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THE CHEMICAL PHILOSOPHY OF THE HIGH-SCHOOL TEXT-BOOKS¹

At the present time the conception of continuity or unity or uniformity plays a great part in all departments of science; not only that continuity in time postulated by geologists and paleontologists, but the idea that all the divisions and classes established by science are but convenient though perhaps indispensable tools of the human mind, while nature, the object of our study, is one and indivisible.

To take examples from biology: modern systematists agree that the conceptions genus, species, variety, race, shade into one another, so that what in one group are regarded as generic distinctions, in another are hardly allowed to differentiate species; the very word biology recognizes the non-existence of a boundary between animal and vegetable; and a group of workers of the present day are busy removing even the distinction between inanimate and animate.

This view of nature, though now so widely accepted, is by no means contemporaneous with the birth of modern science; it came in only when the study of the most striking—because extreme—objects or relations had been followed by that of the less strongly characterized connecting links; and its acceptance has been hindered, in many cases, by the prevalence of certain extra-experimental or extra-observational “explanations” made up to account for the earliest studied, exceptional, phenomena.

¹ Address of the vice-chairman of the Division of Inorganic and Physical Chemistry, American Chemical Society, Indianapolis meeting, 1911.

Thus modern geology was preceded by a period of explanation by "catastrophes," and modern biology by a period in which the theory of separate creation of each of the Linnean species was elevated almost to the rank of a religious dogma; in both cases the main difficulties the new view (of continuity, as I am calling it) had to encounter, were due to the wrench it cost to break with the old familiar extra-experimental theories or explanations. This again was to be expected; the theories were invented by men whose minds were deeply impressed by certain observations or relations, their object was to "explain" these relations and keep them before the mind, so that the theories can hardly be blamed if in addition they kept out of the mind more recently discovered facts whose existence their originators never suspected.

Our own science has passed through a similar evolution. Modern chemistry began with the study of the most striking of all chemical phenomena, the phenomena of combustion; and just when these were robbed of much of their mystery by the discovery that like other chemical reactions they obeyed the law of conservation of weight, a new interest was awakened by the discovery of phases of invariable composition, the typical chemical compounds, whose study laid the foundations of quantitative analysis, and led to the remarkable so-called laws of chemical combination which Dalton's atomic theory was invented to explain.

The existence of such compounds is familiar enough to us, but a century ago one of the most celebrated chemists of his day strove for eleven years to show that no such things could be. This may serve as a measure of the interest and attention attracted by these substances at the time of their discovery; no wonder they alone were designated "chemical" compounds, small

blame to those who thought that substances so striking in some respects must prove unique in all; how natural that the idea of continuity advocated by the defeated Berthollet should be forgotten, most natural that the extra-experimental theories invented at the beginning of the nineteenth century should make a sharp distinction between these chemical compounds and all else.

They did so; and as all good theories of that type do, they kept men's minds on the facts they were invented to explain; while the slowly accumulating "exceptions"—facts out of harmony with the tendency of the theory—being unexplained, and thus lacking a powerful aid to publicity, failed of their due influence on opinion. The discovery of the dissociation of chemical compounds by Deville and Debray—that marble, for instance, could be formed or broken up by the action of an air-pump—had surprisingly little effect at the time; but the work of Horstmann, Gibbs and van't Hoff, not to mention lesser lights by name, has at last made it abundantly clear that the "affinity of the atoms" which binds together the constituents of chemical compounds is subject to the same laws and may be measured in the same way as the forces—hitherto deemed distinct—which are responsible for the formation of solutions and adsorpta.

Thus, hand in hand with the study of chemical equilibrium, the idea of continuity entered chemistry, and has transformed it.

The high-school text books, however, as a class, in their tendency deny this continuity *in toto*.

In them the chemical compound and the element ("chemical individuals" for short) retain their former place as "the only two distinct kinds of matter"; and mechanical mixtures are distinguished by being separable into their ingredients "by mechanical means," thus ignoring the fact

that mechanical means have been found for separating the ingredients of whole groups of chemical compounds, and the modern view that the amount of mechanical work necessary to bring about the separation is the only measure we have of the affinities that brought about their union.

Solutions, in some of these books, are openly classed with the mechanical mixtures, and in all are spoken of in language applicable properly to the latter alone. In brine, for instance, salt and water are said to "retain their properties unchanged." Not to dwell on the ridiculous illustration found in many, that "the salt retains its taste"—as though dry salt could be tasted—this assertion ignores the lowering of the vapor tension of the water, and consequently the lowering of its most characteristically "chemical" property, its chemical potential, or power to enter into reaction. Pure water, to give an instance, reacts at 30° C. with the chemical compound sodium sulphate to form its hydrate Glauber salt, also a chemical compound; the reaction is thus "chemical" in the strictest sense of the word, as none but chemical compounds are involved; when combined with salt to form a saturated brine, however, this power of the water is lost.

The change of chemical properties which is ignored when a solution is formed, is exaggerated when a chemical compound is the result of the union; in that case, "an entirely new substance" is produced, whose constituents have "lost their characteristic properties." Now, surely, the most characteristic property of oxygen is to oxidize; does it lose the power of oxidizing carbon by combining with copper? if so, how are the "combustions" of the organic laboratory to be accounted for? Does it lose this power by combining with hydrogen? if so, what about the manufacture of water gas? In truth, as was the case with water

in brine, the characteristic properties of oxygen in copper oxide and in water are lessened, not lost. It is not even safe to say that chemical combination always brings about the greater change; as Bell has shown, water combined in washing crystals is more "itself" than when sucked up by a dry cigar.

It might be urged in extenuation of this exaggeration, that, after all, chemistry, like other sciences, works by classification, and that children like distinctions sharp. The heroes of boys' books are heroes every inch; their fools and villains likewise Simon pure; and all agree that problem plays—where the problem is to tell the villain from the fool and to guess who is the hero—are not for such as they; a little exaggeration might therefore be defended as good pedagogy, and suited to the childish mind. This might be a good excuse, if it were not that (no doubt in order to be up to date) the texts while denying continuity, include much of the experimental evidence which has forced this conception into our science. The result is that they contradict themselves, and involve the whole subject in a maze of vagueness and mystification foreign to the scientific spirit; an example or two of each will be given, beginning with a typical instance of self-contradiction.

Most of the texts give their readers the impression that gunpowder is regarded as a mixture containing niter, or that sulphur and iron filings form a mixture containing sulphur, or that the high-school grocers' mixture of sand and sugar is a mixture containing sugar *because* the niter or the sulphur or the sugar can be leached out or dissolved by water or by carbon bisulphide, that is, by liquids which dissolve those solids when pure. It is sometimes added that the ingredients of the mechanical mixture have thus been

separated by the "mechanical operation" solution. And yet, every high school chemistry gives instances of solid chemical compounds decomposed by water, and some even speak of the hydrolysis of salts like bismuth nitrate, which can be formed by bringing together bismuth hydrate and nitric acid of the proper concentration and from which by treatment with water all the nitric acid can be removed, leaving the bismuth hydrate behind. Such instances of self-contradiction (where the major premise of some argument is quietly negated elsewhere in the book) are scattered broadcast. "In spite of the most carefulness," to quote from the advertisement of a new German balance, "the rider *will* fall"; and the most carefulness has certainly been employed in books which use syrup instead of brine in their illustrations out of respect for the ions, and which the Roozeboom diagram has driven to substitute platinum for iron in the old misleading statement that "powdered iron, magnetized iron, glowing iron and melted iron are just as truly iron" as a cold poker. For one illustration is as bad as another if it is used to confound solutions with mechanical mixtures, or to obscure the fact that chemical properties change with the temperature, and in some cases are measurably affected even by fine grinding.

The vagueness of the texts, already referred to, serves to keep their self-contradiction in a measure hidden. If every statement is indefinite, all can be reconciled; and what could be less definite than the customary definition of an element as a substance from which "nothing simpler than itself" can be obtained, if the meaning of "simpler" is left to be guessed? Unless perhaps it be the definition of a molecule as "the smallest quantity of a compound that can exist alone," or the

corresponding indefinitions of atom, affinity, stability, valence, solvent and solute.

This vagueness is, naturally, most marked just where clearness of thought and precision of statement would show the untenability of the exceptional position assigned to the chemical individual; so that it is hardly surprising to find that not one of the texts gives a working definition (*i. e.*, one that can be applied in the laboratory) of the very group of substances which figures so prominently in all of them.

One of the Best Sellers defines chemical changes as "those which involve a change in the composition of the matter," while "sugar may be dissolved in water, but neither the sugar nor the water is changed in composition." This book, like the rest of them, brings in all the usual extra-observational hypotheses to "explain" the ordinary "laws of chemical combination," but gives no explanation whatever of this most extraordinary use of the word "composition"; although on this indefinition of chemical change is based the definition of chemical compound, that of mechanical mixture, and by implication that of chemical affinity as well.

Let us enquire what significance is attached in the practise of the present time to the terms mechanical mixture and chemical compound; we shall then be in a position to appreciate the difficulty in which the text-books find themselves and from which they seek to escape by the employment of systematic mystification as an aid to teaching.

Mechanical mixtures which for years have posed in the pages of Dammer as chemical compounds, are by the application of the phase rule daily being removed. What criterion has been adopted in each of these cases? Stripped of technical terminology it is: Whenever the reacting

power, or potential, of a given substance (say niter) at fixed temperature and pressure is not affected by bringing it together with certain other substances (sulphur, charcoal) the resultant body is to be classed as a mechanical mixture with the substance in question (niter) as one of the constituents. In the simple case of gunpowder it is sufficient to find whether or no the solubility of the niter, in water, for instance, remains unchanged; but in the most complicated cases the principle remains the same. The condition of comparison at constant pressure (comparison at constant volume is impossible with solids and liquids) excludes air and such-like "mixtures of gases"; while whenever (as with arsenious sulphide and water) the change in chemical power is so slight as to remain in dispute, a discussion may arise as to whether the resultant "pseudo-solution" is to be classed with the solutions or with the mechanical mixtures—quite naturally, for at this point the two classes run into one another.

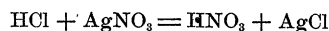
All this is simple and has proved important in practise; but being based on a view of solutions radically different from that of the texts under discussion, it can find no place in them.

The chemical compounds, or rather the substances so classed in the high school texts, may be grouped under three heads. First, silver chloride and other phases of invariable composition, which could be defined by adopting the "law" of combination in definite proportions as the definition of the group; second, water and similar bodies, which though not phases of invariable composition, can be "purified" by fractionation without paying special regard to the pressure at which the distillation is carried out; and third, a group of which sulphuric acid may be taken as the type. In the text books, the "chem-

ical compound" sulphuric acid is described as "an oily liquid of s.g. 1.838 at 15° C."; it is in fact one of the continuous series of sulphuric acids—from dilute to fuming—used in the laboratory, and is thus not a phase of invariable composition; neither can it be "purified" by fractionation like water, while to include it among the chemical compounds because it freezes to a homogeneous solid of the same composition, would open the door wider than is consistent with general usage.

As a matter of fact, the name sulphuric acid and the formula H_2SO_4 were both introduced into chemistry without any special reference to the properties of this particular liquid, and would in all probability have won their way even if no substance of the composition H_2SO_4 could be prepared—such, at all events, was the case with the analogous "compounds" carbonic acid and ammonium hydrate. Formulas like H_2SO_4 , H_2CO_3 , NH_4OH and the names that go with them, are merely relics of one of the past attempts to represent symbolically the properties of solutions; in the old days, reagent bottles of sulphuric acid, whether concentrated or dilute, were labelled SO_3 , then H_2SO_4 was substituted, and now, perhaps, $2H + \bar{S}\bar{O}_4$, the symbol H_2SO_4 being retained with a different meaning. The change from one of these systems of formulation to another was due to a study of the properties of solutions as a class; can the text-books on their principles make this clear? Let us see how they deal with symbols.

The symbols HCl , $AgNO_3$, HNO_3 and $AgCl$ are defined to give the compositions and, when known, the vapor densities of the compounds they represent. Following these definitions the symbol



purports to record what happens when

hydrogen chloride, the gas, and silver nitrate, the solid, are brought together. Perhaps the change represented would actually take place, if the conditions were favorable; let us assume that it would. Throughout the books, however, equations of this type are employed to represent reactions "in solution"; *i. e.*, in the case selected, when hydrochloric acid (a solution of the gas in water) is poured into an aqueous solution of silver nitrate.

Now, it is obvious that the use of symbols is just as legitimate in chemistry as it is in mathematics; and although an experienced analyst would attend to many matters not referred to in the symbol, would use rather more hydrochloric acid, and would expect to get rather less silver chloride than the quantities represented in the equation, yet considering its brevity the symbol gives a fairly accurate idea of the quantities involved, it is therefore of considerable practical use, and deserves careful explanation in the texts. No such explanation is offered, and indeed none is needed by those who regard solutions as mechanical mixtures; in their eyes the water has as little right to representation in the chemical equation as has the glass of the beaker in which the precipitation is made.

From such a starting point, however, a clear idea of the meaning of our present formulation of solutions is not to be reached; the high school treatment of ammonium hydrate and carbonic acid—discussions of the probability of "chemical combination" between ammonia and water, for instance, without first fixing the meaning of the term—only makes things worse; and in the end we find the children "believing" in ions, or "disbelieving" in hydrates-in-solution, just as a few years before they believed in fairies. The idea that our present method of formulating

solutions is but a more or less imperfect symbolic representation of laboratory facts, will come upon them later, if it ever comes upon them, like the discovery that Santa Claus is but a kind thought; one experience of that kind ought to be enough.

Bacon says—I quote at second hand through Huxley—that "truth comes out of error much more readily than out of confusion," and Freeman, speaking of history, says that "the difference between good and bad teaching mainly consists in this, whether the words used are really clothed with a meaning or not." Is chemistry so different? Are vagueness and dodging really necessary in the text-books of our science? They are, so long as in the theoretical part the conception of continuity is negatived, while in the practical part experiments are described which have forced that conception into the science.

A change is unavoidable; but it is wholly unnecessary to give up the interesting chemical experiments for prosy disquisitions on water, ice and steam, or to fill the book with "How Old Is Ann" thermodynamical problems adapted from van Laar. Striking phenomena are as interesting to beginners to-day as they were a hundred years ago, but gradations too exist, and their existence must not be denied.

Until this change is made, children will be trained to accept obscure equivocal and dogmatic statements in place of clear and exact thought, and to be glib with words they do not understand. Such discipline, enforced in the name of science, of our science, far from ensuring the results prophesied by those whose efforts obtained for these new studies the place they now occupy in the schools, can hardly fail to injure pupil and teacher alike, depriv-

ing them of mental self-reliance and the power to weigh evidence and think clearly.

Unless a change be made, chemistry will surely earn a place among that group of pedagogic processes which Huxley strove so hard to have displaced, and which he characterized as the direct and preventible cause of most of the world's stupidity.

W. LASH MILLER

THE GENERAL ESSENTIALS IN TEACHING QUALITATIVE ANALYSIS

THE growing tendency to give more heed to the methods of teaching the natural sciences in the colleges has called forth the following generalizations regarding the second course in chemistry. The pedagogical aspects of the first course have been ably discussed by many teachers. The abundance of text-books on the second course, qualitative analysis, seems to indicate that every teacher follows his own notions and that no book is very generally satisfactory, all of which is unfortunate and perhaps unnecessary. There are, however, certain principles that seem to be regarded as essential by the majority of thoughtful teachers and an effort to present these principles appears to be worth while.

The main essential in conducting this course is to *teach qualitative analysis*. It is valuable and interesting on the side to learn many reactions, but only those reactions which are concerned in separations and identifications can be considered essential to the object in view. The study of other reactions is a study of general chemistry.

Opinions differ as to what introductory tests should be made by the beginner, but the above principle is successfully carried out when each individual substance (ion) is first subjected alone to the same reactions which it will undergo when present in a miscellaneous mixture under analysis. Such a parallel study of the members of a group will reveal to the intelligent student the possibilities of separation.

Secondly, *the procedure must be definite and explicitly stated*. Recent experimental

studies in testing qualitative methods, particularly those of A. A. Noyes and assistants, have shown that the conditions of successful work must be carefully studied out for each step. Separations are very largely based on solubility differences, which is a quantitative matter; the directions must be devised with this in view and must be full enough to leave no room for doubt in the average mind.

Accordingly, it is essential, in the third place, that *the printed procedure be conscientiously followed in detail*. If varying conditions make it necessary to add more or less of a reagent in certain cases, the procedure should give information; but when a procedure has been worked out on the basis of elaborate qualitative and quantitative tests, as have some of our modern procedures, a pupil can not expect to get reliable results, if he follows his own untutored discretion. Analyzing from a memorized procedure is indeed likely to be a dangerous undertaking, since the memories of most young chemists will be liable to lead them astray as to the proper proportions or even the proper reagents. It is not to be understood that the procedure should be blindly followed, *e. g.*, with a false conscientiousness that would lead the worker to filter a solution when no precipitate was formed, but that those operations which are done should be conducted as directed.

In order that the pupil may be able to reproduce the proper experimental conditions for the tests, the pupil must be so carefully trained in the art and language of manipulation that he will have no difficulty in conducting the operations as the author intended.

A fourth essential is to *teach the bases of separation*. This is one of the most important and difficult tasks of the teacher, for much of the logic of the course is herein involved. By bases of separation are meant the differences in the physical and chemical behavior of substances which are utilized for the purpose of separation. These are the real "foundations of analytical chemistry." They should be clearly presented in the lec-