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CHEMISTRY AND MODERN LIFE

IT is my privilege to address you upon this important and auspicious occasion—the opening and dedication of the magnificent chemical laboratories created by the munificence of your generous and far-sighted donor, Mr. Jesse H. Metcalf. It is a gift which will have far-reaching consequences and which will exert influences that will continue to increase and broaden after we ourselves have gone.

Let me consider with you the purpose which these buildings will serve and the position which chemistry and science in general bid fair to attain in the life of mankind.

A chemical department flourishes most when side by side with strong departments of all faculties. It must be filled with the spirit of humanity, its teachers with the spirit of research. They should be a body of men whose zeal for knowledge and desire to increase it are principles of life; and its teaching should be such as to fit the student to be his own teacher and to continue the study of his subject on his own account after he has taken his degree.

Next to personnel comes the necessity for equipment. This is a factor which is seldom adequately taken into account and upon which it is impossible to lay too much stress. Lack of equipment means that work is stultified or crippled and that a building, however good, may become an empty shell; whereas with it the possibilities of the future are infinite.

Again it is perhaps not generally appreciated that a well-furnished library is as indispensable to workers in science as to those in any other faculty. Indeed, there are but few scientific theories whose significance and limitations can be fully understood without some idea of their historical development, which is only obtained by access to the original literature. This is frequently in a foreign language. Mere text-books appear dogmatic and infallible, and the more intelligent student rebels or may be repelled. It is when he turns to the original record that the subject becomes alive. Doubts are fairly met instead of being repressed, the exact implications and possible lines of extension are much more clearly seen.

May I remind you that chemistry has now become a vast subject far beyond the power of any one man, however gifted, to grasp. There are about 40,000

[1] Address delivered at the dedication of the Jesse Metcalf Chemical Laboratory, Brown University.

papers and contributions recorded in the chemical journals each year. Nevertheless, so infinite is nature that it is possible for any one with a general knowledge of the subject to possess himself, within a few months, of all the recorded knowledge on any selected topic. Again so extensive are the ramifications of chemistry and its applications that the number of workers of any scientific standing in any given subject, whether of scientific or industrial importance, is very limited. Truly, the laborers are few although the fields are white unto harvest.

The final requirement for a chemical department is that it should have some direct touch with industry. This brings more reality into academic laboratories which are too apt to be dominated by text-books and examinations, and it gives a better professional training. In the words of the report of the British Government's Privy Council for Scientific and Industrial Research:

> Pure science has in the past owed much to observations, suggestions and difficulties which have come from activities external to the laboratory or study. So will it be again, and it is our desire so to order the relations of workers in pure science to the industries going on around them that they may receive the stimulus of a wider outlook. In this way it may be possible in the end to create such an atmosphere that the new generation of students will cease to draw the distinction between ''theory'' and ''practice,'' and technologists of all ranks will through them attain to the view that sound practice is only theory tempered by compromise.

This *liaison* "ensures the continued contact of the research worker with advanced students—an inestimable benefit in the opinion of all the best authorities. Finally, it enables us to use to the utmost advantage the very limited number of original workers available whether for research or for teaching."

The study of chemistry is but part of the work of a university, an institution which is one of the vital organs of a healthy community. A university has a duty towards and is owed a duty by society, both resting, as they do, upon the need for mutual sympathy and understanding.

This brings us to a consideration of the place that chemistry occupies in modren life. Chemistry is the science of the transformation of matter, lying at the basis of all human industry and of such applied sciences as agriculture and medicine. It is so enormously productive, both of new knowledge and of applications, that this aspect may overshadow its real scientific value. My own part of the subject, namely, physical chemistry, can be defined in two or three words—it is the study of the laws of chemistry. Chemistry during the greater part of its development has been the science of analyzing matter.

We realize that when we can take a thing apart we may be able to put it together again and put the parts together in a way superior, for our purpose, to the original arrangement. I need not labor this aspect of the subject, for I understand that you have heard an address by a very able exponent, Dr. Slosson, on "Creative chemistry." During the last fifty years the study of this science has produced numberless new products which had never appeared in nature before and which have proved of great value to mankind. I do not wish, however, to lend support to the false impression, which is only too current, that chemistry is a kind of black magic. On the contrary, the modern chemist tries to plan a reaction just as an engineer plans a bridge, with the same deliberate design and sustained purpose.

I wish to call your attention to an example taken from the ammonia industry which will illustrate the importance of the study of theory and of pure laboratory experiments. It is natural that I, coming from Bristol, should select this example of the fixation of nitrogen, for it was in Bristol that, in 1899, Sir William Crookes pointed out that the world's food supplies are dependent upon a supply of nitrogenous fertilizers to the soil.

Each crop takes so much out of the soil that unless this essential material is replaced the yield per acre steadily drops. There is an inexhaustible store of nitrogen in the air, but nitrogen as such is one of the most inert of materials. It is only when it has been made to combine with other elements, such, for example, as hydrogen, that it becomes available as plant food. The problem in this case consists in taking from the two abundant sources, air and water, the constituent nitrogen and hydrogen and combining them in the form of a new substance, ammonia.

At the beginning of the present century there was no known method for any such fixation of nitrogen, but as the result of applying pure research there are already many industrial methods of fixing nitrogen in actual operation on a very large scale. We shall now trace in outline the manner in which this great result has been achieved in the important instance I have mentioned, the synthesis of ammonia.

Thermodynamics supplies two of the most fundamental laws of science. The first law is that we can not get perpetual motion, we can not get work for nothing. The second law is that all spontaneous processes (and only these) may be utilized to give work. There is nothing more beautiful than watching the operation of these universal laws, quantitative in their application and as universal as the law of gravitation. They are examples of what Einstein calls "theories of principle," whose charm lies in their logical perfection.

On applying these laws to chemical reactions your famous Willard Gibbs, followed by van't Hoff and others, obtained a mathematical relationship called the Mass Law. This law revealed that it was within the power of the chemist to make the reaction $3H_2 + N_2 = 2NH_3$ go in whichever direction desired, for the effects of changes in such factors as pressure and temperature could be predicted. The first problem was to find the most suitable equilibrium.

Production of ammonia is increased by the application of 200 or even 1,000 atmospheres' pressure. The next problem to be solved was the regulation of the temperature to give the most satisfactory yield. The ammonia must be produced at a practical rate and to bring this about substances termed "catalyzers" are employed to hasten the reaction and in addition materials called promoters have been discovered which have the property of still further increasing the efficiency of the catalyzers. The explanation of the action of such catalyzers illustrates what Einstein terms theories of "construction," whose fascination lies in the simple but ingenious mechanism they reveal.

By applying all these principles the Germans have already succeeded in producing ammonia at the rate of over 1,000 tons a day. Thus, from the knowledge obtained by pure theoretical and laboratory research there has been achieved a result which is vital to the existence of the white population of the world and in this instance essential also for war. Further progress has been made in several countries, and commercial production has begun in England and the United States. Furthermore, concurrently with the development of the direct synthesis of ammonia, other alternative methods have been worked out on the largest scale for the fixation of nitrogen in various forms, and all within twenty years of Crookes' first challenge.

Time lacks for further specific illustration, but I wish to bring before you some more general considerations with regard to science. Pure science is study, and incessant effort to understand, testing every idea by the touchstone of truth. For its pursuit the chief requirement is character. This must be reinforced by enthusiasm and imagination. Constructive imagination must have the fullest play, and it is really surprising to see how difficult it is to liberate our minds from preconceived notions. Finally, it is essential that every conclusion must be rigorously tested and verified by honest experiment.

The results appear as a simplification or limitation of the conceivable possibilities. For instance, the whole material universe appears to be built up from perhaps only two constituents arranged to form fewer than 100 elements, and these are combined in accordance with immutable laws. Sometimes an advance in science is made by the boldest flights of the imagination, at other times it turns on increasing refinement of measurement. There is room for the most varied types of men, provided that they are devoted to the service of truth. Indeed, it is rare for any discovery to be the work of one unaided individual. Most great advances are cooperative, usually they are international, and without free international exchange of ideas, progress is crippled.

The value of refined measurements is so great that I should like to stress what has been pointed out before, that the laboratory that buys a refined scientific instrument is purchasing the thought and skill of all the preceding investigators who made the instrument possible and of the mechanics that brought it into being, thus involving and bringing to bear a great quantity and variety of skill and labor. Such weapons are clearly essential in all scientific laboratories; it is obvious that they will always be expensive and that there will never be finality in the case of any single instrument, each will be improved as knowledge advances. This is an added argument for liberal endowments for equipment and materials.

During the war there was created at Shawinigan Falls in Canada a colossal plant utilizing water power comparable with that which is obtained from Niagara. From coal and limestone they managed to produce on an enormous scale substances like acetone, acetic acid and alcohol. Their proud boast was that these great chemical achievements were entirely the cooperative work of a group of men who were just ordinary chemists.

The chief characteristic of the truly scientific man is the research outlook, detachment of mind and habit of resource; for remember, a mere knowledge of facts or principles does not make a scientist. It is a very partial or even sham knowledge which does not see the implications of a subject and is unwilling to face the test of further crucial experiment. We must take to heart the candid and pregnant words of Faraday, who was one of the most successful experimenters and profound thinkers whom chemistry or physics has known:

> The world little knows how many of the thoughts and theories that have passed through the mind of a scientific investigator have been crushed into silence and secrecy by his own severe criticism and adverse examination, that in the most successful instances not a tenth of the suggestions, the hopes, the wishes, the preliminary conclusions, have been realized.

The central position in pure science is necessarily occupied by research, and a special responsibility rests upon the workers in this field to be single-minded in the pursuit of truth and careful in their acceptance of evidence. Results which are not communicable and not verifiable are not science. Whereas formerly a scientific theory might wait even for generations before any further attention was paid to it, nowadays every advance in pure science is immediately seized upon and applied in the most unexpected directions. Illustrations might be found in any of our large chemical industries—as, for example, that of artificial silk. Or, again, observe how quickly the comparatively recent intangible electron theory has created wireless and its related industries. Even the newly discovered and not yet isolated element hafnium is already being applied in wireless valves. Or we might consider such discoveries as those of radium and insulin. Indeed, during the last twenty years, applications of science in medicine have added ten years to the average expectation of life. Every process we employ, every device and invention of which we take daily advantage in our factories is the result of some former, may be forgotten research.

Some seed corn must be returned if the future is to repeat the successes of the past. Knowledge is power, and it is through scientific knowledge that we gain control over nature.

However, it is not upon utilitarian grounds that we present the claims of science upon the educated community. I would quote the words of President J. E. Barton of our Bristol Rotary (a movement which came to us in England from you):

> The real world is not the world of material prosperity or lack of prosperity. The real world is the world of science and discovery, of art, literature, emotion and passion. These are the things which give color and texture to experience.

J. W. N. Sullivan in his "Aspects of Science" has rightly emphasized that scientific research is thoroughly human; it is at once tentative, imaginative and courageous. In science we find a sense of unlimited possibilities, of adventure and of exultant hope.

In such men as Kelvin and Newton and Willard Gibbs we find the modern prototypes of Aristotle and Archimedes. "Science again affords theories and objects of contemplation which are as delicate, as subtle, as harmonious as the dreams of Plato—and much better founded." Many scientific theories are objects of surpassing beauty. Their innate truth appeals as directly to us as that of a great work of art. It is in this sense that Dr. Norman Campbell has written that "science is the noblest of the arts."

Science is bound to become an integral part of the culture of the future. It is profoundly influencing our conception of the universe and of man's place therein. A liberal education must have some acquaintance with the trend of the new physics, chemistry, biology and psychology, for they are too obviously pertinent to all man's chief preoccupations to be ignored.

Many of the convictions which I have expressed are felt by all scientists, although we do not often care to voice them. They underlie all our efforts in the training of our students, the primary object of university work.

I have tried to justify the statement with which I commenced that this far-sighted benefaction will have long consequences.

It is with these high hopes that we dedicate the Metcalf Chemical Laboratory of Brown University.

James W. McBain

Bristol, England

SOME ASPECTS OF THE RELATION OF SPECIES TO THEIR ENVIRONMENT[1]

The close relation between an individual plant or animal and its surroundings is strongly emphasized. It is recognized that the conditions under which it lives may affect its size, its form, its habits and its methods of reproduction. But the influence of the environment on the groups of individuals which we call species, while recognized, seems not to be given the weight that it deserves. It seems to me, at least, that the environment may play a greater part than is indicated by many of the current writers. While the germ plasm is no longer generally regarded as being as completely isolated and independent as set forth by Weismann, and while most workers recognize the action of the environment in cutting off certain individuals and so maintaining the characters of the species within certain limits, there seems to be a failure to recognize the extent to which external conditions determine that the species now living shall show the characters that they do show rather than some other characters. If this is true, if the collections of individuals which we call species show the characters by which we recognize these groups, not alone because of the inherent properties of their protoplasms, but also because of the molding action of the environment, does it not follow that we must assign to the environment a large share in determining the forms of the species as we recognize them to-day?

Many plants and animals, when transferred to new conditions, have changed their form and structure in response to their new surroundings. Criticisms of these results have usually brushed them aside with the statement that the descendants of these individuals return to their old form and structure when returned to the old conditions. These criticisms seem to fail to recognize the fact that the species show the form and structure which we describe as characteristic for them only under a particular set of conditions. We can not doubt that, if the conditions on the earth were different from what they are, we should have our plants and animals showing different groups of characters from those which they now show. In other

[1] Address of the retiring president of the Association of Virginia Biologists, Norfolk, Virginia, April 27, 1923.