increasing population needs the foodstuffs that may be produced, abundantly, on the irrigated farms, and the "landless" men want the new farms upon which to build independence for themselves and their families. During the last quarter of a century, public and private capital has been poured into the irrigation enterprises of the Great West; vast tracts have been opened for settlement; serious and difficult problems have arisen, which yet await solution. Thousands of investors, great and small, in all sections of the United States, are holding irrigation securities which in many cases are of doubtful value.

As the importance of land reclamation by irrigation became more fully realized, an irrigation literature of great value was produced, which, however, concerned itself chiefly with the construction of irrigation works, or with the actual use of water on the land. Mr. Teele, in the present volume, has had in mind the needs of the great body of our citizens, wherever they may live, who, because of their interest in irrigation, desire a comprehensive yet non-technical discussion of the meaning, extent, purpose, problems and present status of irrigation in the United States. The present volume is devoted, therefore, to a "discussion of the legal, economic and financial aspects" of irrigation.

The author has accomplished his purpose admirably. After a brief discussion of the irrigated section, with respect to climate, water supply and crops, the author takes up the consideration of legislation relating to irrigation, irrigation investments and the organization and operation of irrigation enterprises. This discussion, though brief, is exceedingly clear and comprehensive, and the reader is left with a vivid picture of the real irrigation situation in our country. Elements of weakness or strength are pointed out and wise suggestions are frequently made for improvement. To the seasoned student of irrigation, the last chapter, on the present situation and future of irrigation in the United States, is of greatest interest, for it includes the author's well-reasoned conclusions concerning the methods of stabilizing the economics of irrigation.

The book should be read and studied by national and state legislators, who have to do with the making of irrigation laws; by the projector of new irrigation enterprises; by the investor; by the man on the irrigated farm, and by all who are interested in the gigantic movement to conquer all of our Great West for the use of man.

Mr. Teele is particularly well fitted to speak with authority on irrigation subjects. Through his editorial hands have passed practically every irrigation publication issued by the U. S. Department of Agriculture since 1899. He is personally familiar with the irrigated section, and is an enthusiastic believer in irrigation, though he has never closed his eyes to its difficulties. Irrigation in its present stage of development needs honest friends.

The survey in this volume is so brief that we hope the author may some time find time to enlarge upon his theme for the technical student. Moreover, we shall not know the full meaning of irrigation until its sociological aspects are examined, and this volume only hints at the conditions of human life under the ditch. Nevertheless, Mr. Teele's book is a great contribution to irrigation advancement in that it brings order out of a confusion of knowledge, and points out the way by which our present irrigation difficulties may be overcome.

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SPECIAL ARTICLES

ON THE PHYSICAL CHEMISTRY OF EMULSIONS AND ITS BEARING UPON PHYSIOLOGICAL AND PATHOLOGICAL PROBLEMS

I

WE have been engaged during the past few months in a study of the conditions which determine the making and the breaking of emulsions. In addition to verifying certain well-known observations, this inquiry has brought some new points of view which are of importance for the theory of the stability of emulsions, and for the solution of such technical and biological problems as are embraced in the making of butter, the preparation of therapeutic emulsions, fatty degeneration, the formation of fatty secretions, etc.

Of the long list of mutually immiscible liquids that might have been chosen for a study of emulsification, we have worked chiefly with water and oil. The mixture of two such immiscible liquids may yield two types of emulsions, as Walther Ostwald first showed; one consisting of oil in water, a second, of water in oil. With much water and little oil, the first type of emulsion is usually obtained; with much oil and little water, the second type. When medium amounts of the two liquids are mixed with each other, either type may be produced, depending upon the methods of mixing.

Oil placed in contact with water does not lead spontaneously to the formation of an emulsion. To produce such, the two must be beaten together. The amount of oil that may be emulsified in pure water is very small, in no case exceeding one or two per cent. These emulsions are, however, stabile. The oil particles in such emulsions are rather small, their dimensions lying within the realm of the colloids. These low concentrations of oil in water, therefore, really represent colloid suspensions of oil in water and possess not only the stability characteristics of such systems, but also their well-known "saturation limit."

The term "emulsion" is ordinarily used to cover the subdivision of one fluid in a second in amounts exceeding these low values. The mixture must, moreover, show a fair degree of stability; in other words, the two liquids constituting the dispersoid must not separate in the course of weeks, months or years. A *temporary* subdivision of any quantity of oil in a given volume of water, or the converse, can, of course, be obtained by merely beating the two together.

The problem of emulsification therefore resolves itself into the question of how, once the division of oil in water has been accomplished, this can be, or is, stabilized. Contrary to the general belief of different workers who have each tried to discover some *one* element as responsible for this stabilization, a number of different factors evidently play a rôle, the relative importance of which may not only vary in different emulsions, but in the same emulsion under different circumstances.

It is generally held that the formation and the maintenance of an emulsion depend upon the slight surface tension of the dispersing medium, and its high viscosity. While both these factors undoubtedly play a part, their inadequacy in explaining the stability of all emulsions is generally admitted. Not only does the stability of emulsions not universally parallel the surface tension values of the liquids making up a given dispersoid, but dilute soap solutions with low viscosity act as better emulsifying agents than more viscid glycerin solutions. Pickering has emphasized the importance of a third factor in the maintenance of an emulsion, namely, the development of an encircling film about the droplets of the divided phase through the accumulation in the surface between oil and dispersion medium, of finely divided particles of a third substance. But this explanation, too, seems adequate only for selected examples of emulsions.

II

In reviewing the empirical instructions available for the preparation of emulsions, and in our own attempts to formulate such as would always yield permanent results, we were struck with the fact that their production is always associated with the discovery of a method whereby *the water (or other medium) which is to act as the dispersing agent is all used in the formation of a colloid hydration (solvation) compound.* In other words, when it is said that the addition of soap favors the formation and stabilization of a division of oil in water, it really means that soap is a hydrophilic colloid which, with water, forms a colloid hydrate with certain physical characteristics, and that the oil is divided in this. *The resulting mixture can not, therefore, be looked upon as a subdivision of oil in water, but rather as one of oil in a hydrated colloid.*

The amount of colloid necessary for stabilization, at least in the preparation of an emulsion, is rather great. It must be sufficient to bind all the water. The concentrated soaps show a high degree of water-absorbing power and so are among the best emulsifying agents. Very good, too, are blood-albumin, casein, egg-white and egg-yolk, this last already representing an emulsion of oil in a hydrated protein. Good emulsions may also be prepared with aleuronat, and, when the temperature is properly controlled, with gelatin. Not only may proteins be thus used, but various hydratable carbohydrates do well. Acacia has long been so used. Starch, dextrin (or the dextrinized starches used in baby foods), and, when the temperature is properly regulated, agar, also serve well. Oil can also be maintained in finely subdivided form in cane sugar solutions or glycerin, but these emulsions slowly separate.

The enumerated substances do not all act equally well. This is because, in the production of a hydrated colloid, they behave differently from both a qualitative and quantitative viewpoint. Best results are obtained with those substances which not only have the power of taking up much water, but which yield liquids of good viscosity with all amounts of water that may be added to them. What is wanted is a relatively homogeneous liquid of good tenacity, by which is meant one that possesses good covering power together with great cohesiveness.

The action of casein as a stabilizing agent is particularly instructive. Neutral casein does not absorb much water and it does not in this form serve for the preparation of an emulsion. But when alkali is added, it develops marked hydrophilic properties, on the appearance of which it becomes one of the best stabilizing agents for emulsions known. It might be thought that the alkali element is so important because it forms a soap in contact with oil, and soap has long been known as an effective emulsifier. While some such action no doubt occurs, it is easily proved that the development of hydrophilic properties by the casein is of first importance because acid (which when added to neutral casein converts it into a hydrophilic colloid) works quite as effectively as does alkali.

III

An emulsion breaks whenever the hydrophilic (lyophilic) colloid which holds the aqueous dispersion means is either diluted beyond the point at which it can take up all the offered water, or is so influenced by external conditions that its original capacity for holding water is sufficiently reduced.

Certain emulsions, as those of oil in soap, therefore, tend to break on simple dilution. But agents which dehydrate the hydrophilic colloid act even more rapidly and effectively. What will prove to be effective agents in this regard depends, of course, upon the character of the hydrophilic colloid stabilizing the emulsion. When alkali-casein is used, the addition of acid breaks the emulsion, while alkali will break an emulsion stabilized by acid-casein. The same concentration of acid or alkali is without effect upon an emulsion stabilized by a carbohydrate like acacia, or dextrin. Since even neutral salts will dehydrate an acid- or alkali-protein, they readily serve to break emulsions stabilized by these substances. An emulsion of oil stabilized in soap is readily broken not only by acids and various salts, but also by alcohol. Ether, on the other hand, is relatively ineffective. Practically all these substances in low concentrations are without effect upon emulsions stabilized in hydrated carbohydrates.

The fact that alcohol and ether are by themselves thus relatively ineffective in breaking emulsions explains why the ordinary fat extraction methods are so often only partially effective in getting the fat out of biological materials, and why previous treatment of the material, as by digestion with strong acids or alkalies and by similar methods, yields higher fat figures than extraction with ether or allied materials alone.

IV

The problem of the distribution of fat in living cells or in various secretions from the living tissues may be separated into two divisions; first, a chemical one dealing with such questions as that of the origin and transport of fat, and second, a physical one asking, for example, how smaller or larger amounts of fat may be stored in cells without at one time being visible or demonstrable by micro-chemical methods, while at another, as in "fatty degeneration," they are.

There is scarcely a tissue or fluid of the body which even in the poorest states of nutrition, does not contain some fat. But even the smallest amounts of fat thus found exceed the quantities that can be dispersed in permanent form in pure water. The presence of such amounts of fat in these structures, therefore, at once presents a problem identical with that which asks how it is possible, outside of the body, to maintain a fat in finely divided form in an aqueous dispersion means. *The presence of any amount of fat in a cell or tissue exceeding a fraction of one per cent. is possible only because the tissues contain hydrophilic colloids.*

Looked at from another point of view, even the smallest amounts of fat ever found in cells suffice to prove that *the cell contents are not mere aqueous solutions of various salts and non-electrolytes contained in a semi-permeable bag,* as is so generally believed by the adherents of the osmotic conception of cell constitution.

How completely the notion that our cells are filled with salt solutions must go to pieces, becomes clearly evident when it is recalled that certain of our cells and tissues contain even normally some twenty-five per cent. of fat and fat-like bodies. Thus, of a hundred grams of nerve tissue, seventy grams are water, and over twenty grams are fat. The remainder is protein chiefly. *Nerve tissue and all tissues which, under normal or abnormal circumstances, hold such large quantities of fat are able to do so only because this material is stabilized in a finely divided state through the presence of hydrophilic colloids (like proteins and soap) which hold the water of the cells as a hydration compound.*

While the fat in the cells of the body is not ordinarily visible in the state in which it exists here normally, certain pathological conditions popularly termed "fatty infiltration" or "fatty degeneration" suffice to make the fat readily visible. The older pathologists believed that more fat was thus visible for the reason that the cells had come to contain more (either because this had been brought to, or stored in the cells) or because their protein had been changed to fat. Modern studies of the question have proved the last of these possibilities to be entirely without foundation, so that now both "fatty infiltration" and "fatty degeneration" are at the worst held to be nothing more than states in which an excessive deposition may occur. But quantitative chemical studies have come to show that even the worst types of fatty degeneration in tissues may yield no fat figures lying beyond the amounts commonly found in these same localities under physiological conditions. In the majority of instances chemical analysis fails to show that the affected cells contain any more than their normal fat content. *In essence, therefore, "fatty degeneration" no longer represents a chemical, but a physical problem, which asks how a given quantity of fat usually so distributed in a cell as to be invisible, becomes re-distributed in such fashion as to be readily visible.*

We believe this problem is identical with that which asks how an emulsion of oil in protein or soap (so fine that the individual oil droplets can not be made out as more than granules even with high microscopic magnification) can be broken to the point where the fat granules will coalesce to form more readily visible droplets. As a matter of fact, detailed study of the conditions which are necessary for the production of typical "fatty degeneration" in tissues shows these to be identical with those which lead to the breaking of emulsions of the type of oil in alkali-casein, oil in soap, etc.

The various substances generally listed as capable of producing a "fatty degeneration" (phosphorus, lead, arsenic, mercury, alcohol, ether, chloroform, diabetes, local circulatory disturbances, intoxication with acids, etc.) are all of them means by which the normal hydration capacity of the soaps or of certain of the proteins of the cell (as the globulins) is markedly decreased. The matter is best illustrated, perhaps, by detailing a specific instance.

When a cell, in consequence of injury, is made the subject of an acid intoxication by any of the direct or indirect means enumerated in the last paragraph, the acid makes some of the proteins of the affected cells swell, while another group (the globulins) is dehydrated and precipitated. The combination of swelling with precipitation yields what the pathologists call "cloudy swelling." But as the pathologists have long noted, a persistence of cloudy swelling is followed, almost as a rule, by a "fatty degeneration" of the affected cells. On the basis of our remarks this coalescence of the oil droplets into the larger visible ones of "fatty degeneration" is dependent upon the removal, through the action of the acid, of some of the stabilizing effects of the proteins, soaps and other hydrophilic colloids contained in the cells. The increased swelling represents a dilution of the hydrophilic colloids of the cell, while the clouding represents a dehydration of certain others.

These studies on emulsions contribute toward the explanation of yet another pathological observation. When any tissue, as a portion of the brain, through some such pathological disturbance as a thrombosis is deprived of its normal blood supply, the affected member shows first a cloudy swelling accompanied or succeeded by a "fatty degeneration," and then a "softening" of the tissues. How at least a portion of this (and we are inclined to think the major portion in such tissues as the brain) is brought about is illustrated in the changes in viscosity observable in the preparation of an emulsion or its subsequent destruction. Seven per cent. potassium soap and cottonseed oil, for instance, are both relatively mobile liquids, but when mixed in proper proportion they yield an emulsion so stiff that it will stand alone. This is the analogue of the twenty-five per cent. emulsion of fat and lipoid in hydrated protein which we call the brain. If the oil-in-soap emulsion is broken through the addition of a little acid it yields an impure mixture of oil, water and precipitated colloid material—the analogue of the liquid contents found in any area of brain "softening."

Application may also be made of these studies to the problem of the giving off of such essentially fatty secretions as make up ear wax, vernix caseosa, sebum, the fatty secretions of plants, etc. *These all represent a transition from the normal type of oil in hydrophilic colloid emulsion to that of hydrophilic colloid in oil emulsion.* A homely analogue of this type of change is seen in butter-making, which consists of changing cream (essentially an emulsion of oil in hydrophilic colloid) into butter (a fat into which are divided about fourteen per cent. of water). Similarly, the essentially fatty secretions from the body as well as the fat contained in the adipose tissues of the body, all prove to be fats containing some seven to fifteen per cent. of water emulsified in them.

The details of these observations will be published in the *Kolloid-Zeitschrift.*

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GRAVITATION AND ELECTRICAL ACTION[1]

IN former publications the present writer has suggested that there is an intimate relation between gravitation and electrical action at a distance, or what has been called statical effects. There can be no doubt of the truth of the statement that the attraction between two masses of matter depends not only upon the amount of matter in the two masses, and their distance from each other, but also upon their electrical potential.

The gravitation constant has been determined by finding the attraction between two spheres of metal. In these determinations the electrical potential of the masses has been ignored. It has been assumed that there are no electrical charges on the two masses, if their potential is that of the earth.

Assume that two spheres, having radii R_1 and R_2 composed of metal having a density ρ,

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[1] Extract from a forthcoming number of the *Transactions of the Academy of Science of St. Louis.*