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COOPERATION IN RESEARCH[1]

No one can survey the part played by science in the war without reflecting on the ultimate influence of the war on science. Able investigators have been killed or incapacitated, and with them a host of men who might have taken high places in research. Sources of revenue have been cut off, and the heavy financial burdens permanently imposed upon individuals, institutions, and governments must tend to reduce the funds available for the advancement of science. On the other hand, the usefulness of science is appreciated as it never has been before, and some newly enlightened governments have already recognized that large appropriations for research will bring manifold benefits to the state. The leaders of industry have also been quick to appreciate the increased returns that research renders possible, and industrial laboratories are multiplying at an unprecedented rate. The death of available investigators, and the higher salary scale of the industrial world, have seriously affected educational institutions, members of whose scientific staffs, inadequately paid and tempted by offers of powerful instrumental equipment, have been drawn into the industries. On the other hand, industrial leaders have repeatedly emphasized the fundamental importance of scientific researches made solely for the advancement of knowledge, and the necessity of basing all great industrial advances on the results of such investigations. Thus they may be expected to contribute even more liberally than before to the development of laboratories organized for work of this nature. Educational institutions are also likely to recognize that science should play a larger part in their curriculum, and that men skilled in research should be developed

[1] Address given before the Royal Canadian Institute, Toronto, April 9, 1919.

in greatly increased numbers. The enlarged appreciation of science by the public, the demand for investigators in the industries, and the attitude of industrial leaders of wide vision toward fundamental science, should facilitate attempts to secure the added endowments and equipment required.

On the whole, the outlook in America seems most encouraging. But the great advance in science that thus appears to be within reach can not be attained without organized effort and much hard work. On the one hand, the present interest of the public in science must be developed and utilized to the full and on the other, the spirit of cooperation that played so large a part during the war must be applied to the lasting advantage of science and research. Fortunately enough, this spirit has not been confined within national boundaries. The harmony of purpose and unity of effort displayed by the nations of the Entente in the prosecution of the war have also drawn them more closely together in science and research, with consequences that are bound to prove fruitful in coming years.

The Honorable Elihu Root, who combines the wide vision of a great statesman with a keen appreciation of the importance and methods of scientific research, has recently expressed himself as follows:

> Science has been arranging, classifying, methodizing, simplifying everything except itself. It has made possible the tremendous modern development of the power of organization which has so multiplied the effective power of human effort as to make the differences from the past seem to be of kind rather than of degree. It has organized itself very imperfectly. Scientific men are only recently realizing that the principles which apply to success on a large scale in transportation and manufacture and general staff work apply to them, that the difference between a mob and an army does not depend upon occupation or purpose but upon human nature; that the effective power of a great number of scientific men may be increased by organization just as the effective power of a great number of laborers may be increased by military discipline.

The emphasis laid by Mr. Root on the importance of organization in science must not be misinterpreted. For many years he has been president of the board of trustees of the Carnegie Institution of Washington, and an active member of its executive committee. Thus kept in close touch with scientific research, he is well aware of the vital importance of individual initiative and the necessity of encouraging the independent efforts of the original thinker. Thus he goes on to say:

> This attitude follows naturally from the demand of true scientific work for individual concentration and isolation. The sequence, however, is not necessary or laudable. Your isolated and concentrated scientist must know what has gone before, or he will waste his life in doing what has already been done, or in repeating past failures. He must know something about what his contemporaries are trying to do, or he will waste his life in duplicating effort. The history of science is so vast and contemporary effort is so active that if he undertakes to acquire this knowledge by himself alone his life is largely wasted in doing that; his initiative and creative power are gone before he is ready to use them. Occasionally a man appears who has the instinct to reject the negligible. A very great mind goes directly to the decisive fact, the determining symptom, and can afford not to burden itself with a great mass of unimportant facts; but there are few such minds even among those capable of real scientific work. All other minds need to be guided away from the useless and towards the useful. That can be done only by the application of scientific method to science itself through the purely scientific process of organizing effort.

It is plain that if we are to have effective organization in science, it must be adapted to the needs of the individual worker, stimulating him to larger conceptions, emphasizing the value of original effort, and encouraging independence of action, while at the same time securing the advantages of wide cooperation and division of labor, reducing *unnecessary* duplication[2] of work and providing the means of facilitating research and promoting discovery and progress.

A casual view of the problem of effecting such organization of science might lead to the conclusion that the aims just enumerated are mutually incompatible. It can be shown

[2] Some duplication is frequently desirable.

by actual examples, however, that this is not the case, and that an important advance, in harmony with Mr. Root's conception, is entirely possible.

It goes without saying that no scheme of organization, effected by lesser men, can ever duplicate the epoch-making discoveries of the Faradays, the Darwins, the Pasteurs, and the Rayleighs, who have worked largely unaided, and who will continue to open up the chief pathways of science. Even for such men, however, organization can accomplish much, not by seeking to plan their researches or control their methods, but by securing cooperation, if and when it is needed, and by rendering unnecessary some of the routine work they are now forced to perform.

Let us now turn to some examples of organized research, beginning with a familiar case drawn from the field of astronomy, where the wide expanse of the heavens and the natural limitations of single observers, and even of the largest observatories, led long ago to cooperative effort.

In the words of the late Sir David Gill, then Astronomer Royal at the Cape of Good Hope, the great comet of 1882 showed "an astonishing brilliancy as it rose behind the mountains on the east of Table Bay, and seemed in no way diminished in brightness when the sun rose a few minutes afterward. It was only necessary to shade the eye from direct sunlight with a hand at arm's length, to see the comet, with its brilliant white nucleus and dense white, sharply bordered tail of quite half a degree in length." This extraordinary phenomenon more brilliant than any comet since 1843 marked the beginning of celestial photography at the Cape of Good Hope. No special photographic telescope was available, but Sir David enlisted the aid of a local photographer, whose camera, strapped to an equatorial telescope, immediately yielded pictures of exceptional value. But even more striking than the image of the comet itself was the dense background of stars simultaneously registered upon these plates. Stellar photographs had been taken before, but they had shown only a few of the brighter stars, and no such demonstration of the boundless possibilities of astronomical photography had ever been encountered. Always alive to new opportunities and keen in the appreciation of new methods, Sir David adopted similar means for the mapping of more than 450,000 stars, whose positions were determined through the cooperation of Professor Kapteyn, of Groningen, who measured their images on the photographs.

Stimulated by this success, the Henry brothers soon adapted photographic methods for star charting at the Paris Observatory, and in 1887 an International Congress, called at Sir David's suggestion, met in Paris to arrange for a general survey of the entire heavens by photography. Fifty-six delegates of seventeen different nationalities resolved to construct a photographic chart of the whole sky, comprising stars down to the fourteenth magnitude, estimated to be twenty millions in number. A standard form of photographic telescope was adopted for use at eighteen observatories scattered over the globe, with results which have appeared in many volumes. These contain the measured positions of the stars, and are supplemented by heliogravure enlargements from the plates, estimated, when complete for the entire atlas of the sky, to form a pile thirty feet high and two tons in weight.

The great cooperative undertaking just described is one that involves dealing with a task that is too large for a single institution, and therefore calls for a division of labor among a number of participants. It should be remembered, however, that a very different mode of attacking such a problem may be employed. In fact, although the difference between the two methods may seem on first examination to be slight, it nevertheless involves a fundamental question of principle, so important that it calls for special emphasis to any discussion of cooperative research.

One of the great problems of astronomy is the determination of the structure of the sidereal universe. Its complete solution would involve countless observations. Nevertheless, Professor Kapteyn, the eminent Dutch astronomer, resolved many years ago to make a serious effort to deal with the question. In order to do so, as he had no telescope or other observational means of his own, he enlisted the cooperation of astronomers scattered over the whole world.

In organizing his attack, he recognized that the inclusion of only the brighter stars, or even of all those contained in the International Chart of the Heavens, would not nearly suffice for his purpose. He must penetrate as far as possible into the depths of space, and therefore hundreds of millions of stars are of direct importance in his studies. Moreover, it is evident that if he were to confine his attention to some limited region of the sky, he could form no conclusions regarding the distribution of stars in other directions in space or such common motions as might be shown, for example, by immense streams of stars circling about the center of the visible universe.

As the measurement of the positions, the motions, the brightness, and the distance of all the stars within the reach of the most powerful telescopes would be a truly Utopian task, Professor Kapteyn wisely limited his efforts, and at the same time provided a means of obtaining the uniformly distributed observations essential to the discussion of his great problem. His simple plan was to divide the entire sky into a series of 206 selected areas, thus providing sample regions, uniformly spaced and regularly distributed over the entire sphere. Conclusions based upon the observation of stars in these areas are almost as reliable, so far as large general questions of structure and motion are concerned, as though data were available for all the stars of the visible sidereal universe.

As already remarked, Professor Kapteyn depends entirely upon the volunteer efforts of cooperating astronomers in various parts of the world. One of these astronomers assumes such a task as the determination of the brightness of the stars, of a certain range of magnitude, in the selected areas. Another deals with their positions and motions, another with their velocities measured with the spectroscope, etc. Each observer is able to take a large number of selected areas, covering so much of the sky that he may separately discuss the bearing of his results on some important problem, such as the distribution of the stars of each magnitude with reference to the plane of the Galaxy, the motions in space of stars of different spectral types, the velocity and direction of the sun's motion in space, the dependence of a star's velocity upon its mass. Moreover, each observer is free to use his utmost ingenuity in devising and applying new methods and instruments, in increasing the accuracy of his measures, and in adopting improved means of reducing and discussing his observations. He also enjoys the advantage of observing stars for which many data, necessary for his own purposes, have been obtained by other members of the cooperating group. Outside the selected areas, such data are usually lacking, because so small a proportion of the total number of stars has been accurately observed.

In physics, as well as in astronomy, there are innumerable opportunities for cooperative research. A good illustration is afforded by the determination of the exact wave-lengths of lines in the spectra of various elements, for use as standards in measuring the relative positions of lines in the spectra of celestial and terrestrial light-sources. This work was initiated in 1904 by the International Union for Cooperation in Solar Research, and is now being continued by the International Astronomical Union. The spectrum of iron contains thousands of lines, many of which are well adapted for use as standards. The work of determining their positions was undertaken by the members of an international committee, in accordance with certain specifications formulated by the Solar Union. But those who took part in the investigation were not bound by any rigid rule. On the contrary, they were encouraged to make every possible innovation in the manner of attack, in order that obscure sources of error might be discovered and the highest possible accuracy in the final results attained. The outcome demonstrates most conclusively that organized effort and freedom of initiative are by no means incompatible. Important instrumental improvements of many kinds were effected, sources of error previously unsuspected were brought to light, and means of eliminating them were devised. A by-product of the investigation, of great fundamental interest, was the discovery that the peculiar displacements of certain lines in the spectrum of the electric arc, which are greatest near the negative pole, are due to the influence of the electric field. These displacements, previously unsuspected, are sufficient to render such lines wholly unsuitable for use as standards unless rigorous precautions are observed. The international committee, in the light of the new information thus rendered available, will now have no difficulty in completing its task of determining the positions of standard lines with an accuracy formerly unattainable.

The variation of latitude is another subject in which international cooperation has yielded important results. It was found some years ago by astronomical observations that the earth's axis does not maintain a fixed direction in space, but moves in such a way as to cause the earth's pole to describe a small but complicated curve around a mean position. The change in the direction of the axis is so slight, however, that the most accurate observations made simultaneously at different points on the earth, are required to reveal it. These were undertaken at several stations widely distributed in longitude, in Italy, Japan, and the United States. A new photographic method has recently been devised which will probably render unnecessary the use of more than two stations in future work.

An extensive cooperative investigation planned by the Division of Geology and Geography of the National Research Council involves the joint effort of geologists and chemists in the study of sediments and sedimentary deposits. This is of great importance in connection with many aspects of geological history, and also because of its bearing on economic problems, such as the origin and identification of deposits or accumulations of coal, oil, gas, phosphates, sodium nitrate, clay, iron, manganese, etc.

The essential requirements are sufficient information on (1) modern sediments and deposits and (2) changes in sediments after deposition and the causes of such changes.

In the study of sediments now in process of formation it is important to learn the mechanical state and shapes of particles of different sizes, their mineralogical and chemical composition, the arrangement of the material composing the deposit, the source of the material, the transporting agencies, and the cause of precipitation. Modern deposits must be studied in the scores of forms in which they are laid down: in deserts and arid regions and in humid climates, in the beds of great lakes, in the track of glaciers, and in marine beds off the coast, in deltas and bays, or on submarine plateaus, in lagoons, and on reefs in subtropical and tropical waters.

In much of this work chemical investigations are essential, especially on the composition of the waters flowing into the ocean, yielding data on the chemical degradation of the continent and the amount of soluble material discharged into the sea.

In undertaking this extensive investigation, which would include the studies just cited and others on ancient deposits, the following procedure is proposed: (1) To make a more complete survey than has yet been made of the investigations that are at present under way in the United States and Canada. (2) To prepare, in the light of present geological knowledge, a program for the investigations needed to supply an adequate basis for interpreting sediments. As knowledge advances, the program will have to be modified. (3) To canvass the field for existing agencies that are suitable in prosecuting such investigations. (4) To assign problems to those institutions or individuals prepared properly to prosecute researches of the kind needed. (5) To provide additional agencies for the study of problems of sedimentation and thereby make possible investigations for which there are either no provisions or only inadequate provisions at present.

It is easy to see how an investigator choosing to deal with some aspect of this large general problem would be assisted by information regarding related work planned or in progress, and how readily, as a member of the group, he could render his own researches more widely useful and significant.

Another interesting piece of cooperative research, which involves the joint activities of geographers, physicists, zoologists, and practical fishermen, is centered largely at the Marine Biological Laboratory at La Jolla, California. Systematic measurements of the temperature of the Pacific near the coast show occasional upwelling of cold water. Simultaneous biological studies reveal a change in the distribution of microscopic organisms with the temperature of the water. This has an immediate practical bearing, because the distribution of the organisms is a dominant factor in the distribution of certain food fishes. The source of the temperature changes and their influence on meteorological phenomena, are other interesting aspects of this work.

In the field of engineering, the possibilities of cooperative research are unlimited. The fatigue phenomena of metals have been chosen by the Engineering Division of the National Research Council, acting in conjunction with the Engineering Foundation, as the subject of one of many cooperative investigations. Metals and alloys which are subjected to long-repeated stresses frequently break down, especially in aircraft, where the weight of the parts must be reduced to a minimum. The elastic limit and, to a lesser degree, the ultimate strength of steel can be raised by working it cold, provided that a period of rest ensues after cold-working. The tests indicate, however, that increased static strength due to cold working does not necessarily indicate increased resistance to fatigue under repeated stress. In the case of cold-stretched steel, for low stresses the fatigue strength is actually less than for the same steel before stretching.

These phenomena, and others that illustrate the complexity of this problem, afford abundant opportunity for further research. The membership of the committee includes representatives of educational institutions, the Bureau of Standards, and several large industrial establishments. The work was divided among the members, two dealing with its metallographic features, two with machines for testing, two with mechanics of the materials involved, and one with a survey of the subject from the standpoint of the steel manufacturer. The results already obtained promise much for the future success of this undertaking.

Scores of other illustrations of effective cooperation in research might be given, especially in astronomy, where each of the 32 committees of the International Astronomical Union is constituted for the purpose of organizing cooperative investigations. In spite of the length of this list of committees, it can not be said that astronomy offers any unique possibilities of joint action. The division of the sky among widely separated observers is only a single means of cooperation, which may be paralleled in geology, paleontology, geography, botany, zoology, meteorology, geodesy, terrestrial magnetism and other branches of geophysics, and in many other departments of science. Most of the larger problems of physics and chemistry, though open to study in any laboratory, could be attacked to advantage by cooperating groups. In fact, it may be doubted whether research in any field of science or its applications would not benefit greatly by some form of cooperative attack.

As for the fear of central control, and of interference with personal liberty and individual initiative, which has been entertained by some men of science, it certainly is not warranted by the facts. Cooperative research should always be purely voluntary, and the development of improved methods of observation and novel modes of procedure, not foreseen in preparing the original scheme, should invariably be encouraged. They may occasionally upset some adopted plan of action, but if the cooperating investigators are following the wrong path, or neglecting easily available means of improving their results, the sooner this is discovered the better for all concerned.

Canada and the United States, enjoying similar natural advantages, and lying in such close proximity as to permit the greatest freedom of intercourse, are most favorably situated to profit by cooperation in research. In both countries national movements for the promotion of research are in progress and important advances are being made. The example set by the Canadian government in establishing the Honorary Advisory Council for Scientific and Industrial Research and that of the Royal Canadian Institute in organizing this series of addresses on research and its applications, have stimulated and encouraged us in the United States. The friendly bonds that have joined the two countries in the past have been greatly strengthened by the war, and I am sure that our men of science will welcome every opportunity to cooperate with yours in common efforts to advance science and research.

GEORGE ELLERY HALE

GENERAL CHEMISTRY AND ITS RELATION TO THE DISTRIBUTION OF STUDENTS' SUPPLIES IN THE LABORATORY

THE object of the general chemistry laboratory is, I take it, to teach chemistry. Its mechanical aspect is clearly a business on a par with any other undertaking that has a special object in view. True, the methods will differ somewhat from other endeavors, but the main idea of striving "to put across" a definite proposition puts the laboratory side of teaching chemistry on a straight business basis, and subject to the ordinary rules of business. Now a business firm no matter what the character of its work, knows that if they are to compete with others, they must avail themselves of every method, scheme or device that will cheapen production, facilitate transportation, add to the efficiency of their employees, or in any other way make better goods at a lower price than the competing firm. They are ever on the watch for a new idea and many dollars' worth of machinery are often scrapped to give place to a newer and more efficient machine. Many firms employ efficiency experts constantly seeking to improve or save anywhere and everywhere throughout the works. No progressive firm ever stands still, but is ever changing its methods for better ones. This does not seem to be true always in the conducting of a chemical laboratory. What "Bunsen did" many years ago is good enough now, and the old song, "the old time religion is good enough for me" seems to apply very appropriately to the management of many laboratories.

Such a state of affairs should not be, and these laboratories with unchanging methods will go to the wall as surely as will a business house run on similar ideas.

A recent questionnaire sent to a large number of institutions in all parts of this country reveals the fact that general chemistry is regarded as the most important and vital course in the department. The grade of work done in all other courses is determined by the nature of this course. If it is poorly given, all other courses are built on a poor foundation, and a poorly trained chemist is the result. The importance of this course is further brought out by this questionnaire, when we note that the number of laboratory hours in general chemistry varies from six to eight per week, for one year. In some cases this is in addition to a year of physics and chemistry in the high school. This, in many cases means that a student before he can take qualitative analysis in college has had in the high school one year of chemistry of say five hours a week for forty weeks, which makes a total of two hundred hours. In college, he has two laboratory afternoons of three hours each and three or four recitation hours a week for a year of thirty weeks, which amounts to 270 hours as a minimum. In other words, the student has had 200 hours in high school and 200 hours in college, or a total of 470 hours, exclusive of all home study both in high school and college. A few years ago these same institutions gave only five hours a week to general chemistry, but the growth of chemistry in this country has demanded a correspondingly increased preparation of students (on the part of institutions) and a very generous response has been given all over America. This increased preparation has been made possible by putting into the students earlier and basic training the best the institu-