A Method of Teaching Diffusion and Osmosis in Connection with Biological Work.

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Osmosis and diffusion are processes met with in many lines of biological science, and the problem involved in an attempt to make the phenomena clear, especially to an elementary class, is often a difficult one. It is not proposed to add here anything new from the physical or chemical standpoint to the array of facts already clustered around these subjects; it is intended, rather, to give clear, concise definitions of the terms and to present a method of teaching the subjects which has been found successful in connection with elementary botany. The need of such presentation has been felt after the perusal of twenty-five or thirty text-books on general botany and plant physiology, most of which are noncommittal or inconsistent with facts when discussing these phenomena.

When the name *osmosis* was coined, the process was little understood and many irrelevant considerations were connected with it. Since then the process has been found to be of much more general occurrence than was at first supposed, and our definitions and explanations must be generalized to meet our better understanding of it. A brief history of the explanations of diffusion and osmosis that have been before biologists of the last few years will help to clear up the situation.

Pfeffer looked for the secret of osmosis in the behavior of solutions of cane sugar, potassium nitrate, etc., when separated from the pure solvent, usually water, by membranes of various kinds. He did much to bring the process to the attention of biologists, but he necessarily saw only a limited portion of the field to be covered.

Van't Hof attempted to generalize the problem and asserted that in dilute solutions the dissolved substance behaved approximately as it would in the gaseous form, the temperature and volume being the same as that of the solution, and osmotic pressure being substituted for gas pressure. But this hypothesis has been found to attempt to explain too much even for dilute solutions and is of no avail at all in connection with more concentrated solutions, which are also capable of demonstrating osmotic pressure. It also has the defect of not making sufficient allowance for membranes that are not perfectly semipermeable.

The kinetic theory offers an explanation based upon the assumption that certain molecules bombarding a membrane are able, because of

some characteristic, presumably size, to make their way through even against a greater pressure than they themselves are exerting by their motion, while certain others fail to penetrate the membrane, even when aided by a difference of pressure. The most obvious objection to any consideration on this basis is found in the fact that certain liquids having large molecules—as some of the alcohols—are able to pass through certain membranes more readily than water.

Kahlenberg reports numerous experiments, both qualitative and quantitative, to show the fallacy of many of these theories. He makes no attempt to deal with the subject on a biological basis, but his results bring us near a working explanation for biological purposes. He attributes osmotic pressure to the relative affinities of two fluids for each other and for the separating membrane.

The report of the recent symposium of the Faraday Society on the subject of osmotic pressure was consulted in the hope that it would be of material aid; but it was found to contain little that is tangible or serviceable from our standpoint. Like Pfeffer's classic works, it was found to contain much about the mathematics of osmotic pressure and little about the process of osmosis.

The text-book definitions and discussions of osmosis and diffusion have been based upon one or a mixture of the theories here outlined. The prevailing influence of Pfeffer's work is evident in most of them, and, consequently, we see in them much about water and aqueous solutions of various densities. Osmotic pressure is too often emphasized at the expense of osmosis, and students of biology, who should be trying to understand the nature of the process and its relation to the plant, are still bored by having to read books and listen to lectures which emphasize the stupendous pressures exerted in cells; many a student finishes his course with a firmly fixed idea that relative density is the thing that makes the gases of the air and the water of the soil enter the plant body, and that density alone prevents all the sap of a plant from leaking out through the root hairs.

By means of a condensation and organization of what is known of the processes involved, there has been worked out a set of definitions and a method of presenting the subject which is believed to be superior to that given in most text-books of botany and plant physiology.

The first step in the teaching process is the well-known experiment of placing a crystal of some colored soluble salt, such as copper sulphate or sodium bichromate, in the bottom of a tall glass jar of water and watching the color ascend for a few days. The process is named *diffusion*, and the student is encouraged to work out his own definition. Diffusion is seen to consist of *the dispersal of the particles of one substance among the particles of another substance, without aid from external*

sources. It is also pointed out that an energy transformation has taken place in the migration of the particles of the salt upward through the water; the source of this energy is in the chemical affinity between the salt and the water.

The next step is to demonstrate the existence of this energy in its static form. The ordinary osmosis experiment, in which a parchment diffusion shell filled with a thick sugar syrup is immersed in a jar of water, is set up. When the difference in level has been established, the process that has taken place is named *osmosis*, and a definition of osmosis is in order. It is seen that the syrup and water have tended to diffuse into each other through the membrane, but the water has been more successful than the syrup in getting through; in other words, the membrane is more permeable to the water than to the syrup. Osmosis may be defined, then, as *the diffusion of two fluids through a membrane that tends to be semipermeable.*

It is necessary to speak of two *fluids*, rather than two *liquids*, as many texts do, because the process is characteristic of gases also under proper conditions, and this phase of the process is a very important one in a biological connection. It is not deemed wise to complicate the definition or the explanation with reference to the few cases in which osmosis has been shown to take place between a solid and a liquid.

It seldom, if ever, happens in practical work that the membrane is perfectly semipermeable. If we were defining the ideal process, it might be well to speak of an ideally semipermeable membrane; but, after all, our aim is to make the situation clear to a student of biology, and he seldom has to deal with questions of complete semipermeability. To define osmosis as merely *diffusion through a membrane*, as some texts do, is insufficient, for a membrane equally permeable to both fluids would not demonstrate osmosis.

It will be noted that the student is not confused by the introduction of relative density into the definition here proposed. The density idea is a remnant of the day when the full application of the process was not understood—when combinations of solution and pure solvent, separated by a suitable membrane, constituted practically the only system that had been thoroughly investigated. Now osmosis is known to take place between numerous combinations of pure substances, and numerous examples are afforded where the old rule of density works the wrong way.

The reference to density is especially deceptive in certain cases where one of the diffusing substances is a gas. An interesting illustration of this is afforded by an experiment often made to show the "lifting power of evaporation." A thistle tube filled with water has a piece of wet bladder tied over the larger end in contact with the water, and the tube

is supported in a vertical position with the smaller end dipping into mercury. As evaporation removes water from the wet membrane, water from the tube takes its place, and compensation is made for the decreased pressure by a rise of mercury into the lower end of the tube. But this is really a demonstration of osmosis. Evaporation in this case is merely the diffusion of water and air, and the process takes place through a membrane which allows water to pass more readily than air. It will be noted that the major flow is from water to air rather than from a less dense medium to a more dense.

It is true that when a solution and the pure solvent are considered, density may sometimes act, both qualitatively and quantitatively, as an indicator within certain limits; but we are by no means sure that it will work in all cases. It is probably worth mentioning that most of the experimental work that has been done with solutions and pure solvents have dealt with solutions whose density is greater than that of the pure solvent; but some combinations are possible in which the opposite is the case, and some interesting results might come from experiments with some of these. In the cases where the comparative density rule does work in determining the direction of the major flow and the ultimate pressure produced, color would probably serve as well for an indicator if a colored solute were selected and a sufficiently sensitive method of measuring intensity of color were devised; yet no one would think of connecting color with the fundamentals of the process. Density has about the same relation to the process as has color; chemical affinity is the driving force and the only consistent indicator of the qualitative and quantitative features of the process.

It will be seen that much depends upon the nature of the membrane through which the diffusion takes place, and to the physical chemist or the research student of physiology this is a very important thing. But to the student of the elementary aspects of biology, whose welfare is now being considered, the mechanism of the membrane is less important if he knows that for some reason it tends to be semipermeable. Whether the permeability of living membranes can be explained on a purely physico-chemical basis, or whether we must still have recourse to a vitalistic explanation until physics and chemistry have made sufficient progress to include these phenomena, is still an interesting problem of research.

It must be emphasized that, from the biological point of view, the effort expended in explaining diffusion and osmosis is lost if we fail to make clear their definite application to problems of plant and animal life, and many of our text-books fail to do this satisfactorily. Many of the texts examined make the assertion or leave the impression that the cell wall is the osmotic membrane concerned, and many leave with

the student the impression that osmosis takes place only in root hairs and is concerned only with supplying the plant with water and mineral food. The student should be led to connect osmosis with his knowledge of cell structure and to see the general nature and importance of the process. All the living matter (protoplasm) in the plant or animal body is disposed in definite units (cells), whose unity is determined by the plasma membrane. The whole normal contact of the cell with its physiological environment—food, water, soil, air, digestive fluids, other cells, etc.—is defined and regulated, in so far as it is regulated at all, by this membrane. Thus, it is seen that all the life processes—respiration, photosynthesis, imbibition by living tissues, transpiration, secretion, excretion, etc.—which involve the exchange of fluids between the cell and its environment, depend upon the selective influence of semipermeable membranes.

I take this opportunity to acknowledge valuable assistance given me in the study of this problem by Professor O. W. Brown of the Department of Chemistry, Indiana University.

References.

It is not deemed necessary to give here a detailed bibliography Standard texts will illustrate the defects pointed out; the historical side of the question is given in most good texts on physical chemistry. Kahlenberg's work is described in the Journal of Physical Chemistry, Volume 10.