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ANNOUNCEMENT OF CHANGES IN ELECTRICAL AND PHOTOMETRIC UNITS

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PREFACE

The system of electrical units designated as "international" has been in use for more than 50 years, and the latest adjustment of the units was made in 1912. It was then considered more important to keep the units as nearly as possible constant in magnitude than to make them consistent with the fundamental mechanical units. Since that time, however, the increasingly close connection between physical constants in various fields has emphasized the desirability of using practical electrical units concordant with other units, as they were originally intended to be. The changes announced in this Circular have been agreed upon by national and international organizations to accomplish such a unification of systems of units.

Photometric measurements involve psychological factors, and consequently units and standards in this field cannot be put on an absolute physical basis. The system herein announced is admittedly arbitrary, but it represents a worldwide agreement on a practical basis for a set of units not greatly different from those already in use in this country.

E. U. Condon, *Director.*

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ABSTRACT

This Circular gives a short account of the development of new international agreements on practical units of electricity and of light. In pursuance of these agreements, the electrical units based upon the resistance of a column of mercury and the rate of deposition of silver in a voltameter will be superseded on January 1, 1948, by units derived from the fundamental mechanical units of length, mass, and time. This will increase the numerical values of resistances by 495 parts per million and those of voltages by 330 parts per million. The magnitude of photometric units will be fixed by assigning the value 60 candles per square centimeter for the brightness of a black-body radiator at the temperature of freezing platinum, and using certain standard spectral luminosity factors for the measurement of light differing in color from that of the black-body primary standard. This change in definitions of the units will involve little change in ratings of the common types of lamps.

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I. GENERAL ANNOUNCEMENT

In pursuance of decisions of the International Committee on Weights and Measures, the National Bureau of Standards will introduce as of January 1, 1948, revised values of the units of electricity and of light. Although the definitions of the units and the methods of fixing their magnitudes will be quite different from those of the present practical systems, the changes in magnitude will be so small as to affect appreciably only measurements of high precision. In certificates for standards and instruments issued by the Bureau during 1947, values will be given in both the old and the new units.

The electrical units of the "international" system will be superseded by those of the "absolute" system derived from the fundamental mechanical units of length, mass, and time by use of accepted principles of electromagnetism, with the value of the permeability of space taken as unity in the centimeter-gram-second system or as 10^{-7} in the corresponding meter-kilogram-second system. Actually, all of the common electrical units fall into the mks system. This revision con-

stitutes a return to the basic principle, always recognized as desirable, of having the electrical units consistent with the fundamental mechanical units.

The international ohm and volt now in use are slightly larger than the corresponding absolute units; consequently, numerical values of resistance and voltage are slightly larger when expressed in absolute units than when expressed in international units. In the United States the factors recommended for conversion to the absolute basis are 1.000495 for resistances and 1.00033 for voltages. For power or energy therefore the factor is 1.000165, but for most purposes the round value 1.0002 is amply precise.

The new system of photometric units takes as the primary standard a black-body radiator operated at the temperature of freezing platinum. The "candle," unit of intensity, is defined as one-sixtieth of the intensity of 1 square centimeter of such a radiator. Other units are derived from the candle, with the provision that when differences of color are involved the evaluation shall be made by means of standard spectral luminosity factors that have been adopted by the International Commission on Illumination and the International Committee on Weights and Measures. For the types of lamps now in common use the ratings under this new system will be practically the same as those now in effect.

II. ELECTRICAL UNITS

1. HISTORY

The adjustment of values of the units now proposed will consummate a movement initiated by committees of the American Institute of Electrical Engineers in 1927. The formal action of the Institute was a resolution adopted by the Board of Directors on June 27, 1928, reading in part as follows:

> Whereas the legalization of the absolute ohm and ampere and the units derived from them (these units to be realized by the national standardizing laboratories) would avert the recurring proposals for revision of the values of the legalized units, and would establish the electrical units on a permanent legal basis: Therefore be it
>
> *Resolved*, That the American Institute of Electrical Engineers hereby urges the Bureau of Standards and foreign national standardizing laboratories to undertake as soon as possible the additional researches necessary in order that the absolute ohm and absolute ampere based on the centimeter-gram-second electromagnetic system, with the absolute volt, watt, and other units derived from them, may be legalized in place of the international ohm and ampere and their derived units.

In order to obtain a consensus of American organizations the National Bureau of Standards had formed an Advisory Committee consisting of representatives named by the National Academy of Sciences, the American Institute of Electrical Engineers, the American Physical Society, the National Electric Light Association, the Association of Edison Illuminating Companies, the National Electrical Manufacturers' Association, and the American Telephone and Telegraph Company. On June 16, 1928, this committee unanimously adopted the following resolution:

> *Resolved*, That in the opinion of this committee, in view of improvements which are being made in absolute measurements, electrical standards should in future be based upon the absolute system of units.

These proposals were presented by the National Bureau of Standards to an Advisory Committee on Electricity established in 1927 by the International Committee and the Seventh General Conference on Weights and Measures. The proposals were accepted in substance, and in 1929 the International Committee adopted a resolution translated as follows [1]: [1]

> In view of the great importance of unifying the systems of electrical measurement upon a basis free from arbitrary characteristics, the absolute system, derived from the centimeter-gram-second system, should replace the international system of units for all measurements in science and industry.

The Eighth General Conference in 1933 [2] approved the principle of substituting the absolute system of electrical units for the international system, and delegated to the International Committee the power to fix the ratios between the corresponding units of the two systems and to set the date for adoption of the new units without waiting for another Conference. It was then expected that standards of the absolute system could be established, at least provisionally, in 1935.

In 1935 the International Committee felt compelled to allow more time, but set the end of 1938 for the completion of absolute measurements, February 1939, for establishment of values for standards by the Advisory Committee on Electricity, and January 1, 1940, for the introduction of the new values in practice. At meetings of the International Committee in 1937 and of the Advisory Committee on Electricity in 1939, reports from the national laboratories were reviewed, and detailed arrangements were made for introducing the new units. The outbreak of war in September 1939 prevented the execution of these plans. In October 1946 the International Committee met again and chose January 1, 1948, as the date for putting the new units into use.

2. MAGNITUDE OF UNITS

The international units now in use [3, 4] were intended to be exact multiples of the units of the centimeter-gram-second electromagnetic system, but to facilitate their reproduction, the ampere, the ohm, and the volt were defined by reference to three physical standards, namely, (1) the silver voltameter, (2) a specified column of mercury, and (3) the Clark standard cell. This procedure was recommended by the International Electrical Congress of 1893 in Chicago and was incorporated in an Act of Congress of July 12, 1894. However, modifications of the international system were found to be necessary or expedient for several reasons. The original proposals were not sufficiently specific to give the precision of values which soon came to be required, and the independent definitions of three units brought the system into conflict with the customary simple form of Ohm's law, $I=E/R$. Furthermore, with the establishment of national standardizing laboratories in several of the larger countries, other laboratories no longer needed to set up their own primary standards, and facility of reproduction of those standards became less important than the reliability of the units.

[1] Figures in brackets indicate references in the final section of this Circular.

The magnitudes of the international units as now used are the result of decisions made at an International Conference on Electrical Units and Standards held in London in 1908, supplemented by experimental determinations carried out by an International Technical Committee in Washington in 1910. It was then known that the international units were not exactly concordant with the centimeter-gram-second units, but the Conference decided to retain the ohm as defined by the mercury column and the ampere as defined in terms of deposits of silver. Starting from these two units, the Technical Committee established a value (1.0183 volts) for the electromotive force of a newer type of standard cell, the Weston Normal Cell. The magnitude of the international volt was changed as of January 1, 1911, [5] to make it consistent with the international ohm and international ampere in the relation $I=E/R$. Since that time the international units actually used in this country have been maintained continuously by groups of wire resistors for the ohm and of Weston cells for the volt, without any intentional change in magnitude. National laboratories in other countries have followed almost the same course, although a few determinations by means of mercury columns and silver voltameters have been made as checks on the values of the units, and in some cases the values have been modified in consequence of these determinations.

In preparation for the expected change in units, laboratories in several countries made absolute measurements of resistance and of current. The results of these measurements and the magnitudes of the international units as maintained in the national laboratories of France, Great Britain, Germany, Japan, the U. S. S. R., and the United States were correlated by periodic comparisons of standard resistors and of standard cells sent to the International Bureau of Weights and Measures. Nearly all of the absolute measurements at the National Bureau of Standards were carried out under the direct supervision of Harvey L. Curtis, and the results of such measurements at the Bureau and elsewhere were summarized by him in 1944 [6]. Units of the new system will actually be maintained, as were the old international units, by groups of standard resistors and of standard cells, and consequently the change to be made is most simply represented by stating the relative magnitudes of the ohms and of the volts in the two systems. The relations accepted by the International Committee on Weights and Measures at its meeting in Paris in October 1946, are as follows:

1 mean international ohm=1.00049 absolute ohms
1 mean international volt=1.00034 absolute volts.

The mean international units to which the above equations refer are the averages of units as maintained in the national laboratories of the six countries (France, Germany, Great Britain, Japan, U.S.S.R., and U. S. A.) which took part in this work before the war. The units maintained by the National Bureau of Standards differ from these average units by a few parts in a million, so that the conversion factors for adjusting values of standards in this country will be as follows:

1 international ohm (U. S.)=1.000495 absolute ohms
1 international volt (U. S.) =1.00033 absolute volts.

Other electrical units will be changed by amounts shown in the following tabulation:

1 international ampere	=0.999835 absolute ampere
1 international coulomb	=0.999835 absolute coulomb
1 international henry	=1.000495 absolute henries
1 international farad	=0.999505 absolute farad
1 international watt	=1.000165 absolute watts
1 international joule	=1.000165 absolute joules.

The factors given should be used in converting values given in international units in National Bureau of Standards certificates to the absolute system.

III. PHOTOMETRIC UNITS

1. HISTORY

Units of light have never been established by law in the United States. In 1909 the National Bureau of Standards by agreement with laboratories in France and Great Britain introduced the "international candle" [7]; the agreement, however, did not provide for any primary reference standard. Pending the development of a satisfactory basic standard the "candle" was represented by groups of carbon-filament lamps. As other types of lamps were developed, working standards of the new types were set up independently in various countries. This required visual comparison of lights of different colors, which is very difficult, and led to some diversity of units. Moreover, Germany and Austria never accepted the international units of light.

As a result of years of discussion and experimental work on standards of candlepower and on photometry of lights of different colors, general agreement was reached on two points: first, the best type of primary standard now available is a radiator of the type known as a black body at a temperature controlled by molten platinum at its freezing point; second, lights of different colors should be evaluated by using certain standard luminosity factors representing the spectral sensitivity of the average eye under specified conditions.

These two elements give a basis for a complete system of photometric units when a numerical value is assigned for the brightness of the platinum—black-body standard. Its brightness expressed in international units was experimentally determined to be 58.9 candles per square centimeter [8]. In 1936 the National Bureau of Standards proposed that the round value 60 candles per square centimeter be adopted as defining a new basic unit to be extended to lights of other colors by means of the accepted luminosity factors [9]. This proposal was approved by the United States National Committee of the International Commission on Illumination after favorable recommendation by a committee including representatives of the American Institute of Electrical Engineers, Illuminating Engineering Society, Optical Society of America, National Electrical Manufacturers' Association, Edison Electric Institute, Association of Edison Illuminating Companies, Electrical Testing Laboratories, and lamp manufacturing companies.

The new system of units was adopted by the International Committee on Weights and Measures in 1937 and approved by the International Commission on Illumination in 1939 with the expectation that it would be introduced in practical use as of January 1, 1940. As in the case of the electrical units, the execution of this plan was delayed by the war, and the date of January 1, 1948, has now been chosen so as to make the change in both sets of units at the same time.

2. MAGNITUDE OF UNITS

The light from the platinum—black-body radiator is not greatly different in color from that given by carbon-filament standard lamps as the color temperature of the lamp filaments is about 2,100° K, whereas the freezing point of platinum is 2,046°. In this range of color the new unit of intensity is about 1.9 percent smaller than the old international candle, and sources of light are correspondingly given higher numerical ratings. However, when light sources of higher color temperature are compared with these basic standards, the accepted spectral luminosity factors give slightly lower values for the "whiter" sources than were obtained by visual measurements when the present international units were established. The difference between the two scales therefore grows less as the color temperature of the sources measured is increased, and for sources in the range of ordinary vacuum tungsten-filament lamps, around 2,500° K, the new scale crosses the international scale as used in the United States. Furthermore, when the range of standards was extended to gas-filled tungsten-filament lamps and other new types, the measurements were made by methods nearly in accord with the luminosity factors. Consequently, the present ratings of tungsten-filament lamps in this country will be practically unaffected by the change, no type being changed by more than 1 percent.

In European countries somewhat higher values have been assigned for light from the high-temperature sources. Introduction of the new scale will bring about reductions of several percent in their ratings, but these changes will not be so great as would have resulted if the standard luminosity factors had been used to step up from the international candle as represented by carbon-filament lamps.

IV. LEGAL STATUS OF UNITS

When the electrical units were defined by law (Public Law No. 105, 53d Cong.) in 1894 it was supposed that the international units were practically identical with the corresponding multiples of the centimeter-gram-second electromagnetic system. Alternative definitions were given for most of the units, and those definitions which appear to be legally controlling were taken partly from one system and partly from the other. The joule and the watt, for example, are clearly defined as multiples of the cgs units. In brief, the absolute units have as good a legal basis under the terms of that act as do the present international units. New legislation is being proposed to remove the ambiguities of the old act, but there should be no objection on legal grounds to the general adoption of the absolute units even in advance of Congressional action.

The photometric units now in use were adopted by common consent of those interested, and as previously stated have no statutory basis. The new system might therefore be adopted in the same way, but authorization for it is included in the proposed legislation.

V. NAMES OF UNITS

During the period of transition to the new units, in order to avoid any doubt as to the units used in giving precise data, the International Committee on Weights and Measures has recommended that the adjectives "international" (abbreviation "int") and "absolute" (abbreviation "abs") be used with the names of the electrical units. Similarly, with names of photometric units the use of the adjectives "international" and "new" is recommended. The use of these distinguishing terms will become unnecessary, except in referring to old data, within a few years.

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