CHAPTER VII

THE CHEMISTRY OF THE HUMAN BODY

We shall open this chapter by giving the composition of the average human body, expressed in terms of the several elements which are present in the chemical compounds actually present :

Percentage Composition of Average Human Body

Oxygen	65	Calcium	1·5	Sodium	0·15
Carbon	18	Phosphorus	1·0	Chlorine	0·15
Hydrogen	10	Potassium	0·35		
Nitrogen	3	Sulphur	0·25		

The remainder consists chiefly of iron, magnesium and iodine, and traces of silicon and manganese.

It will be seen that oxygen and hydrogen represent 75% of the weight of the human body, and of this an amount equal to about 60% of the body is present in the form of ordinary water. This is an astonishing fact. Nearly two-thirds of our bodies are merely water ! This water is to be found everywhere throughout our bodies, in fact everywhere life exists and living processes are possible. Life and water are inseparable. Some idea of the amount of water constituting the various parts of the body can be obtained from the following table.

Percentage of Water Contained in Some Parts of the Human Body

Brain	75	Kidneys	83	Blood	79
Muscles	76	Liver	69	Bile	86
Skin	72	Fat	30	Gastric juice	97
Bone	49	Spinal cord	70	Lymph	96

In the previous chapter, an attempt was made to visualise how life first came into being in the form of a protoplasmic cell. As stated before, protoplasm is a solution in water of organic bodies and, significantly enough, of just those inorganic compounds that are found in the sea—that source of all forms of life. Living cells are filled with aqueous solutions, and as the body, in effect, is made up of millions of cells, it will be appreciated that the science of life is intimately wrapt up in the properties of aqueous solutions. The organs and muscles are composed of millions of very small cells knit together in a cellular structure. Not all cells, however, are stationary. Thus the red corpuscles of the blood are really cells that are about one-fifteen-thousandth part of an inch in diameter and float about in the blood-stream.

The most abundant salt in the body is calcium phosphate. It forms more than one-half of the bone material, and a large proportion of that of the teeth. The structure of bone is cellular. The formation of bone can be traced to masses of cells first secreting a fibrous substance known as collagen, and then encrusting these fibrous growths with insoluble calcium phosphate and, to a lesser extent, calcium carbonate. It is a surprising fact that these salts are precipitated upon the cell-coverings along those portions where stresses and strains prevail. The immediate cause of the separation of the calcium salts from the cell solutions is due to an increased alkalinity being set up through the chemical changes introduced in the protein matter of the cell as the result of the strains. Dry bone contains about one-third of collagen (in bones it is more often called ossein), 57% of calcium phosphate, $Ca_3(PO_4)_2$, 7% of calcium carbonate, $CaCO_3$, 1% to 2% of magnesium phosphate, and 1% of calcium fluoride. It might be mentioned that collagen constitutes much of the connective tissue and of the skin, in addition to its being the foundation-material on which the mineral matter of the bones is laid. On prolonged boiling with water, collagen is converted into gelatine.

As the life of the body is the resultant of the activities of multitudes of cells in transforming chemical energy into mechanical action, and as these transformations of energy are effected by the action of the aqueous solutions that are both outside and inside each cell, it would be advantage here to pause awhile and pay some little attention to the nature and properties of solutions. When many substances are dissolved in water, despite the fact that the substances may have appreciable volumes, only very slight variations, if any, take place in the solutions obtained when compared with the original volumes of water used. This is a surprising fact, for if the water completely fills the volume apparently occupied by it, then it is not easy to understand why it is able to dissolve a substance without undergoing a marked increase in volume caused by the additional volume of the dissolved substance. Another property of a solution is that the molecules of the dissolved substance are in active motion, known as the Brownian movement, and also exert a pressure throughout the entire volume of the solution in just the same way as molecules of gas exert a pressure on the walls of the vessel in which it is contained. The pressure exerted by the dissolved molecules is known as *osmotic pressure*, and by its action at the surfaces of cells water and certain types of dissolved substances are able to pass across the cell boundaries. Unlike the pressure exerted by gaseous molecules, the osmotic pressure set up by dissolved substances cannot be measured by a direct method on account of there being a pressure arising from the water molecules as well. It is the existence of this osmotic pressure that causes a piece of salt, placed at the bottom of a tumbler of water, after dissolving, to diffuse uniformly throughout the entire volume of water. It can, however, be measured and demonstrated by means of a somewhat indirect method. Molecules of dissolved substances differ from those of the water in that they are larger. Hence if only a porous diaphragm or membrane could be obtained, the pores of which were large enough to allow molecules of water to pass through, but too small for the dissolved molecules, then it would be possible to separate a concentrated solution by such a diaphragm from water and to let the concentrated solution in its effort to become more dilute pull water through the semi-permeable diaphragm. This is the same as saying that if "the mountain will not come to Mahomet, then Mahomet must go to the mountain," in other words if the dissolved molecules cannot go to the water, then the water molecules must go to the dissolved molecules.

A diagram of a simple form of apparatus for measuring osmotic pressure is given in Fig. 14.

The semi-permeable diaphragm is situated in the walls of the porous clay pot by depositing within its pores a gelatinous precipitate of copper ferrocyanide. This precipitate contains extremely fine pores that are permeable only to molecules of water but not to any molecules of greater dimensions such as those of sugar and salt. If, therefore, a solution is placed inside the pot and water outside, the osmotic pressure exerted by the dissolved molecules in the solution will cause water to pass inwards through the membrane. This increased volume in the pot will force downwards the mercury in the left limb of the manometer. The difference in the levels of the mercury in the two limbs of the manometer will constitute a measure of the osmotic pressure of the solution.

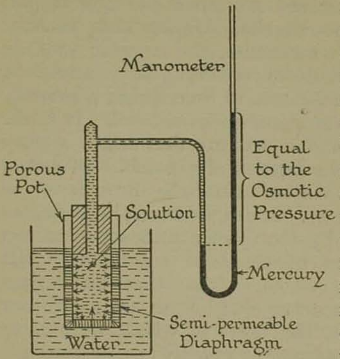

FIG. 14.
The Measurement of Osmotic Pressure.

Some idea of the magnitude of this osmotic pressure may be obtained from the facts that a solution of 8 grams of glucose in 1 litre of water exerts a pressure equal to that of an atmosphere, whilst a solution of 180 grams per litre gives rise to an osmotic pressure equal to that of no less than 23·7 atmospheres. It is no wonder, therefore, that considerable difficulties have been experienced by experimenters in making diaphragms capable of withstanding such considerable pressures. Those substances such as acids, salts and bases which on dissolving in water cause the resulting solutions to conduct the electric current, give rise, molecule for molecule, to much greater osmotic pressures. This is of a vast importance in life processes for many of the body liquids contain appreciable proportions of these electrolytes.

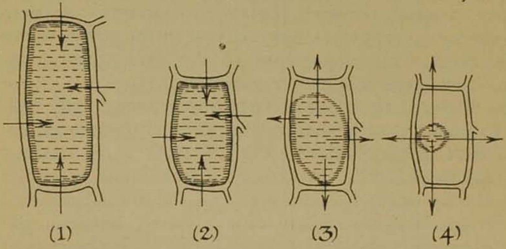

FIG. 15.—Osmotic Pressure and Cells.

It is this phenomenon of osmotic pressure that is responsible for the transference of liquid and dissolved substances to and from the solutions surrounding the cells in the body and the contents of the cells respectively. Thus if the concentration of a particular substance in the cell liquid should increase, water will be attracted into the cell, and should the cell membrane be sufficiently pervious there will be a distinct tendency for the substance to escape from the cell into the extra-cellular solution. If the cell wall is able to resist the outward passage of the substance, then water will pass into the cell and distend the cell wall as shown in Fig. 15, No. 1. There the distended cell-wall is seen to be distending the cellulose framework in which the cell is held. In No. 2 the protoplasm is maintained in close contact with the framework due to a more concentrated solution being outside the osmotic pressure of which tends to equalise that of the protoplasm in the cell and consequently only sufficient water passes through the cell wall into the cell to keep it distended. Nos. 3 and 4 show the shrinking of cells caused by the transference of water from the cells on account of there existing a greater osmotic activity in the surrounding solutions. The separation of the protoplasm from its framework is known as *plasmolysis.*

Water is therefore of vital importance to the cell. If too much water should leave the cell the concentration of the liquid inside the cell may easily attain a toxic value, whilst if too much water should enter the cell may burst. Life depends on the maintenance of the equilibrium, chiefly of the water, between the plasma on both sides of the cell wall. The labours of physical chemists, such as Arrhenius, Wilhelm Ostwald, Donnan and Loeb have rendered great assistance in the solution of this vital problem.

The mineral salts dissolved in the aqueous body fluids also play a very important part in the functions and life of the cell, so also does the property known to the chemist as " the reaction." Molecule for molecule substances like common salt exert nearly twice the osmotic pressure as glucose, and consequently their behaviour at the cell interface will be more vigorous. The Swedish chemist, Arrhenius, advanced an excellent theory to explain this enhanced osmotic activity. It happens that solutions of many organic compounds are very little better conductors of the electric current than is the water from which they are made, which is very poor. On the contrary, just those substances which on dissolving in water exert an increased osmotic pressure, also confer upon the solution the power of superior conductance of electricity. To explain the phenomenon of the breaking-up of substances dissolved in water by the passage through them of the electric current, Faraday postulated that the current must have been carried to the opposite poles or electrodes by those substances that were subsequently there set free. Thus if the solution electrolysed be one of hydrochloric acid, then hydrogen gas will be liberated at the negative pole or cathode and chlorine gas at the positive electrode, i.e., the anode. To account for this, it is considered that the gases while travelling to the electrodes before being discharged must have borne electric charges, either positive or negative, according as they move either to the negative or positive poles respectively. In view of the hydrogen being set free at the negative pole, it must have travelled through the solution under the influence of the electric current and in fact have been the means of carrying the electricity. Faraday considered the molecule of hydrochloric acid to have been disrupted into the constituent atoms, hydrogen and chlorine, bearing electric charges, positive and negative respectively. The property of these charged atoms was, according to Faraday, wandering, and so he called them "ions" or "wanderers." Arrhenius carried this idea of molecules splitting up into ions one step further, and that step was that the dissociation of the acid salt or base must occur immediately it dissolves, so that the existence of the ions would explain both the increased electrical conductivity and the increased osmotic activity. Odd though it may seem, this idea of Arrhenius has formed the foundation on which much of our knowledge of the chemistry of life has been built. In spite of mineral salts forming only a small proportion of our bodies, they constitute much that is essential in the skeleton, nerves, and even in the body juices.

Water, as we have said, is a very poor conductor of electricity. It does, however, allow some current to pass through, though it happens to be the minutest amount. The conclusion, therefore, is that the molecules of water must split up into ions to the minutest extent in order to make this conductance possible. This dissociation may be represented as follows :

$$H_2O \rightleftharpoons H^{\cdot} + OH'$$

the $H^{\cdot}$ denoting an atom of hydrogen bearing a positive electrical charge, and OH', the hydroxyl group carrying a negative charge. This ionisation in the case of pure water takes place to an infinitesimally small extent, though nevertheless to a measurable extent. Out of every 556 millions of water molecules only 1 molecule ionises ! It might be mentioned here that it is the charged hydrogen atoms, better known as hydrogen-ions that give rise to the phenomenon of acidity when acid-forming substances are dissolved in water, whilst hydroxyl ions, OH', are produced when bases and alkalis dissolve in water and are essential to give rise to alkalinity. Pure water might be regarded, therefore, as both an acid and alkali, but as the characterising ions are liberated in equal amounts, the opposing tendencies are neutralised, and water is consequently neutral in reaction.

Another point of interest concerns solutions of acids and alkalis. They dissociate into ions, e.g., hydrochloric acid gives rise to hydrogen-ions and chlorine-ions, $HCl \rightleftharpoons H^{\cdot} + Cl'$; sodium hydroxide, $NaOH \rightleftharpoons Na^{\cdot} + OH'$, to sodium-ions and hydroxyl-ions. But the water in which they are dissolved is still able to ionise into both hydrogen-ions and hydroxyl-ions. True, an acid solution, such as hydrochloric acid, will contain a relatively large number of hydrogen-ions that have ionised from the acid molecules, but there will also be an extremely small proportion coming from the molecules of water, and these will be accompanied by hydroxyl-ions, the ions giving rise to alkalinity. The solution will be acidic in its reaction simply because of the overwhelming number of hydrogen-ions present. In like manner a solution of sodium hydroxide, being in water, contains some hydrogen-ions, but the relatively large amount of hydroxyl-ions originating from the sodium hydroxide causes the solution to be alkaline. It has been found that at a given temperature in one litre of any water solution the number of ions of hydrogen-ions multiplied by the number of the hydroxyl-ions is always the same. As acidic and alkaline solutions each contain hydrogen-ions and hydroxyl-ions, it will be understood that it is the ratio in which they happen to be present that will determine the reaction of a solution. Very accurate physico-chemical methods have, during recent years, been developed, by which these ion concentrations may be determined. Acidity and alkalinity may now be measured with an accuracy which hitherto has been impossible.

Another point is that all the variations from a strongly acid solution through the state of neutrality to the opposite condition of strong alkalinity is now capable, not only of measurement, but of careful control. Instead of using such vague terms as "strongly acid" or "weakly alkaline," modern chemists now refer to degrees of acidity in a similar way to that in which one speaks of temperature by referring it to a thermometer scale. The ability to measure and to refer conditions of acidity and alkalinity to an exact "scale" has made it possible to follow the very small but all-important changes which occur in the fluids in the body. Blood is almost neutral in its reaction, though very soon after death a very slight amount of alkalinity develops and so causes the blood to congeal.

Some idea of this acidity scale may be obtained from the Table of page 79.

Chemists consider acidity in terms of hydrogen-ion concentration, such as are given in the first three columns of the foregoing table. Some of these concentrations are almost beyond the limits of human imagination. Thus consider the concentration represented in the last line. It means that a solution contains one hundred billionth part of a gram per litre of hydrogen ionised as the acid producing hydrogen-ions. Whether this is actually the case or not, he can obtain, by means of certain exact electrical measurements, values of the electro-motive forces which can be readily and satisfactorily interpreted in the terms of such infinitesimally small concentrations. Of course, solutions having such low concentrations of hydrogen-ions do not contain enough to make the solution acidic in its reaction; in fact, any solution

Scale of Acidity

Gram per litre of hydrogen present in acids in ionised state, i.e., as hydrogen-ions.			pH value.
1	1	10^{-0}	0
0·1	$\frac{1}{10}$	10^{-1}	1
0·01	$\frac{1}{100}$	10^{-2}	2
0·001	$\frac{1}{1,000}$	10^{-3}	3
0·000,1	$\frac{1}{10,000}$	10^{-4}	4
0·000,01	$\frac{1}{100,000}$	10^{-5}	5
0·000,001	$\frac{1}{1,000,000}$	10^{-6}	6
0·000,000,1	$\frac{1}{10,000,000}$	10^{-7}	7
0·000,000,01	$\frac{1}{100,000,000}$	10^{-8}	8
0·000,000,001	$\frac{1}{1,000,000,000}$	10^{-9}	9
0·000,000,000,1	$\frac{1}{10,000,000,000}$	10^{-10}	10
0·000,000,000,01	$\frac{1}{100,000,000,000}$	10^{-11}	11
0·000,000,000,001	$\frac{1}{1,000,000,000,000}$	10^{-12}	12
0·000,000,000,000,1	$\frac{1}{10,000,000,000,000}$	10^{-13}	13
0·000,000,000,000,01	$\frac{1}{100,000,000,000,000}$	10^{-14}	14

containing less than 10^{-7} of 1 gram of hydrogen in the ionised form per litre is alkaline. They contain a predominance of hydroxyl-ions. The actual number can be calculated from the fact that the molecular concentration of hydrogen-ions multiplied by the molecular concentration of hydroxyl-ions is, at ordinary temperatures, equal to 10^{-14}. This means that the solution containing one hundred billionth of a gram of ionised hydrogen per litre must contain 17 grams of hydroxyl-ion per litre, this being the relative weight of one hydroxyl group, OH, i.e., when expressed in grams. Similarly a solution possessing 10^{-10}th part of one gram of ionised hydrogen per litre must contain 10^{-4}th part of the weight of one hydroxyl group expressed in grams, i.e., 10^{-4}th of 17, in the form of ions per litre. In such a solution the ratio of hydroxyl-ions to that of the hydrogen-ions is 10^{-4} : 10^{-10}, or expressed in words, the solution contains no less than a million hydroxyl-ions to every one hydrogen-ion. The solution is, therefore, alkaline. Acidity and alkalinity are thus seen to be due to the presence of both hydrogen-ions and hydroxyl-ions, the condition of acidity prevailing when the hydrogen-ions are in excess, and that of alkalinity when the hydroxyl-ions are in excess. It is, however, convenient to think of both of these conditions in terms of the hydrogen-ions alone, and consequently there is being adopted what is known as the *p*H scale, indicated in the last table, by which the varying degrees of acidity and alkalinity are considered in terms of the negative power of concentration of the hydrogen-ions referred to the base 10, as in the last column but one of the table.

We shall constantly have occasion to make use of this scale, especially when we consider the chemistry of digestion of food. The concentration of hydrogen-ions in body fluids has much to do with the combinations into which, for example, the proteins may enter, and in consequence determines the size of the aggregates of protein molecules. There is much evidence to show that the activity of the respiratory centre of the higher animals is governed by changes in hydrogen-ion concentration. The *p*H value of the blood of healthy persons varies from 7·35 to 7·45. Slight variations occur during the day, and it may be influenced by behaviour such as strenuous exercise or by forced breathing. In the event of strenuous exercise the *p*H value may fall as low as 7·05 through the passage of carbon dioxide into the blood, whilst forced breathing may raise the blood to *p*H 7·85. When blood acquires *p*H values lower than 7·3, a condition of "acidosis" obtains. Should the *p*H value fall below 7·0, as may occur in diabetes and uræmia, the recovery of the patient will be highly improbable. It is a remarkable fact that the health of the blood is very largely dependent on the amount of carbon dioxide which it contains. If the amount of carbon dioxide contained in the blood were present alone in pure water it would set up an acidity equal to *p*H 4·51, a state of affairs which would mean instant death. Actually the concentration of hydrogen-ions in blood is about one-thousandth of that in such an aqueous solution. This diminution is made possible by the fact that blood contains sodium bicarbonate, proteins, and certain phosphates, which cause the ionisation, as far as hydrogen-ions are concerned, to be repressed.

Though the liquid contained in a cell appears to be homogeneous to the naked eye, many of the substances that are held therein are not in the state of true solution. This applies to the protein matter. It happens that the molecules, or more likely molecular aggregates, are too large to enable them to dissolve, and consequently they remain suspended in the aqueous medium in much the same way as very fine dust particles are dispersed throughout the atmosphere. Little is really known of the actual mechanism of dissolution of substances, but whenever the true explanation becomes known it is fairly safe to prophecy that the vast surface forces which are known to exist at the interfaces between the dissolved molecules and the solvent will be found to play an essential rôle. Those substances which, though not actually dissolving in a medium, remain in suspension, are known as being in either colloidal solution or colloidal suspension. The particles thus suspended may be so very small that they cannot be detected by the naked eye, though it often happens on very careful examination with an instrument, the ultra-microscope, that shadows of these particles can be seen and, moreover, can be observed to be in a state of unceasing motion. It must be understood that these colloidal particles are often so small that they cannot be seen directly by means of any optical instrument, however great may be its magnifying power. In designing the ultra-microscope advantage is taken of the fact that when a strong beam of light is sent through the medium containing these colloidal particles shadow-effects are produced by them, that can be seen when observed at right angles to the direction in which the beam is made to travel. This is the reason why the air in the beam of sunlight in a room appears to be full of dust when viewed at right angles to the sunbeam. Actually no dust itself is seen and the air in the rest of the room seems to be perfectly free from dust. Due to the fact that light travels in a wave motion, the wave-lengths of which are of the same order of magnitude as the infinitesimally small dust particles suspended in the air, these particles interfere with the wave-motion of the incident light with the result that a beam of light is thrown off at right angles in which these shadow-effects are seen. The production of such a beam by colloidal solutions was observed by Tyndall, and is now one of the criteria of colloidal solutions. Particles are visible in the highest power ordinary microscope if they are not smaller than one hundred-thousandth part of a centimetre in breadth, i.e., $\frac{1}{254.000}$th part of an inch. The smallest particles which have been investigated by means of the ultra-microscope have a diameter slightly greater than one two-millionth part of a centimetre or one five-millionth part of an inch.

Molecules are invisible in the ultra-microscope and are, therefore, smaller than one two-millionth part of an inch. They are, indeed, of the order of one two-hundred-and-fifty-millionth part of an inch in width, i.e., $\frac{1}{250.000.000}$ inch. The hydrogen molecule and that of water vapour have approximately this diameter, whilst that of common salt is nearly three times as great, and the sugar molecule about seven times. Compared with these molecular dimensions may be mentioned objects that are directly visible in the ordinary microscope. Thus the red corpuscle in human blood is about one three-thousandth part of an inch thick, about the same size as a rice starch granule, and the length of the anthrax germ is about one four-thousandth part of an inch. Regarding solutions that are known as true or homogeneous solutions and those that are colloidal and heterogeneous, it will be understood that the essential difference is one of particle size. In true solutions the molecules are so very small as to make them optically clear, whilst in colloidal solutions the somewhat greater particles dispersed may cause opalescence or, if the particles are sufficiently large, turbidity. It might be mentioned, in passing, that the atoms, of which all matter is composed and in which such huge amounts of energy are stored, are certainly not greater than $\frac{1}{250.000.000}$th part of an inch in diameter.

As we have already said, proteins are essential to the life of the cell. They are perhaps the chief constituent of the protoplasm or cell-liquid. In the cell these proteins are produced by some such manner as indicated on page 16 by the joining-up of one, after another, of certain comparatively simple amino-acids. Of these acids about twenty are known, and it is with these that the highly complex proteins are built up by making about one hundred, and in some instances two hundred, linkages. It is fairly certain that the character of any particular protein is determined not only by the proportion of the various amino-acids used, but by the precise order in which they are linked together. The number of such combinations that are possible is appallingly large, yet in the natural process that takes place within the cell these amino-acids are so selected, arranged and combined that only a relatively small number of proteins are produced. The chemist can with comparative ease break down these proteins into their constituent amino-acids, but up to the present he has been unable to put them together again to re-form the original proteins. He has not yet learnt from Nature how to select, arrange and cause the amino-acids to combine. This wonderful process appears to be possible only within the living cell, and seems to be one of the secrets wrapt up in the mystery of life. Until man has learnt from Nature the mechanisms of synthesing the proteins that feature so much in his food, and, indeed, on which his very existence depends, there is no possibility of natural foods becoming replaced by synthetic foods. It is not certain whether protoplasm is alive, and that life is confined only to the cell-nucleus. The life of any individual starts in a single cell, and the chromosomes that are present in the nucleus are believed to have within them all the potentialities that determine the characteristics of the body of the developed individual, even to the minutest detail such as the colour of the eyelashes. Nucleic acids constitute about 40% of these all-important chromosomes. The single cell, the fertilised ovum, in which the life of the human-being begins is not more than one one-hundred-and-one-twenty-fifth part of an inch in diameter. In the first stages of development this cell becomes divided and sub-divided into multitudes of cells. Thus it will be realised that the chemical nature of the chromosomes, when better understood, will in all probability assist in the formulation of a more complete theory of genetics. Sufficient has been written to indicate what an important part may be played by bio-chemical research in the solution of the mystery of life.

Some cells contained in various parts of the body have particular duties to perform and when these are done the cell shrivels up, dies and the nucleus thus becomes functionless. This is true of the cells constituting the connective tissues in producing the collagen of which they and skin are formed. Collagen is a protein body, and as it is manufactured within the cell it is reasonable to assume that the nucleus itself is the centre at which the protein building actually takes place. In like manner it is in the cells of the mammary gland that the proteins found in milk are made. They are : casein, lactalbumin and lactoglobulin.

The study of milk is full of interest, as it is the fluid that Nature has ordained as suitable for the feeding and development of her young. It is not surprising, therefore, to find that it contains all the substances of which the body is made. A typical analysis of cows' milk is 3·5% of fat, 3·5% of protein, 4·8% of lactose and 0·7% of mineral matter. Human milk contains the same amount of fat; less protein, viz., 1·5%; more lactose, 6·8%; and only 0·2% of mineral matter. Though containing somewhat less fat and a little more inorganic matter, the milks of the mare and ass approach more nearly human milk as far as composition is concerned than does the milk of any other animal. The inorganic matter contains lime and phosphoric acid, required for bone and teeth formation, and also some potash, soda, magnesia and hydrochloric acid. These substances are present in the combined state, and a portion of the bases unite with the protein material. In so doing the milk acquires a very slight acidity suitable for digestion by the particular young. One of the reasons for the difficulties encountered in feeding infants with cows' milk is that it is somewhat difficult to digest. It happens that human milk is more acidic than cows' milk, the *p*H value of the former, while fresh, being about 6·5, compared with *p*H 5·5 of human milk. It has been found that cows' milk can be rendered more digestible by adding sufficient acid, which may be either hydrochloric or lactic acids or better in the form of fresh lemon juice, to bring about the increase in acid intensity. The use of lemon juice is preferable in that it also introduces the antiscorbutic vitamin.

Fresh milk contains no lactic acid, but it is soon produced as the result of bacterial action. Except in the case of disease, bacteria do not penetrate into the blood and the liquids contained in the cells of the body.

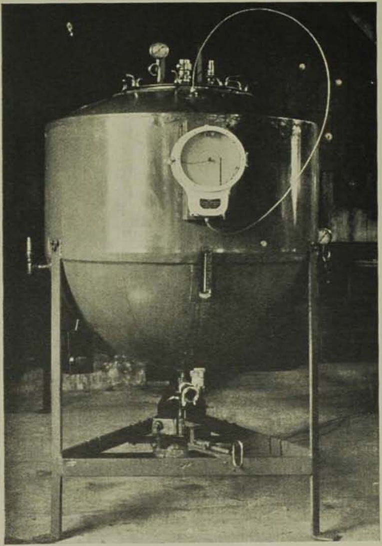

FIG. 16.—Nickel Pasteurising Tank.
(Courtesy, Messrs. The Mond Nickel Co., Ltd., London.)

Except for the milk which is the first drawing and which consequently might have become infected by germs that gained access to the teats, milk as it leaves the body is free from bacterial contamination. The milk, however, may soon become infected by coming into contact with the exterior of the udder, and also from the air and the use of bottles that have not been thoroughly sterilised. Hygienic conditions in the farm and in the dairy are of paramount importance, but in these days, when milk has often to be transported long distances, which thus allows ample time for bacterial reproduction, some means for the sterilisation of milk is necessary. Microorganisms are able to withstand low temperatures, though their rate of reproduction is considerably diminished. Adult forms, especially of the disease-producing type, are easily killed by heating to 70° C. for a short time. Unfortunately their spores are not so easily killed, and on cooling the milk they recover their activity, grow and reproduce. It should be stated, however, that maintenance of the milk at the freezing point of water or at a few degrees above retards the growth of the spores. This method of heating for a short time at 70° was introduced by Pasteur. Repeated "pasteurisation" has been advocated, so that between each heating the milk is kept at a lower temperature to facilitate the development of the spores that were not killed during the previous heating in order that they may be more susceptible to death during the subsequent heating. Boiling is more efficient as regards the killing of bacteria.

Milk is a colloidal solution and the proteins are in the state of suspension. The suspended particles can be reduced in size by forcing the milk through very fine jets by the application of pressure. Milk so treated is commercially known as " homogenised milk "; the fineness of the particles tends to render it more digestible and therefore to be of some service to invalids and infants.

The protein, casein, found in milk finds considerable application in industry. Thus casein cements are sometimes used in the manufacture of three-ply wood. Casein forms the basis of certain plastics, used in making buttons, and also of water-paints or wall-distempers.