The National Standards of Measurement*

LYMAN J. BRIGGS
National Bureau of Standards, Washington, D. C.

A BRIEF historical background may prove helpful in presenting the present status of our national standards of measurement, particularly those concerned with our customary system of weights and measures. The difficulties under which commerce had been carried out among the thirteen Colonies, owing to the lack of uniform standards, were probably responsible in part for the provision of the Constitution which delegates to Congress the power "to fix the standard of weights and measures." In the early days of the new Republic, Washington in his presidential messages to Congress repeatedly urged the importance of carrying out this constitutional provision; but for eighty years no formal action was taken by Congress to "fix" the standards, save for the adoption in 1828 of a standard Troy pound for coinage purposes.

Not that the subject was ignored. Repeatedly the matter came up for discussion, without definite action. A standard of length which could if necessary be independently reproduced from physical observations repeatedly intrigued the interest of Congress. Jefferson, as Secretary of State, submitted a proposal for a standard of length based upon the length of a uniform cylindrical pendulum beating seconds at sea level at 45° N. Lat. In 1795 President Washington presented to Congress a communication from the Minister of the French Republic suggesting the adoption by the United States of the metric system of weights and measures. This proposal, however, met with little favor. A standard based on the length of one ten-millionth of the earth's quadrant apparently had less appeal from the standpoint of reproducibility than one based on the length of a pendulum beating seconds.

Meanwhile, various State legislatures were imploring Congress to take some action to bring about uniformity; and in 1821, John Quincy Adams, as Secretary of State, urged Congress "to fix the standard with the partial uniformity of which it is susceptible at present, excluding all innovations. To consult with foreign nations for the future and ultimate establishment of universal and permanent uniformity." Prophetic words! Not yet has the goal been reached.

In 1830 the Treasury Department, which was charged with the collection of customs, was instructed through a resolution of the Senate to investigate the weights and measures in use in the various custom houses of the country, with a view to bringing about uniformity in the collection of customs. The Secretary of the Treasury gave a broad interpretation to this authority to "investigate," and the outcome was that the various custom offices were supplied, without further action by Congress, with uniform sets of weights and measures. These included an avoirdupois pound of 7000 grains, and a yard of 36 inches, based upon standards which Hassler, the first Superintendent of the Coast and Geodetic Survey, had secured in England.

So well pleased was Congress with this solution of its difficulties that the Secretary of the Treasury in 1836 was directed through a joint resolution to deliver to the Governor of each State a complete set of all the weights and measures used by the Treasury Department in the collection of customs. Although no Congressional action was taken to legalize these standards, a number of the States adopted them independently, and a groundwork for uniform weights and measures was at last provided.

It was not until after the Civil War that Congress took the first formal step to legalize a system of weights and measures, and this oddly enough did not relate to the weights and measures in common use, but to the metric system, rejected in 1795. The act of 1866 reads as follows: "It shall be lawful throughout the United States of America to employ the weights and measures of the metric system; and no contract or dealing

* Retiring address of the President of the American Physical Society, presented at the Washington meeting, December 28, 1938.

or pleading in any court shall be deemed invalid, or liable to objection, because the weights or measures expressed or referred to therein are weights or measures of the metric system."

We have thus the anomalous situation in this country of a legalized system of metric weights and measures which is used for scientific purposes, and a customary system of weights and measures which is in common use but has never been formally legalized. When Congress passed the Metric Act in 1866, it realized that the country had no metric standards and accordingly included the approximate equivalents of the metric system in English measure. The length of the meter was defined in inches, even though the length of the inch had never been "fixed." That Congress had in mind only an approximation to the true ratio of the units in the two systems is evident from the fact that the meter is given as equivalent to 39.37 inches, while the millimeter is rounded off to 0.0394 inch.

The platinum-iridium meter and kilogram, supplied to our Government as a result of its participation in the Metric Convention, provided this country with far better material standards than it had ever had before. Both the meter bar and the kilogram had been carefully compared with the international prototypes, and the coefficient of expansion of the meter bar had been measured. Moreover, they constituted, together with the Troy pound, the only legal material standards possessed by the Government. Accordingly, in the absence of further congressional action, Superintendent Mendenhall of the Coast and Geodetic Survey in 1893 issued the following order: "The Office of Weights and Measures with the approval of the Secretary of the Treasury, will in the future regard the international prototype meter and kilogram as fundamental standards, and the customary units, the yard and the pound, will be derived therefrom in accordance with the act of July 28, 1866."

It will be recalled that the Act of 1866 defines the meter in terms of the inch, and when this is transposed by the Mendenhall order it leads to the incommensurate relation

$$1 \text{ inch} = 0.02540005 + \text{meter}.$$

It is obvious that it is not practicable to lay off this incommensurable decimal fraction on a meter bar, so that this relation defines a theoretical inch rather than one that can be derived with exactness from the meter bar. The inch thus defined is also about four-millionths longer than the British inch, which is determined directly from the Imperial yard.

As a matter of fact, the inch now used for engineering purposes both in the United States and Great Britain, and in thirteen other countries as well, is based upon the simpler relation, one inch equals 25.4 millimeters exactly. From this simplified relation it is practicable to derive the inch from the meter bar. Furthermore, it is possible to shift from English to metric units on a screw-cutting lathe by the introduction of a gear having 127 teeth. Finally the ratio 25.4 falls midway between the present accepted values of the British and the United States inch. Both countries could adopt this value without disturbing industry in the slightest, because a change of two parts in a million would not be detected in any industrial operation.

To summarize the situation, the United States for 150 years has been using a customary system of weights and measures without "fixing" the standards on which the system is based. A bill was presented to the last Congress with the simple objective of putting the Government's house in order in this respect. The bill provided that the inch and the pound should be fixed in terms of the meter and the kilogram, respectively, by means of specified ratios. The ratio proposed for the inch was

$$1 \text{ inch} = 0.0254 \text{ meter}.$$

The bill also carried a supplementary definition of the inch in terms of light waves. This was based upon the value adopted by the International Committee on Weights and Measures for the number of wave-lengths of the red radiation of cadmium in a meter, a value which, as I shall show later, is well supported by several independent determinations.

This bill did not come to a vote. Hearings were held by the Committee on Coinage, Weights, and Measures, and the provisions of the bill were found to meet with the general approval of industry. In fact some men directly concerned with precise industrial measurements were inclined to urge that the inch be defined directly in terms of wave-length. It seems desirable, however, to have the inch, like the centimeter, based upon an actual material standard. And it is important that this standard should be common to the two systems of units in order that the ratio of the two units of length may be unequivocally fixed.

Opposition to the bill came from an unexpected quarter. The system of plane coordinates which forms the basis for Federal and State surveys is in terms of English units. Now the primary triangulation surveys of the U. S. Coast and Geodetic Survey are all carried out in the metric system, and in converting these measurements to plane coordinates in feet, the ratio 1 meter = 3937/1200 feet has been used. Those engaged in these mapping operations naturally do not wish to see this procedure changed, and with this viewpoint the National Bureau of Standards is in complete sympathy. An amendment to the original bill has therefore been proposed, authorizing the continued use of the adopted ratio in the conversion of metric geodetic measurements to English units in connection with plane coordinates, elevations, and other map data. This amendment provides full authority to maintain the present procedure in geodetic conversions without sacrificing all the other desirable provisions of the bill. It should be emphasized that the point involved relates only to a computation, the conversion into feet of measurements originally carried out in meters in making primary surveys. A change of two parts in a million in the basic value of the inch would not have any effect whatsoever upon any surveys made directly in feet because such surveys cannot approach this order of accuracy. As a matter of fact the hundred-foot tapes calibrated by the National Bureau of Standards are certified to only one part in a hundred thousand.

TABLE I. *Wave-length of the red line of cadmium in angstroms.*[1]

Date	As Originally Given	After (a) Correction and (b) Adjustment to Uniform Conditions*	Difference from Mean
1895 Michelson and Benoit	6438.4722	6438.4691	−0.0002
1905–6 Benoit, Fabry and Perot	6438.4696	6438.4703	+0.0010
1927 Watanabe and Imaizumi	6438.4685	6438.4682	−0.0011
1933 Sears and Barrell	6438.4711	6438.4708	+0.0015
1934–35 Sears and Barrell	6438.4709	6438.4709	+0.0016
1933 Kosters and Lampe	6438.4672	6438.4672	−0.0021
1934–35 Kosters and Lampe	6438.4685	6438.4685	−0.0008
	Mean	6438.4693	±0.0012

* Note: The values originally quoted by the authors are corrected in the fourth column to take account of subsequent conclusions (a) regarding the values to be attributed to the standards of length employed, and adjusted (b), so far as the information available permits, to uniform conditions of "normal" air—i.e., dry air at 15°C and 760-mm pressure, containing 0.03 percent of CO_2.

[1] J. E. Sears, Sci. Prog. 31, 209 (1936).

THE PRIMARY STANDARD OF LENGTH

The national primary standard of length is represented by the platinum-iridium meter bar No. 27. Its use is limited to comparisons with the working standards. A companion bar, No. 21, of identical form and composition, has borne the brunt of extensive comparisons for more than 40 years, particularly in connection with the certification of geodetic tapes for the Coast and Geodetic Survey. The Bureau also owns two other platinum-iridium meter bars of an earlier alloy, one of which is graduated in millimeters.

The stability of these bars in service reflects the wise judgment of those who were responsible for the selection of the alloy from which the prototypes were made. Meter No. 21, which has been used so much and subjected to the thermal shock of innumerable ice baths, has increased in length about 1 micron during its 50 years of service. Meter No. 27, the national prototype, has been certified by the International Bureau of Weights and Measures as follows:

In 1888–89

No. 27 = 1 meter − 1.50 microns at 0°C.

In 1921–23

No. 27 = 1 meter − 1.48 microns at 0°C.

These equations indicate that within the limits of measurement the length of meter bar No. 27 has remained invariable in relation to the international prototype for the period covered. This fact alone does not of course preclude the possibility that both bars are drifting. The conclusion that they are not is supported by other intercomparisons and can be examined in another way. During a period of 40 years, various determinations have been made of the length of the meter in terms of wave-lengths of the red radiation of cadmium. The meter bars used in these measurements were compared with the international prototype at the time they were used. Any change in the length of the international prototype would thus tend to be reflected in the derived value of the wave-length, in microns, of the red line of cadmium. Table I shows no evidence of any systematic drift.

It will be noted that the mean value of the determinations agrees closely with the original value of Benoit, Fabry and Perot (6438.4696 angstroms), which since 1907 has been used by the International Astronomical Union as the standard to which all spectroscopic wave-length measurements are referred. In view of this fact, the National Bureau of Standards proposed, in the legislative bill referred to above, that the meter and the inch should be given supplemental definitions in terms of wave-lengths of the red radiation of cadmium, consistent with the relation adopted by the International Astronomical Union. These supplemental definitions, if adopted, will legalize the direct use of interference methods in the precise determination of the length of gage blocks and similar working standards. The practical value of this procedure cannot be too strongly emphasized.

End Standards

In the past few years the close tolerances placed on the mass production of interchangeable parts has led to the extensive use of precision end gages. These are blocks, usually of metal, with two opposite faces accurately plane, parallel and a specified distance apart and are used to check various measuring instruments. The extent to which these gages are used can be judged by the fact that more than 50,000 have been tested at the National Bureau of Standards. Using interference methods the surfaces of such gages can be tested and the length determined with greater accuracy than by referring to line standards.

In order to provide the Bureau with end standards of the highest precision, C. G. Peters and W. B. Emerson undertook the construction in 1934 of a series of end standards by direct interference methods, based upon the standard wave-length of the red line of cadmium. Fused quartz was chosen for the blanks, because its low expansivity (about 1/30 that of steel) removes the necessity of accurate temperature control, and it can be given a high optical polish free from imperfection.

Fifteen blanks 2 cm square in cross section and 10 cm long were cut from blocks of optically-clear fused quartz. These were annealed by heating to 1150°C and then ground and polished to size. Extended measurements of these gages were carried out during a period of two years, including measurements made by the International Bureau, the National Physical Laboratory and the Physikalisch-Technische Reichsanstalt. From all of these determinations, no measurable change in dimension with time has been detected in any of the quartz gages. The end surfaces were plane and parallel within less than 0.02 micron and the maximum difference in various determinations of the length of any one gage did not exceed 0.02 micron, or 2 parts in 10 million.

In making these standards the decimeter length was chosen because this is about the maximum length for which clear interference rings can be obtained with the sharpest spectral lines. With these lines the number of waves in the path ranges from 300,000 to 400,000. The fractional order can be measured to about 0.01 of a wave-length, so it is possible to attain a precision of 1 part in 30 to 40 million in the comparison of two wave-lengths and about 1 part in 10 million in the direct determination of a material length standard.

Standard Wave-Lengths

The international primary standard of wave-length is the red radiation of cadmium. The wave-length of this radiation as officially adopted by the International Committee of Weights and Measures is 6438.4696 angstroms under specified standard conditions.

Tribute should be paid to the painstaking studies of Michelson 40 years ago that led him to select the red radiation of cadmium as the standard wave-length to be evaluated in terms of the meter. All of the spectroscopic work which has been done since that time, including the study of the spectra of helium, krypton, neon and other gases then unavailable to Michelson has failed to disclose another strong line of superior quality. Two krypton lines are the closest rivals for this honor.

Using the cadmium line as a primary standard, the International Astronomical Union has adopted a series of secondary wave-length standards, including 20 neon lines, 20 krypton lines and about 300 lines in the iron arc. The measurements of Meggers, Kiess and Humphreys at the National Bureau of Standards have contributed substantially to the establishment of all of these secondary standards. Most of the neon and krypton standards are known relative to cadmium with a precision of 2 or 3 parts in a hundred million, while the precision of the iron standards is about one order less. These standards provide the framework of all spectroscopic measurements.

The Standard Plane Surface

In order to secure a surface which is optically plane to a high degree of precision, it is necessary to prepare 3 surfaces, which when tested in pairs in any of the 3 possible combinations and in any orientation one to the other show uniformly straight interference fringes. The plane surfaces are actually developed by working these 3 surfaces one against another in rotation, up to the final stages of polishing.

The standard plane surface of the Bureau is maintained by means of 3 fused-quartz disks, each 28 cm in diameter and about 4 cm thick. One surface of each is a true plane within one-hundredth of a fringe. In other words, these surfaces depart less from true planes than they would if they conformed strictly to the curvature of the earth.

In testing these planes, care must be used to support the disks in such a way as to prevent them from bending under their own weight. The stability of the fused-quartz disks has been most gratifying; no measurable deviation from planeness has taken place in the last 10 years.

Angular Measure

Angular quantities must be measured with great precision in carrying out primary geodetic surveys. In determining the errors of a completely-graduated circle, the Bureau uses a special comparator which is provided with 4 fixed micrometer microscopes spaced 90° apart around the central rotating table carrying the circle. No standard circle is needed in this case because we are dealing with a closed system. Errors as small as 0.2 second in a 9-inch graduated circle can be measured if the graduation lines are of the highest quality.

The Bureau's circular dividing engine is used mainly for graduating precision theodolite circles for the U. S. Coast and Geodetic Survey. B. L. Page has graduated solid silver circles 9 inches in diameter to 5 minutes of arc with no error throughout the circle as great as 2 seconds of arc; that is, with no line displaced from its correct position by more than 1 micron.

The Standard of Mass

The national standard of mass is represented by the cylinder known as the prototype kilogram No. 20. It is made of the same platinum-iridium alloy as that used in the prototype meter-bars. This national standard was recently taken to Paris for a new comparison with the international prototype. Its certified mass was 0.99999998 kilogram, a change in mass of only two parts in a hundred million in 50 years. This difference is within the uncertainty of measurement.

Two other standard kilograms, one of platinum-iridium and one of pure platinum, are used as working standards.

Standard of Capacity

The standard of capacity, the liter, is established by weighing. It is defined as the volume occupied by a kilogram of water at its maximum density. This volume is unfortunately not exactly 1000 cubic centimeters as the founders of the metric system had intended. One milliliter $=1.000027$ cc. The discrepancy is within the error of measurement of most volumetric determinations, but in precise density measurements the unit of volume (cubic centimeter or milliliter) must be specified.

The Standard of Frequency

The national standard of frequency is maintained by means of 7 quartz oscillators, with natural frequencies of 100 or 200 kc/sec. They are carefully protected from external vibration and the temperature and pressure are closely controlled. These oscillators are intercompared constantly and they are also compared daily with time signals from the Naval Observatory. For this purpose, one of the oscillators, with the aid of a submultiple generator, drives a synchronous motor clock which indicates mean solar time.

This group of oscillators serves to control the precision of the standard frequencies of 5000 kc/sec., 10,000 kc/sec. and 15,000 kc/sec. which are broadcast several days each week from the Bureau's station WWV at Beltsville, Md. These frequencies do not deviate more than 1 part in 5 million from the assigned value.

By means of this service, broadcasting stations throughout the United States are enabled to adhere closely to their assigned frequencies. In addition, the emissions are modulated to give certain standard frequencies in the audible range, which have been found very useful by physicists and engineers. These modulations include a frequency of 1000 c/sec. as well as sharp one-second pulses, accurate to 0.00001 second. The broadcasting of the standard of musical pitch, 440 c/sec., representing "*A*" above middle "*C*" has also met with wide favor both by musicians and laboratory workers alike.

Electrical Standards

The standard of resistance

Since 1908 the national standard of electrical resistance has been represented by a group of ten one-ohm manganin coils, the average value of which has been assumed to remain constant. The value originally assigned to each coil was based upon standards certified by the Physikalisch-Technische Reichsanstalt in 1908. When any member of the basic group of 10 coils showed a pronounced tendency to drift in relation to the group, it was replaced by a coil from the reserve group. The NBS "international unit" of resistance is derived from the mean of the values of the resistances of this primary group.

The present evidence is that the mean value of this group has drifted at the rate of about 1 part per million per year since the group was established in 1908. With the hope of eliminating this drift in resistance standards, J. L. Thomas undertook the development of a new precision one-ohm coil at the National Bureau of Standards in 1928.[1] The manganin resistance after winding was annealed in vacuum at a red heat (550°C) to remove all locked-up stresses, and special precautions were taken to avoid straining the coil afterward while assembling it in its double-walled annular container. These coils have shown remarkable stability, at least relative to one another. The relative changes within the group have been of the order of 1 part in a million in the past 5 years, compared with similar changes of the order of 10 parts per million in the coils of the older group. In 1932 the 10 coils of the standard group were replaced by coils of the new type.

The standard of electromotive force

The national standard of electromotive force was maintained up to 1937 by a group of twenty saturated Weston cells, with many others in reserve. At that time 9 acid cells which had shown gratifying stability were added, and 3 cells were discarded. The present primary group of 26 cells contains 17 cells that have remained honored members of the group since it was established in 1906. These cells are kept at a constant temperature. The NBS "international unit" of electromotive force is derived from the mean value of the 26 cells of the primary group.

Decision to define the electrical standards in absolute units

At the conclusion of the work of the Washington conference of 1910 the standards of resistance and electromotive force of the United States, England, France, Germany, Japan and Russia had been brought into good agreement. But subsequent comparisons showed that the standards were slowly drifting apart, and by 1930 differences as large as one part in ten thousand were found in the standards of electromotive force of the different nations, while similar but smaller changes had taken place in the standards of electrical resistance.

A discrepancy also exists between the "international" electrical units now in force and the mechanical units. For example, if the same amount of power were measured first in terms of the electrical units now in use and then in terms of the mechanical units, the difference would amount to approximately one part in five thousand owing to the discrepancy of the units.

For these reasons the International Committee on Weights and Measures decided to replace the present international electrical units with absolute electrical units, the new system to go into effect January 1, 1940.

In order to carry out the wishes of the International Committee it has been necessary for the National Bureau of Standards and the national laboratories of other countries to determine in absolute measure the value of their electrical standards of resistance and electromotive force with the highest attainable precision. A brief description of the Bureau's contribution to this program, which has extended over a number of years, will now be given.

Inductance and current are the most suitable quantities for evaluation in absolute measure because they can be determined to a high degree of precision without involving the measurement of any additional electrical quantity. But the final objective in absolute measurements is the value of the standard of resistance and the standard of electromotive force. The procedure is as follows: (1) The inductance of a coil is computed from its geometrical dimensions and the permeability of the material on which it is wound; (2) this known inductance, when measured experimentally in terms of time and a standard resistor, serves to fix the value of the resistor in absolute measure; (3) current is determined in absolute value from the geometrical dimensions and positions of the coils of a current balance, supplemented by the absolute measurement of the force exerted between the coils; (4) the potential drop across the standard resistor when connected in series with the current balance serves to fix the value of a standard cell in absolute measure.

The absolute measurement of electrical resistance

Two independent groups at the National Bureau of Standards have been working on the absolute measurement of electrical resistance. Curtis, Moon and Sparks have used an improved self-inductor with an intermediary capacitance in determining the absolute value of the ohm, while Wenner, Thomas, Cooter and Kotter have determined resistance in absolute measure by a method using commutative direct current in a mutual inductor.

Self-inductor method with intermediate capacitance[2]

In this method the self-inductance of an inductor is measured in terms of time and a laboratory standard of resistance. The ratio of the computed to the observed inductance provides the correction factor which is to be applied to the resistance standard to give the resistance in absolute measure. The four inductors used in this investigation were of different dimensions and were wound on nonmagnetic forms of different materials; namely, porcelain, Pyrex glass and fused quartz. The most recent form consists of a heavy-walled glass cylinder 120 cm long and 35 cm in diameter, on the surface of which a very accurate screw-thread was ground and lapped to insure uniformity in the pitch of the helix. The electrical measurements required the use of an intermediary capacitance, so that a resistance was first measured in terms of inductance and capacitance by an alternating-current bridge; then the capacitance was measured in terms of resistance and time by the charge-and-discharge method with a Maxwell bridge. Assuming the capacitance to remain the same under these conditions, it is eliminated between the two bridge equations. Time signals from the U. S. Naval Observatory were used to calibrate a piezoelectric oscillator which controlled the 100 c/sec. generator.

The most recent work by Curtis, Moon and Sparks gives the value

1 NBS international ohm
= 1.000483 absolute ohms,

which the authors believe to differ from the true value by less than 20 parts in a million.

Mutual-inductor method using commutated current

This method was devised by Dr. Frank Wenner. A direct current is passed through the resistor and through the primary winding of the mutual inductor. The current through the primary of the mutual inductor is reversed at regular intervals without changing the current through the resistor. Another commutator reverses the connections to the secondary of the mutual inductor in such a way that the pulses of induced electromotive force are always in the same direction. This rectified electromotive force is balanced against the constant potential drop through the resistor. A direct-current galvanometer is used to indicate the balance.

The commutators which control the connections in the primary and secondary circuits are mounted on the same rotating shaft along with an inductor generator and a current-reversing generator. Consequently these units all operate strictly in synchronism.

Without attempting to discuss the circuits in detail, it may be said that if the current in the secondary of the mutual inductor is zero at the time the connections are reversed, and if the average value of the current through the galvanometer is zero, then the resistance in absolute measure is four times the product of the speed and the mutual inductance. The precision of the method is limited theoretically only by the precision with which the speed of rotation of the shaft and the geometrical dimensions of the mutual inductor can be measured.

The shaft is driven by a direct-current motor, automatically synchronized by a current of 1000 cycles per second; this latter frequency is controlled by the primary quartz frequency-standards in the Bureau's radio laboratory. Over periods of an hour or more the frequency of the control current is constant and known to one part in 10,000,000, while the speed of rotation, averaged in the way in which it affects a deflection of the galvanometer, is uniform within a few parts in 1,000,000.

The absolute determination of the ohm by Wenner, Thomas, Cooter and Kotter gives the relation

1 NBS International ohm
$= 1.000485$ absolute ohms.

The absolute determination of the ampere

H. L. Curtis and R. W. Curtis[3] have made a new determination of the ampere in absolute measure, employing with some modifications the current balance originally used by Rosa, Dorsey and Miller for this purpose in 1911. The most important modification was the use of coils in which the current distribution closely approached that assumed in the theoretical derivation of the force. The value in absolute amperes of the current in the coils of the balance was computed from the dimensions and positions of the coils, the permeability of the material and the electromagnetic force between the coils, the latter being measured in local gravitational units.

In such measurements, we must know the absolute value of the local acceleration of gravity, and Heyl and Cook[4] have recently completed this determination at the National Bureau of Standards using pendulums of fused silica. They found, at the Bureau station:

$$g = 980.08 \text{ cm sec.}^{-2},$$

which indicates that the absolute value of gravity at Potsdam, heretofore generally accepted, is about 2 parts in 100,000 too large.

The current through the balance coils was measured simultaneously (1) in absolute value by means of the balance and (2) in "international" amperes as determined by the potential drop across a standard resistor in series with the balance coils.

The result of the most recent measurements with balance coils of improved design is:

1 NBS International ampere
$= 0.999852$ ampere (absolute).

The international temperature scale

The thermodynamic scale of temperature introduced by Lord Kelvin has long been accepted by physicists as the ideal temperature scale. However, the experimental difficulties incident to the practical realization of the thermodynamic scale by means of the gas thermometer and the consequent discrepancies that arose in the temperature scales used by different nations led the national laboratories of Germany, Great Britain and the United States in 1911 to undertake the unification of their temperature scales. This culminated a quarter of a century later in the adoption by the International Committee of Weights and Measures of the International Temperature Scale.[5]

This scale conformed with the thermodynamic scale as closely as knowledge permitted at the time, and was designed to be definite, conveniently and accurately reproducible and to provide means for uniquely determining any temperature within the range of the scale. It is based upon 6 fixed and reproducible equilibrium temperatures to which numerical values are assigned; namely, the oxygen point (−183°C), the ice point (0°C), the steam point (100°), the sulphur point (444°), the silver point (960.5°) and the gold point (1063°). Intermediate temperatures are determined by means of interpolation instruments calibrated according to a specified procedure at the fixed temperatures.

From the oxygen point to 660°C the temperature t is deduced from the resistance of standard platinum resistance-thermometers; from 660°C to the gold point, by means of a standard platinum *vs.* platinum-rhodium thermocouple; and above the gold point, from Wien's law by means of the intensity of blackbody radiation, measured by an optical pyrometer.

The International Temperature Scale was adopted with the understanding that it was susceptible to revision and amendment. The first meeting for the consideration of possible revisions will be called in Paris in June, 1939.

There is great need for the official extension of the scale from the oxygen point down to the triple point of normal hydrogen (−260°C). At present the National Bureau of Standards maintains the scale in this region by means of a group of well-seasoned resistance thermometers. Hoge and Brickwedde[6] have shown the feasibility of establishing a number of fixed points in this part of the scale, represented by the equilibrium states of coexisting phases of pure substances. With these points once established, resistance thermometers need be used only for interpolation.

Another matter that requires consideration is the value of c_2 in the radiation equation. The value now specified in defining the International Scale is $c_2=1.432$ cm degrees. More recent determinations indicate that this value should be increased to 1.436 cm degrees. This would decrease the present value of the platinum point by about 3°C.

Radiation Standards

The international roentgen

The international roentgen is the quantity of x-rays that will liberate one electrostatic unit of charge from 1 cm^3 of air by ionization under specified standard conditions. It is realized at the National Bureau of Standards by means of a standard ionization chamber developed by Taylor and Singer,[7] which has now been adopted as the ionization standard of 6 other countries besides our own. The calibration of x-ray dosage meters in roentgens is carried out by means of this standard chamber.

Radium standards

Radium is certified by the National Bureau of Standards in terms of the weight of radium element, but the measurement which is actually made is the determination of the ratio of the gamma-ray intensity of the specimen to that of a radium standard. The Bureau has three primary radium standards carrying certificates from the International Radium Commission. The first of these (International value 15.44 mg) was prepared by Madame Curie (1913) and the other two (International values 38.10 mg and 20.36) by Honigschmid (1936) from radium chloride of high purity. The Curie standard when corrected for decay is in accord within 0.1 percent with the values assigned by Honigschmid to the standards he prepared. Radium standards must be systematically corrected for decay. The initial rate of decay is about 0.043 percent per year.

Standards of radiant flux

The National Bureau of Standards maintains standards of radiant flux, based upon absolute measurements by Coblentz.[8] Lamps are now supplied by the Bureau with certificates giving the total radiation in microwatts per square centimeter at a specified distance from the source.

The standard of brightness

International agreement has now been reached regarding the adoption of a primary standard of brightness, defined as the intensity of the radiation from the interior of a blackbody at the temperature of pure platinum at its freezing point. This standard was originally proposed by Waidner and Burgess in 1910 but was first actually realized at the National Bureau of Standards in 1931 by Wensel, Roeser, Barbrow and Caldwell,[9] following the development of the thoria crucible.

Using the same device operated at the freezing points of rhodium and iridium in addition to platinum, Wensel, Judd and Roeser[10] established an accurately reproducible scale of color temperature. This scale is made available to the public through the distribution of color-temperature standards in the form of tungsten-filament lamps.

Comparison of the blackbody standard with the present international candle as maintained by groups of carbon-filament lamps showed that the brightness of the new standard was about 58.9 international candles per square centimeter. However, a uniform procedure has not been followed internationally in the step-up from the yellower sources to the modern tungsten lamps, and E. C. Crittenden found that a better agreement with present practice would be reached by defining the brightness of the standard blackbody radiator as equal to 60 candles per square centimeter. Other national laboratories have agreed to the Bureau's suggestion to adopt this value, and this recommendation has been approved by the International Committee of Weights and Measures. In stepping up from the blackbody standard to tungsten lamps, it is proposed to use the luminosity factors recommended by Gibson and Tyndall[11] of the Bureau staff in 1923, and later adopted by both the International Commission on Illumination and the International Committee of Weights and Measures. At last we have an international primary standard of brightness.

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