PHYSICAL CHEMISTRY AND ITS APPLICATIONS IN MEDICAL AND BIOLOGICAL SCIENCE

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PHYSICAL CHEMISTRY

AND ITS APPLICATIONS IN MEDICAL AND BIOLOGICAL SCIENCE

BEING A COURSE OF SEVEN LECTURES DELIVERED IN THE UNIVERSITY OF BIRMINGHAM

BY

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PREFACE

The rapid development which has taken place in Physical Chemistry during the past two decades, and the success which has attended the application of physico-chemical principles and methods to the study of problems in Medical and Biological Science, render it of essential importance for students and workers in these departments to become familiar with the chief facts and theories, as well as methods, of Physical Chemistry.

As this Science is not usually included in the curriculum of study imposed on students of the biological sciences generally, it was with pleasure that the writer acceded to a request to give a short course of lectures on the subject, having in view, more especially, the requirements of members of the medical profession. No attempt at completeness has been made, for that would have been impossible in the short space of time available; but rather the desire was to give an elementary introduction to the subject, with the hope of encouraging and facilitating a more systematic and thorough study of physical chemistry on the part of students of medicine and biology.

In compiling these lectures the writer has received much assistance from the books by E. Cohen, *Vorträge für Ärzte über physikalische Chemie* (which has also appeared in English translation); R. Höber, *Physikalische Chemie der Zelle und Gewebe*; H. Koeppe, *Physikalische Chemie in der Medizin*; and especially from the standard work by H. J. Hamburger, *Osmotischer Druck und Ionenlehre in den medizinischen, Wissenschaften*; and he desires also to acknowledge the courtesy of the Editor in permitting the lectures to be reprinted from the pages of *The Birmingham Medical Review*.

A. F.

PHYSICAL CHEMISTRY AND ITS APPLICATIONS IN MEDICAL AND BIOLOGICAL SCIENCE.

By ALEX. FINDLAY, M.A., Ph.D., D.Sc., *Lecturer on Physical Chemistry in the University of Birmingham.*

WHEN we look back on the course of development of any of the branches of experimental science, we always observe that the progress of development is a discontinuous one, consisting of periods during which a rapid and vigorous development is succeeded by slower and feebler growth. Each of these generations in the life of the science begins with the conception of a new hypothesis and the birth of a theory which not only enables us to see the line of co-ordination binding together the isolated results of experimental enquiry, but also sends a beam of light, more or less intense, into the darkness of the unknown, thereby revealing paths along which further advance can be made. As advance proceeds farther and farther from the source, the light becomes fainter, and many facts and phenomena are encountered which are imperfectly illumined, and remain only partially understood until they also are lit up by the radiance of a new theory.

Thus it is that the great development in the study of solutions dates from the time when, in 1886, the Dutch chemist and physicist, van't Hoff, put forward his theory of solutions, and when, in the following year, the Swedish physicist, Arrhenius, propounded his theory of electrolytic dissociation of salts in solution. Not only did these twin theories co-ordinate a large mass of isolated facts and phenomena which were imperfectly understood, but they also opened up a new and large world for scientific investigation. Nor has the development which has taken place as the result of these theories been confined to physical chemistry; almost all the other experimental sciences have been markedly affected.

Since the laws of solution are nowhere of more importance than in connection with the animal and vegetable world, it is not surprising that the theories of van't Hoff and Arrhenius should have exercised an important influence on the development of medical and biological science. Thus we find that whereas, formerly, the function of biological chemistry was to investigate the nature of the compounds existing in plants and animals, and to discover the methods of isolating and producing them; recently, attention has been increasingly paid to the study of the vital processes taking place in the organisms, more especially in relation to the nature of the various solutions constituting the different body fluids of animals and the cell sap of plants. That work of great interest and importance has already been accomplished in this direction is known to every student of the biological sciences. One only requires to recall the work of Pfeffer and of de Vries on the application of the laws of osmotic pressure of solutions to the study of the movements and growth of plants; of Hamburger, on the hæmolysis of the red blood corpuscles; of Mascart and of Vladimiroff, on the relations between the osmotic pressure of solutions and their chemotactic influence on bacteria; as well as the similar experiments of Pfeffer on the spermatozoa of cryptogamic plants; and lastly, the almost startling experiments of Loeb on the influence of osmotic pressure and of certain ions in the production of artificial parthenogenesis.

In thus furthering the advance of biology, physical chemistry was only paying a debt which it owed to the biological sciences themselves; for it was largely owing to the experimental work of the botanist, Pfeffer, and of other biologists, that van't Hoff was able to establish his theory of solutions. While this is so, it can, however, also be said that the debt has been paid with interest, for by the introduction of the theories of solution, a development was assured to the biological sciences such as they probably would not otherwise have attained. That in this way the two branches of science—the physical and the biological—have been so mutually helpful, cannot but give the greatest satisfaction to all scientific workers.

In view of the great influence which physical chemistry is exercising on the development of the biological sciences, it was with great pleasure that I undertook, at the request of some of my colleagues, to give a short account of some of the more important theories and methods of physical chemistry, and to indicate some of the problems to the study of which these have been applied.

As it is probably the theories of solutions that have exercised the greatest influence on the biological sciences, it is with the properties of solutions that I propose chiefly to deal, and pass on in the first place to consider

DIFFUSION AND OSMOTIC PRESSURE.

When two gases are brought into contact, then, as you are aware, diffusion takes place—the one gas passes into the other—and this process continues until the whole gas mixture has become uniform in composition throughout. Thus, the light gas hydrogen will diffuse *downwards* into the heavy gas carbon dioxide, and the latter will diffuse *upwards* into the hydrogen. This process is rendered very evident by placing a small quantity of bromine at the bottom of a cylinder containing air. In a few minutes it will be seen that the bromine vapour, although more than five times as heavy as air, has passed up to the top of the cylinder. The driving force of this process is the difference of the partial pressures of the two gases at the different parts of the vessel.

A similar process also occurs in the case of substances in solution. If two solutions of different substances, or of the same substance but of different concentration, are brought into contact, diffusion also takes place, although much more slowly than in the case of gases; and this process also continues until the solutions become of uniform concentration throughout. This diffusion can be easily shown with a test-tube filled with a solution of gelatine to which a little phenolphthalein has been added, and placed mouth downwards in a dish containing a solution of caustic soda. The alkali diffuses up into the tube and reddens the phenolphthalein. I have chosen the experiment in this form because of the fact—a fact of importance in physiological work—that the addition of gelatine, agar-agar, and other substances of the same nature scarcely affects the velocity with which diffusion of salts and crystalloids takes place, although it prevents, or almost entirely prevents, the diffusion of other gelatinous or colloidal substances. The presence of the gelatine is also of value in that it prevents mixing by means of convection currents.

This diffusion of dissolved substances can also be shown by means of the familiar apparatus, the dialyser. If a solution of salt is poured into a vessel closed by means of parchment paper and placed in water, we find that after a short time some of the salt has passed through the parchment into the pure water, and this process will continue until the concentration of the salt is the same outside and inside the dialyser. In the case of gases the driving force we saw was the difference of the gas pressures; in the case of solutions the driving force is called the *osmotic pressure*.

How can this osmotic pressure be measured? If we place the dialyser with the salt solution in a vessel of pure water, we shall find that water will pass into the dialyser faster than solution passes out, so that the level of the solution will rise and produce a hydrostatic pressure. This is the phenomenon of endosmosis. The height to which the liquid rises, however, cannot be taken as a measure of the osmotic pressure of the solution, for the level of the liquid never remains stationary, but after reaching a certain height begins to fall again, until the levels outside and inside the vessel are the same. If we placed in the dialyser or endosmometer different solutions having the same osmotic pressure, we should find that the level to which the liquid rose was different in the different cases. The production of a pressure is to be ascribed to the difference in the velocity of diffusion of the dissolved substances through the membrane. The greater the velocity of diffusion, the lower will be the level to which the liquid inside the endosmometer will rise. We must therefore distinguish between the temporary pressure produced owing to the difference in the velocity of diffusion and