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A FUNDAMENTAL BASIS FOR MEASUREMENTS OF LENGTH

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ABSTRACT

1. *Relation between yards and meters, inches and millimeters.*—There is at present a slight difference in the legal or official relation between yards and meters in the United States and in Great Britain. In the United States the official relation is

$$\frac{1 \text{ yard}}{1 \text{ meter}} = \frac{3,600}{3,937}$$

In Great Britain the official relation is

$$\frac{1 \text{ yard}}{1 \text{ meter}} = \frac{3,600}{3,937.0113}$$

From these official relations may be derived the following approximate relations:

1 United States inch = 25.40005 millimeters
1 British inch = 25.39998 millimeters

While this difference in the units is so small as to be of no importance in the ordinary transactions of everyday life, amounting as it does to about 1 part in 363,000, it is of great importance in the more precise length measurements of science and industry, where an accuracy of 1 part in 1,000,000, or even higher, is not uncommon. It is obvious that conversions between yards and meters, inches and millimeters, can not be made with a higher precision than that to which the relation between the units is known.

2. *Definition of the meter in terms of light waves.*—The paper recommends that the meter be defined in terms of wave lengths of light from cadmium vapor, under standard conditions of temperature, pressure, and humidity, on the basis of the determinations of Benoit, Fabry, and Perot.

3. *Acceptance of simple relation between yards and meters, inches and millimeters.*—The paper recommends the adoption of the simple relation 1 inch = 25.4 millimeters. If this relation is adopted as exact, then the corresponding relation, 1 yard = 0.9144 meter, will also be exact.

4. *Definition of the yard in terms of light waves.*—If the meter is defined in terms of light waves, and the relation between the meter and the yard is fixed, then the yard is also automatically defined in terms of light waves. For example, if 1 meter = 1,553,164.13 waves and 1 yard = 0.9144 meter, then 1 yard = 0.9144 × 1,553,164.13 = 1,420,213.28 [1] waves.

5. *Simplicity and international uniformity.*—Official action by the United States defining the yard and the meter in terms of light waves, and adopting the relation 1 inch = 25.4 millimeters as exact, would not only give official sanction to a simple and convenient relation already widely used in both the United States and Great Britain, but would tend to bring about its universal adoption. This value lies between the values now legal in the United States and in Great Britain, and it could, therefore, be accepted by both without inconvenience. In fact, the change would never be felt except in cases of extreme accuracy, such as the manufacture and testing of precision end standards and graduated linear scales.

[1] In cutting this value off to two decimal places the error introduced does not exceed 1 part in 3,000,000,000.

CONTENTS

I. RELATION OF UNITS

In order that measurements of length may be comparable they must be expressed in terms of a single standard or in terms of standards bearing a known relation to each other.

Lengths are ordinary expressed in terms of yards or meters or some multiple or subdivision of these units.

The following units and their appropriate abbreviations, or symbols, are often used for expressing lengths of small magnitude:

Micron	$= \mu$ =	0.001 millimeter	$= 10^{-3}$ mm
Millimicron	$= m\mu$ =	.000001 millimeter	$= 10^{-6}$ mm
Angstrom	= A =	.0000001 millimeter	$= 10^{-7}$ mm
Milliangstrom	= mA =	.0000000001 millimeter	$= 10^{-10}$ mm

In general, the relations between the various units of any given system of measurement are relatively simple and are well known; for example, the relation between inches, feet, yards, and miles; and between millimeters, centimeters, meters, and kilometers. On the other hand, the relations between the various units of different systems of measurement are, in general, not so simple or so well known; for example, the relation between inches and millimeters, yards, and meters, miles, and kilometers.

Comparison of lengths expressed in the two systems of measurement in common use is further complicated by the fact that no single basic relation between the units of the two systems is at present universally recognized.

In the United States the basic relation officially recognized is that contained in the law of July 28, 1866, and set forth in the Mendenhall order of April 5, 1893; namely,

$$\frac{1 \text{ yard}}{1 \text{ meter}} = \frac{3{,}600}{3{,}937}$$

In Great Britain the present basic relation is that contained in the Order in Council of May 19, 1898, namely,

$$\frac{1 \text{ yard}}{1 \text{ meter}} = \frac{3{,}600}{3{,}937.0113}$$

This slight difference in the legal relation between the units of the customary and the metric systems, although of no importance in the ordinary transactions of everyday life, is of very great importance in the more precise measurements of length required by present-day science and industry.

II. DISTINCTION BETWEEN UNITS AND STANDARDS

Before proceeding to a technical discussion of the above relation, or legal definition, it will be necessary to make a clear distinction between two terms which are often confused, namely, units and standards.

A unit, as applied to length measurements, is a nominal distance in space, fixed by definition. It is independent of temperature, pressure, or other physical condition.

A standard is the physical embodiment of a defined unit. In general, a standard is not independent of temperature, or other physical conditions. It is a true embodiment of the definition it purports to represent, only under definite, standard conditions.

An example will serve to make the above definitions clear. The meter, as a unit of length, is defined as a certain definite distance in space, namely, the distance between two lines on a certain bar of platinum-iridium alloy when this bar is under certain definite conditions of temperature and is supported in a certain definite way. This unit remains constant so long as the bar under standard conditions, in terms of which it is defined, remains constant.

A meter standard, or standard meter, is any physical representation of the above definition. It may be of platinum-iridium, bronze, steel, or any other material. In general, it is a true representation of the unit only at a single temperature and under a certain method of support. Its length at other temperatures, and when supported in a different manner, depends upon its shape and the material of which it is made.

Similarly, the British imperial yard as a unit of length is by definition the distance between two lines on a certain bronze bar when under certain standard conditions. This unit remains constant so long as the bar in terms of which it is defined remains constant.

A yard standard, or standard yard, is any physical representation of the above definition. As in the case of the standard meter, it may be of platinum-iridium, bronze, steel, or any other material. In general, it is a true representation of the unit only at a single temperature and under a certain method of support. Its length at other temperatures, and when supported in a different manner, depends upon its shape and the material of which it is made.

Such confusion as has occurred in the use of the terms "units" and "standards" has come about largely through the use of the same name to designate both the unit and the standard. Thus, the term "meter" is used to designate both the unit (that is, the defined distance in space) and the physical embodiment of the unit (that is, the standard); and the term "yard" is similarly used to designate both the defined unit and the physical embodiment of the unit. This dual use of the terms "yard" and "meter" makes it necessary in any technical discussion of length measurements to indicate clearly the sense in which the terms are used.

At the present time practically all precise measurements of length throughout the world of science and industry are based upon either the international meter, the United States yard through the international meter, or the British imperial yard. The importance of having a definite and known relation between these units is, therefore, readily apparent.

III. HISTORY OF WEIGHTS AND MEASURES OF THE UNITED STATES

The history of weights and measures in the United States has been admirably given by L. A. Fischer [2] and will not be given in detail here. It may, however, be stated that prior to 1893 the United States yard was regarded as identical with the British yard and any deviations found were regarded as errors in the United States standards.

IV. UNITED STATES STANDARD OF LENGTH

Since 1893 the United States yard and its subdivisions have been derived from the international meter by means of the relation contained in the law of 1866 and set forth in the Mendenhall order already referred to. This change in policy on the part of the United States followed the receipt of the metric standards and the recognition of their superiority, from the standpoint of accuracy and permanency, over the standards previously available. The change has been amply justified by the remarkable constancy in the length of our national prototype meter standard over the period subsequent to 1893. Within that period it has been twice recompared with the international standard and while at the first recomparison, in 1903, it was thought to have changed slightly it was subsequently shown that the suspected change had not, in fact, occurred but was attributable in part to a change in one of the secondary standards used in the

[2] B. S. Sci. Paper No. 17, recently reissued as B. S. Mis. Pub. No. 64.

comparison and in part to the assumption of an incorrect temperature coefficient. The later comparisons of 1922 and 1923 showed that our national prototype (meter No. 27) had remained constant in length, as compared with the international meter, within the limits of error of the most precise comparisons over the period from the original comparisons of 1888 to the latest comparisons of 1923.

Comparisons between the United States national prototype meter and the most authentic copies of the British imperial yard available in this country having shown that, as nearly as could be determined by comparison, the relation between the yard and the meter was that contained in the law of 1866, that relation was adopted as exact, and this action was made official by the issuance of the Mendenhall order. Since that time no attempt has been made to follow any variations that may have occurred in the length of the British imperial yard. That measurable variations have occurred, and, in fact, are still occurring, appears more than probable.

V. BRITISH STANDARD OF LENGTH

The present primary standard of length of Great Britain—the British imperial yard—was made in 1845, and was adopted as the primary standard of length in 1855. In 1878 this imperial yard was continued as the primary standard and the relation between the yard and the meter was established[3] as

$$\frac{1 \text{ yard}}{1 \text{ meter}} = \frac{3{,}600}{3{,}937.079}$$

In 1898 the relation between the yard and the meter was changed to

$$\frac{1 \text{ yard}}{1 \text{ meter}} = \frac{3{,}600}{3{,}937.0113}$$

this relation being based on comparisons carried out at the International Bureau in 1894 by Benoit. That relation still stands as the official relation between the British yard and the meter, but it has been informally announced, and unofficially published, that recent comparisons have shown that the actual relation at the present time is

$$\frac{1 \text{ yard}}{1 \text{ meter}} = \frac{3{,}600}{3{,}937.0131}$$

It may well be asked, "How can it be said with certainty that this changed relation has not been caused by a change in the standard meter rather than by a change in the standard yard?" In answer it must be admitted that it can not be said with certainty but that the

[3] This relation follows from the equivalent, 1 dekameter = 10 yards, 2 feet, 9.7079 inches, which is contained in the law.

evidence is overwhelmingly in favor of the belief that most, if not all, of the change is attributable to the yard. Comparisons have shown that its relation to the secondary standards has changed, and other standard yards of the same composition made at the same time are known to have changed relative to it and to each other while the several copies of the international meter, with the exception of two laboratory standards at the International Bureau are known to have remained essentially constant with reference to each other and with reference to the international prototype.

VI. RELATION BETWEEN THE YARD AND THE METER

Briefly, then, the situation as to the relation between the yard and the meter is that in the United States the relation contained in the law of 1866 and set forth in the Mendenhall order of 1893 is regarded as official, while in Great Britain a different official relation exists and this official relation is not now regarded as the most exact actual relation.

With this situation in mind the futility of attempting to bring about uniformity in the practice of converting from one system of units to the other, without first agreeing upon a uniform basis, is at once apparent. Uniformity of practice is obviously impossible so long as dual standards with a nonuniform, unknown, or changing relation between them, continue to be recognized.

VII. ADOPTION OF A SINGLE BASIC STANDARD RECOMMENDED

The universal adoption of a single basic standard of length, and the derivation of all other standards from this through the adoption of a fixed relation of units, would seem to offer a means by which we might emerge from our present dilemma.

The following is suggested as a feasible basis for such action:

In 1893 the number of wave lengths of the red radiation from cadmium vapor equivalent to a length of 1 meter was very accurately determined by Michelson. Fourteen years later the determination was repeated by Benoit, Fabry, and Perot, and the results obtained were in agreement with Michelson's value when reduced to the same basis, to better than 1 part in 15,000,000.

VIII. RELATION BETWEEN THE METER AND THE WAVE LENGTH OF LIGHT

The relation between the meter and the wave length of cadmium light, as determined by Michelson and by Benoit, Fabry, and Perot, may be conveniently expressed in the following form:

Wave length of red cadmium light, when transmitted through dry air, at 15° C. (hydrogen scale), at a pressure of 760 mm of mercury [with g=980.67 cm/sec.² (45° N. Lat.)]

cd. red----{Michelson; reduced by Benoit, Fabry, and Perot.} $=6438.4700\times10^{-7}$ mm

cd. red-----Benoit, Fabry, and Perot------- $=6438.4696\times10^{-7}$ mm

When transposed, these relations become, respectively:

1 meter=1,553,164.03 wave lengths of red cadmium light as determined by Michelson (reduced by Benoit, Fabry, and Perot).

and

1 meter=1,553,164.13 wave lengths of red cadmium light as determined by Benoit, Fabry, and Perot.

In each case the wave length has been reduced to the standard conditions of humidity, temperature, and pressure specified above.

The work of Michelson (1892–93) and that of Benoit, Fabry, and Perot (1906) is described in detail in Travaux et Mémoires du Bureau International des Poids et Mesures, volumes 11 and 15, respectively. A study of these reports shows that the three independent series of measurements carried out by Michelson gave the following results:

Series number	Number of wave lengths in 1 meter
1	1, 553, 162. 7
2	4. 3
3	3. 6
Mean	1, 553, 163. 5

These values are not corrected for humidity. The humidity was not observed by Michelson and correction can therefore be made only on the basis of an assumed humidity. Sixty per cent is the humidity usually assumed as being most probable, and this gives a reduced value of

1,553,164.03 waves per meter in dry air.

Benoit, Fabry, and Perot carried out seven independent series which gave the following results:

Series number	Number of wave lengths in 1 meter
1	1, 553, 163. 33
2	3. 75
3	4. 11
4	4. 15
5	4. 21
6	4. 27
7	4. 07
Mean	1, 553, 163. 98

The values obtained in series Nos. 1, 2, and 6 were rejected by the experimenters as being of somewhat doubtful value. The remaining series Nos. 3, 4, 5, and 7 give as a mean value

1,553,164.13 waves per meter

under standard conditions of temperature, pressure, and humidity.

The mean value of Michelson's result, when reduced to the basis of dry air, using 60 per cent humidity as the assumed condition of observation, is in agreement with the mean of the best values obtained by Benoit, Fabry, and Perot, to 0.1 wave length per meter; that is, to slightly better than 1 part in 15,000,000.

The final value of Benoit, Fabry, and Perot, namely, 1,553,164.13 waves per meter, is probably correct to 1 part in 10,000,000; that is, the meter may be defined, in terms of light waves, with an accuracy of 1 part in 10,000,000.

IX. FURTHER DETERMINATIONS NOT NECESSARY

In view of the attainment of this high accuracy it may well be questioned whether any attempt should be made to improve upon this numerical value. It would seem that future work in this field might better be directed to further refinements in the specification of standard conditions rather than toward a revision of the numerical value. Indeed, should a new but different and more precise value be determined there would be a question as to whether or not the standard meter had changed; and the new value would be in no way more satisfactory or useful than the value already available.

X. CONSTANCY OF WAVE LENGTH OF CADMIUM LIGHT

In regard to the matter of improved or additional specifications of standard conditions, reference should be made to recent work of George S. Monk,[4] of the University of Chicago, and to that of M. Pérard,[5] at the International Bureau of Weights and Measures. Mr. Monk found that although differences in intensity of radiation were produced by variations in the type of source and method of excitation, no variation in wave length could be detected. M. Pérard found that with the use of an entirely different type of lamp, under an applied voltage of 200, the red radiation from cadmium remained remarkably monochromatic. Extensive and conclusive work in this field has also been done by Meggers and Burns at the Bureau of Standards.[6] The following is quoted from their paper:

> In this connection we wish to express our faith in the constancy and reproducibility of the wave lengths as emitted by a tube containing cadmium at low pressure. Since 1915, when one [7] of us pointed out the ease with which the

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[4] George S. Monk, Univ. of Chicago: "Effect of the type of source on the primary standard of wave length." Bull. of Am. Phys. Soc., **1**, No. 5, Program of Chicago meeting, Nov. 27, 28, 1925.

[5] Proces-Verbaux du Comité International des Poids et Mesures 11, p. 26; 1925.

[6] W. F. Meggers and Keivin Burns, B. S. Sci. Paper No. 441, May 24, 1922.

[7] B. S. Bull., **12**, p. 203; 1915.

separation of interferometer plates could be determined from observations on neon interferences, this laboratory has always photographed the neon spectrum along with that of cadmium. For the majority of these exposures the quartz tube containing neon as described (loc. cit., p. 202) was used, always under the same conditions. The radiations emitted by this neon tube have thus been compared with the red radiation from many different cadmium tubes because the latter are relatively short lived on account of the electrode sputtering and more frequent breakage of tubes operated in a furnace. The usual variations in operating conditions (temperature 250 to 320° C., current 20 to 200 ma, and pressure 0.005 mm Hg to, perhaps, several centimeters due princiaplly to occluded gases in tubes not properly exhausted) showed no systematic displacements of cadmium lines relative to the adopted values of neon.

Furthermore, a special investigation was made to detect, if possible, any measurable variation in the neon wave lengths emitted by different tubes containing gas at different pressures. For this purpose special tubes were filled with neon gas at "high" and "low" pressures, the limits in pressure (about 0.1 mm Hg to several centimeters) being considerably outside the range (2 to 5 mm) found in ordinary tubes. The radiations from these "high" and "low" pressure neon tubes were carefully compared with the cadmium red radiation, the same cadmium tube being used under constant conditions for this series of experiments. No change as large as 1 part in 10,000,000, which is the probable error of observation, could be detected in the wave lengths derived from the fundamental standard.

The mean of three series of comparisons made at the Bureau of Standards [8] on more than 20 neon wave lengths referred to cadmium show a maximum disagreement of 1 part in 16,000,000, and a similar comparison made by Meissner [9] shows practically the same close agreement with the mean of those made in our laboratory. In view of these facts, the wave lengths in both cadmium and neon sources may be considered to be reproducible in the same and in different laboratories well within the limiting precision attainable in wave-length comparisons.

The wave lengths of the cadmium lines presented in Table 1 are, therefore, considered suitable secondary standards, leaving out of consideration, of course, the red line 6,438.4696 A, which has the deserved distinction of being the primary standard for all measurements of wave lengths of light in international Angstrom units.

In 1907 the wave length of cadmium light, as determined by Benoit, Fabry, and Perot, was adopted by the International Union for Cooperation in Solar Research (now the International Astronomical Union) as the international standard for all spectroscopic work. Since that time many other wave lengths have been determined, so that there are now available a very great number of secondary wave length standards accurately known in terms of cadmium waves.

The idea of using the wave length of light as a standard of length is not new; it has been proposed by metrologists from time to time beginning even before Michelson's work.[10] Michelson saw clearly the possibility of establishing the length of a meter bar at any future

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[8] B. S. Bull., **14**, p. 765; 1918.

[9] Ann. d. Phys., **51**, p. 115; 1916.

[10] Peirce, C. S., Note on the progress of experiments for comparing a wave length with a meter, Am. J. of Sci., 18, p. 51; 1879. Michelson, A. A., and Morley, E. W., On a method of making the wave length of sodium light the actual and practical standard of length, Am. J. of Sci., 34, pp. 427–430; 1887.

time by reference to light waves if once the value of the wave length were determined,[11] and pointed out the possibility of restoring the prototype meter if it should suffer loss or damage and also the possibility of detecting any change in the standard meter bars.[12] The possibility of such a control was also emphasized by Fabry, Perot, and Benoit [13] who pointed out that the earlier proposals and laws for using a seconds pendulum or the earth's quadrant for these purposes do not fulfill the needs of modern metrology. In 1923 [14] McMahon, of Great Britain; Tanakadate, of Japan; and Stratton, of the United States, believing that light waves should be made the fundamental length standard, submitted a resolution to the subcommittee on instruments and work of the International Committee of Weights and Measures favoring the adoption of a wave-length standard for linear measurements and advocating that further experimental investigations be carried out to study some disputed points. The subcommittee's recommendation, which was adopted by the committee, was that the investigations be undertaken without delay, but that the question of adoption of wave lengths as standards be tabled since a report on the investigations should first be received.

Within the past few years wave-length standards have been widely used in industry and in science entirely outside the field of spectroscopy, and in all cases the relation between millimeters and wave lengths has been that adopted by the International Astronomical Union. The work of Michelson, Benoit, Fabry, and Perot, and the action of the International Astronomical Union have, therefore, taken on an antirely new significance in the field of precise length measurements, and have assumed an importance far beyond that originally contemplated.

XI. NEED FOR INCREASED ACCURACY

Not many years ago the measurement of machine parts to an accuracy of a thousandth of an inch was regarded as work of high precision. To-day hundreds of manufacturing concerns throughout the United States, and elsewhere, are turning out products which are accurate to a few ten-thousandths of an inch. To do this they require limit gauges which are accurate to a few hundred-thousandths of an inch; and the production of these gauges in turn demands the use of standards which are accurate to a few millionths of an inch.

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[11] Michelson, A. A., and Morley, E. W., On the feasibility of establishing a light wave as the ultimate standard of length, Am. J. of Sci., 38, pp. 181–186; 1889. Michelson, A. A., Light waves and their uses, Chicago, 1907. See especially chapter V (Light waves as standards of length).

[12] Michelson, A. A., Light waves and their application to metrology, Nature, 14, p. 56; 1893.

[13] Fabry, C., Perot, A., and Benoit, J., Nouvelle détermination du rapport des longueurs d'onde fondamentales avec l'unité metrique. Travaux et Mémoires du Bureau International des Poids et Mesures, 15; 1913. See especially pp. 3, 4, and 134.

[14] Procès Verbaux du Comité International des Poids et Mesures, 10, p. 67; 1923.

These standards (precision gauge blocks) are measured by an interferometer method in terms of wave lengths of light.

Under these conditions it is apparent that an exact knowledge of the relation between wave lengths, millimeters, and inches is of the most vital importance, since most of the precision gauge blocks in use in the United States and Great Britain have their nominal dimensions in inches. It is apparent that an exact translation from light waves to inches requires not only an exact relation between light waves and the meter, but also between the meter and the yard; or failing in that, a direct relation between light waves and the yard.

As pointed out earlier in this paper there is at present an outstanding difference in the relation between the United States yard and the meter and the British yard and the meter amounting to 1 part in 363,000.

There need be little wonder, then, that discrepancies occur in translations from wave lengths to inches or yards to an accuracy of 1 part in 1,000,000 or higher. They will inevitably occur until their cause is removed; that is, until a single fundamental standard of length is accepted and all measurements of length are expressible in terms of that standard.

XII. WAVE LENGTH OF CADMIUM LIGHT RECOMMENDED AS FUNDAMENTAL STANDARD OF LENGTH

The fact that since 1907 the wave length of red cadmium light has served adequately and satisfactorily as the universally accepted standard for spectroscopy, one of the most exacting fields of the whole realm of science, may well be regarded as one of the strongest possible arguments in favor of its adoption as the basis for all measurements of length. Its acceptance as such would, unquestionably, constitute the greatest step that could be taken to advance the science of metrology. It would be an achievement comparable in importance with the definition and adoption of the international meter.

It is apparent, however, that in order for the proposed action to attain its maximum value it will be necessary to define the yard as well as the meter in terms of light waves, and this action presupposes, of course, an agreement as to the relation between the yard and the meter.

It has already been pointed out that at present a different relation exists between the United States yard and the meter and the British yard and the meter. This difference must in some way be overcome, and the obvious way would seem to be so to define the yard and the meter, in terms of light waves, that a satisfactory relation between them would result.

XIII. A SIMPLE RELATION BETWEEN INCHES AND MILLIMETERS DESIRABLE

While the legal or official relation between the units of length of the customary and metric systems is expressed in terms of the number of inches in a meter, it is believed that the difference is more readily comprehended when expressed in terms of the number of millimeters in an inch. In this form the relation becomes—

1 United States inch = 25.40005 millimeters (approx.).

1 British inch = 25.39998 millimeters (approx.).

In each case the equivalent value of 1 inch is not exact, but is carried to the nearest one-hundred-thousandth of a millimeter. These values are seen to differ but little from 25.4; the United States inch being larger and the British inch being smaller than 25.4 millimeters by 5 parts and by 2 parts in 2,500,000, respectively; that is, by 1 part in 500,000 and by 1 part in 1,250,000, approximately.

Through a fortunate circumstance very few precise measurements of length made in industry are expressed either in feet or yards, but rather in inches and multiples or decimal fractions of an inch, and in millimeters and multiples or decimal fractions of a millimeter. That being true the process of converting measurements from one system of units to the other is usually most conveniently carried out by multiplying or dividing, as the case may be, by the number of millimeters in an inch. For this purpose the numerical value 25.4 is very often employed in both the United States and Great Britain even though it is not the exact legal equivalent in either country. The reason for the wide use of this value is no doubt its simplicity and the consequent ease with which it is remembered and used. It has the further practical advantage that by including in a gear train a gear having 254 or 127 gear teeth it is possible to cut screw threads or to rule scales in one system of units by means of a lathe or graduating machine the lead screw of which is in terms of the other system. For example, by including a 127-toothed gear in the gear train of a lathe having a lead screw with an integral number of threads to the inch it is possible to cut metric screw threads with pitches of any desired number of millimeters. Similarly, by including a 127-toothed gear in the gear train of a graduating machine or dividing engine having a metric lead screw it is possible to graduate scales in any desired fractions of an inch. In the above and similar cases the relation between the pitch of the lead screw and the resulting screw or graduated scale will be on the basis of the assumed relation, 1 inch = 25.4 millimeters. Official acceptance of this relation would serve to harmonize the theoretical relation with necessary mechanical practice.

At a meeting held in New York April 20, 1926, by chairmen and secretaries of the national standardizing bodies of various countries (the American Engineering Standards Committee, the British Engineering Standards Association, and the corresponding organizations of Austria, Belgium, Chile, Czechoslovakia, France, Germany, Holland, Italy, Japan, Norway, Poland, Russia, Sweden, and Switzerland) it was voted to adopt the relation, 1 yard = 0.9144 meter, and the corresponding relation, 1 inch = 25.4 millimeters, as the conversion factors to be used in all translations between yards and meters, inches and millimeters. While this action can, of course, have no effect upon the legal relation between the units of the two systems of measurement, it may serve to bring about a uniform practice in the industries.

It will be readily seen that the acceptance of the simple relation, 1 inch = 25.4 millimeters, would result in a correspondingly simple relation between feet and meters, and between yards and meters, namely, 1 foot = 12 × 25.4 = 304.8 millimeters = 0.3048 meter, and 1 yard = 36 × 25.4 = 914.4 millimeters = 0.9144 meter.

The above relation is at least as convenient as the present legal relation between United States inches and millimeters, yards and meters, and probably somewhat more convenient. It is certainly more convenient than the present legal relation between the British units of length and those of the metric system. It has the further advantage that it lies between the United States and the British relations and might, therefore, be adopted without undue change on the part of either the United States or Great Britain.

In this connection it will be of interest to note Mendeleeff's comments [15] with reference to the relation between the British imperial yard and the meter:

According to the law of Peter the Great, the Russian measures of length have a simple and precise relation with the English measures; that is to say, it was agreed that:

1 sagène = 7 feet (English) = 7 feet (Russian) = 3 archines

The English measures (1 yard = 3 feet) have been compared many times with the meter (Kater, Clarke, Tittmann, Rogers, and others), but the most precise comparisons were made at the International Bureau in 1895 by Benoit on two copies of the yard which had already been studied in London by Chaney, Blumbach, and others. The yard being defined at a temperature of 62° F., the international conference has agreed that this temperature corresponds to 16°667 of the centigrade scale hydrogen thermometer. On this supposition there has been obtained as the value of the yard, 0.9143992 meter.

Since, in the determinations (principally on account of the considerable width of the lines which determine the yard), there are found differences of ±0.0000010 meter and also some values of the yard which exceed 0.9144000, one can not fix the ratio of the yard to the meter more exactly than a few millionths; thus, for the calculation of Tables 1 and 2, there has been taken as the basis

1 yard = 0.914400 meter

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[15] D. Mendeleeff, Procès-Verbaux, Comité International des Poids et Mesures, 1897. Appendix.

and in all the ratios only six figures have been given because the seventh figure and those following are doubtful and have not, even now, any application in practical geodesy.

XIV. CONCLUSION

It is recommended that the meter and the yard be defined in terms of light waves from red cadmium vapor under standard conditions of temperature, pressure, and humidity, the meter being defined directly on the basis of the determinations of Benoit, Fabry, and Perot as equal to 1,553,164.13 wave lengths and the yard being defined as equal to 1,420,213.28 wave lengths through the acceptance of the relation

$$1 \text{ yard} = 0.9144 \text{ meter}$$

Under the Constitution of the United States, Congress has power * * * "to fix the standard of weights and measures." The fixing of the yard and meter in terms of light waves is therefore clearly within the field appropriate for congressional action.

The action proposed would result in the adoption of a yard differing slightly from both the present United States yard and the British yard and lying between them, and in the continuation of the meter without change. If taken by the United States alone, this action would reduce the difference between the units of length now legal in the United States and in Great Britain to about two-sevenths of its present value. That in itself would be a notable achievement. Furthermore, in the event of such official action on the part of the United States, it might reasonably be expected that similar action would be taken by Great Britain, thus bringing about complete uniformity in the units of length of the two countries.

WASHINGTON, May 21, 1926.