International Basis for Uniform Measurement

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Measurement is the indispensable foundation of science, industry, and our material wealth. Since the arts and humanities flourish best when wealth gives leisure it can also be argued that measurement makes a very basic contribution to all aspects of our civilization. Without continual improvement in the precision and accuracy of measurement, progress in science and industry would be at first critically handicapped and, in due course, stopped. Unfortunately these thoughts are so well accepted that they are now platitudes and, as a result, too many people tend to feel that measurement was taken well in hand long ago by the pioneers of science, and that somehow or other it is automatically improving and adjusting to need by following a conventional and well-determined path. In short, although the value of measurement is questioned by no one, this does not always obtain for measurement science the generous support that it requires to keep up with demands for increasing accuracy and precision. The situation is not helped by its lack of superficial glamor, for it is too commonly, but most wrongly, associated in the minds of many with relatively simple operations of routine calibration. Research for better measurement requires very special imagination and skills. Today, as always, it needs the best research talent. It requires strong financial support because, in common with other branches of science, it becomes ever more complex, and what is today up-to-date apparatus becomes very quickly obsolete. The measurement of length and time, to name only two important areas, call on the ultimate resources and latest discoveries of spectroscopy in all regions of the spectrum, interferometry, lasers, masers, and atomic and molecular beams, as well as other specialties. Every breakthrough to a new order of measurement must, by the nature of things, include challenges of a comparable nature. Therefore first-class research scientists, excellent research facilities, and financial support are mandatory if progress is to be made. Support of the degree required is never spontaneously given, and usually has to be desperately fought for in competition with the demands of more glamorous subjects. In these circumstances efforts to restore the vitality of the well-worn truth that measurement science is of basic importance are justified. Those controlling budgets for measurement science must make certain that they hold the scientific, economic, and social importance of measurement in the correct perspective and are fully aware that the necessary support is inevitably expensive because of the intrinsic difficulty and complexity of the field.

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International Acceptance of a Measurement System

Even when adequate research has been established in a number of well-supported laboratories there is still much that must be done before our measurement needs can be satisfactorily met. To be really useful a measurement system must have international acceptance. Worldwide uniformity must be assured and permanent arrangements made for continual improvement. When such widespread scientific arrangements are necessary they usually start at the national level before reaching the international level. In the case of measurement it has been the reverse. This activity was organized first internationally, with its own supporting laboratory, some 10 years before the *Physikalisch-Technische Bundesanstalt,* the first of the great national laboratories, was established and a full quarter of a century before the next two—the British National Physical Laboratory, and the U.S. National Bureau of Standards. One must conclude from this sequence of events that measurement science is a particularly basic aspect of human activity.

There are probably three possible approaches to the international organization of measurement science for the purpose of attaining uniformity, precision, and accuracy. First, we could have an internationally operated laboratory that would do all the things that a national physical laboratory now does, but do them in an international perspective. Second, the task could be done by a bureaucratic type of institution that collected and coordinated the data provided by national and other laboratories, in order to develop common decisions. A third possibility would be a compromise between the first and the second.

There is a general agreement that the first of these can be rejected quite quickly. The expense would be much too great by any measure of the profit to be attained and such a procedure would almost certainly involve unnecessary duplication on a colossal scale because it is unlikely that the larger countries would be happy to leave the work exclusively to an international laboratory. The international center would constitute, at the minimum, a copy of the best measurement facilities to be found in other laboratories, but to assure its scientific viability it would have to do a substantial amount of fundamental measurement research. If it merely took over techniques from others it would inevitably degenerate into a second-class institution.

The second proposal should deserve rejection with equal confidence and promptness. However, there are always those who are attracted by what seems to be the least expensive, and consequently this form of organization has had its supporters and is, from time to time, suggested even now as the desirable way of dealing with the problem. Like many cheap solutions it has inherent weaknesses which destroy the value of the saving. If there is no associated laboratory, the central organization becomes a group of people who, because they are far removed from the atmosphere and spirit of laboratory research, become that unde-

sirable breed—professional scientific bureaucrats and committeemen who inevitably become scientifically sterile. Their scientific qualifications would enable them to serve as mediocre chairmen or secretaries of international groups of scientific workers from the great national laboratories, but they would lack the leadership, the authority, and the feel for the science that can only come from direct participation in relevant laboratory work.

Thus the arguments that reject the second method of international organization give justification to the third proposition, and the arguments against the first require a carefully controlled size for the laboratory allowed under this arrangement.

A neutral and competent scientific authority can be a very important component in reaching international scientific decisions, because scientists are not always as dispassionate as reputed, particularly when they are representing national interests within a certain scientific area. Such differences can usually be resolved, but the best cure for such scientific rivalry is usually an independent view resulting from successful scientific work. Such a neutral viewpoint can also prevent premature national positions that often obstruct or delay ultimate agreements.

There is an additional important argument for an international laboratory of at least limited scope. It would provide for countries that do not possess national physical laboratories a place where their own national standards can be calibrated, and thus assure solid foundations for their measurement systems. It can be argued that if the international laboratory did not exist these countries could seek help from the great laboratories of other countries. But national pride works against it and, whether such pride is laudable or not, it must be taken into account. There are also practical disadvantages. It is hardly satisfactory for a country to be dependent on the generosity of another for an essential service that concerns industry and trade. All national laboratories are very busy and, although generally they are willing to give help to other countries, these services can never be guaranteed as to promptness or regularity. Political changes also may alter or disrupt cooperation between countries. Finally, commercial interests, may have a bearing on the promptness with which a request is met. All in all, it is far more satisfactory if there is a neutral international laboratory to provide the service. It is also invaluable to have an international laboratory where comparisons can be made between national standards.

Convention du Mètre

It is very interesting to find that the best method of organizing international measurement—a secretariat with some degree of laboratory support of its own—has in fact been in effect for nearly 100 years since the signing of the Convention du Mètre in 1875. This Convention clearly laid out in desirably broad lines the work to be done. At the same time it prescribed certain operational arrangements in some detail. Considering that nearly a century has passed since the treaty was signed, and that initially it was created to deal only with length and mass—the meter and the kilogram—it is rather surprising and much to the credit of those who wrote the Convention du Mètre that the document contains such wisdom and flexibility that so far it has been possible to do within its terms all the work that modern science and technology have demanded.

The terms of the Convention did three important things. It established that there should be a plenary Conference on weights and measures attended by properly accredited representatives of the signatory governments at least every 6 years. This constitutes the ultimate authority within the organization on all matters of science, diplomacy, and administration. Second, to ensure a continuing responsible body that would look after scientific and administrative matters between Conferences, it established, under the authority of the Conference, the International Committee of Weights and Measures, composed of 18 members. These members are elected by the Conference for their personal distinction in metrological science and, although not more than one member is allowed from any one country, their membership in the Committee is personal and in no way are they official representatives of their countries. Instead they are servants of the Conference as a whole. The advantages of this particular arrangement have always been quite marked, but in today's rather troubled international atmosphere they are especially significant. Third, the Convention du Mètre established the International Bureau of Weights and Measures. This Bureau, under the direction of the International Committee, was to carry out the operational functions of the organization. For day-to-day operation it depends on its director who is appointed by and responsible to the International Committee of which he is a member. The Bureau includes a scientific laboratory founded in 1875, and, as far as can be determined, this is the oldest international laboratory supported by a budget contributed in common by a group of states. The French government donated the Pavillon de Breteuil in the beautiful Parc de St. Cloud as a permanent home for the International Bureau and its laboratories. Additional buildings have been built since and the property was extended in 1964. This was an act of great generosity on the part of the French government as the Parc de St. Cloud is one of France's most beautiful and highly prized historic sites.

Revision of the Convention

By 1921, due to the work of Giorgi and others, it was clearly recognized that the two units of length and mass, together with a unit of time, were insufficient bases for a convenient rational and coherent measurement system. Accordingly the Convention was revised in 1921 to extend the responsibilities of the Bureau to electrical phenomena and to other measurements that might contribute to precision and uniformity in the fields to which the units belonged. This important revision was sufficiently broad to give authority to the development over the years of a complete measurement system—the International System of Units (S.I.)—that was adopted by the 10th General Conference in 1954. This system can be regarded as the modern development and expansion of the original metric system.

Whereas the metric system rested on two basic units, length and mass, the S.I. is based on length (the meter), mass (the kilogram), time (the second), electric current (the ampere), temperature (the thermodynamic degree), and luminous intensity (the candela). These particular quantities are in no way considered the final word on the matter. Contrary to some former writings, it is now clearly recognized that no group of quantities are

intrinsically more fundamentally significant than any other for use as a basis of measurement. The choice of the basic quantities is dictated almost entirely by the ultimate accuracy and precision attainable in proposed standards. The permanence of the standards at all places and all times is another important consideration. Finally, the need for the system of measurement to be rational and convenient imposes limitations on the number and choice of the basic quantities, and on the size of the units and their corresponding standards.

The revision of the Convention du Mètre in 1921 gave the International Committee power to co-opt distinguished scientists to help with the work. Under this authority the Committee has established a number of consultive committees, each charged with a particular field of measurement, to assure a broad scientific base for important decisions. Members of these consultive committees are either named for their personal expertness in the particular field of science or because they represent the great national laboratories and international organizations concerned with the same field. In this way the Bureau has always had available the best counsel from world scientists. Currently there are seven consultive committees: Definition of the Meter, Definition of the Second, Thermometry, Photometry, Electricity, Ionizing Radiations, and Units. The chairman of each committee is usually a member of the International Committee.

The 11th General Conference of 1960 decided that because of the difficulties that confronted expert scientists in making accurate and uniform measurement in the field of ionizing radiations the Bureau should extend its scientific activities into this region, even though the field presented no requirement that a new basic unit be added to the International System of units.

Scope of Bureau's Activities

The Bureau's activities greatly expanded between 1875, when it was concerned only with the creation of better standards for mass and length, and the present when it is concerned with the complex and difficult physics related to the six basic S.I. units and with bringing uniformity and accuracy to the field of ionizing radiations. Nevertheless the change has been a natural and orderly growth along a logical path which, although not always seeming completely clear in advance, has usually proved so in retrospect. Some would say it has been too conservative in its growth. However, to such critics, one can point to the present standard for the candela which many would say was rather impetuously adopted. But generally speaking, development has accurately reflected the best thinking in the scientific world on measurment systems and standards at a particular time.

Dr. J. Terrien, the present director of the International Bureau, recently defined the scope of the Bureau's activity as an attempt to set up the *"points de départ"* of the world measurement system. This includes work on the six basic units, their improvement, refinement, or possible replacement by others. In addition it can include such work as must be done in a particular field of measurement because lack of a suitable departure point makes it impossible for even the very best world experts to attain the desirable precision, accuracy, and uniformity. The Bureau's entry into ionizing radiations and its current experiment to determine the acceleration of gravity by absolute methods are studies of this latter sort.

This concept of departure points not only defines the breadth of the Bureau's bureaucratic and committee activity but, at the same time, sets very definite limits to the area in which it is appropriate to do scientific work in its own laboratory.

However, although the philosophy just given is useful for defining the general areas in which the Bureau's laboratory may properly work, it is necessary to make choices in these areas in order to keep the size of the experimental activity reasonable but useful. For this there are two criteria. First, it is the Bureau's primordial duty to keep at the forefront of the best techniques of measurements for the six basic standards and any associated special fields, such as ionizing radiations. This competence is required to assure authoritative comparisons of national standards and measurements. It is a very challenging and difficult function as well as very expensive. Instruments and techniques become obsolete within very few years and must be replaced. To uphold the highest quality of measurement functions and to attract and keep competent scientists, the Bureau must maintain facilities for effective research. The choice of this research is the function of the International Committee. While seeking always to avoid a sprawling growth, the committee must recognize the necessity for a certain degree of flexibility in exercising its judgment, lest it impose frustration on scientists of quality. In short, it must follow the general principles that guide any good mission–oriented laboratory operation.

Summary

The influence and importance of the International Bureau have never been greater than they are today and there seems little doubt that its position will be enhanced in the future. The rapid development of science and technological industry during recent decades has placed heavy demands on fundamental metrology to keep ahead of immediate needs. This trend is likely to increase. Other organizations also have an important role to play in measurement and its ultimate application. However, if the International Bureau conserves its competence, the fact that it has always envisaged its role as that of providing leadership in the development of an international scientific consensus rather than developing and imposing its own ideas, combined with the authority that is conferred only by international treaty, will assure its position as the international focus for world measurement. Inevitably this will call for expansion of the Bureau's activities. Not all demands made on it will be legitimate or wise. It will be the responsibility of the International Committee to keep the situation under continuous study and bring imaginative yet prudent recommendations to the Conference.