PHYSICO-CHEMISTRY AND BIOLOGY.

THE RELATION OF ANIMATE TO INANIMATE MATTER.

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HITHERTO the physico-chemical side of the question of the synthesis of elementary organisms has been neglected, probably because it has been divined that physico-chemistry must undergo a transformation before it can be extended to the phenomena of life.

The object of this article is to present some novel ideas suggested by the experiments of Myers, Dixon, Baker, Lebeau, and others, and to formulate the general principles which distinguish absolute physico-chemical reactions between absolutely pure substances from thermo-catalytic reactions effected by an organization which is developed under the influence of foreign bodies.

Myers has discovered the incombustibility of carbon in dry oxygen, Dixon has shown that a mixture of carbon monoxide and oxygen loses its inflammability on being dried over phosphoric anhydride, and Baker has collated numerous examples of reactions retarded or entirely prevented by the absence of moisture. In particular, Baker and Lebeau have proved that absolutely dry hydrogen and oxygen combine only at a temperature nearly as high as the melting point of platinum.

The interpretation of these facts, in accordance with my theory of the continuity of normal physico-chemical reactions, leads to the following principles:

1. Two gases which are absolutely pure, chemically and physically, combine only at the temperature of dissociation of the resulting compound, at the given pressure.

2. This principle may be extended to all chemical combinations in the sense that for absolutely pure substances the temperatures of combination and of dissociation are identical. I call this point the "true" temperature of the compound.

3. For any given pressure there is a "true" temperature of combination and dissociation, as there is a "true" temperature of evaporation and condensation (the boiling point) and a "true" temperature of fusion and solidification. These temperatures form the sufficient and necessary conditions for the total accomplishment of the corresponding changes and they are also the highest temperatures at which these changes can regularly take place at the given pressure.

4. Any tendency to or commencement of dissociation or combination, or of change of physical state, below the "true" temperature of the change in question must be due to the presence of foreign bodies, which I call "thermo-catalyzers" because the essential result of their presence is an apparent lowering of the "true" temperature. There is no evidence of the existence of substances which raise temperatures of combination, dissociation, ebullition, etc.

5. Hence thermo-catalysis, like most other phenomena, involves a degradation of energy. Animal life, if we regard it (as I do) as an oxidation of carbon under conditions of maximum thermo-catalysis, offers an extreme example of this degradation, for the oxidation is effected at a temperature below 100 deg. F., while the "true" temperature of this reaction is supposed to be about 5,400 deg. F.

According to the views expressed above, thermo-catalysis is a physical process which is very different from the mechanical process which is commonly understood by the term catalysis. Everything goes on as if the energy which is necessarily disengaged when the reaction takes place at its "true" temperature (for all reactions occurring at their "true" temperatures are exothermic) appeared at the lower temperature in an electrical form at first, made a way for itself through the catalyzer, which serves to close the circuit, and was thus degraded and converted into heat. The name odogenesis, or "path making," has been given to this automatic construction of an electric circuit. The degradation thus effected electrically corresponds exactly with the thermal degradation which is represented by the lowering of the temperature below the "true" temperature of the reaction.

It should be observed that some foreign bodies modify the field of a reaction by increasing the area of contact of the two substances, or the rate at which that area is renewed, by promoting diffusion or circulation. In this mechanical acceleration of the reaction there is no odogenesis, and the substances which produce it, though commonly called catalyzers, are quite distinct from the thermo-catalyzers which we are considering and for which "degraders" would be a more appropriate name.

Furthermore, absolutely inert substances may act as thermostats and lower the temperature by absorb-

ing heat. Here, again, notwithstanding the lowering of temperature, there is no odogenesis, and these bodies must not be confounded with thermo-catalyzers, although most of the latter also exert a thermostatic effect.

The double conception of an absolute physico-chemistry, confined to reactions occurring at their "true" temperatures, and a thermo-catalytic physico-chemistry, treating of reactions modified by thermo-catalysis, flows necessarily from the preceding considerations.

All absolute physico-chemical reactions must be vigorously reversible, for at the "true" reaction temperature combination, solidification or condensation of vapor occurs if heat is abstracted, and dissociation, fusion or vaporization takes place if heat is added. Thermo-catalytic reactions, on the other hand, are not necessarily reversible. For example, reversibility is impossible in certain reactions of organic substances, where thermo-catalysis is accompanied by so great an increase in the complexity of the mass that the stability of the compounds formed is incompatible with an elevation of temperature without increase of pressure.

The principle of thermo-catalysis, which is derived from the principle of degradation of energy, suggests that the substances which act as thermo-catalyzers, or degraders, need not be either foreign to the reaction or very small in quantity, as the current theory of catalysis assumes. A compound in process of formation, or its components, may exert a thermo-catalytic as well as a thermostatic influence upon another combination which takes place simultaneously with or subsequently to the first combination.

It is not unlikely that successive repetitions of this process may result in the formation of a series of compounds, susceptible of dissociation by a reversal of the process, the necessary condition being that each particular compound must be dissociated at the pressure at which it was formed.

The constituents of alloys and of liquid mixtures thus act as "auto-degraders" and lower the temperatures of fusion and vaporization respectively.

The problem of catalysis might have been attacked in another way. If we had simply proposed to maintain, in a catalytic reaction, the velocity proper to the same reaction unaided by catalysis, we should have found it necessary to lower the temperature, and thus we should have recognized the essentially degrading character of catalysis. We should have found, likewise, that a definite decrease in temperature would prevent the catalytic decomposition of any given compound by destroying the possibility of odogenesis.

The great retardation of physico-chemical processes—evaporation, for example—which can be effected by the employment of perfectly pure substances, proves nothing against the existence of "true" temperatures corresponding to those processes. From the viewpoint of absolute physico-chemistry, indeed, the usual conditions of reactions appear abnormal. Every physico-chemical reaction involves energy and, consequently, time. Its accomplishment under normal conditions implies a continuity which is not usually realized and involves the consideration of force rather than that of work.

It follows that the reaction must be regulated or organized in order to become continuous and normal, so that it can go on indefinitely at a constant rate. This normal organization requires a continuous supply and removal both of material and of energy. The absence of this makes possible the accomplishment of ebullition, for example, above its "true" temperature. Continuity, like the presence of thermo-catalyzers or degraders, would prevent this abnormal and accidental elevation of temperature.

The degradation or fall of temperature caused by thermo-catalysis appears to be necessary to the formation of very complex and unstable molecules. The great degradation which results in the formation of living tissue and the combustion of carbon at 100 deg. F. instead of 5,400 deg. F. cannot be effected by thermo-catalysis applied to purely chemical reactions between substances in definite proportions, because the number of available chemical thermo-catalyzers is far too small. It is necessary to invoke the aid of colloidal thermo-catalyzers, and it is worthy of remark that colloids are peculiarly sensitive to the electrostatic forces which necessarily accompany thermo-catalysis.

Carbon, in its successive higher combinations ending with protein, represents the thermo-catalytic

medium, both chemical and colloidal, which is best adapted to develop self-organizing reactions, for a continuous supply and removal of material is possible only in media of extreme complexity. The entrance of a highly oxidizable germ into such a medium starts the process of oxidation and the electrical forces thereby set at work enable the cell to assimilate from the medium the materials required by its several parts. This power of "selectrolysis," as I have called it, is simply the consequence of the electrical conditions of the elements involved. The elementary organism thus engendered acts thenceforth, in its continuous and simultaneous growth and decay, as a transformer which automatically degrades the potential energy of the elements of the reaction.

The extreme complexity postulated above may apparently be attained by combinations of very diverse elements. It appears probable:

1. That to every chemical compound corresponds an elementary organism, which may or may not be realizable under appropriate conditions of pressure and temperature and which contains this compound in small but definite proportion.

2. That the number of possible organic types is, therefore, incalculably great.

3. That every thermo-catalyzer is a possible agent of self-organization.

4. That carbon and oxygen play the chief parts in these phenomena.

These extreme generalizations, which are merely a development of theoretical views which I have already expressed,* are strikingly confirmed by the recent researches of Kossel and Fischer on the nature of albuminoids. Fischer has shown that these bodies are built up of a great number of atomic groups, most of which occur more than once in the albuminoid molecule, and that the various albuminoids, from the simplest to the most complex, form a series which may fairly be called evolutionary. Analysis of the compounds of these groups reveals the characters indicated in my early speculations as those of vital reactions, showing the colloidal nature of the protamic nucleus and the proteids, their instability and their faculty of acquiring and losing definite properties, as well as the tendency of albuminoids in general and the protamic nucleus in particular to take up certain elements and form non-ionized combinations with them and to reject other elements and atomic groups. These facts strongly corroborate my views concerning "selectrolysis" and the evolutionary character of organized reactions. The protamic nucleus—the first manifestation of life—appears to be the real nucleus of vital structure, for it possesses the power of combining to form more complex molecules and of accomplishing an infinite differentiation of properties.

In general, the most recent experimental researches appear to justify the theoretical views which I first expressed in 1893.—Condensed for the SCIENTIFIC AMERICAN SUPPLEMENT from *Revue Generale des Sciences pures et appliquees*.

According to ideas generally prevalent, gases have a density far smaller than that of even the lightest liquid. In fact the density of a gas has not so far been sufficiently increased by compression or cooling to exceed that of a liquid in contact with which it may be placed, it being supposed that the gas is neither liquified nor dissolved in the liquid. A memoir recently published in *Archives Néerlandaises* by Dr. Kammerlingh Onnes describes a rather striking experiment in which a bubble of compressed helium was caused to descend in liquid hydrogen, as a drop of water descends in oil. A mixture of hydrogen and helium was compressed in a capillary tube dipped into the liquid hydrogen. At a pressure of less than 49 atmospheres the hydrogen was confined to the bottom of the tube, and liquefied nearly entirely. Beyond that pressure a bubble of practically pure helium (which at the beginning had been floating at the surface) was seen to descend to the bottom of the liquid, and did not rise unless the pressure was reduced to 32 atmospheres, its volume being controlled by the Mariotte law. Apart from its originality, this experiment deserves special interest, allowing as it does the co-volume as well as the density limit (quotient of molecular weight by the co-volume) to be determined, which latter, according to theory, would equal that of heavy metals.

* "Du rôle de l'électricité dans les phénomènes de la vie animale" Bruxelles, 1893.