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GENERAL CONFERENCE ON WEIGHTS AND MEASURES
AND
INTERNATIONAL COMMITTEE OF WEIGHTS AND MEASURES

Proposals regarding definition and relation of units and standards of length submitted in behalf of the National Bureau of Standards of the United States of America.

1. It is recommended that the Conference adopt the wave length of the red radiation from cadmium vapor, as determined by Benoit, Fabry and Perot, as the fundamental standard for the wave length of light.

The length of this wave is 6438.4696 x 10^{-10} meters when the light is transmitted through dry air at 15°C (hydrogen scale) at a pressure of 760 mm of mercury, with g equal to 980.67 cm/sec^2 (45° N. Lat.). The light shall be produced by high voltage electric current in a vacuum tube having internal electrodes. The lamp shall be maintained at a temperature not higher than 320°C, and shall have a volume not less than 25 cubic centimeters. The effective value of the exciting current shall not exceed 0.05 amperes. At room temperature the tube shall be non-luminous when connected to the usual high voltage circuit.

(This shall define the meter:) 1 meter = 1553164.13 wave lengths of the red radiation from cadmium, under the standard conditions specified.

In support of the reliability of the red radiation from cadmium as a permanent fundamental unit of length which can be produced in any laboratory, at any time, with the maximum precision obtainable in optical measurements, the following theoretical considerations are submitted.

The structures of cadmium lines have been investigated by Michelson, Fabry and Perot, Hamy, Janicki, Wali-Mohammad, Takamine, Wood, McNair, and others. The red line 6438.4696A, has always been observed to be single, narrow, and symmetrical.

The spectral series notation for this line is $2^1P_1 - 3^1D_2$. Hyperfine structure analysis of Cd lines in which 2^1P_1 plays a part have shown that this term is single; its absolute value is 28846.60. The value of 3^1D_2 is 13319.24 but it has not been postively established that this term is single. In case it should be found to be complex, the fact that $2^1P_1-3^1D_2$ has always been observed as a single line means that a rigid selection rule limits the emission to one component.

The normal state of the cadmium atom is represented by the term 1^1S_0=72538.81 which is 43692.21 units (nearly 5 volts) lower in the energy diagram than 2^1P_1, the final state for the radiation of the 6438A line. This relation between final states is favorable to the production of the primary standard as an unreversed emission line; only atoms which have been energized by 5 volt electrons are in condition to absorb this radiation, and since 2^1P_1 is not a metastable state, only under exceptional conditions is self reversal of this line observable.

On account of the fact that the atomic energy states involved in the production of Cd 6438A lie in the upper part of the CdI energy diagram this line is likely to be displaced by pressure; it has indeed been observed broadened and shifted redwards in quartz lamps containing alloys when the vapor pressure was high, but such effects are inappreciable when the line is produced in a Michelson tube containing pure Cd at 320°C.

The theoretical half-width of this line, assuming that the width is due entirely to Doppler-Fizeau motion of the atoms, is 0.005A, which agrees closely with 0.006A measured by Michelson.

From the practical side it may be emphasized that this line was adopted in 1907 as the fundamental standard for spectroscopic measurements, it is the definition of the international angstrom unit, and is the basis of the system of secondary standards throughout the spectrum. All of this has been sanctioned by the International Astronomical Union and is actually the international usage.

An enormous number of gauge blocks(end standards) have come into use for precision measurements. All of these have been either directly calibrated by means of light waves, or compared with standards derived from these. During the past ten years over 40,000 such gages have been calibrated at the Bureau of Standards. These include end standards for the Bureau, standards for the manufacturers of precision gage blocks and gages for use in the shop. The results on a one inch gage (Table 2, p. 699, Scientific Paper of the Bureau of Standards No. 436) are typical of those for all the other gages tested. For single measurements of the optical path, on seven different wave lengths, the

Maximum difference in the length from two wave lengths is $\frac{11}{50,000,000}$

Maximum difference from the mean is $\frac{7}{50,000,000}$

Average difference from the mean is $\frac{4}{50,000,000}$

Experience shows that the standard wave lengths will, in general, give the distance between the two plates within 0.005 micron. In transferring this length to the gage the error made depends upon the quality of the gage. The best gages that could be selected in 1919 from some twenty sets of Johansson blocks had parallelism and planeness errors of from 0.07 to 0.2 micron. These errors made uncertainties of the order of 0.07 micron in the length of these gages as standards. Since 1919 the Bureau's end standards have been kept within that tolerance. This year Johansson submitted a set of 81 gage blocks, almost all of which are plane and parallel within 0.02 micron and correct in length within 0.05 micron. With gages of that quality the results from two single measurements should agree within 0.02 micron. It was found, however, that gages one to two inches in length at room temperature of 23°C when put in a constant chamber held at 20° within .01° continued to change in length for 100 minutes. It was therefore found necessary to hold them at the standard temperature for two hours before making the measurements.

Accurate line-ruled scales have been constructed by stepping off, with a Michelson interferometer, intervals which have been measured in terms of light waves. Thus, the Brown and Sharpe Company uses twelve 6-inch line scales made at this Bureau from light waves in their calibrating machines. Millimeter scales subdivided by means of light waves into 10-micron intervals have been constructed for the calibration of micrometer microscopes. The error in an interval between any two lines is not over 0.02 micron. All the haemacytometers tested at this Bureau are calibrated relative to a standard produced from light waves.

Reason

2. It is recommended that the conference adopt the following relation between the yard and the meter

1 yard = .9144 meter
and 1 inch = .0254 meter

From this may be derived the relation

39.370078 inches = 1 meter.

The present official relation of the United States

39.37 inches = 1 meter

differs from the British legal relation

39.370113 inches = 1 meter

by about 2.5 parts in a million. With lengths even as small as 1 inch this difference is a measurable quantity; therefore the need for uniformity in all countries is apparent.

The advantages of the proposed relation over the two just mentioned are that: It greatly reduces the number of decimal places in the relations between the yard and meter and the inch and millimeter. It lies between the present official relations of the Great Britain and the United States.

A further reason for the adoption of the above recommendation is that in all mechanical transitions from one system of units to the other, that is, from inches to millimeters, or vice versa, through the medium of gear trains and lead screws, the proposed relation is already in universal use.

Recom

3. It is recommended that the Conference adopt 20°C (68°F) as the standard temperature at which industrial standards of length shall have their correct nominal length. It is recommended that in all calibrations the length standard shall be held for two hours at the standard temperature within .01°C before making the measurements.

Two important reasons for urging the adoption of 20°C for the above purpose are: First, that it is a convenient and practical temperature for the use of industrial standards, and second, that it is already in practically universal use in the United States and in very wide use in European countries. The only important exceptions are England and France. In England 62°F (16 2/3°C) and in France 0°C (32°F) are generally used. These temperatures are both believed to be too low for satisfactory use, and their use too restricted to warrant their universal adoption.

In the case of industrial standards the use of a standard temperature which differs widely from that at which the standards are ordinarily used, is particularly objectionable in that such use requires the arbitrary assumption of a coefficient of thermal expansion for both the standard and any material measured in terms of the standard. Where precise dimensions are required, as in the case of precision gage blocks, this practice is likely to lead to confusion, errors, and lack of interchangeability of measured parts.

Recom

4. It is recommended that the Conference consider the desirability of having all certificates issued by the International Bureau of Weights and Measures contain all relevant test data to permit conditions of comparison to be known and reproduced, in order that reduction to such other standard conditions as may be required by National Standardizing Laboratories may be made with the highest possible accuracy.

In the case of standards of length these test data should include the temperatures of comparison, the assumed coefficient of thermal expansion, the method of support, and method of illumination of the standard certified, the standard with which comparison was made, the equation representing its change of length with change of temperature; and any other conditions which might affect reproducibility.

5. In view of the ever increasing demands for a knowledge of the exact lengths of the National Prototype Meter Standards, it is recommended that the Conference urge upon the International Bureau of Weights and Measures the desirability of expediting the study of the lengths and coefficients of thermal expansion of these standards, in order that any necessary changes of certificates may be authorized by the Eighth General Conference.

The need for such revision is shown by the following table:

	Meter 27	Meter 21	Meter 4 (1874)	Meter 12 (1874)
Certified Correction at 0°C	-1.6μ	$+2.5\mu$	-5.9μ	$+3.3\mu$
Certified Coefficient	$8.657\ T + 0.00100\ T^2 \times 10^{-6}$	$8.665\ T + 0.00100\ T^2 \times 10^{-6}$	$8.655\ T + 0.00100\ T^2 \times 10^{-6}$	$8.634\ T + 0.00100\ T^2 \times 10^{-6}$
Correction at 20°C (computed from certificate)	$+171.9\mu$	$+176.2\mu$	$+167.6\mu$	$+176.4\mu$
New Coefficient (given in letter to Bureau of Standards from Int. Bureau Dec. 5, 1925)	$8.621\ T + 0.00177\ T^2 \times 10^{-6}$	$8.621\ T + 0.00177\ T^2 \times 10^{-6}$	$8.600\ T + 0.00177\ T^2 \times 10^{-6}$	$8.600\ T + 0.00177\ T^2 \times 10^{-6}$
Correction at 20°C using new coefficients	$+171.5\mu$	$+175.6\mu$	$+166.8\mu$	$+176.0\mu$
New value at 0°C (given in letter of Dec. 5, 1925)			-5.0μ	
New value at 20°C			$+167.7\mu$	
Variations of new tentative values from certified values — at 0°C			$+0.9\mu$	
Variations of new tentative values from certified values — at 20°C	-0.4μ	-0.6μ	-0.8μ / $+0.1\mu$	-0.4μ