amount passing through the brain may make all the difference between the sense of power and the feeling of utter helplessness.

Beside dictating the character of the breathing and determining the volume and distribution of the blood-flow, the lower part of the brain exercises control of the alimentary canal and, in varying degree, of the glands. To mention these facts is merely to recapitulate what has already been pointed out. It must be recalled that the government of the glands is partly through direct communication with their secreting cells and partly through vasomotor regulation of their blood-supply. In many cases of sustained glandular activity both features exist at the same time.

CHAPTER XXVII

THE NERVOUS SYSTEM—ITS HIGHER WORK

"Our wills are ours, we know not how. . . ."

In the last chapter emphasis was constantly placed on the subconscious nature of the multifarious adjustments which are each moment secured through the action of the central nervous system. We are accustomed to think that the use of our sense-organs and the employment of our skeletal muscles are activities with which consciousness is far more closely concerned. While this is broadly true, we need to recognize that a great part of these reactions also goes on without our notice and beyond the reach of our intervention. This is readily admitted of the breathing. It will be found almost equally characteristic of the maintenance of the balance at rest and during locomotion.

The ability to stand is dependent on the occurrence of inconspicuous but indispensable reflexes which check each swaying movement of the body as it threatens a fall. When one walks the attention seems for the most part to be detached from the elaborate muscular performance and to be given to other matters. The contact of the feet with the ground, the gliding of one joint surface on another, the shifting of stresses from one muscle or tendon to a neighbor—these local changes become in a regular sequence the source of impulses which ascend to the brain and evoke appropriate responses. It has been generally believed that the division known as the cerebellum has a peculiar importance in this connection.

The position of the thinker himself with reference to the great afferent and efferent departments of his nervous system may be likened to that of the general in command of a great army. From his headquarters he can see but a small proportion of his troops. Their line of battle stretches for miles beyond his sight. He issues the order for a general advance. His aides ride to the right and left, bearing the word to the commanders of corps and divisions. The simple act of the general has been followed by a train of events which becomes each moment more difficult to trace. The original order is transmitted to officers of lower rank and interpreted by them in conformity with local needs. When the private soldiers are at last put in motion it is at the word of colonels and captains. The impossibility of having the voice of the commander-in-chief the source of guidance in each company is perfectly evident. It is not merely that he is too far removed from most of his men, but that there are too many problems arising at one time. The minor ones must be solved at the discretion of his subordinates.

So in the living body the will to walk—which seems as simple as the dictation of the first order from headquarters—is promptly followed by the action of many nervous mechanisms whose function is to distribute impulses and to apply them in helpful sequence. We have no sense of the subdivision which is involved. We cannot analyze the groups of muscular movements which take place. Yet it is plain that there is an apportionment of stimulation, more to this muscle and less to that, without which the effective result could not be secured. How utterly we should fail in the attempt to regulate the part taken by each of a hundred co-operating muscles by giving attention to each in its turn! The efforts necessitated would be like those of the general deprived of his staff and messengers who should seek to ride swiftly from point to point in the endeavor to direct all his soldiers by his spoken word. The organization of the highly developed nervous system is that of a disciplined hierarchy.

The comparison we have been using can be made to serve even further. We can find in it a place for the afferent side of nervous action. We have said that reflex elements can be found in almost any elaborate movement. In walking, for example, the assumption of a given position by the body insures the return to the centers of impulses which cause the next appropriate change. We do not consciously resolve to take each step. The very idea is painful. One step accomplished makes the taking of another the natural sequel. Turning to our analogy, we readily see that when the grand advance is under way the continuance of the march will probably be intrusted to the direction of lower officers. Difficulties encountered they will report to the general if this seems necessary; minor obstacles they will meet upon their own responsibility. Thus when we walk we may be aware of gutters to be crossed, but we do not notice at all the incessant slight adjustments which are made for the lesser inequalities of the path.

The human brain contains at birth connections which make possible the execution of a moderate number of useful reflexes. Among these are sucking, winking, coughing, sneezing, and vomiting. Of course, there are also the requisite mechanisms for the government of breathing, the circulation, and the digestive tract. Such a brain appears to differ from that of one of the lower animals chiefly in its capacity for continued development. Loeb has shown that all that is acquired in the experiences which come to the child may be covered by the term "associative memory." The expression as used by him does not refer to the power to review past experience as a conscious process, but only to the power to acquire new reactions to environmental conditions. An early gain in this direction is the attainment of the ability to reach after and grasp an object which has stimulated the visual department of the nervous system. This seems to signify the opening of a pathway in the brain from the region receiving impulses from the retina to the region from which impulses go out to the muscles controlling the hand.

In similar fashion we can picture the acquirement of one accomplishment after another. All imitative action must be made possible by the establishment of bonds between receiving and discharging stations in the surface gray matter of the cerebrum. As these connections are formed the conduct of the individual under given circumstances becomes predictable; in other words, we have here the physical basis of mannerisms and habits. It is even permissible to say that the foundations of character are defined in the direction which these association ties are found to take. All of education, so long as it is viewed from without and not from within, consists in the cultivation of response to varied influences. There can be no doubt that the anatomic accompaniment consists in the multiplication of brain pathways.

During the last hundred years the question has been much debated whether particular powers have definitely localized registration in the structure of the brain. In the first half of the nineteenth century the phrenologists attracted much favorable attention by their claims of very precise subdivision of the brain into "organs of different faculties." The notion of "bumps" is still current, though it is usually referred to in a jocular spirit. The literature of phrenology is very large, and it is probable that it would repay a critical review, but the advocates of the cult went much farther than the facts warranted and their conceptions fell into disrepute. By 1850 the reaction had carried scientific opinion to the belief that there is little localization in the brain.

Since then a great many experimental studies, together with observations of the consequences of injuries suffered by human brains, have united to encourage the view that there is some degree of localization. The new doctrines have not followed the old traditions at all. Where the phrenologists sought to refer mental functions to particular regions of the brain surface, modern students have looked with more success for the central representation of bodily processes. They have shown that a certain area stands in definite relation with the skeletal muscles, that another area is the place for the reception of the visual impulses, and so on. In most respects the human brain has been found to be organized in a manner closely corresponding with what is traceable in the brain of the ape and hinted at in the brain of the dog.

Yet the distinctive accomplishments in which man excels the lower animals must be coupled in some way with his cerebral equipment. One or two of these distinguishing features seem to have quite definite positions. This is especially clear in the case of the well-recognized "speech center." The belief is commonly held that the mechanisms which are correlated with such acquired powers as speech, reading, and writing are restricted to one-half of the brain, usually the left. The right hand, which in most subjects is so much superior in skill, is governed from the left side of the cerebrum. A charming account of the apparent relations between the human brain and human capacities is given in W. H. Thomson's "Brain and Personality." The claims made for precise localization in that book are regarded by many conservative writers as extreme. It is certainly fair to say that at present the most learned interpreters of brain physiology are placing emphasis on the development of paths between centers rather than on the organization of the centers themselves.

The characteristic of early life is the ease and freedom with which these paths are opened and the comparative frequency with which they are changed. During the long period of mature efficiency they are less subject to multiplication and are used with increasing regularity and with rarer deviations. The man is becoming a creature of habit and acquiring "ruts." In old age, as has been finely said, the nervous system, instead of holding a prophecy of what may be, contains a record of the past. It is a fascinating fancy—though it is nothing more—that a physician of surpassing insight might look upon the warp and woof of fibers in a dead brain and tell us of the tastes, talents, and pursuits of its former possessor. When we walk through the rooms of a deserted house we can tell by the worn places on the floors and thresholds and by the grimy edges of the doors just where the tenants came and went most often. The lifeless brain must bear a more subtle registry of the same order.

Afferent fibers reach the brain from all parts of the body. Many of these have had their origin within its tissues, where they are normally stimulated by conditions that belong to the organism itself rather than to its environment. The impulses that enter the brain from such sources are most of the time serving their purpose in promoting subconscious adaptive reflexes. When they affect consciousness it is to bring to the attention the so-called "general sensations"—those feelings which we refer to states of the organs. Such are hunger and thirst, many kinds of pain, satiety, nausea, faintness, fatigue, and the like. The majority of these general sensations seem to signify conditions that need to be rectified and they are mostly unpleasant.

Contrasted with these are the "special sensations," which are referred to causes acting upon the afferent apparatus from outside. Various terminal structures are developed at or near the surface of the body which serve to transmute different forms of environmental energy into nerve-impulses. Such structures are called sense organs or "receptors." A very suggestive distinction has been made between the "proprio-receptors," which are affected only by the literal contact of the stimulating substance, and the "distance-receptors," which respond to forms of energy radiating from places more or less remote. The nerve-endings in the skin which are acted upon by pressure and by temperature changes are proprio-receptors. So are those in the tongue on which various dissolved substances take effect, giving the conscious subject sensations of taste. The olfactory endings high up in the nasal cavities are reckoned by most writers to be in the same class.

The ear is a distance receptor. The energy which sets its intricate mechanism into vibration may have originated as far away as the thunder-cloud hanging near the horizon.

The possession of an ear greatly extends the compass of the environment which can exert directing influences on the conduct of an animal. If this is true of the ear, how shall we estimate the widening of environment that comes with the addition to the receptor system of an eye! Our ability to see the stars means nothing less than this: that the reactions of the organism so endowed may be modified by energy proceeding from the incomprehensible distances of the stellar universe.

Throughout this book we have held steadily to the point of view defined in its very first paragraphs: that all living things are transformers of energy, and engaged so long as they live in reacting according to the principles of mechanics and chemistry in response to external changes. A presentation in this spirit provokes resentment and protest from many readers. It seems to leave out of account all that is instinctively held to be highest and finest in human life. To this remonstrance we are glad to give place. The scientist is, after all, a man, and no scientist was ever so ruthlessly logical as to convince himself that his friend was no more than a reflex mechanism. The impression that the study of science deprives one of the philosophic outlook and of the conviction of moral responsibility belongs to the earlier stages of the student's experience. Later it is seen that no incentive to right conduct and no worthy consolation is to be taken away.

A few years ago a brilliant astronomer was concluding a course of lectures in which he had traced the long story of planetary evolution. He had pictured the ages of formative process, the slow condensation and cooling of the globe, the gradual approach to conditions suitable for organic life. He had sketched the brief flourishing of that life, the remorseless chilling of the planet, and its frigid and sterile old age. His hearers were weighed down with the appalling sense of futility and insignificance. At the very last he asked abruptly: Which, after all, is the greater —these awful ranges of time and reaches of space or the mind of man which comprehends and ponders them?

REFERENCES

Chapter I: Sedgwick and Wilson, " General Biology," Holt, New York, 1895, chaps. i, ii, iii.—Bunge, " Text-book of Physiological and Pathological Chemistry," Kegan Paul, Trench, Trübner & Co., London, 1890, chap. i.

Chapter II: Sedgwick and Wilson, chap. xvii.—Bunge, chaps. ii, iii.

Chapter III: Howell, " A Text-book of Physiology," 4th ed., Saunders, Philadelphia, 1911, chap. xl.—Fischer, " Physiology of Alimentation," Wiley, New York, 1907, chap. iv.—Starling, " Recent Advances in the Physiology of Digestion," Keener, Chicago, 1906, chaps. i, ii.—Bayliss, " The Nature of Enzyme Action," Longmans, London, New York, Bombay, and Calcutta, 1908.

Chapter IV: Hough and Sedgwick, " The Human Mechanism," Ginn, Boston, 1906, chaps. iii, iv.

Chapter V: Hough and Sedgwick, chap. vii.

Chapter VI: Kimber, " Anatomy and Physiology for Nurses," 3d ed., Macmillan, New York, 1910, chap. xiv.

Chapter VII: Howell, chap. xli.—Fischer, chaps. i, iii, v, x.—Starling, chap. iii.

Chapter VIII: Howell, chap. xxxix.—Cannon, " The Mechanical Factors of Digestion," Longmans, New York, 1911, chaps. iv, v, vi, ix, x.—For Alexis St. Martin, see Osler, " An Alabama Student and Other Biographical Essays," Oxford University Press, American Branch, New York, 1909, pp. 159–188.

Chapter IX: Howell, chap. xlii.—Starling, chap. iv.—Fischer, chaps. v, vi, xi.

Chapter X: Howell, chap. xliii.—Cannon, chap. xi.—Starling, chap. v.—Fischer, chaps. vi, viii, xii, xiii.

Chapter XI: Cannon, chap. xii.—Howell, chap. xliii.

Chapter XII: Martin, " The Human Body," 9th ed., Holt, New York, 1910.

Chapter XVII: Howell, chap. xxiv.

Chapter XIII: Martin, chaps. xix to xxi.

Chapter XIV: Howell, chaps. xlii, xliii.—Fischer, chaps. xiv to xvii. —Starling, " The Fluids of the Body," Keener, Chicago, 1909, chaps. ii, iii.

Chapter XV: Howell, chap. xlviii.—Lusk, " Elements of the Science of Nutrition," 2d ed., Saunders, Philadelphia, 1909, chap. vii.

Chapter XVI: Howell, chap. xlvii.—Lusk, chaps. iv, v.—Abderhalden, " Text-book of Physiological Chemistry," Wiley, New York, 1908, chaps. x to xiv.

Chapter XVII: Howell, chaps. xxxvi, xlv.—Martin, chaps. xxiii, xxiv, xxxi.

Chapter XVIII: Howell, chap. xlvii.—Lusk, chap. i.—Schäfer, "Text-book of Physiology," Macmillan, New York, 1898, vol. i, article " Metabolism," p. 868.—Tiegerstedt, " A Text-book of Human Physiology," Appleton, New York, 1906, chap. iv.

Chapter XIX: Howell, chaps. l, li.—Lusk, chap. i.—For Count Rumford, see Jordan, " American Men of Science," Holt, New York, 1910.

Chapter XX: Howell, chaps. l, li,—Lusk, many sections, especially chaps. vi, viii.

Chapter XXI: Hough and Sedgwick, chap. xii.—Lusk, chap. iii.

Chapters XXII, XXIII: Hough and Sedgwick, chap. xix.—Lusk, chap. ix.—Chittenden, " Physiological Economy in Nutrition," Stokes, New York, 1904.—Fletcher, " The A-B-Z of our own Nutrition," A, B, C Life Series, New York, 1903.—Benedict, " American Journal of Physiology," August, 1906.—Crichton-Browne, " Journal of the Royal Institute of Public Health," 1908, vol. xvi, pp. 471, 527.—Meltzer, " The Factors of Safety in the Animal Structure and Animal Economy," Jour. of Amer. Med. Assoc., 1907, vol. xlviii, p. 655.—Pyle, " Personal Hygiene," 4th ed., Saunders, Philadelphia, 1910, pp. 9 to 51.—Herter, " Common Bacterial Infections of the Digestive Tract," etc., Macmillan, New York, 1907.—Metchnikoff, " The Nature of Man," Putnam, New York, 1903.

Chapter XXIV: Billings, " Physiological Aspects of the Liquor Problem," Houghton, Mifflin & Co., Boston, 1903.—Kelynack, " The Drink Problem," etc., Methuen & Co., London, 1909.—Hough and Sedgwick, chap. xx.

Chapter XXV: Howell, chap. xlvi.—Tigerstedt, chap. xi.

Chapters XXVI, XXVII: Tigerstedt, chaps. xxii to xxiv.—Howell, chaps. ix, x, xiii.—Thomson, " Brain and Personality," Dodd, Mead & Co., New York, 1907.—Münsterberg, " Psychotherapy," Moffat, Yard & Co., New York, 1909, chap. iii.—James, " Psychology," Holt & Co., New York, 1892.—Pyle, pp. 275 to 314.

ADDITIONAL REFERENCE BOOKS ON FOODS AND NUTRITION

Hutchison, " Food and Dietetics," Wood, London, 1911.

Thompson, " Practical Dietetics," Appleton, New York, 1902.

Pattee, " Practical Dietetics," 6th ed., published by the author, Mount Vernon, New York, 1910.

Locke, " Food Values," Appleton, New York, 1911.

Sadler, " The Science of Living," McClurg, Chicago, 1910.

Sherman, " Chemistry of Food and Nutrition," Macmillan, New York, 1910.

Jordan, " Principles of Nutrition," Macmillan, New York, 1911.

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