titanium in animal and vegetable growth, it is hoped that Dr. Wait's work will throw some light upon the subject. Doubtless had we as delicate and covenient tests for the other less common elements we should find their occurrence as widespread. Thus the asseverated belief of Hillebrand in the universal occurrence of all the elements in the earth's crust is extended.

Titanium was determined by Weller's well-known method as modified by W. A. Noyes, Dunnington, and Hillebrand.

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THE RELATION OF PHYSICAL CHEMISTRY TO TECHNICAL CHEMISTRY.[1]

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Received October 2, 1899.

STUDENTS ask me often what use physical chemistry can be to them if they are going into technical work and, once or twice, a manufacturer has said to me that "of course, physical chemistry has no practical usefulness." It is this idea, that physical chemistry is not a necessary part of the technical chemist's equipment, which I wish to combat. Let me warn you in advance, however, not to take anything that I shall say as an argument in favor of substituting a study of physical chemistry for a study of organic or inorganic chemistry. Nothing is farther from my thoughts. A good working knowledge of inorganic and organic chemistry is absolutely essential to the man who is going to use his physical chemistry either for purely scientific purposes or for technical purposes.

To understand the usefulness of physical chemistry to the manufacturer, it is necessary to ask what the manufacturer needs. He is interested in the discovery of new and useful compounds, and in the improvement of methods for making compounds already known. The discovery of new and useful compounds may be left, for the present, to the man who is an inorganic or an organic chemist, pure and simple: it is his especial province. What I wish to emphasize is that this is, as a rule, a matter of secondary importance. There are very few manufacturers who make their profits entirely from the sale of a compound which they alone have the right to make. The

1 Revised from a paper read before the American Chemical Society at Columbus, September 21, 1899.

American chemist makes and sells compounds which others also make and sell. He has to face competition in this country and competition from abroad. His chance of making money, apart from advantages of position, lies in the use of better methods, in getting a larger yield at the same cost or in getting the same yield at a less cost. How to do this is the problem of the manufacturer and no course of education can be considered really satisfactory which fails to take this into account.

Having found out what is needed, the next question is how to get it. To my mind, specialization and research work in organic or inorganic chemistry do not give the proper training. Let us consider for a moment what sort of training a man gets from a study of organic chemistry. Organic chemistry is at present the chemistry of new compounds. The object of a thesis in organic chemistry is to make new compounds. or to bring out more clearly the relation between two or more compounds. A man specializing in organic chemistry gets a training in manipulation and in methods of making new compounds; in addition, he increases his knowledge of chemistry and of chemical phenomena. This work qualifies him to meet one of the requirements of the manufacturer; he can make himself valuable in discovering new and useful compounds, and in working out new methods of making compounds already known. His training has not been of a nature to make himself especially valuable in improving methods. In ninety-nine cases out of a hundred, the man doing research work in organic chemistry is interested in making a reaction go, or in getting enough of any given substance to go on with. While he would rather get a ninety per cent. yield than a ten per cent. yield, he is too much interested in the substance that he is getting, or in the one that he is going to make from that, to be willing to spend much time in a possibly fruitless effort to increase the yield. By this, I do not mean to imply that the organic chemist has necessarily erred in his choice of goal; he has modern organic chemistry to show as a result. I wish to emphasize the fact that the ideals of the organic chemist are not the ideals of the manufacturer, and that a training in organic chemistry is not the best training for a technical chemist. I have laid stress on the training in organic chemistry rather than on the training in inorganic chemistry, because organic chemistry rather overshadows inorganic chemistry in most of our universities and colleges. It is, however, equally clear that inorganic chemistry, as now taught, does not offer the ideal training for a technical chemist.

Let us now turn to physical chemistry. If organic chemistry be called the science of new compounds, physical chemistry will have to be defined as the science of methods. The physical chemist studies the reaction and not the end products. The organic chemist, or the inorganic chemist, as the case may be, tells him what the initial and final products of a reaction are, and the physical chemist then proceeds to study that reaction qualitatively and quantitatively, with special reference to such factors as initial concentration, temperature, solvent, pressure, electrical stress, and time. He does more than this. He correlates his facts and draws conclusions from them, so that it becomes possible to generalize from one reaction to all reactions. It is here that the value of physical chemistry as a training for the technical chemist comes in. It is no longer necessary to work each step of reaction out by itself. We can profit by what we have learned with regard to other, apparently dissimilar, reactions. A single instance will make clear what I mean. A certain reaction gives a fifty per cent. yield under certain conditions, and the question comes up whether changing the temperature will help matters. The man who has not studied his physical chemistry will be forced to make one experiment at a higher and one at a lower temperature in order to determine whether raising or lowering the temperature will increase the yield. If there happens to be a secondary reaction taking place, this may mask the primary reaction, and even cause false conclusions to be drawn. The man who has studied his physical chemistry finds out whether the reaction absorbs or evolves heat, and can then predict the effect of a change of temperature. If the actual result does not tally with that expected, he knows that there must be some secondary reaction taking place, and he will then proceed to minimize this. A most striking instance of this waste of money due to lack of theory is to be found in the history of the blast-furnace.

I am indebted to Dr. H. W. Wiley of the Agricultural Department for the following illustration of the practical application of a fact that appears at first sight to have theoretical interest only. It was found recently in California, after a very dry summer, that beet-sugar could not be made in the usual way, owing to the presence of a relatively large amount of colloids in solution. Mr. E. C. Burr took advantage of the fact that colloids diffuse much less rapidly than crystalline substances, and solved the problem by shortening the time of extraction. It is evident in this case that a man with no theory to guide him might have experimented a very long time before finding the right conditions.

Even in cases where there is no theory applicable as yet, a training in physical chemistry will prove invaluable. In many industries, the color industry for instance, the physical state of a preparation is of great importance. While we cannot at present predict the conditions necessary to produce a product having the required properties, the man who has been trained to vary one factor at a time, and to note the effect of that change, will reach the goal more quickly than the inorganic or organic chemist who, quite unconsciously, allows two or more factors to vary simultaneously. If any one doubts this, let him look up the literature on the allotropic forms of the elements, or on the transformation of isomers and he will see how little attention has been paid in the past both by the inorganic and organic chemist to the conditions affecting equilibrium.

A point of great interest, technically, is the question whether a reaction will run on a large scale as well as on a small one. Many factors, such as stirring, filtration, keeping the temperature constant, etc., are often negligible in the laboratory and yet become of vital importance when the work is carried out on a large scale. Here again the training of the physical chemist should stand him in good stead. Having worked out the conditions under which the reaction goes properly, he is in a position to tell whether the disturbing factors are of such a nature as to become serious when the quantities are increased. In connection with this, I wish to call your attention to the importance of determining the conditions under which the reaction does not go as well as those under which it does go. Experimenting on a large scale is only possible to a limited extent owing to the expense involved and it should never be necessary to fail twice in the same way. While it is not always possible to do on a large scale what can be done on a small scale, there is something wrong when a chemist cannot repeat in the laboratory the results he has obtained in the factory.

A training in physical chemistry means, or should mean, a training in methods and in the application of general principles to particular cases. A physical chemist has two advantages over another chemist when it comes to attacking a technical problem. He has had previous practice along that line, and he has his general principles or laws to guide him so that he does not need to grope aimlessly, waiting for a fortunate accident. It is thus clear that the young man who has studied physical chemistry should be more serviceable to the manufacturer than the young man who has not; but we then come face to face with the question whether we so teach physical chemistry that our students are really as superior to other students as they ought to be. I am afraid that this is not the case as yet, and that the fault lies in our teaching.

Personally, I do not believe in the teaching of technical chemistry as technical chemistry. To my mind, a comparison of German results with English results shows very conclusively that the best way to teach technical chemistry is to teach scientific chemistry. There are, however, many ways of teaching scientific chemistry and I am quite willing to admit that we do not yet teach physical chemistry in the best possible way. Physical chemistry, in its present form, is a development of the last fifteen years. Although lectures on this branch of chemistry are given at most of the universities in this country, chairs have been established only at Wisconsin and at Cornell. Under these circumstances, it will be profitable to consider, for a moment, what our shortcomings are and how they are to be remedied.

The chief criticism that I should make on all teachings of physical chemistry, including my own, is that we fail to emphasize the fact that the laws of chemistry are tools to be used rather than things to be remembered. Everyone who has worked in a laboratory appreciates the wide gulf that exists between knowing a thing and being able to use that knowledge. The ability to use knowledge comes from practice and our laboratory courses should be extended so as to include practice in applying the general principles that have been learned. I use the word "applying" in contradistinction to the word "demonstrating" because I do not mean laboratory work supplementing the lectures. That we now have. We give our students practice in freezing-point, boiling-point, reaction velocity, conductivity determinations, etc., etc. These experiments are intended to familiarize the student with the method and the apparatus, to enable him to test the general principles, and thus to make him understand and remember them; but these experiments do not teach him how to apply the general principles in concrete cases and I think it is more than probable that a student might do all these and yet not prove himself markedly superior in technical work to a man who had not had these advantages. It seems to me that the training is bound to be incomplete unless, in addition, each man takes up some method, not necessarily a technical one, and studies that in detail, finding out how the yield can be increased, why it can be increased, and how that could have been discovered with the minimum expenditure of time. After such a drill, the student begins to appreciate that the theoretical generalizations are meant for use; he also learns what will be of immense service to him in case he goes into technical work, that it is often possible to obtain an enormously increased yield by relatively slight changes in the conditions of the experiment. We have had an instance of this at Cornell during the past year. One of my students took up the question of the electrolytic reduction of potassium chlorate and had no difficulty in increasing the efficiency from below ten per cent. to ninety per cent. and upwards. This particular reaction will never be of any technical importance because potassium chlorate is now made on a large scale by the electrolytic oxidation of potassium chloride. The training obtained by determining the effect of the different factors on the percentage yield will stand that man in good stead, no matter what problem in electrochemistry he may be called upon to solve. Another problem which has been taken up at Cornell during the past year is the question of the best method of separation by fractional distillation. Although these experiments are not yet finished, we have already obtained results which are distinctly superior to any that have been reached previously.

These two instances are cited to show the feasibility of the plan that I am advocating. There is no limit to the amount of work that can be done along this line. For instance, it would be most profitable to take any one of the little laboratory manuals in organic chemistry and work through the experiments with a view of improving the conditions. From a cursory inspection, I should say that there are very few cases in which an increased yield could not be obtained. The advantages of such a drill would be very great whether the student was going into technical work or intended to devote himself to pure science.

There is no reason, save lack of time, why the student should not be given a training in the application of general principles to methods. This lack of time will disappear as soon as teachers, students, and manufacturers appreciate the importance of such work. There is one other point in which the physical chemistry is still seriously defective. The majority of the papers on physical chemistry published every year deal with so-called dilute solutions, solutions containing less than two per cent. of one of the components. Practically all of our quantitative theory of solutions fails to apply to ninety-six per cent. and over of the possible field. We have accomplished a great deal inside the narrow limits we have set ourselves, but it is obvious that we are handicapped seriously in the application of physical chemistry to technical chemistry so long as we discuss quantitatively only such solutions as do not occur in technical work. Quite apart from the technical bearing, we can never obtain for physical chemistry its proper title as the science of chemistry until we can say that we do cover the whole field.

The whole matter can be summed up in a few words. A good training in physical chemistry is the best possible preparation for a technical chemist; but the ideal training in physical chemistry cannot be obtained until we have broken away from the shackles of 'ideal' solutions and until we have introduced laboratory work showing the application of general principles to methods.

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