THE POINT OF VIEW IN CHEMISTRY.

By ALEXANDER SMITH,
University of Chicago.

In an important sense it is not the particular selection of topics that determines the real value of a course in chemistry, but the point of view of the teacher who presents them. Yet, although all-pervading and all-important, this point of view is of all things the most difficult to define or describe. It may be felt in every word uttered in the class room, but is itself almost impossible of capture and of crystallization in words. We may seize some of its characteristics best, perhaps, by dipping into the teacher's version of the science here and there, taking a few samples and considering the mode of their treatment. The choice of samples may be determined by noting the points on which authors differ and the points in regard to which one's own views have changed; consideration of the points where there is a diversity of views and where changes in view have occurred should give some indication of the deeper seated, fundamental ideas whose influence determines the choice or suggests the change.

Let us take, first, the question, What principle is most fundamental in all chemical work; what fact is the basis of our performance and interpretation of every chemical experiment? Is it the atomic hypothesis? Many chemists used to think so, and some chemists still think so. In a recent text-book the most of the first chapter is devoted to a discussion of the minute subdivisions of matter and of the conceptions arising from a consideration of this subdivision. The treatment is logical, and satisfactory from the point of view that this is the fundamental idea at the basis of chemical thought and work. But, after all, does the chemist in point of fact carry on his work by considerations of this kind? Are there not facts about *masses of material* which are more continually in his thought? Would not a man who had encountered animal matter only at meal times in a Chinese restaurant have a rather distorted idea of the nature and structure of fish, flesh, and fowl, and does not the reduction of the carcass to chop suey obliterate or obscure some facts of large significance in Zoology? And does not, in the same way, a premature consideration of an imaginary process of utter disintegration withdraw the attention from the common aspects of chemical behavior as it really appears? The answer, of course, depends on one's point of view.

What, then should demand our attention, before the pulverization begins? Is it the principle of definite proportions? Does not this presuppose the conception of compounds and is not therefore the idea of elements and compounds more fundamental? Is this then itself the fact of which we are in search, the fact which is at the basis of all chemical work? But how do we recognize a compound? Is it not by obtaining from the compound two or more substances, with properties which distinguish them from one another and from the parent substance? Is not the basis, then, of chemical work the fact that each substance has its own set of specific, physical properties by means of which the substance is recognized and by use of which the substance is separated from other substances when necessary? In the point of view with which at present I sympathize, it is. And this particular view must have a large influence on the way in which emphasis is placed in doing and discussing chemical experiments. It at once puts in the foreground, as the object of every experiment, the observation of physical phenomena and the discussion of the observations in terms of physical realities.

Let us now turn to another subject, the treatment of which may give indications of the point of view. The atomic hypothesis has already been mentioned. At what stage may this hypothesis most usefully be introduced? The answer is found by asking, what fact in chemistry was it primarily devised to explain? Was it not the fact that the proportions by weight in which a given element enters into all sorts of combinations may always be expressed by a fixed number, or by whole multiples of this fixed number? The hypothesis comes in, then, when combining proportions by weight are discussed. In other words, the hypothesis is used in explaining the quantitative laws of chemical combination. May it be used at an earlier stage, for example, to explain the *fact* of chemical combination and the qualitative features associated with it? Does it clear up the mystery of the properties peculiar to cupric sulphide to say that a little piece of copper, "which has all the properties of a large quantity of the substance," when stuck to a little piece of sulphur, will give a little aggregate whose properties will be absolutely unrelated to those of the constituent atoms? Would not even a child see that the properties of a mass composed of the aggregates ought to be the average of those of two masses composed, respectively, of the pieces of copper and the pieces of sulphur? And if the

child realized that this notion—that the approximation of little pieces of different materials gives aggregates with entirely new properties—was a product of the imagination and simply an invention devised to explain the changes in properties, while the change itself was a fact, would he not tell you that your fairy story, regarded as an explanation of the fact, was a singularly complete misfit? As for the fact of combination itself, is not the cohesion of the particles of one substance individually with those of another just as difficult to conceive as the combination of the materials as wholes? In short, does the atomic hypothesis as commonly given, adequately explain the nature of the tendency to combine (affinity), or the mode of the combination, or the new properties of the product of combination, or the heat developed during the process of combination, or, indeed, anything, save the possession by each element of an individual unit of weight which it employs in all its combinations and, at a much later stage, however, some features in the chemical behavior of complex substances? And if we invite beginners to believe as a fact that diverse atoms are united into pairs, and that the properties of the aggregates are unrelated to those of the constituents, and associate these two inconsistent ideas every time a substance is discussed, shall we not, as a result of persistent suggestion, finally hypnotize the pupil into a frame of mind in which logical consistency is no longer a test of credibility, and shall we not thus undo in a few weeks the results of the slowly wrought training, in which the instructors in other sciences and in mathematics have prided themselves? Will it not, after all, indicate a saner point of view if we say as little as possible about the relation of the atomic hypothesis to those things which it was not primarily devised to explain?

A science may be compared to a large territory. The study of the science means the exploration of the territory; the examinations of its mountains and minerals, of its rivers and lakes, of its trees and diversified vegetation, and of its numerous animal inhabitants. A lifetime is required for any sort of full knowledge of the territory. But for the purpose of giving some introduction to its chief features, say to the student who can spend only a few hours a week for a year upon the task, the best way is to take him to some point from which those chief features may be seen. From this viewpoint we describe to him the objects he has not himself time to visit and by the help of short

excursions give him the opportunity of handling a few of the more accessible things, and so enable him to realize to some extent the nature of the others. Now, obviously, to give a true conception of the whole, the viewpoint must be chosen with some care, otherwise a hay-stack may cut off half of the horizon, or an ant-hill on a plain may seem to overtop the Rockies. Some of us, feeling confident that our viewpoint has been chosen with exceptional success, set up a camera, take a snap-shot of the subject, and circulate the prints under the name of So and So's *Complete Chemistry*. And if the photographer has been less judicious in his choice of a viewpoint than we could have wished, the result may be very confusing to our pupils. We teachers, who have seen the science from other sides, may have considerable difficulty in explaining the picture so as to restore to their true proportions objects near to and far from the viewpoint. How unfortunate, for example, it is that the camera is so often planted right behind a molecule! What a heavy task this lays upon the teacher who has to reduce the all too obvious atoms to their true place and proportions! Naturally the more distant objects, the trees and mountains, are assumed to be stuffed with atoms, such as abound in the foreground. Naturally, also, the excursions from which we had hoped so much turn out a disappointment; atoms prove to be unexpectedly scarce in the laboratory.

It is not suggested that the text-book as a whole is not true; the camera is always truthful and the photograph is perfectly correct as far as its limitations permit. There *are* molecules and atoms in chemistry. But, if our amateur photographers would study the work of professionals before "exhibiting," they would find that hardly one in a thousand of the detail photographs taken by chemical investigators show any atoms that are visible to the eye in the finished print. Perhaps, if they made this study they would see that their products should go, if anywhere, to the editor of the "freak photograph" section of one of the magazines, rather than into the hands of beginners in chemistry.

The result of getting atoms into the foreground of the picture is to inject thoughts of them into everything else in view, and therefore to crowd out other and more practical conceptions. Ozone and oxygen, for example, appear in the print, but the most obvious difference between them is, not that one is deep blue and the other pale blue, that one is easily liquified and the

other not, that one rusts silver and the other not, and so forth. No, it appears rather that one has three atoms of oxygen in its molecule and the other only two. And what then does this way of stating the difference amount to? It means simply that ozone is, bulk for bulk, one-half heavier than oxygen, a fact which is, primarily, not chemical, but physical. Again, why is the formula of hydrogen written H_2 ? Shall we say that it is because there are two atoms in its molecule? Or shall we say that formulæ represent the composition of equal volumes of gaseous substances, that, when we determine the quantities of hydrogen in equal volumes of hydrogen gas and of hydrogen chloride, we find twice as much of the element hydrogen in the former as in the latter, that, therefore, if we assume the latter substance to contain the unit quantity of hydrogen represented by H , the former contains two unit quantities and must receive the formula H_2 ? It all depends on our point of view. We may use the literal language of experiment, or we may use the figurative and much more difficultly interpretable language of hypothesis. But there can be little question which mode of expression will convey the actual facts, with the least trouble to the halting mental activity of the beginner. Still again, in what light does the nascent state present itself? An element is "nascent" when "it is just being liberated," we say, and, before we can stop ourselves, the atoms in the foreground have cast their shadow on the subject and we add, "the 'atomic state' and the 'nascent state' are therefore synonymous expressions." But, apart from the possibly over-emphasized circumstance that it has just been produced, what is peculiar about hydrogen which is being generated from zinc and hydrochloric acid? It is free hydrogen, still adhering to the surface of the zinc. Is not its activity then due to the contact action of the zinc as a catalytic agent? Why is the nascent hydrogen from tin and hydrochloric acid different in its activity, and why does that from aluminum and caustic soda represent still another degree of activity? As far as age is concerned they are all equally recent in their formation. But the metals in contact with the hydrogen are different and their catalytic effects may therefore well differ. Why use an imagined explanation when a real and plausible one is available? A different, but equally satisfactory set of considerations can be adduced to show that "nascent" oxygen too is simply another

hallucination, born of an unhealthy and too engrossing contemplation of atoms.

But we must leave this diverting subject and look for another of those parts of the science whose treatment is significant of the point of view. The definitions and statements of principles will be found to afford an admirable supply of "test samples." The same chemist who states the law of multiple proportions, as nearly all do, in the literal concrete way with which we are familiar, is likely to become figurative even when he deals with so practical a subject as "physical change." He may say that it is a change in which the relations of the molecules have been altered, while those of the atoms are not affected. Yet he might easily say something that would be of more assistance to a beginner who was watching a vessel of boiling water. Fortunately "physical" and "chemical change" often are clothed in everyday language, but there is at least one conception that is almost never defined in literal terms, namely, valence. For example, "the valence of an element is that property which determines the number of atoms of another element which it can hold in combination," or, "the valence of an atom is its power for holding other atoms in combination, that of hydrogen being the standard." We note, in passing, that one defect of the atomic method of defining valence seems to be that a really exact statement is seldom made. A close reasoner, if such should be found in the class, would discover that, according to the former definition, the valence of hydrogen might be infinity. A chemist reading the second would say that the power of an atom of gold for holding atoms of chlorine in combination is not three times as great as that of an atom of hydrogen, as the definition seems to state, but is in fact very much less. But, even if a theoretical definition free from these defects could be made, as it easily can, would not a literal definition in terms of experimental facts be easier to understand and use? Is not zinc said to be bivalent because an atomic weight of this element combines with two equivalents of chlorine or of oxygen (16 grms.), and displaces two equivalents of hydrogen? Is not the valence of an element, therefore, the number of equivalents of some other element which its atomic weight combines with or displaces? Again, why is zinc bivalent and why does an atomic weight of it displace two atomic weights of hydrogen? Is it not because its atomic weight contains two equivalents of zinc? And is not the valence

of an element, therefore, also, the number of equivalents of the element contained in its atomic weight? The pupils measure equivalents in the laboratory, so they know what an equivalent is, if they know anything.

But let us hasten to take another "test sample." There is no difference in weight between the candle and the consumed oxygen, on the one hand, and the products of the combustion on the other. "We know this because the law of conservation of matter tells us that matter is never created or destroyed." Is our point of view then, that the facts of the science are inferred from the laws? "The periodic system is the expression of a great law, the interpretation of which is one of the achievements of modern chemistry." Do the memoirs of the great chemists show that they busied themselves much with interpreting the statements of fact devised by other chemists? When, by any chance they do so, the abstractor, who seeks to boil down the literature and extract from it the important facts, dismisses the article with the remark "a purely polemical paper," and his point of view is that of the majority.

It would be interesting, if there were time, to take other test samples from the overflowing store. We might ask whether graphic formulæ are really methods of representing valence, or modes of showing the structure of molecules, or attempts to represent chemical behavior graphically. We might inquire whether planting a kodak behind an ion is not as much of a farce as planting it behind a molecule, and whether the older term radical would not, in most cases, convey the meaning in more concrete and tangible shape. We might consider the point of view which brings efflorescence and deliquescence so closely in line that, in spite of their real remoteness, they get into the same page of the finished photograph. But we must try now to sum up our results.

First, and foremost, observation is the only method of securing facts and none can be safely obtained by inference from, or interpretation of laws. Observation in chemistry consists in noting and using experimentally the specific, physical properties of substances.

Secondly, plain, literal, experimental terms are the best for stating facts. Facts are understood to include laws and also definitions of conceptions based on facts. The final statements are to be in terms of physical realities exclusively.

Thirdly, hypotheses are to be used only for explaining and relating facts. They furnish the intermediate steps needed to help us in following the relations of facts, but when we have grasped the relation the steps are no longer required. They are like the scaffolding by which the inaccessible parts of a building are reached during construction. But it would be a poor architect who managed to cause parts of the actual structure to rest here and there on portions of the scaffolding, so that the latter could not all be removed at last. Is there in chemistry any fact, law, or conception based on facts which cannot be cleared of hypothesis and stated finally in experimental terms?

Do not these three propositions constitute a creed for the teacher of chemistry, or indeed of any other science? And by a creed is meant, not a formula which is repeated daily without conscious thought, but a touchstone in constant use for determining the genuineness of every utterance. May not the habitual employment of these propositions lead to the acquisition of a point of view whose outward manifestations will be sound, sane, and above all intelligible speech, a point of view fitted to guide one in the presentation of the elements of the science, with a reduction in scale suited to the purpose, but without needless and misleading distortion?

For the fourth time in the history of the United States the production of coal in 1905 reached a total of over 300,000,000 short tons, showing an actual output of 392,919,341 tons of 2,000 pounds, valued at \$476,756,963. Of this total the output of anthracite coal amounted to 69,339,152 long tons (equivalent to 77,659,850 short tons), which, as compared with the production of 65,318,490 long tons in 1904, was an increase of 4,020,662 long tons, or 6 per cent. The value of the anthracite coal at the mines in 1905 was \$141,879,000, as against \$138,974,020 in 1904.

The output of bituminous coal (which includes semianthracite and all semibituminous and lignite coals), amounted in 1905 to 315,259,491 short tons, valued at \$334,877,963, as compared with 278,659,689 short tons, valued at \$305,397,001, in 1904. The increase in the production of bituminous coal in 1905 over 1904 was therefore 36,599,802 short tons in quantity and \$29,480,962 in value.