ESSENTIALS OF
PHYSIOLOGICAL CHEMISTRY

BY

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PREFACE

In writing this book it has been my purpose to present the more important facts of biochemistry as related to the animal body in a form which will be understandable to a student with a limited preparation in chemistry and biology. However, this book presupposes at least a brief course in organic chemistry.

It is my opinion that a thorough knowledge of the chemistry of biological compounds is a prerequisite to an understanding of biochemistry. For this reason more emphasis is placed on the chemistry of the carbohydrates, lipids, and proteins than is found in many of the elementary books in this field.

Since laboratory work is usually an important feature of a course in biochemistry I have felt justified in presenting considerable material with laboratory work in view. Many of the questions which students ask in the laboratory are answered in the text. In this way it is felt that lecture and laboratory work are more closely tied together.

With regard to references for substantiating statements made or for the purpose of stimulating outside reading, it has been my experience as a teacher that very little use is made of these by the undergraduate student. For this reason only a few of the more important general references are included at the end of each chapter. If the student will refer to these books he will find in most cases rather complete bibliographies on the subjects concerned.

Many of the subjects considered in this book are controversial. I have attempted to avoid controversy as much as possible, and perhaps have erred in leaving the student with the impression that the explanations presented are final. In a brief book such as this it has seemed unwise to confuse the student with arguments pro and con. It has been thought best to leave these for more comprehensive books used in more advanced courses in biochemistry.

This book is an outgrowth of a course which I have given to students in home economics who have had courses in general inorganic chemistry, household chemistry, and a brief course in organic chemistry. It is designed to furnish a background for future courses in dietetics and nutrition. Although designed for students of human nutrition, it is hoped that this book will prove of value in more general courses in animal

biochemistry such as are given to pre-medical, agricultural, bacteriolog
ical, and other biological students.

I wish to take this opportunity to thank all of those who have so kindly
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ESSENTIALS OF PHYSIOLOGICAL CHEMISTRY

CHAPTER I

INTRODUCTION

Every student of organic chemistry is familiar with Wöhler's epoch-making discovery, in 1828, of the synthesis of urea from ammonium cyanate. The importance of this discovery was not that a difficult organic synthesis had been performed, but rather that it set aside important conceptions regarding the nature of organic compounds. Before Wöhler's discovery, organic chemistry concerned itself with the compounds found in living matter, that is, in plants and animals, and it was thought that these compounds bore little relationship to what we now know as inorganic compounds. In fact, it was felt that the compounds found in plants and animals owed their origin to some mysterious vital force which was beyond the scope of human intelligence. Urea was a very typical organic compound, according to these early conceptions, being the main nitrogenous constituent of human urine, whereas ammonium cyanate was classed as an inorganic compound. The synthesis of urea by simply boiling a solution of ammonium cyanate showed that organic compounds could be made in the laboratory and that a vital force was unnecessary.

Most of the compounds found in plants and animals contain the element carbon, so that even according to the old idea organic chemistry dealt mainly with carbon compounds. Since Wöhler's synthesis of urea hundreds of thousands of carbon compounds have been synthesized in the laboratory, and most of these are in no way associated with living things. Today all carbon compounds are included under the head of organic chemistry, which has been defined as the chemistry of carbon and its compounds. The chemistry of the carbon compounds found in plants and animals has become a minor part of organic chemistry.

That branch of chemistry which we are about to consider resembles in many ways the old conception of organic chemistry in that it deals with the chemistry of living things. It is called **biochemistry.** Much of the earlier work in this field was done on animals and is an outgrowth of the study of animal physiology. Because of this it has been known as

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physiological chemistry. More recently much work has been done on the chemistry of plants, and some have chosen to call this branch of biochemistry **phytochemistry.**

There is no fundamental difference between the chemical processes going on in animals and plants which would necessitate a subdivision of biochemistry into the two branches above indicated. Both animals and plants are made up of cells, and every living cell is filled with a substance called **protoplasm** which is fundamentally the same whether it is found in animal or plant cells. Protoplasm is the fundamental substance concerned with life. Biochemistry then becomes the study of the composition of protoplasm and the chemical changes which take place in it.

It would be difficult to give a concise definition of living matter which would distinguish it from lifeless material. Perhaps it can best be done by mentioning certain properties which are common to all living matter and which are for the most part lacking in lifeless material. These properties are: first, living things have the power within themselves to **move.** This is very evident in animals, which may move from place to place. It is less evident in plants, but a study of plant habits by means of speeding up motion pictures has revealed startling movement in plants also. The opening of the flowers of the four o'clock each afternoon is a good example of motion in a plant. Second, living things **grow**; they increase in size, not as a stone in the bottom of a creek might enlarge by deposition of material upon it, but from within, by the increase in the size or in the number of cells. Third, living matter is **irritable**, or in other words, it responds to stimuli. A living animal will move if pricked with a pin; a dead one will not. The sensitive-plant will close its leaves in response to a touch, and plants in the dark will grow toward light. Fourth, living matter has the power of **reproduction.** Living matter which is at present on the earth either must have existed forever, or must have been a product of reproduction from some pre-existing organism. We know that the second alternative is the only reasonable explanation. Fifth, living matter is constantly undergoing chemical changes known as **metabolism.** All the properties of living matter mentioned above are the results of metabolism. Growth is the result of the absorption of food and its conversion into new tissue. Motion requires energy which comes from the oxidation of foods. The oxidation of foods which involves the utilization of oxygen and the liberation of carbon dioxide is a prominent phase of metabolism known as **respiration.** Even apparently lifeless tissues like those in seeds, vegetables, and fruits have perceptible respiratory exchanges. An important feature of the metabolism going on

in protoplasm is that it is regulated. The chemical changes do not take place in protoplasm in a haphazard manner but are of a nature suited to the needs of the particular process going on in a given mass of protoplasm. We may, then, define living matter as something which has the power of motion, growth, irritability, reproduction, and metabolism. No lifeless thing has all these properties.

Because of the remarkable properties which protoplasm exhibits, one might expect to find some very rare elements in its make-up. As a matter of fact, protoplasm is composed of the commonest elements which are found on the earth. Perhaps the most striking thing about the composition of protoplasm is its high water content. The amount of water present varies from 70 to 90 per cent. In general we may say that the more reactive protoplasm is, the higher is its water content. Inorganic elements in the form of common salts are found in relatively small amounts. About 1 per cent of protoplasm is ash, which is composed of sodium, potassium, calcium, magnesium, iron, phosphates, carbonates, sulphates, and chlorides in comparatively large amounts, together with traces of such elements as copper, manganese, zinc, silicon, tin, and iodine.

From 10 to 25 per cent of protoplasm is made up of organic matter. This may be divided into four main classes of compounds, namely, the carbohydrates, the fats and related compounds, proteins, and a miscellaneous group of compounds commonly called extractives. These will be discussed in detail later.

CHAPTER II

PHYSICAL CHEMISTRY

In order to discuss intelligently the subjects which are to follow, certain fundamental things which belong to the field of physical chemistry should be considered.

Properties of Water of Biological Importance. As has been stated in the last chapter, protoplasm contains from 70 to 90 per cent of water. Many of the properties of water are extremely important in biology. Water has a **high specific heat.** With a few exceptions it may be said that it takes more heat to raise the temperature of a given weight of water 1°C. than it does for any other known substance. Likewise water gives off more heat when it cools than any other substance. Water has a high **heat of vaporization.** It requires 539 calories to convert 1 gram of water at 100°C. to a gas. When we perspire and water evaporates from the surface of the body there is a cooling effect. The above properties of water are undoubtedly of extreme importance to an animal in the functioning of its heat-regulatory mechanism. Water is the best substance we could have in our bodies to aid us in maintaining a constant body temperature. It is a remarkable fact that our body temperature remains constant in health, and the fact that our bodies have such a high water content undoubtedly has much to do with it.

Another property of water which is of great advantage to a living organism is its ability to dissolve things. No other known liquid is such a **universal solvent** as water. All substances which go to make up protoplasm are more or less soluble in water, so water makes an ideal medium for carrying nutrients to and waste products away from the cells. Protoplasm may be looked upon as a **combination** of a true and colloidal solution of its various constituents.

Properties of Solutions. Osmotic Pressure. If it is true that protoplasm is a solution of its constituents in water, a knowledge of some of the properties of solutions should be of value in order to understand what is going on in protoplasm. In many respects a substance in solution conducts itself as though it were a gas. It will be recalled that in beginning chemistry much stress was laid on the gas laws. One of these, known as **Avogadro's law,** states that there are the same number

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of molecules in equal volumes of all gases at the same temperature and pressure. It will also be remembered that 1 gram-molecule of any gas at 0°C. and 1 atmosphere of pressure (760 mm. of mercury) occupies 22.4 liters.

If one places a solution, containing 1 gram-molecule of a substance which does not ionize in 1 liter of water, in a **semipermeable membrane** (a membrane permeable to water but not to the dissolved substance) and then places the membrane in water, it will be found that water will pass through the membrane and dilute the solution. A common method of preparing such a membrane is to take a porous cup and deposit in its pores copper ferrocyanide. This is done by filling a porous cup with a solution of $CuSO_4$ and suspending the cup in a solution of $K_4Fe(CN)_6$. As the two solutions meet in the pores of the cup they form a precipitate of $Cu_2Fe(CN)_6$. The copper ferrocyanide becomes the membrane which is given rigidity by the porous cup. If one fills this with the molar solution described above and seals the opening with a manometer, a device for measuring pressure (see Fig. 1), and places the cup in water, it will be found that a pressure of 22.4 atmospheres will develop in the cup if the volume is kept constant. If the experiment were repeated using a solution of such strength that 1 gram-molecule is dissolved in 22.4 liters of water, the pressure would be 1 atmosphere. This pressure is called **osmotic pressure** and may be defined as the pressure which must be applied to a solution to prevent an increase in volume when it is separated from water by a semipermeable membrane. The passage of water through a semipermeable membrane is called **osmosis**. From the examples just given, it will appear that a substance in solution acts very much like a gas with respect to the volume occupied by a gram-molecule and the pressure exerted. In physical chemistry a common method for deter-

Fig. 1. Apparatus for measurement of osmotic pressure. The porous cup A, with the $Cu_2Fe(CN)_6$ membrane deposited in its walls, contains the solution to be tested. B is a mercury manometer. D is a glass tube which is sealed when the level of the mercury at C is the same as the level of the solution in A. The cup A is placed in distilled water. From "Introduction to Physiological Chemistry" by Bodansky.

mining the molecular weight of a substance which can be converted into a gas is to measure the volume occupied by a given weight of
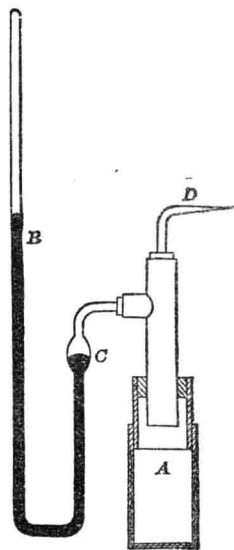
the substance when converted into a gas. From this one can calculate the weight of a substance necessary to give a volume of gas of 22.4 liters at 0°C. and 760 mm. pressure, and the result is the molecular weight of the substance. In a similar manner one may use an osmotic-pressure method for determining the molecular weight of a substance which is soluble in water. For example, if 10 grams of a substance which does not ionize, dissolved in a liter of water, gives an osmotic pressure of 1 atmosphere, 224 grams in a liter would give an osmotic pressure of 22.4 atmospheres. Hence 224 would be the molecular weight of the substance.

Many theories have been advanced to explain osmotic pressure, but none seem to be entirely satisfactory. It does appear, however, to be related to the attraction which exists between a substance in solution and the solvent. When a substance in solution is separated from water by a semipermeable membrane, water undoubtedly passes both in and out of the membrane. Owing to the attraction of the solute for the
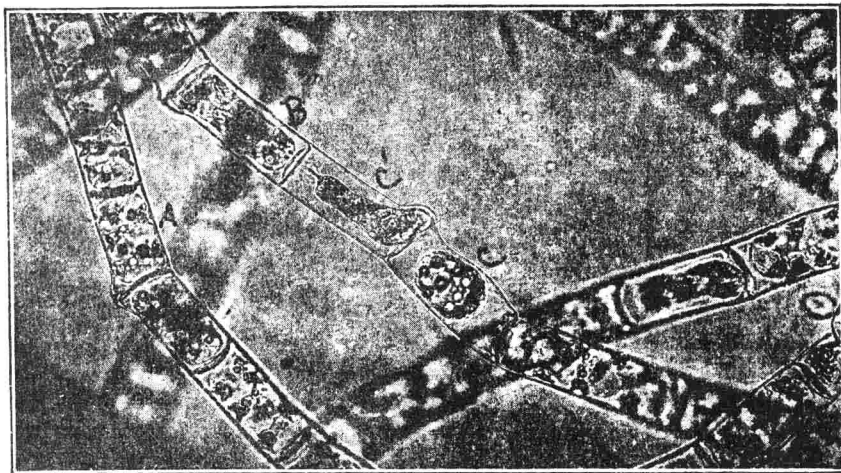

Fig. 2. Plasmolysis of cells of spirogyra in 0.35 M sucrose solution. Cell A is essentially normal. Cells B, C, and C¹ show various degrees of plasmolysis (after Lloyd). From "Outlines of Biochemistry" by Gortner.

solvent, water passes in more readily than out and hence the volume tends to increase on the inside, or if this is prevented, a pressure develops.

Most membranes are not strictly semipermeable, but will allow other simple molecules to pass through them besides water. Because of this, it is possible to separate simple molecules from complex molecules by

allowing the simple molecules to diffuse through such a membrane. This process is called **dialysis**.

Since the cells of the body are filled with solutions and since the cell walls are membranes, it is evident that osmosis and diffusion are important factors in life processes. The absorption of food from the intestine, the distribution of food throughout the body, and the elimination of waste products from the cells are at least in part due to these phenomena.

One can measure the osmotic pressure of cells by placing them in a series of solutions of different osmotic pressures. If the osmotic pressure of a solution is greater than that of the cell, water will pass from the cell to the solution and the cell will shrink. Such a solution is said to be **hypertonic** to the cell, and the shrinkage of the cell is called **plasmolysis**. (See Fig. 2.) If the solution has a lower osmotic pressure than that of the cell, water will pass into the cell from the solution and the cell will swell. Such a solution is said to be **hypotonic** to the cell, and the swelling of the cell is called **plasmoptysis**. If the solution has the same osmotic pressure as the cell, the cell will neither shrink nor swell, and the solution is said to be **isotonic**. If one knows the osmotic pressure of a solution isotonic to a cell, he knows the osmotic pressure of that cell.

If one tests human blood cells in the above manner, it is found that their osmotic pressure is 7.2 atmospheres. A solution containing about 0.9 per cent of NaCl has an osmotic pressure of 7.2 atmospheres and is often spoken of as an **isotonic** or **physiological salt solution**. In medicine, when it becomes necessary to introduce solutions into the blood stream, it is extremely important to use isotonic solutions. Lack of care in this respect would destroy the delicate membranes of the blood cells, with very serious consequences.

Depression of the Freezing Point. A second important property of solutions is that a substance in solution lowers the **freezing point** of the solvent. As with osmotic pressure, we find that the lowering of the freezing point is proportional to the amount of substance dissolved. One gram-molecule of a substance which does not ionize, dissolved in a liter of water, will depress the freezing point $1.86°C$. Since a definite relationship exists between the amount of substance in solution and the osmotic pressure and the depression of the freezing point, it is easily seen that osmotic pressure and freezing-point depression are related to each other. In fact, because of the difficulties of technique involved in determining osmotic pressure directly, the usual method is to determine it indirectly by means of the freezing-point method. Just as osmotic-pressure determinations are used in determining the molecular weights

of substances in solution, so also the depression of the freezing point may be used. For example, if one dissolves 50 grams of a substance in a liter of water, and the freezing point is depressed 0.93°C., it is readily seen that 100 grams in the same volume would be required to depress the freezing point 1.86°C., hence 100 would be the molecular weight of the substance in question.

This property of substances in solution to depress the freezing point is of great importance to the biochemist. It places at his disposal a simple and accurate method for determining the osmotic pressure of biological materials, the importance of which has already been discussed. It explains why a slight frost may not be a killing frost. Because of the substances in solution, protoplasm will not freeze at the freezing point of pure water. A very practical application of this property of solutions has been used in the dairy industry to test milk for added water. The **freezing point of milk** has been found to be very constant at −0.56°C. If water is added to milk the freezing point is nearer 0°C. Tables have been prepared which tell with a high degree of accuracy the amount of water added to milk corresponding to freezing points from 0°C. to −0.56°C.

In explaining why the freezing point of a solution is lower than that of pure water, one may resort to an explanation similar to the one used to account for osmotic pressure. When a solution freezes, pure water separates from the solution. In other words, water is taken away from the dissolved substance, and since the solute has an attraction for the solvent, a lower temperature is necessary to bring about freezing than if water alone were frozen.

Elevation of the Boiling Point. A third property of solutions which is related to osmotic pressure and to the freezing point is the **boiling point.** Since at the boiling point many of the compounds of protoplasm are altered in nature — the coagulation of albumin is an example — the boiling-point method is not often used in dealing with biological materials. However, it will be mentioned briefly. One gram-molecule of a substance which does not ionize dissolved in a liter of water will elevate the boiling point 0.52°C. Because this value is related to the molecular weight, this method also may be used to determine the molecular weight of a substance and likewise to determine the osmotic pressure of a solution. However, owing to difficulties of technique, this method is seldom used.

The explanation of why the boiling point should be elevated by a substance in solution is based on the fact that substances in solution lower the vapor pressure of water. Since the boiling point is the point at which the vapor pressure is equal to the atmospheric pressure, it is

evident that a higher temperature would be required for a solution to reach the boiling point than for pure water. It might also be pointed out that, in the boiling of a solution, solvent is being separated from solute. Since an attraction exists between solvent and solute, as has been stated above, one might account for the elevation of the boiling point of a solution as being due to the extra effort necessary to separate the solvent from the solute.

Since osmotic pressure, depression of the freezing point, and elevation of the boiling point are so closely related, one often hears them spoken of as the **colligative** properties of solutions.

Surface Tension. A fourth property of solutions of biological importance is that substances in solution alter the **surface tension** of the solvent. Since surface phenomena are so important in life processes, it will be well to refresh our minds as to the meaning of surface tension. Everyone is familiar with the fact that a needle may be made to float if it is carefully placed on the surface of water. The water gives the
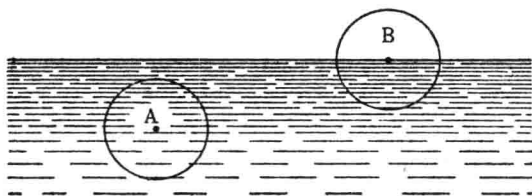

FIG. 3. Diagram showing forces of molecular attraction acting on molecules. The circles represent the field of attraction on molecules at their centers. In *A*, within the liquid, the force is equal in all directions. In *B*, at the surface, the force is greater downward than upward owing to the higher concentration of molecules in the liquid than in the vapor phase.

appearance of being covered with a thin elastic surface film. This surface film is due to a contraction of the liquid at its surface caused by surface tension. Surface tension is the resistance of a surface film to rupture. In the center of a body of liquid the molecules are attracted equally in all directions by other, similar molecules. (See Fig. 3.) At the surface the molecules are attracted more toward the center of the liquid than they are by the molecules of air above the liquid, hence it is assumed that, at the surface, the molecules are more compact. This concentration of molecules at the surface may be sufficient to give the surface layer the properties of a solid and in this way may account for the surface film.

Surface tension exists not only at the boundary between a liquid and air but wherever a liquid is in contact with something else, be it another

liquid or a solid. It will be evident, then, that the surfaces which exist in protoplasm, which is filled with particles of colloidal size, are enormous, and surface tension becomes a factor to be reckoned with in biochemistry. It should be noted that the contraction at a surface requires energy and that surface tension is a form of energy. Many of the energy changes which take place in protoplasm may be accounted for by changes in surface tension. If surface tension is reduced in a system, the energy liberated becomes available for other purposes.

Substances in solution alter the surface tension of the solvent. In general, the inorganic salts increase it whereas substances like fat, soap, and bile salts decrease it. A well-known principle states that the amount of free energy in a system will decrease if possible. Since surface tension is such a form of energy, it is not surprising to find that substances which lower the surface tension of water will concentrate in the surface film so as to lower the surface energy as much as possible. This concentration at a surface is called **adsorption.** Substances which increase surface tension tend to stay away from the surface film in order to increase the surface energy as little as possible. This is spoken of as **negative adsorption.**

Hydrogen-ion Concentration

Acidity and alkalinity, often spoken of as the reaction of a solution, are extremely important factors in the proper functioning of living organisms. If the reaction of our blood changes only slightly, acidosis or alkalosis will result which will end in death if allowed to go too far. Muscular contraction has been explained on the basis of the changes in reaction taking place in muscle fibers. In bacteriology great care must be taken to regulate the reaction of media in order to make them suitable for the growth of a particular micro-organism. In order to understand modern biology, it is quite necessary for the student to know what is meant by **hydrogen-ion concentration,** and to do this he should be familiar with some of the theory back of it.

Quantity Factor of Acidity. An **acid** has been defined as any substance which gives hydrogen ions when in solution. When we speak of the strength of an acid we may be considering either one of two factors, namely, the quantity of acid in a given volume or the intensity of acidity. In that part of quantitative analysis which deals with acidimetry and alkalimetry we are interested in the amount of acid present in a given volume of solution. We do not care whether the acid in solution is in the molecular or in the ionic form. A solution which contains 1 gram-atom, i.e., 1.008 grams, of acid hydrogen per liter is called a **normal solution of an acid.** A solution of a base of such a

strength that it will neutralize an equal volume of normal acid is called a **normal solution of a base.** A **base** has been defined as a substance which will give OH ions when in solution. When a base neutralizes an acid the H ion of the acid combines with the OH ion of the base to form H_2O. Hence an OH ion in a base is equivalent to an H ion in an acid. A normal solution of a base is a solution containing 1 gram-radical of OH, i.e., 17.008 grams, per liter. To make a liter of a normal solution of HCl, one must take 1 gram-molecule of HCl, or 36.458 grams, in order to get 1.008 grams of hydrogen. In like manner one must take 40.008 grams of NaOH to obtain 17.008 grams of OH for 1 liter of normal solution. If one wishes to make a normal solution of H_2SO_4 he must dissolve $\frac{1}{2}$ gram-molecule of this acid in a liter, since in this quantity of H_2SO_4 there are 2 gram-atoms of hydrogen. The same principle would apply for bases, such as $Ba(OH)_2$, where there are 2 gram-radicals of OH per gram-molecule. In practice one rarely uses an exactly normal solution, but instead, carefully standardized solutions whose strengths are designated by normality factors. A **normality factor** is a number, by which one may multiply, to convert any number of cubic centimeters of solution into cubic centimeters of normal solution. If one should use 100 cc. of a solution whose normality factor is 0.1252, it involves a very simple calculation to arrive at the conclusion that this is equivalent to 12.52 cc. of normal solution. For brevity the letter N is usually used for normal, and the above solution would be designated 0.1252 N. A tenth normal solution is often written $N/10$ or 0.1 N. Any solution the exact strength of which is known is called a **standard solution.**

The determination of the quantity of acid in such a biological fluid as the urine is often desirable. One does this by adding to a definite quantity of the urine a solution of alkali whose normality or strength is known. Phenolphthalein is used as an indicator to tell when the acid in the urine has been neutralized. Results are expressed as the number of cubic centimeters of $N/10$ alkali necessary to neutralize a 24-hour sample of the urine. In this way one can easily calculate the quantity of acid eliminated per day. This is what is known as **titratable acidity,** and it should be noted that it is a measure of the quantity of acid present, not of the intensity of the acidity.

Intensity Factor of Acidity. We will next pass to a consideration of the intensity of acidity. When an acid is dissolved in water some of the molecules dissociate into H ions and acid radical ions. The intensity of an acid depends upon the degree of this dissociation, or rather upon the concentration of H ions. Speaking of an acid solution from the intensity standpoint we would call an acid normal if there were

1.008 grams of ionic hydrogen per liter. Such a solution might be many times normal from the standpoint of quantity of acid present.

In order to understand the subject of hydrogen-ion concentration one must first understand the **law of mass action,** which states that the speed of a chemical reaction is proportional to the molecular concentration of the reacting substances. In the reversible reaction

$$NaNO_3 + H_2SO_4 \rightleftharpoons NaHSO_4 + HNO_3$$
$$a \qquad\quad b \qquad\qquad c \qquad\qquad d$$
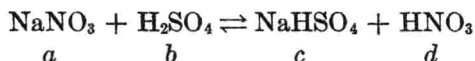
the speed from left to right is proportional to the concentrations of a and b. In algebra we are taught that, if a thing is proportional to two things, it is proportional to their product. Hence the speed from left to right is proportional to $a \times b \times k$, where k is a constant whose value depends on conditions such as temperature. In like manner the speed of the reaction from right to left is proportional to $c \times d \times k'$. When the reaction has proceeded to equilibrium the speeds in each direction must be equal, hence

$$a \times b \times k = c \times d \times k'$$

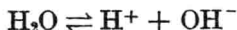from which we may derive the following formula:

$$\frac{a \times b}{c \times d} = \frac{k'}{k}$$

Since a constant divided by a constant is equal to a constant, we have

$$\frac{a \times b}{c \times d} = K$$

This K is called the **equilibrium constant.**

In water we find that some of the molecules ionize thus:

$$H_2O \rightleftharpoons H^+ + OH^-$$

Thus, if we apply our definitions of acid and base to water, we find that water is an acid and at the same time a base. Since a molecule of water gives an equal number of H^+ and OH^- we say it is neutral because it is just as strong an acid as it is a base. If one adds to water a substance which gives H^+ in solution there will be more H^+ than OH^-, and hence we say the solution is acid.

If we apply the law of mass action to the last equation as we did to the first, we find

$$\frac{\text{Conc. } H^+ \times \text{Conc. } OH^-}{\text{Conc. } H_2O} = \frac{k'}{k} = K$$

Since water ionizes only slightly, the value of the Conc. H_2O becomes very great and for all practical purposes may be considered a constant. Hence the equation becomes

$$\frac{\text{Conc. } H^+ \times \text{Conc. } OH^-}{k'} = K$$

or

$$\text{Conc. } H^+ \times \text{Conc. } OH^- = k' \times K$$

or

$$\text{Conc. } H^+ \times \text{Conc. } OH^- = K$$

Methods are available for determining the H-ion concentration of pure water. It has been found that pure water is $1/10{,}000{,}000$ N with respect to H ions. Mathematically the fraction $1/10{,}000{,}000$ is usually expressed as 10^{-7}. We then say that the H-ion concentration of pure water is 10^{-7} N. Since in pure water the Conc. H^+ and Conc. OH^- are equal, the concentration of each must be 10^{-7}, and K is then 10^{-14}

$$\begin{array}{ccc}
\text{Conc. } H^+ \times & \text{Conc. } OH^- = & K \\
10^{-7} & 10^{-7} & 10^{-14}
\end{array}$$

Pure water, then, may be looked upon as an acid which is 10^{-7} N with respect to H^+ and also as a base which is 10^{-7} N with respect to OH^-.

If one adds to water some acid the concentration of H^+ will increase. Let us suppose that the solution becomes $1/100$ N with respect to H^+. The Conc. H^+ of such a solution is 10^{-2} N. From our original equation we know that Conc. $H^+ \times$ Conc. $OH^- = 10^{-14}$. If we know that the Conc. H^+ is 10^{-2}, then we also know that the Conc. OH^- is 10^{-12} since $10^{-2} \times 10^{-12} = 10^{-14}$. If we should add a base to water we would increase the Conc. OH^- above that of pure water. Let us suppose that we added enough base to water to give a solution which is $N/1000$ with respect to OH^-. The Conc. OH^- would then be 10^{-3} N. Knowing this, we could easily calculate the Conc. of H^+. It would be 10^{-11} because the product must be 10^{-14}:

$$10^{-11} \times 10^{-3} = 10^{-14}$$

Thus it is seen that if one knows the Conc. H^+ he also knows the Conc. OH^-. It thus becomes possible to express degrees of alkalinity in terms of H^+ Conc. If the negative exponent of 10 is 7, the solution is neutral; if less than 7, acid; and if more than 7, alkaline.

Since in expressing H^+ Conc. one always uses the expression 10^-, Sörensen has suggested leaving 10^- out and using only the numerical value of the negative exponent. He calls this the *p*H value. The expression *p*H really means the power (exponent) of hydrogen. Mathe-