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ADDRESS OF THE PRESIDENT OF THE ROYAL SOCIETY[1]

By Sir WILLIAM BRAGG, O.M.

THE tragic happenings of these times have necessarily had their effect on the activities of the society. On the outbreak of war, the offices were moved—as had been decided sometime beforehand—to Trinity College, Cambridge, and I take this opportunity of expressing the gratitude of the society for the hospitality which we have found there. We could not have wished, if we were to be in exile, any greater happiness than to be housed in the college of Isaac Newton and many another of our fellows, past and present. Many of our irreplaceable possessions were removed to places of safety.

The meetings for the reading of papers have been suspended temporarily, but their early resumption is possible, and will certainly take place if circumstances allow. The publication of papers has not been interrupted, though it has seemed well to place some limits on their length. Most of the other activities of the society, including the administration of funds for research, are proceeding as usual.

The council's report deals with the business of the society during the past year, and the second volume of "Notes and Records" tells of many other matters of interest. I am thereby relieved of the necessity of referring in this address to several subjects already considered. I propose to say a few words on the general position of the Royal Society at this special time. But first I would speak of the debt which the society owes to its retiring treasurer, Sir Henry Lyons. We owe to him the complete and valuable reform of our finances carried out during years when the monetary transactions and responsibilities of the society have been growing at a great rate; he has made welcome

[1] Anniversary meeting, November 30, 1939.

improvements in the conduct of our business; our house and rooms are much the better for his care: nor can we forget the successful introduction and maintenance of "Notes and Records" to which I have already referred. In very many other ways we are his debtors. The society parts reluctantly with the treasurer, who has so splendidly filled his office for the past ten years. Perhaps his effectiveness does not disappear with the tenure of his office, for as long as he is with us his critical yet friendly eye will make it impossible for any one to be careless in the society's business.

A very large number of our fellows are serving in different capacities for the prosecution of the war. Twenty-five years ago the war, which to so many of us seems to have been resumed after a very short interval, taught the world the importance of science and its application, and that not merely in the war itself but in many subsidiary activities and indeed by example and by inference in all human undertakings. The lesson has not been forgotten in the years that have intervened, and the present outbreak finds all our defence services far ahead of 1914 in the employment of science and scientific men. For this we must be profoundly thankful; for it is clear now that any nation which fell behind in this respect by even a few years of study and application would quickly be overwhelmed. It is early to form a complete estimate of the effectiveness in the present war of the attention that has been given to science in the last twenty years, but there is no little promise in what we are permitted to know of what is going on. There is evidence that the application of science in all sections of war-activity, land, sea and air, are proving their value and more than justify all that has been spent upon them.

There is indeed a wide-spread recognition of the general effectiveness of science. The ways of using science and scientific men are being slowly discovered. But the process is slow. It would, I think, be hastened, if certain fundamental truths were generally known and recognized. I venture to state them in the form of a few propositions:

(1) Science, that is to say, the knowledge of nature, is of fundamental importance to the successful prosecution of any enterprise. For example, a nation is obliged to make all possible use of science in preparation for war, whether aggressive or defensive: and, again by way of example, in the maintenance of public health and social welfare. Of course, science is not alone in being a necessity in either case.

(2) Science is of general application. There are not one science of chemistry, another of electricity, another of medicine and so on: there are not even distinct sciences of peace and war. There is only one natural world, and there is only one knowledge of it.

Experience shows that an advance in knowledge or technique or skill in any direction may be based on some item of knowledge acquired in a far distant field of research. For that reason, it is necessary to resist strongly a natural tendency for those who study science or apply it, to separate into groups without mutual communication.

(3) Fruitful inventions are alway due to a combination of knowledge and of experience on the spot. Unless the man with knowledge is present at the place and the time when some experience reveals the problem to be solved he misses the fertilizing suggestion. Neither can the mastering idea suggest itself to the man who has the experience only but no knowledge by which to read the lesson that the experience teaches. The man with knowledge may be a temporary or special introduction, or, which is much better, he may be the man who meets with the experience.

(4) There are difficulties peculiar to the application of science to war purposes. While the war proceeds scientists as a body are anxious to put all their knowledge at the service of their country: but when the time comes they are anxious to get away to their work on pure science or the applications of science to the problems of peace. Government may preserve and most fortunately has preserved a nucleus of able scientific effort during the last 20 years of peace, so that a certain connection is maintained between these particular applications and the general body of science: but from the very nature of their respective occupations, and on account of a certain secrecy which one of the two bodies is forced to maintain, the connection is not always strong. It can easily happen that the solution of a particular difficulty in the war service may lie in some piece of knowledge far away from the immediate science of the enterprise and unknown to those who need it.

I believe that the four statements which I have just made and briefly amplified are true, and must be acknowledged to be true by all careful observers. That being the case, it is of the utmost importance to move in the direction in which they point. We must ourselves be interested in any attempt to do so. We must wish to see that the vast and growing body of natural knowledge is most effectively employed in the service of the nation.

The tremendous use of science in the present war compels us to think about the method of its use. Many suggestions have already been made: as, for example, that a ministry of science should be formed immediately. In my opinion there is no solution here. A ministry would be too formal and rigid at any rate for immediate needs; the most successful ways of using knowledge are personal and elastic. We must not attempt too much at once. We might be content if we could in some way bring science as a whole into close relation with government as a whole, if we could attach a central authority of science to the central authority of the country. The immediate application of science in any department of the country's business should be made from within the department, not from without, and we have already a number of instances in which this principle is followed. The Department of Scientific and Industrial Research, which we are proud to think of as an original device of the society, correlates many branches of industry with science: it is entrusted with the administration of large funds, and has had great successes. Similarly, the Medical Research Council administers funds and encourages research in the interests of the health of the people, and again the Agricultural Research Council has its own field of action. Each department of the defence forces takes care of its own applications of science. This is satisfactory so far as it goes. The need is rather for means whereby the government, in its care for the whole sweep of the country's business, can rely on and make use of the whole range of scientific knowledge.

It would seem that our society itself is a body which is not used as it might be, though, as I have said already, a large number of our fellows are individually taking part in the application of natural knowledge. Within its ranks are to be found men with knowledge of every form of natural science. It would be well if by way of some small group of fellows, selected for the purpose, it were consulted without hesitation whenever the need arose, and if it were kept so well informed that it might foresee occasions and needs. If that could be achieved, a forward step would be made, which in due time would be followed by others. It would be a very proper step to take, being a continuation and extension of a process which already exists. To use a modern term, science is irresistibly making its way into general use by a "peaceful penetration," which in the end is far more effective than a violent movement; all the more so because science is not out to fight present methods of rule and economy but rather to strengthen with new knowledge of facts and principles. We have often proved in this country the practical value of making use of existing institutions rather than founding new ones, when the old are full of vigor and can carry new grafts without strain. That is why the Royal Society, as a body of high consultative value, is ideally fitted to form the next link between knowledge and practice.

There are two subsidiary consequences of the present position of science which need to be remembered. We have not long passed the stage, if indeed we have quite gone past it, when our knowledge of nature is used as a reference library is used. The knowledge is there, on the shelves, to be taken down when any one wants information on a particular point and happens to remember where possibly it may be obtained.

Any one who wants to use a library effectively must already have some knowledge of the same nature as that which he hopes to find there. If not, he does not know where or how to look; nor can he grasp fully what he finds, even if he happens to hit upon the right book. For a parallel reason, it is most important that a general knowledge of science should be diffused among the people, and especially among those to whom it falls to guide and govern.

A second consequence is that the supply of men capable of the study and interpretation of the natural world must be made continuous. An instance, special to the moment, is the present policy of reserving able men in their final year at universities and technical institutions so that they are not absorbed too early into the fighting services nor into inappropriate branches thereof. This is necessary; but it is not all that is necessary. National interests demand that the water shall not be diverted higher up the stream.

And it may be well to add here that the care for those who can in due course be expected to supply the knowledge of nature and to assist in its use is not the nation's only care. It would be absurd to overlook other knowledge: I am but limiting myself to matters with which the society is especially concerned.

Let me now turn to a question of pure science. When the new methods of x-ray analysis were first introduced a quarter of a century ago there was naturally no clear realization of the extent and character of the fields of research in which they would eventually be employed. Certain applications were found for them at once, but the years have brought wide and unexpected developments. Some of these are gathering themselves together, and, in conjunction with other methods of physics and chemistry, begin to form what might well be called a new branch of science.

In the early phase of the x-ray crystal studies the object of interest was the perfect crystal; in the later phase attention is directed towards the departures from perfection, which turn out to be of the greatest interest and importance.

It will be remembered that the method of analysis of the structure of matter by means of x-rays was based upon a suggestion made by Dr. Laue. If the atoms in a crystal were in regular array, the passage of ether waves through the crystal should be accompanied by diffraction effect provided that the lengths of the waves were of the same order of magnitude as the spacings of the atoms. In the case of the ether waves emitted by an x-ray bulb—if indeed the x-rays were ether waves, of which there was some doubt at the time—there were reasons to suppose that the wavelengths were of the magnitude required. The experiment was made, and was successful.

The diffraction effects provided means whereby the crystalline arrangements could be calculated. The researches of the first few years of x-ray analysis were therefore concerned with the character of the crystalline arrangement in a number of the simpler cases. As confidence grew and skill increased more difficult structures were attacked, and indeed it has been very surprising to find what complicated structures can be unravelled. One helpful circumstance has been the existence of families of substances, since the progressive differences in the members of a family gave rise to corresponding changes in the diffraction patterns. Thus, for example, the large family of silicates was examined and the connections between composition and diffraction effects, and again between the latter and structure, were observed and compared. Certain simplicities and informities then appeared and it became possible to put in order a mass of details which had not previously appeared to have any relation with each other.

It was not long before the results in the field of research became so numerous that books of no small size were required to contain them. In thousands of cases the dimensions of the unit cell of the crystal were determined, and at least the space-group or character of the arrangement of the atoms within the cell. In a number of these cases the exact relative positions of the atoms could be found, though this additional task has often been formidable. Work of this kind continues and rightly so, to be the occupation of many investigators. All such work belongs to the first phase to which I have referred.

The application of the x-ray methods has for some time been entering on a second phase. It now deals with a natural phenomenon differing entirely from that which was the first to be examined. The earlier work was concerned with the arrangement of the atoms in a perfect crystal, that is to say a body in which the mutual forces are balanced, and the arrangement is complete. Thermal movements may still be there, but the average dispositions of the atoms are settled, and are uniform throughout the body of the crystal.

It is doubtful whether there is such a thing as a perfect crystal large enough to be handled; perhaps the crystals of diamond and graphite are nearest to perfection. In almost all cases there are deviations from complete uniformity. A crystal that has every appearance of being perfect may consist of an assemblage of minute crystallites, more nearly perfect individually but lacking uniformity of orientation to a greater or less degree. Other bodies that do not appear to be crystalline at all may consist of crystallites oriented so irregularly that the bodies seem to be isotropic. The crystallites may vary in size as well as in relative orientation. Two or more crystal forms may be present in the same body, so mixed together that only the x-ray methods can make any attempt to disentangle them. Sometimes one greater lattice overrides in a more or less regular fashion a smaller lattice as a pattern of ploughed fields may override a pattern of furrows. Also a lattice may be distorted by strain. In a substance in the liquid state there may be associations and partial arrangements sufficient to show x-ray diffraction.

Moreover, arrangements and dimensions may vary with time, both in solids and liquids; some forms or extents of arrangement may even disappear, new forms may appear at the expense of the old. Perfection of crystalline arrangement is a goal which is never achieved. And in fact the processes of the world are based upon such deviations from perfection, and their continuous modification. If all arrangements of atoms were complete, there would be nothing left but stagnation and the peace of death.

It will be seen, therefore, that a new field of research of extraordinary interest is being opened up. It is in this field that the physicist and chemist and indeed scientists of every persuasion must look for explanations of many of the properties of their materials such as their relations to magnetism and electricity, thermal conductivity, tensile strength, various surface effects and so on: as also the time-changes in these properties, such as the creep to which the engineer has to give so much attention. Properties such as these have been called by Orowan and others the "sensitive" properties since they depend on the particular state of a body, which state in turn depends largely on the conditions of the new field of which I am speaking. The biologist finds interest in it, because the life processes seem to involve the relations between large aggregates, molecules or assemblages of molecules, with one another or with media in which they are imbedded. Somewhere in this field life and matter are first found in association.

It may seem unreasonable to expect help in the resolution of such complications from the x-ray diffraction effects. It is to be remembered, however, that the x-ray photographs are very rich in information. The gratings are three-dimensional and may be examined from a variety of aspects; each photograph or spectrometer record is a two-dimensional diagram of positions and intensities of diffracted spots. A light spectrum of the ordinary kind is uni-dimensional only. The photographs vary in definition, being less easy to read as they deal with more complicated cases; but the technique is rapidly improving.

The earliest of these phenomena of the larger field was the so-called mosaic effect. A crystal of rocksalt, for example, is a mass of small crystals, each of which approaches to regularity far more completely than the whole. The separate crystallites are not in perfect alignment with each other. Hence arose one of the perplexities of the early days. It was extraordinary to find that the less perfect crystal reflected the x-rays in greater intensity than the more perfect and that the reflections from the face of a crystal, quartz, for example, might be increased if the surface was roughened. The puzzle is solved if we remember that, as Darwin and others pointed out, one crystallite may screen another. If the orientations of the two are exactly the same, and they are set at the proper angle for reflecting the incident x-rays the first crystallite will partly absorb the rays in producing its own reflection and the lower will not have its full opportunity. But if, as is usual, the crystal is moved through small angles about the above setting so as to give every crystallite its chance—provided that the x-rays can penetrate the crystal so far as to reach it—then the second will be in the right orientation for reflection when the first is not. The incident rays get through the first and are reflected by the second; the integration of all effects therefore gives a larger total when the crystallites are not parallel. This mosaic character is very common, even in crystals of the purest material. There are indications, as remarked by Goetz and others, that in some cases at least it is the state of greater equilibrium. Thus W. A. Wood shows that crystals of copper and other metals of extreme purity are reduced by cold working to crystallites in more or less complete disarray. The substances do not then return to their former state, though they can be taken some way toward it by moderate heating. To restore them to their original state it would be necessary to begin over again from the melt. A similar effect was shown by Ewald to occur in the case of rocksalt. It may also be significant that of the two forms of diamond examined by Robertson and Fox, that which is the more transparent to infra-red and ultra-violet and may therefore be taken to be in greater internal equilibrium is also the one in which there is some mosaic character.

If this form of disintegration of a larger crystal into crystallites is really due to the release of energy, it might be expected to proceed until the process was complete and the substance became amorphous. Wood shows that it does not proceed indefinitely and that the copper crystallites have an average linear dimension of about 700 A; for silver the figure is 800, for metal 1,200, and so on. The disintegration ceases at a certain point. The metals were of extreme purity. Unless it appears that the mere trace of impurity governs the effect, it must be supposed that the disposition to form aggregates of definite magnitude is present in the copper atoms themselves.

The presence of crystallites of a definite pattern, their dimensions, their preference for any particular orientation in relation to the body which contains them and their proportional amounts are all determined by the x-ray photographs. It is to be remembered that the diffraction spectra of a compound of different crystallites do not modify nor disturb each other's evidence. The data on which calculations are based are the forms and intensities of the spots and lines in the x-ray photography. The calculations are often difficult and lengthy because so many factors have to be taken into consideration; in fact there is plenty of evidence, and the most troublesome part of the business is its interpretation.

It will be readily understood that such measurements as these can be of great assistance in the study of metals. It is possible to examine in a new and most effective way the phase diagrams of the metallurgist, and the various effects of composition, temperature and time, and this not only for binary alloys but also for ternary and still more complicated mixtures. With these powers in hand, and with the remarkable accuracy of the modern x-ray spectrometer which can show minute changes of form due to temperature or an admixture of foreign atoms and can show also any variations in the extent of order and disorder in the atomic arrangements, it is not surprising that theoretical metallurgy has acquired a new life and that practical metallurgy begins to gain thereby.

Since the x-ray methods can do so much to discover the composition of molecules, even very large molecules such as the phthalocyanines (Robertson) or the sterols (Bernal, Crowfoot and others), and also to determine the arrangement of the molecules in crystalline aggregates and yet further to find any preferred orientations that there may be, the methods can be fitly used for the examination of fibrous materials. In cotton, silk, rubber and many other substances there are long chain molecules which are linked together into crystallites having preferred orientations along the length of the fiber. So also nerve, muscle, horn and such like contain proteins and keratins in fibrous forms. It is even possible, as Bernal has shown, to find some details of the composition, structure and arrangement of immense molecules such as those of a virus. Very interesting papers on these subjects have been communicated to our society, some of them during the present year.

It is to be observed that the extension of the x-ray methods to these larger scale problems is greatly facilitated by extrapolation from simpler observations. In the case of organic substances the modes of assemblage into characteristic combinations of atoms, such as the association of carbon atoms in the benzene ring, are governed by rules which are so closely followed in the simpler cases that they can be assumed to hold in the more complicated. These rules relate to the distance from atom to atom in various cases, and the mutual orientations of atoms. In this way very important suggestions have been made in respect to the construction of the more difficult assemblages.

It is to be remembered, of course, that there are other physical methods of observation which contribute to the understanding of the complex substances of nature, which are all the more efficient now that the x-ray methods are able to make their characteristic contribution. First of all comes chemical science, the power of which is so obvious and well known that I need not do more than refer to it. Optical properties have been found to be extremely useful. So also the magnetic properties are found to be closely related to structure. Thus, for example, the disposition of a molecule containing benzene rings can often be predicted from diamagnetic measurements.

The sum total of these powers, some new, some old, all reinforcing each other in a common advance, is so great that, as I have already said, a new field of inquiry of first-rate importance has been well entered. That which the eye can see is one thing; that which the microscope reveals is another. Far beyond any vision is the individual atom and the atomic nucleus, of which so much has been discovered in recent years. But a vast range of magnitudes, lying approximately between 10 and 10,000 A has never been accessible to the direct attack which the ranges on either side of it have experienced. Within this range lie all the processes which are concerned in the building of living substances, animal and vegetable, and in the changes of growth and decay. In this range lie also elements that are the origin of the properties of our materials, alloys, glasses, fibrous substances of all kinds, and here take place transformations which change these properties, some of them rapid especially when urged by heat, some so slow that centuries must pass before they become visible or effective. The recent advance into this new field is only the preliminary to what is sure to follow. We have before us an inquiry of supreme interest.

OBITUARY

HAVEN METCALF

1875–1940

DR. HAVEN METCALF, principal pathologist in charge of the division of forest pathology, of the U. S. Bureau of Plant Industry, died on May 23, at Washington, after long suffering from an incurable disease. He was born on August 6, 1875, the son of George Shepard and Prudence (Grant) Metcalf of Winthrop, Maine. The family history is given extensively in E. S. Stackpole's "History of Winthrop." His earliest American ancestor, Michael Metcalf, son of Rector Leonard Metcalf, of Totterford, Norfolk County, England, came over on the ship *John and Dorothy* in 1637. The Metcalf clan was prominent and included physicians, ministers, public officials, professors, authors and editors and manufacturers. Joseph Addison Metcalf (1795–1845) founded a school now known as Gettysburg College (Pa.).

After finishing high school at Winthrop, Metcalf attended Colby from 1892 to 1894 and Brown, from which he received the degrees of B.S. in 1896 and A.M. in 1897. This was followed by further graduate work in botany, bacteriology and mycology at Brown in 1897–98, Harvard in 1899, Indiana in 1900 and with Professor Charles E. Bessey, at Nebraska, from which he received his Ph.D. in 1903. On June 28, 1899, he married a fellow student of Colby and Brown days, Flora May Holt, who died on April 26, 1935. Interspersed with his research, he was an instructor in botany at Brown from 1896 to 1899, instructor in bacteriology at Nebraska from 1901 to 1902, and assistant professor in botany and bacteriology at Clemson Agricultural College and state botanist, South Carolina, from 1902 to 1906. He also gave special lectures at Martha's Vineyard Summer Institute from 1896 to 1899 and the South Carolina State Summer School from 1903 to 1905. He joined the U. S. Bureau of Plant Industry as pathologist in 1906–07, and thereafter organized and administered the Division of Forest Pathology and its many branch offices.

Metcalf joined the Department of Agriculture when it was beginning to break away from purely systematic work and was attracting numbers of university graduates trained in the quantitative and mathematical methods of physics, chemistry and other sciences. Dr. Lyman J. Briggs, then biophysicist in plant industry, tells of the scientific club embodying such a group of enthusiastic young scientists, including Dr. E. R. Smith, in whose pathology laboratories Metcalf had worked a year. Smith reported at one meeting that a certain organism behaved differently on culture-media neutral to methyl orange than it did on the same media neutralized to phenolphthalein. He was puzzled. Briggs explained the matter in terms of the then current rudiments of present-day pH control. Metcalf had consistently believed in the advantages of the application of the physical sciences to biology. Shortly afterwards he visited the laboratories of the writer in the Johns Hopkins University, where colorimetric (indicators), electrometric and conductimetric pH methods were being evolved. Official cooperations on the development and application of such physical-chemical technique to forest pathology begun by them in 1914 continued to the present time, and were used increasingly in Metcalf's laboratories. He established close contacts with a number of leading universities and their scientists, many of whom later joined his staff, in order that forest pathology might be developed and applied with broad understanding.

His cooperative attitude, his stimulating combina-