CHAPTER VIII

THE MAINTENANCE OF THE BODY: RESPIRATION AND DIGESTION

The natural life of an individual is the direct result of the activities of a multitude of living cells. The life of each cell is maintained by the nutriment that it is able to obtain from the circulating liquid by which it is surrounded. This all-important liquid is composed of the lymph and the liquid portion of the blood, viz., the plasma. In the case of human beings and the higher animals, this liquid penetrates the tissues and fills all the interstices between the cells. Thus we see that the life of the individual as a whole is intimately connected with the lives of the cells, which are directly influenced by the nutriment-supplying liquid, the blood, and by the fact that the waste products of the cells find an outlet in the blood. This, in turn, is dependent on the efficiency of the working of the mechanisms involved in the digestion of food, the aeration of blood, and the manner in which the cells are constantly kept bathed in fresh fluid. During recent years our knowledge of the nature and function of blood has been appreciably extended, and it is the object of the author in this chapter to give some idea of this advance.

It will be necessary, however, to consider for a moment the main processes by which the blood derives its supplies of food and oxygen. Human blood on microscopic examination is seen to be composed of a pale yellow fluid in which is floating red and white corpuscles, the ratio being 500 to 700 red cells to each white one. Of these red corpuscles no less than 500 millions are present in 1 cubic centimetre of the blood of a healthy man, whilst in that of a healthy woman the number is about 450 millions. They occupy between two-fifths and one-half of the total volume of the blood. They are composed chiefly of hæmoglobin, the essential constituent of which is iron, though the percentage amount is less than one-half. Besides hæmoglobin, these cells contain minute amounts of lecithin and cholesterol, but no simple fat. The exact composition of hæmoglobin has not yet been ascertained, but the formula, $C_{758}H_{1203}N_{195}FeSO_{218}$, has been advanced to represent the number of the atoms of the various elements present. Except that it contains iron, hæmoglobin has many of the characteristics of the proteins, and has in blood the property of combining with mineral bases such as soda. The white corpuscles, also known as leucocytes, are mainly "phagocytic" in their behaviour, i.e., they have the power of absorbing bacteria that find their way into the blood. These corpuscles are nucleated cells, and in composition are similar to that of the contents of pus cells. The blood-plasma contains 91% to 93% of water, 6% to 8% of proteins, 0·1% to 0·15% of glucose, 0·1% to 0·2% of neutral fats, lecithin and cholesterol, 0·02% to 0·05% of urea and uric acid derivatives and 0·85% of mineral salts, chief of which are common salt (0·5%) and sodium bicarbonate. The other salts comprise the chlorides, sulphate, phosphates and bicarbonates of potassium, calcium, magnesium and iron. Of the proteins the fibrous, stringy substance, *fibrin*, constitutes only 0·3% approximately of the plasma. In addition, plasma contains the gases, oxygen, carbon dioxide and a little nitrogen. The percentage amounts of hæmoglobin differ somewhat during the life of a person, and also when suffering from some disease such as phthisis, cancer and pernicious anæmia. Though the iron contained in the hæmoglobin accounts for only 5 parts of every 10,000 parts of blood, it is of vital importance, and has therefore been called the "gold currency of the body." It confers on blood its wonderful power of absorbing oxygen, through the conversion of hæmoglobin into a loosely-bound body, namely oxyhæmoglobin. Firm combinations of hæmoglobin with either carbon monoxide, the poisonous constituent of coal gas, or prussic acid are set up, which thereby incapacitate the blood to absorb further supplies of oxygen. One of the dangers of inhaling tobacco smoke is that the smoke contains a relatively large amount of carbon monoxide which on passing into the lungs combines with the blood as carboxyhæmoglobin, so that the red corpuscles so attacked are unable to perform their proper function of conveying oxygen to the tissues. It should be emphasised that the power of hæmoglobin to unite with carbon monoxide is vastly greater than that with oxygen. Thus it has been found that hæmoglobin exposed to air containing 21% of oxygen and only 0·07% of carbon monoxide as an impurity, no less than one-half of the hæmoglobin combines with the impurity. This explains the highly toxic nature of modern coal gas and also stresses one of the risks taken by smokers of tobacco. Carbon monoxide is a product of the incomplete combustion of carbonaceous matter, whereas carbonic acid gas or carbon dioxide represents the final stage of combustion. It has been ascertained that during the smouldering of tobacco, without air being drawn through the burning mass, one atom out of every forty atoms of carbon is converted into carbon monoxide. By sucking air through intermittently, as in ordinary smoking, the proportion of carbon monoxide to carbon dioxide is appreciably raised, viz., 1 to 3 parts : 10. J. S. Haldane and his collaborators have found that when the 20% of the hæmoglobin of the blood is combined with carbon monoxide dizziness and shortness of breath during exertion ensue. Increasing amounts of carbon monoxide aggravate these symptoms, so much so that when one-half of the red corpuscles of the blood have combined with the gas the person is hardly able to stand without his becoming temporarily unconscious. During exertion the oxygen present in the blood gets used up by the muscles, especially those of the heart, and it is possible that if death does not occur there will have been caused permanent injury to the heart. Amounts of carbon monoxide in the air greater than 4 parts in 1,000 usually cause death, whilst 1·4 parts are distinctly dangerous. Coal gas poisoning is almost entirely caused by the carbon monoxide that it contains, and therefore every effort should be made to rectify any leaky pipes. Incomplete combustion of coal gas is especially likely to occur when a gas flame is allowed to play on a cool surface such as that of a geyser used for heating water in bathrooms. In every case, therefore, where geysers are installed in bathrooms it is imperative that every precaution be made to ensure that the burnt gases are entirely removed. No risks should be taken of down-draughts occurring in the flue. It is an interesting fact that the impaired hæmoglobin, carboxy-hæmoglobin, assumes a higher red colour, and its presence in blood can readily be detected in blood by means of the spectrometer. By means of this instrument and also by chemical tests carboxy-hæmoglobin can often be detected in the blood of inhaling smokers.

A few words here on the physiological action of the other oxide of carbon, carbon dioxide, or CO_2, will indicate the striking difference of the effects of the two gases. Unlike carbon monoxide, carbon dioxide is ever with us. In ordinary air the average is 3 parts by volume in 10,000 parts, and on this basis it has been estimated that the air contains no less than 2,400,000,000,000 tons. This gigantic supply is obtained from the vapours emitted by mineral springs, volcanoes, grottos, e.g., the Death Gulch of Yellowstone Park, California, direct combustions of fuel and indirect combustions such as those caused by living processes and during the decay of organic matter. Some gas is being continually removed by plants and also by its action in conjunction with water in the weathering of rocks. As previously stated, calcium carbonate becomes soluble in the waters of the earth through the formation of the bicarbonate, and this in turn is used by living organisms in the formation of their skeletons. The asphyxiation which may be set up by the presence of too much carbon dioxide in the air is one of suffocation, rather than that of poisoning, in that the blood is not materially damaged and recovery of the affected person is possible if an adequate supply of oxygen is available.

The air in crowded halls may contain as much as 5 parts per 1,000 without appreciable effects being experienced by the inmates. Should it reach 3%, both breathing and the pulse increase, and prolonged exposure to air containing 25% of carbon often ends in death. As will be understood later, muscular action which is essential to life becomes impossible, and this is followed by asphyxia, coma, and death. The immediate action of carbon dioxide is caused by the amount that finds its way into the *alveolar air*, or *air within the alveoli of the lungs*. Haldane has found that normally the carbon dioxide constitutes about 5·6%; when it becomes about 8% dizziness and loss of memory ensue, and that no immediate danger arises until it has reached 20% to 30%. Holding one's breath as long as possible leads to an enrichment of the alveolar air with carbon dioxide from the blood. This may be as great as 7% to 10%. It is apt to occur during diving or some active sport, though in the latter case the giving-up of carbon dioxide by the blood is largely governed by the intake of oxygen.

We have referred to the absorption of oxygen by the blood as being a process promoted by the iron which it contains. Iron then is essential to life, and seeing that the total amount in the body is so minute, it is interesting to see how it is conserved in the body. The red corpuscles on passing through the liver are continually being destroyed and the iron-free decomposition product eventually appears in the bile as the yellow bile-pigment, bilrubin, which incidentally forms the colouring matter of urine. The iron is stored within the liver cells, from whence it passes to the red marrow of bone, again to be incorporated in fresh red-blooded corpuscles which are there formed.

Blood is the vital fluid of the body, and forms about one-thirteenth of the body-weight. All the muscles, nerves and, indeed, every tissue in the body, depend on it for nutritive material, oxygen supplies and for the removal of carbon dioxide and other products of decomposition. As is well known, the heart is a muscular organ which pumps the blood round the body. The main course taken by the blood is diagrammatically shown in Fig. 17 (*b*). The beating of the heart is essentially that of the mechanical activity of the heart-muscles, which in common with the functioning of other muscles is intimately connected with the nutriment supplied to it in the blood.

It will be as well to see what light chemistry has to throw on the behaviour of muscles. Meat is chiefly comprised of muscles, which are made up of stringy fibres that are held together by means of connective tissues. The fibrous matter is made of the protein, elastin, and the connective tissues of collagen, the protein found in ordinary skin. In between these tissues are a number of fat cells. Three-quarters of the muscles are water, 18% to 20% is proteins, and 0·5% to 1·0% is fat. The precise amount of fat varies with the age of the body and also the type of animal The chief proteins contained in the muscle liquids are myosin, muscle-albumin and hæmoglobin. Immediately after death the protein, myosin, separates from the colloidal solution in a gelatinous form upon the muscle fibres, thereby rendering them stiff and causing the phenomenon known as *rigor mortis*. The chief reason for this coagulation is the very slight increase in alkalinity of the juices that occurs at the time of death. The death-stiffening ultimately passes off, chiefly on account of the development of lactic acid, which causes the coagulated protein to pass back again into solution. Parenthetically, it may be stated that the existence of this *rigor mortis* is the cause of meat being tough if eaten soon after the animal has been killed, and also explains why it is preferable to allow meat to stand some time before consumption. The development of the acid also imparts a more satisfactory taste to the meat. Sometimes meat is softened by soaking in vinegar solutions, i.e., in solutions of acetic acid.

The cells of living muscle are constantly removing oxygen from the blood and sending carbon dioxide back to the blood. During contraction of the muscle considerably more oxygen is required, and owing to the increased oxidation, or, if you like, "combustion," more carbon dioxide is set free. This reaction causes heat to be evolved. Now the muscle cells do not as a rule burn up their contents directly, i.e., to carbon dioxide, the last stage of combustion, but the first chemical change to take place during the contraction of a muscle is the formation of lactic acid, and this causes the hydrogen-ion concentration of the muscle juices to increase. The lactic acid seems to be formed from carbohydrates, very probably either the simple sugar, glucose, or a compound of this sugar and some other substance. There is no lactic acid in the resting muscle, but it can be generated by bringing the muscle into action, and this can be done even in the absence of oxygen. The formation of this lactic acid is, therefore, not one of oxidation.

If the lactic acid is unable to escape, then the acid accumulates within the muscle and takes the place of nutritive matter, with the direct consequence that the muscle becomes fatigued. Fortunately, the oxygen coming from the blood into the muscle cell soon effects the removal of this unwanted acid by oxidising it into carbon dioxide, thus :

$$\underset{\text{lactic acid}}{C_3H_6O_3} + \underset{\substack{\text{oxygen} \\ \text{from blood}}}{3O_2} \longrightarrow \underset{\substack{\text{carbon} \\ \text{dioxide}}}{3CO_2} + \underset{\text{water}}{3H_2O}$$

Thus it is seen that the removal of lactic acid from the muscles and, therefore, their proper functioning, are directly dependent on the way in which the blood is able to bring up fresh reserves of oxygen to the working muscles. Hence not only good circulation of the blood but also efficient aeration of the blood in the lungs, i.e., respiration, are essential for the perfect functioning of the muscles. In a well-trained athlete or a good manual worker little or no lactic acid should accumulate within the muscles, and the oxidative process should immediately follow every contraction of the muscle. In causes of faulty health, lactic acid may accumulate in the muscles, pass into the blood stream and finally be excreted in the urine. During severe exercise a man may excrete in a given time as much as one hundred times the amount normally excreted during a period of rest. It is estimated that about one quarter of the energy liberated during the oxidation of the lactic acid by the blood-oxygen is utilised in the form of actual work, the remainder being required to maintain the temperature of the body.

The alternation of the " breathing-in " and " breathing-out " processes of the respiratory organs, viz., the lungs, are caused by the contraction and relaxation of the lung muscles. In turn, they are governed by a centre of a system of nerves situated in the grey matter lying at the base of one of the ventricles of the heart. Curiously enough the activity of this so-called respiratory centre is largely influenced by the slight variations in the reaction of the blood that passes through the fourth ventricle. These variations are consequent upon the fluctuations in the amount of the carbon dioxide that occur in the blood. It happens that the hydrogen-ion concentration of blood is established almost entirely by the ratio of carbonic acid (H_2CO_3) sodium bicarbonate ($NaHCO_3$) present at any time in the blood. The reason for these variations will be apparent by considering the first stage of ionisation of carbonic acid, thus :

$$\underset{\text{un-ionised carbonic acid}}{H_2CO_3} \rightleftharpoons \underset{\text{hydrogen-ions}}{H^{\cdot}} + \underset{\text{bicarbonate-ions}}{HCO_3'}$$

Now
$$\frac{(\text{concentration of hydrogen-ions}) \times (\text{concentration of bicarbonate-ions})}{(\text{concentration of un-ionised carbonic acid})}$$

is, whatever variations may occur in any of the concentrations involved in the expression, equal to a constant value for any given temperature. At ordinary temperatures it is approximately 10^{-7}. As far as the blood is concerned, the other essential constituent, sodium bicarbonate, ionises almost completely thus :

$$\underset{\text{un-ionised sodium bicarbonate}}{NaHCO_3} \rightleftharpoons \underset{\text{sodium-ions}}{Na^{\cdot}} + \underset{\text{bicarbonate-ions}}{HCO_3'}$$

It will be seen that this salt sends into the blood bicarbonate-ions, which will therefore tend to increase the concentration of these ions included in the above expression. The consequence is that as the expression must remain equal to a constant value there must follow a diminution in the number of hydrogen-ions, i.e., the fundamental ionisation of the carbonic acid will be somewhat repressed. A consideration of these two ionic reactions will show that the ratio mentioned above is therefore all-important. When the blood is ladened with carbonic acid obtained from the tissues, then the respiratory centre is stimulated by the increased hydrogen-ion concentration and the lungs are compelled to expel some of the gas contained in the blood on its passage through the lungs. When the hydrogen-ion concentration of the blood becomes only slightly increased, due to an increased carbon dioxide content, deeper breathing is set up in the attempt of the lungs to drive off the undesired amount of carbon dioxide, a condition known as *hyperpnœa*, whilst if the carbon dioxide falls below a certain level, the decrease in hydrogen-ion concentration so caused may cause a state of *apnœa*, i.e., a temporary cessation of breathing. Thus it is seen that the respiratory centre is extremely sensitive to variations in hydrogen-ion concentration, and controls and varies the respiratory action of the lung in such a way as to maintain the reaction of the blood wonderfully constant.

As shown in Fig. 17 (*b*), the venous blood, i.e., the blood on the return journey through the veins, returns to the heart, from whence it is pumped to the lungs. Here it comes into contact in the alveoli of the lungs with the air contained therein.

This air contained in the lungs is widely different from ordinary air in that it is a mixture of ordinary air and gases that are in a kind of dynamic equilibrium with the gas contained in the blood passing through the lungs. It contains 5% to 6% of carbon dioxide, 13% to 14% of oxygen, and the remainder is nitrogen. Blood on leaving the lungs for the heart, from which it is pumped throughout the artery system of the body, contains 18 to 18·5 volumes of oxygen and 45 volumes of carbon dioxide in every 100 volumes. The returning or venous blood has its oxygen supply depleted to 12 to 13 volumes and the carbon dioxide content increased to 50% to 51%. The function of the lungs, therefore, is to allow the blood to liberate its excess of carbon dioxide during exhalation, and to make good its oxygen content by combination with hæmoglobin during inhalation directly from the alveolar air. The reception of oxygen by hæmoglobin may be represented by the scheme

$$\text{Hæmoglobin} + \text{oxygen} \rightleftharpoons \text{oxyhæmoglobin}$$

Where the pressure of oxygen gas is high, as in the alveolar air, the reaction follows the upper arrow almost completely, but where the tension of oxygen gas is very low, as is the case at the tissues, the reaction follows the lower arrow and the oxygen is received by the tissues in accordance with its requirements and hæmoglobin is once again regenerated. If the oxygen pressure of the inhaled air is inadequate to oxygenate the blood sufficiently the breathing will become deeper and giddiness and loss of consciousness may result. This is one of the dangers of flying at high altitudes and of mountaineering. To enable men engaged in these pursuits oxygen is often administered by breathing the gaseous oxygen evaporating from liquid oxygen carried in Dewar or " Thermos " flasks. This method was used by the German pilots when bombing London. It was through breathing oxygen that the American pilot, Grey, was able to rise to a height of over eight miles, actually 42,470 feet, as shown by his recording instruments. His oxygen supply failed before reaching the ground and he lost his life. It is the sparseness of the air at the summit of Mount Everest, the oxygen there being about one-third of that in the air at sea-level, that makes it almost impossible for climbers to reach it, unless a sufficiently light oxygen-breathing apparatus can be invented.

It is not the lack of oxygen that is immediately responsible for the difficulty of breathing. It so happens that the respiratory centre is much more sensitive to changes in the concentration of hydrogen-ions in blood deficient in oxygen, and this state of affairs is aggravated by the fact that, in the absence of sufficient oxygen, muscular activity leads to the production of lactic acid which ultimately finds its way into the blood stream and thus creates a marked change in its reaction.

In the foregoing account, we have seen how the blood is maintained in the oxygenated condition and how the combustions, or better, oxidations, of the tissues are made possible. Blood, moreover, is the medium in which nutriment is brought up to the tissues and, with the exception of the cells of the spleen and the liver, is then conveyed to tissue-fluid, or lymph as it is commonly called, from which the cells constituting the various organs derive the necessary food, and to which carbon dioxide and other waste products are excreted. The excreta from the organs pass through the lymphatic system into the venous blood stream. In the case of the organs, spleen and liver, the blood comes into contact with the cells. In composition lymph is similar to that of blood-plasma.

It now remains to consider in this chapter how the nutrient material is derived by the blood and the lymph, and this brings us to a study of the processes entailed in the digestion of food. In the body there is a continuous system through the chambers of which food in different stages of disintegration must pass before it can be absorbed into the blood stream, or in the case of non-digestion before it can be cast off by way of the rectum. These chambers are: the mouth, stomach, duodenum, and small intestine, and their relative positions are indicated in Fig. 17 (*a*).

The ordinary articles of food are of very complicated structure. With the exception of the mineral salts which they contain, and substances like sugar and fat, the foods are composed of very complex aggregates of molecules. They are in the colloidal state. As a result, they cannot be absorbed in the original condition into the blood. The purpose of digestion is, therefore, to break down these complicated substances into the simple molecules from which they were formed so that they can dissolve in water and then be absorbed. Thus the protein matter has to be broken down to the simple amino-acids before absorption can begin. True, the blood and the body as a whole is composed of much protein matter, but these proteins have been built up anew within the body from the elementary amino-acids which were originally absorbed. During recent years the chemist has acquired a considerable measure of success in decomposing proteins—he has, however, obtained very little success, if any, in reconstructing them. But in order to decompose them he has had to use many of the aids of the chemical laboratory—high temperatures and pressures, concentrated acids and alkalis, and so forth. All this is accomplished in the chemical laboratories of body, the alimentary canal or digestive systems, without any of these aids and certainly without the use of concentrated solutions of corrosive acids. Moreover, in the healthy body these decomposition reactions go on so smoothly that the person is not aware of what is going on inside of himself. If, however, insufficient attention is given to one's food it is quite possible that these reactions may be somewhat troublesome and make themselves felt by the individual in the form of pain.

To carry out these decompositions in the human or animal body, Nature has prepared and introduces into different parts of the digestive tract peculiar substances, known as *enzymes*, which convert tendencies of particular substances to decompose into actualities. Each different enzyme is specific in its action. It can only facilitate the decomposition of a particular substance in a particular way. Enzymes are colloidal in nature and hitherto have only been obtained from substances that have been involved in some living process in either the animal or vegetable kingdom. Though enzymes are obtained from fluids of cells that once were living, the enzymes themselves are in no sense living. The particular substance of which a certain enzyme will promote its decomposition is called the *substrate.* The great German chemist, Emil Fischer, likened the enzyme to " the key that will fit the lock," the *substrate.* These enzymes can be extracted and made to bring about decompositions of substances outside the animal body, in fact many industries, leather tanning, alcohol and vinegar manufacture, brewing, cheese-making, all depend on enzyme action. The liquids contained in the yeast cell contain several enzymes.

The conversion of sugar into alcohol and carbon dioxide in the presence of yeast dates from the remotest antiquity. The effervescence which accompanies this reaction caused the process to be regarded as a type of boiling, and therefore the name fermentation was assigned, having been derived from *fervere,* to boil. Pasteur held that fermentation was intimately connected with some living ingredient in the yeast. This view was not accepted by Liebig, and in 1878 Kühne introduced the term " enzyme," by which he attributed the fermentation to something dissolved in the fluid in the yeast cell (εν ξυμη, in yeast). It was not, however, until 1897 that the yeast liquid was definitely proved by Buchner to contain some inanimate substance capable of promoting fermentation. Enzymes are substances that " aid and abet " a reaction, but they themselves do not enter into the reaction. Nowadays the terms " enzyme " and " ferment " are used to denote any such agent, whether it is or is not obtained from yeast. Putrefaction usually refers to the decomposition of nitrogenous or protein matter. This, too, is caused directly by enzymes, though it must be mentioned that these enzymes are very often excreted by bacteria that are living in the putrefying mass.

Different enzymes require different, but specific, conditions of acidity or alkalinity in order that they may exert their maximum influence. It is not surprising, therefore, as enzymes play a considerable part in the digestion of food, that different hydrogen-ion concentrations are set up in the mouth, stomach and intestines, in order that in each organ or chemical laboratory, as each really is, some definite stage in the process of decomposing the food may be accomplished. It is probable that one of the functions of an enzyme is to assemble upon its surface, i.e., to adsorb, large quantities of its particular substrate, so that any other substance, e.g., hydrogen-ions, that may be involved in the reaction may have a better chance of attack than it would have were the simple molecules or aggregates floating about in the solution in a haphazard manner.

From the mouth to the rectum the system of chemical laboratories, in which digestion occurs, extends over a length of about 28 feet in the average adult. It is not until the digested food gets well into the small intestine or bowel that it acquires a condition to enable it to be absorbed into the blood or, in the case of fats, after appropriate decomposition to pass through the lymph channels leading to the blood vein at the back of the neck. A glance at the diagram, Fig. 17, will make the course clear. The passage of the food through this enormous length is made possible by a motor mechanism set up by the muscles which surround the organs.

We will now consider the digestive organs in turn. The first, the mouth, is the laboratory which is controlled partly by the mind of the individual, and to some extent, unconsciously, by the nervous system. Faulty methods of eating impose a great tax on the organs through which the food has subsequently to pass. The usual consequence is the troubles attributed to indigestion, caused by the difficulty or else inability of the organs to cope with

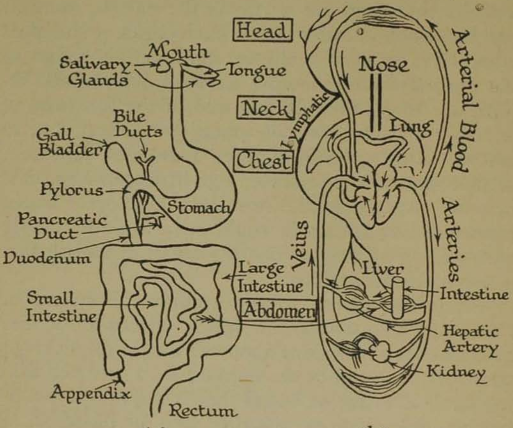

FIG. 17.—The Chemical Laboratories of the Human Body.

the food in the condition in which it is received. In the mouth are three glands which excrete a liquid, saliva, originally obtained from the blood. This fluid imparts to the mouth a reaction similar to that of blood itself, i.e., slightly alkaline, *p*H 7 to 7·5. In a way, this is a most unfortunate state of affairs, for they constitute just those conditions of hydrogen-ion concentration that are most suitable for the growth and reproduction of the germs which cause deadly diseases such as diphtheria, tubercolosis, pneumonia, tetanus, typhoid fever. As a rule, acidities of *p*H values below 6 are sufficient to cause the destruction of these germs. That is, however, not so with the *Bacillus coli communis*, which can flourish within the range *p*H 4·4 to *p*H 7·8. It happens, however, that those germs living above *p*H 6 are most likely to be killed in the stomach. Their mode of approach, therefore, is from the mouth into the respiratory tract. On the other hand, it is possible for the *B. coli*, often present in bad water, to pass through the stomach into the intestines, where once again the conditions are favourable to its life, and there to cause its ravages.

Saliva contains a valuable enzyme, ptyalin, the duty of which is to assist the hydrolytic decomposition, i.e., by means of water, of complex carbohydrates, such as starch, glycogen and dextrin, into the much simpler sugar molecules of maltose, thus :

$$2(C_6H_{10}O_5)_x + xH_2O \longrightarrow x\ C_{12}H_{22}O_{11}$$

$$\underset{\text{molecules}}{2\ \text{starch}} + \underset{\text{molecules}}{x\ \text{water}} \longrightarrow \underset{\text{molecules}}{x\ \text{maltose}}$$

In the above equation x is approximately equal to 30. To enable this important reaction to take place, it is essential that not only must the food remain in the mouth long enough, but that it shall be masticated to a pulp in order that this enzyme action shall be able to proceed to its full extent. Rarely, however, in these days of rush is this the case. It should be stressed that, if use is not made of this opportunity, the large concentration of hydrogen-ions in the stomach fluid, the gastric juice, will bring the action of the ptyalin enzyme to a standstill, except in those parts of the moistened food-pulp that do not come immediately into contact with the juice. It is possible that in such cases where the reaction has been able to begin it will not be completely arrested for upwards of half an hour after taking a meal.

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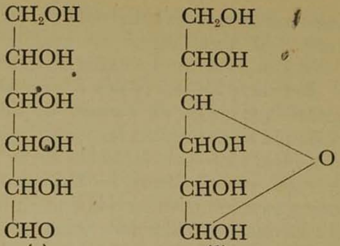
A note here on the chemical nature of the various classes of carbohydrates that occur in food will enable us to get a clearer insight into the several digestive processes. In the first instance we shall deal with the *sugars*. Although by the word " sugar " one is apt to think of ordinary " cane " or maybe " beet " sugar, to the chemist it is a general term applied to a particular class of carbohydrates. The simplest sugars are the *hexoses* or *mono-saccharides*. Each molecule contains six carbon atoms, twelve hydrogen atoms, and six oxygen atoms, and therefore the empirical formula of the molecule is $C_6H_{12}O_6$. Regarding their constitution, *cf.*, Chapter II, each molecule contains five alcoholic groups, —OH, and depending on the particular hexose either one aldehyde group, —CHO, or one ketone group, =CO. The hexose with which we are most concerned is *glucose*, for it is an essential nutrient material always found in the blood. Its simple structural formula is (*a*), though the formula (*b*)



(a) (b)

involving a slight rearrangement of some of its atoms, is sometimes considered to be a more satisfactory representation. As an example of a hexose containing a ketone group may be mentioned *fructose.* It is found, together with glucose, in fruits and honey. Another aldehydic hexose is *galactose.* A molecule of this simple sugar exists in combination with glucose in the form of *lactose* or *milk sugar*, the union having involved the loss of a molecule of water. This brings us to a consideration of *di-saccharides*, viz., sugars formed from two hexose molecules. These are sugars having identical empirical formulæ, namely $C_{12}H_{22}O_{11}$. This formula reveals that the molecule is composed of two hexose molecules with the elimination of one molecule of water, e.g.,

$$\underset{\text{hexose}}{C_6H_{12}O_6} + \underset{\text{hexose}}{C_6H_{12}O_6} = \underset{\text{di-saccharide}}{C_{12}H_{22}O_{11}} + H_2O$$

Now as there are several different hexoses, it will be understood that there should be several different di-saccharides. Thus cane sugar is made from a molecule each of glucose and fructose ; milk-sugar or lactose, from one molecule of glucose and one of galactose; whilst maltose is derived from two molecules of glucose. All these sugars are readily soluble in water and can therefore be easily absorbed into the blood. But there are many other more complicated saccharides, apparently all formed by the combination of simple hexose molecules with the elimination of water molecules—one molecule being abstracted during each union. Thus in the union of two hexoses one molecule of water is liberated; in the union of three hexose molecules two water molecules are lost, i.e., the number of water molecules abstracted is always one less than the number of hexoses involved. Hence the formula of an *x*-hexose or *x*-saccharide, where *x* is the number of hexose molecules, would be

$$xC_6H_{12}O_6—(x—1)H_2O.$$

When *x* is very large, we see that the formula becomes approximately

$$xC_6H_{12}O_6—xH_2O$$
$$=(C_6H_{10}O_5)_x$$

In view of the photosynthesis of glucose from carbon dioxide and water which we saw in Chapter V takes place in the leaves of plants, it is not surprising to find that these polysaccharides are formed in plants, fruits and vegetables. As *x* becomes larger and therefore the molecule, so also does the solubility in water become less and less. *Starch* is such a polysaccharide. It may be obtained from potatoes, rice, sago, tapioca, arrowroot. *Glycogen* or *animal starch* can be obtained from the liver of animals. In starch and glycogen *x* is so great that the substances are insoluble in water, but are able to form colloidal solutions. Substances, known as *dextrins*, have lower values for *x* than have starch and glycogen. Under certain conditions starch can be converted into dextrin, which in cold water can form a gummy solution. The heat treatment accorded to starched linen during ironing causes a thin glossy layer of dextrin to be formed upon the surface. Cellulose is a polysaccharide in which x is very great and it is therefore insoluble in water. Acids and alkalis tend to break it down, though it is one of the few substances that must pass through the human digestive tract undigested, for there is no enzyme present in it capable of effecting its decomposition. Cellulose is the chief constituent of the cell-walls of plants, and hence we see why cooking and careful mastication are necessary to fracture these indigestible cell-walls and to render available the matter contained within the separate cells. It is interesting to note that the cellulose obtained from cotton wool and paper on boiling with a concentrated solution of sulphuric acid breaks down to yield glucose.

Manufacture of Sugar

At this stage, we shall consider the manufacture of sucrose or cane sugar. The two main sources are the sugar cane and the sugar beet. Whilst the percentage content of sugar in canes varies from 11 to 16, that of sugar beets ranges from 12·7 to 18. Although the existence of something sweet, similar to " honey produced without the aid of bees," in sugar canes was known centuries before the Christian Era, it was not until some centuries afterwards that cane sugar, and that in a very crude state, was extracted by the Arabs and Egyptians. Beet sugar is of a much more recent date. As early as 1747, Marggraf in Germany

FIG. 19.—Vacuum Pans.
(Courtesy, Messrs. Tate & Lyle, Ltd., London.)

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extracted a considerable amount of sugar from beetroot. Factories in France, Germany and Austria sprang up during the Napoleonic wars, and the new industry was enthusiastically supported by Napoleon, who founded schools for instruction in sugar manufacture. It was not until 1860, however, that the beet sugar industry became general in Europe, and not until the Great War that it was taken up seriously in this country.

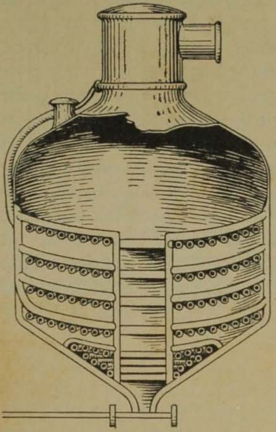
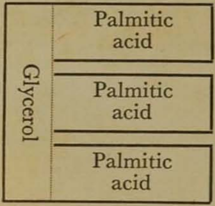


Fig. 18.—Section of a Vacuum Pan, showing Interior and Steam Coils.

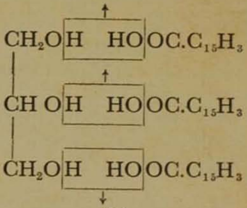
Cane sugar juice, containing numerous impurities, is expressed from sugar canes by milling. The remaining fibre, or *bagasse*, is used to make mill-board. Purification of the sugar juice involves bleaching, precipitations of foreign matter by adding slaked lime, and finally crystallisation. This is done in vacuum pans, that is, the refined juice is evaporated in vessels that are heated by internal coils carrying steam and the temperature at which boiling occurs is considerably lowered by reducing the pressure above the liquid by means of exhaust pumps. Extreme care is necessary in refining the juices, or there will remain in solution certain substances that will tend to render the juices uncrystallisable, and even when crystals do form they will be covered with sticky matter or *molasses*. Beet sugar is made in a similar manner, with the exception that the beet roots are not now ground to a pulp, but are cut into slices from which the sugar contained in the cells, thus ruptured, is allowed to diffuse into water or more usually into hot juice of low sugar concentration. The nearly exhausted slices are subjected to the action of hot water in order to remove the last traces of sugar.

. . . .

Both plants and animals store up within their tissues substances of the nature of fats. They are compounds formed from glycerine, or as it is more usually known to the chemist, glycerol, and fatty acids, generally either palmitic, stearic or oleic, and the fats are called palmitin, stearin and olein, respectively. Their structure may be represented by the following schemes :



(*i*)



(*ii*)

In (*i*) the dotted lines show where the chemical combination takes place in the formation of palmitin, whilst in (*ii*) the three-ringed portions indicate the formation of three molecules of water which on liberation render possible the chemical union between the molecule of glycerol and the three molecules of

FIG. 20.—Soap Boiling. View in Pan Room.
(Courtesy, Messrs. Lever Brothers, Ltd., Port Sunlight.)

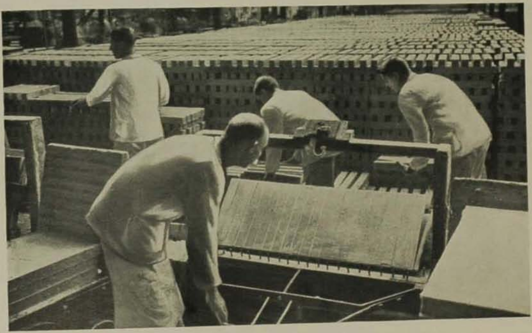


FIG. 21.—Cutting Slabs of Soap into Bars.
(Courtesy, Messrs. Lever Brothers, Ltd., Port Sunlight.)

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palmitic acid. If the three molecules of water can be given back to each molecule of fat then glycerine and the three molecules of fatty acid will be released. This can be done either by treatment with superheated steam, or by boiling with acid solutions, or by employing the appropriate enzyme, lipase, in a suitably alkaline medium such as occurs in the small intestine. Boiling with sodium hydroxide solutions also effects the decomposition of fats. In this case glycerine is set free, but the fatty acids combine with the alkali to form salts :

$$\underset{\text{palmitic acid}}{C_{15}H_{3}\,COOH} + \underset{\text{sodium hydroxide}}{NaOH} \longrightarrow \underset{\text{sodium palmitate}}{NaOOC\cdot C_{15}H_{3}} + \underset{\text{water}}{H_2O}$$

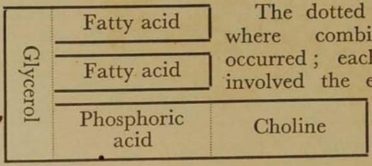
To the salts formed from metallic bases and fatty acids the name *soaps* is given. Soaps are formed to some extent during the enzyme decomposition of fats in the small bowel. The nature of the fat is governed by the fatty acid from which it has been formed. Beef and mutton fats are chiefly palmitin and stearin. Softer solid fats such as human fat and lard also contain olein. Oils are, strictly speaking, liquid fats—palm oil is chiefly palmitin ; and olive oil, olein. Linseed oil and castor oils are fats composed of other fatty acids.

Manufacture of Soap

It will be of interest to make a brief enquiry into the manufacture of soap. The animal and vegetable fats are carefully blended and run into a steel vessel or pan and gradually mixed with the requisite quantity of a solution of caustic soda. Usually these pans are very large and may hold as much as 60 tons of soap. Here the mixture is boiled with the aid of steam until the fats have been completely decomposed or saponified. When this has occurred, the solution contains soap and glycerine. In the larger soap works this glycerine is recovered from the solution after the soap has first been removed by evaporation in vacuum pans. The soap is thrown out of the boiling solution in the form of " curd " by adding sufficient common salt. The curd is purified further by boiling and washing with brine until it has acquired the desired standard of purity. After thorough stirring, the still liquid soap is run down to the cooling room where it solidifies in " frames " or rectangular steel boxes. Cutting into slabs and bars then follows. Shredded soaps are prepared by running the uncooled molten soap on to water-cooled rollers. Colouring and perfuming materials are incorporated in toilet soaps when in a fine strip condition, rendered so by cutting up the bars.

. . . .

Another type of fatty substances, which are intimately connected with living processes, is the *lecithins*. They are found in the nerves. In egg yolk they form about 10%; liver and blood each contain about 2%, and vegetable tissues from 0·25% to 1·5%. Their constitution might be represented in the following way :



The dotted lines indicate where combinations have occurred; each union have involved the elimation of a molecule of water. On degeneration of the lecithin molecule these molecules of water again take their places and a molecule of glycerol, two molecules of a fatty acid, either stearic, palmitic or oleic, one molecule of phosphoric acid and one molecule of the nitrogen bearing substance, choline. A glance at the constituents of the substance will suffice to show that it contains many of the essential elements required by the body. One can therefore appreciate the importance of such a substance in the yolk of an egg.

. . . .

After thorough chewing and mixing with the saliva in the mouth, the food passes by the aid of a wonderful motor muscular mechanism down through a tube, about one foot long, into the stomach. Here the food is subjected to the action of the gastric juice, a solution which is unlike any other in the body in that it contains a free mineral acid, viz., hydrochloric acid. This acid is certainly produced in the body from the common salt, sodium chloride, present in the blood. How the body prepares it is by no means clear. Its hydrogen-ion concentration corresponds to *p*H 1–2, and thus it is approximately one million times more acid than blood, when regarded from the point of view of acid-intensity. The free hydrochloric acid in the gastric juice is about one-half per cent. This relatively great acidity is essential in carrying on the decomposition of the food a distinct stage further. The increased concentration of hydrogen-ions greatly accelerate the decomposition of sugar molecules (dissaccharides, e.g., cane sugar) into the smaller sugar molecules, glucose and fructose. The gastric juice contains the enzyme, *pepsin*, and the conditions of acidity prevailing are those necessary for its maximum activity. Its function is to decompose hydrolytically protein molecules to the less complex substances, peptones and proteoses. Starches, the simple sugars and fats are not reacted upon in the stomach. The volume of the stomach in the average adult is about two litres. The food remains in the stomach for periods ranging from one to four hours, and when it reaches half-way down a series of muscular movements come into action, which churns up the food so as to expose every part of it to the gastric juice. These muscular motions are set up in waves and cause the food to be gradually forced downwards to the pylorus. Exact measurements of the hydrogen-ion concentration of the contents of the stomach may sometimes be useful in the detection of disease. A high concentration of hydrogen-ions such as may be produced by excessive amounts of hydrochloric acid may be indicative of gastric ulcer, whilst in cases of cancer of the stomach hydrochloric acid may be entirely absent which would be revealed by a low concentration of hydrogen-ions.

At suitable times the pylorus, an opening in the base of the stomach leading through the duodenum to the small intestines, opens and a jet of the acid stomach contents, *chyme*, squirts into the duodenum. The pylorus is surrounded by a ring of muscles which are sensitive to changes in acidity. If the liquid in the duodenum remains in the acid condition, then the muscles remain contracted and the opening closed. But the acid chyme gradually becomes neutralised and, indeed, is rendered very weakly alkaline by the juices of the intestine. As soon as the chyme has acquired a suitable concentration of hydrogen-ions, the pylorus again opens and more chyme is admitted to the duodenum. It has been stated that if the chyme on entering the duodenum is excessively acid the closing of the pylorus is so violent that some of the alkaline contents may be forced back into the stomach and thereby tend to reduce the too great acidity there prevailing.

Immediately the food reaches the duodenum, the glands in the wall are excited and secrete a substance, "secretin," which enters the blood stream and on reaching the pancreas and to a lesser extent, the liver, stimulates these organs into emitting fluids, pancreatic juice and bile respectively, into the duodenum. Secretin is a kind of chemical messenger which rushes to the particular organ and stimulates it into action. In the body, a variety of these chemical messengers are formed. To them the general name of "Hormones" is given. The secretion of bile by the liver is continuously taking place and being stored up in the gall-bladder until required to assist in the digestion of food. Both the pancreas and liver can be stimulated into action by means of hydrochloric acid and so we see why the juices are poured into the duodenum on the arrival of the chyme. Fatty foods which are not digested in the stomach tend to prevent the flow of gastric juice. They, however, excite the pancreas and liver into action, probably directly through the formation of soap on encountering the alkaline intestinal fluids which in turn accelerates the production of secretin. About a pint per day of pancreatic juice and of bile is poured, as required, into the intestines.

The pancreatic juice and bile are both alkaline media that are sufficient to bring the acid chyme to the condition of alkalinity most suitable for the enzymic actions which occur in the intestine. Pancreatic juice is about *p*H 9, which represents greater alkalinity than that of the intestinal contents, taken as a whole. This juice on entering the intestine yields several enzymes which assist in the break-down of proteins. On the other hand, bile appears to contain no enzymes, though its salts certainly further increase the rate of the enzymic actions caused by the pancreatic juice. The partly digested food on passing through the duodenum enters the small intestine where the pancreatic juice and bile become mixed with yet another juice. This is secreted from the walls of the intestine. The small intestine is usually about 20 feet long and a little more than one inch in diameter. The chief enzyme, *trypsin*, required for the decomposition of proteins is derived from the pancreatic juice. Oddly enough, this enzyme as it exists in the pancreatic juice is not active ; in its inactive form it is known as *trypsinogen*. It is rendered active by another enzyme *enterokinase*, present in the intestinal secretion. When in the active form, trypsin is best able to effect protein disruption in a medium having a *p*H value between 6·8 and 9. It is within this range that the reaction of the liquid in the intestine lies, being about *p*H 8. If given sufficient time, the decomposition of the proteins can be carried as far as the constituent amino-acids by means of this enzyme. But as a rule, its enzymic activity becomes considerably impaired and it is therefore improbable that this enzyme can be used to such an extent in the intestines. Fortunately, another protein decomposing enzyme exists in the intestinal juice that is capable of completing the decomposition, begun by trypsin. This enzyme is *erepsin*. The chief amino-acids so formed are leucine, tyrosine, glutamic acid, tryptophane, aspartic acid, cystine, together with the nitrogeneous bases, lysine, arginine and histidine. These are absorbed into the blood system through the walls of the small intestine in which there is provided about sixteen square feet of a special absorbing surface, composed of a structure made up of *villi*. It is the amino-acids which can be derived from proteins that determine their value as body-builders, one amino-acid being of greater service than others, though each appears to be essential. Deprivation of the body of one or more of these amino-acids may lead to retarded growth or even to death. Thus rats, fed on *zein*, the protein in maize, which produces no lysine or tryptophane after digestion, ultimately died; others fed on zein plus tryptophane continued to live, whilst those fed on zein, together with tryptophane and lysine, not only lived but grew. The inference to be drawn is the need of a mixed protein diet.

With the exception of cellulosic matter with which, as already stated, the human digestive system is unable to deal, the decomposition of the starchy matter, dextrin and disaccharides, is completed in the small intestines. The starchy matter is converted into simple hexoses, chiefly glucose, and as such are absorbed into the blood. As shown on an earlier page these reactions necessitate the incorporation of water moclecules by the polysaccharides and this is made possible by one or other of the following enzymes, maltase, invertase, lactase, obtained from the intestinal juice. After absorption through the walls of the intestine, the simple sugar molecules proceed in the blood stream to the liver where they are stored in the form of complex carbohydrate molecules, glycogen, $(C_6H_{10}O_5)_X$. The liver is able to hydrolyse these molecules to those of the simple sugar, glucose. It is then conducted to the general blood stream of the body. From this the muscles receive their nourishment and they are able, moreover, to lay in reserves for their own individual use and again this is done in the form of the condensed glycogen molecules. Sufferers from diabetes have lost their power to store up glycogen within the liver. The consequence is that all the glucose enters the blood stream and some is excreted in the urine. Its presence can there be easily detected by either Fehling's or Benedict's solutions. One obvious way to counteract this excess of sugar entering the blood stream is to reduce the intake of sugar and carbohydrates in the food. This method of treatment was found to introduce other difficulties in the body in its dealing with fat. In healthy individuals, the amount of glucose in the blood is rigorously controlled by means of a secretion or hormone, known as "insulin." This "chemical regulator" originates in and is secreted by certain ductless glands of the pancreas, to which the name "Islets of Langerhaus" has been given, and from which, incidentally, the term "insulin" has been derived. One of the chemical characteristics of insulin is the fact that it contains sulphur, otherwise it is a protein body and is apparently synthesised in the glands from about fifteen different amino-acids. Its composition corresponds approximately to the formula $C_{74}H_{114}O_{24}N_{20}S$.

We shall pay some attention to the function of the bile. One of its first actions is to cause the protein matter that has been partly broken down in the stomach to separate in the solid form from solution. This occurs soon after the chyme has passed into the duodenum. By so doing, the rate of passage of the food through the small intestine is very much reduced and so gives time for the various enzymes to have their full effect. Another effect is in connection with the digestion and absorption of fat, for it is known that if a fatty meal passes through the intestine into which no bile is allowed to flow, 60% of the fat will be rejected in the fæces, compared with about 5% normally undigested. The condition necessary for the absorption of fat appears to be that it must be broken down into glycerol and fatty acids, which by interaction with alkali present in the intestine tend to form soaps. The hydrolysis of the fat is facilitated by the enzyme, lipase, and it is extremely likely that the bile salts help to emulsify the fats, i.e., to bring them into a state of very fine colloidal suspension of the fat globules. In this condition, the relatively large surface of the fat globules render the fat much more easily hydrolysed. Though it is only the constituents of the fat that appear to be able to pass through the intestinal wall, it is a curious fact that soon after a fatty meal the channels of the lymphatic system are found to be carrying a milky fluid which on close examination can be seen to be due to the presence of suspended fat globules. By some means or other, the fat molecules are reformed soon after the absorption of their constituents. Fats are the only products that, after absorption, do not pass through the liver. Ultimately, the fat enters the blood stream by which it is carried to sites where fat reserves are deposited.

In concluding this chapter, some reference will be made to the large intestine. Food absorption occurs exclusively in the small intestine and it is practically complete by the time the contents have reached the ileum, i.e., its exit into the large intestine. Hence little food, if any, is absorbed through the walls of the large intestine. Its function appears to be the absorption of water. The large intestine is the haunt of billions of harmless bacteria. They flourish on the undigested cellulose and other food material, and by so doing, set up therein fermentation and putrefaction. Though cellulose matter cannot be made use of as a food by human beings, the taking of cellulose matter into our bodies, seems to be a matter of importance. There is some evidence for the belief that it keeps the large intestine in a state of healthy activity and thereby assists the organ to absorb water.

Sewage Disposal

Methods of sewage disposal are intimately connected with bacterial action in converting waste material into gaseous substances and solid matter, which can be easily filtered, or in the more recent " activated sludge " process which will rapidly settle out. Activated sludge consists of semi-solid matter which is replete with bacteria. If given an adequate supply of air, they will multiply and at the same time will very speedily digest the nauseous sewage matter which has been conducted into the tank. Aeration may be effected simply be agitating the surface liquid.