DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON

Letter
Circular
LC 449

STANDARDS OF LENGTH, MASS, AND TIME

September 19, 1935

This letter circular has been prepared to serve as a reply to requests for information on the subjects of length, mass and time. In case the information contained in this letter circular is found inadequate to meet the needs of an inquirer the Bureau will be glad to go in greater detail into any questions on the general subject of weights and measures.

LENGTH

The primary standard of length in the United States is the United States Prototype Meter 27, a platinum-iridium line standard having an X-shaped cross section. The length of this bar which is deposited at the National Bureau of Standards in Washington, is known in terms of the International Prototype meter which is deposited at the International Bureau of Weights and Measures at Sèvres, near Paris, France.

A supplementary definition of the meter in terms of the wave length of light was adopted provisionally by the Seventh General (International) Conference on Weights and Measures in 1927. According to this definition the relation for red cadmium light-waves under specified conditions of temperature, pressure, and humidity, is

$$1 \text{ meter} = 1\ 553\ 164.13 \text{ wave lengths.}$$

From this relation the wave length of the red radiation from cadmium, under standard conditions of temperature, pressure, and humidity, is found to be 6438.4696×10^{-7} millimeters.*

The United States yard is defined by the relation

$$1 \text{ yard} = \frac{3600}{3937} \text{ meter (exactly)}$$

From this relation it follows that

$$1 \text{ yard} = 0.9144018 \text{ meter (approx.)}$$

$$\text{and} \quad 1 \text{ inch} = 25.4000508 \text{ millimeter "}$$

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* Benoit, Fabry, and Perot. Trav. et Mem. du Bu. Int. des Poids et Mesures, vol. 15, p. 131.

For industrial purposes a relation between the yard and the meter has been adopted by the American Standards Association (A.S.A. B48.1-1933), and by similar organizations in 15 other countries. This relation is

1 inch = 25.4 millimeters (exactly)

from which 1 yard = 0.9144 meter "

The adoption of this relation by industry, for use in making conversions between inches and millimeters, did not change the official definition of the yard or of the meter. Its legal adoption in the United States and in Great Britain would be a very desirable step in the direction of international uniformity in precision length measurements.

The National Bureau of Standards tests standards of length including yard bars, meter bars, miscellaneous precision line standards, steel tapes, invar geodetic tapes, precision gage blocks, micrometers, and limit gages. It also measures the linear dimensions of miscellaneous apparatus such as penetration needles, cement sieves, and haemacytometer chambers. Tests are made in accordance with test-fee schedules, copies of which may be obtained by application to the Bureau.

The Bureau does not test carpenter's rules, machinist's scales, draftsman's scales, and the like. Such apparatus, if tes is required, should be submitted to State or local weights and measures officials.

In general the Bureau accepts for test only apparatus of such material, design, and construction as to ensure accuracy and permanence sufficient to justify test by the Bureau.

Detailed information in regard to test of length standards i given in references (4), (7), and (10).

MASS

The primary standard of mass for this country is United States Prototype Kilogram 20, which is a platinum-iridium standard kept at the National Bureau of Standards. The value of this mass standard is known in terms of the International Prototype Kilogram, a platinum-iridium standard which is kept at the International Bureau of Weights and Measures.

For many years the British standards were considered to be the primary standards of the United States. Later, for over 50 years, the avoirdupois pound was defined in terms of the Troy Pound of the Mint, which is a brass standard kept at the United States Mint in Philadelphia. In 1911 the Troy Pound of the Mint was superseded, for coinage purposes, by the Troy Pound of the National Bureau of Standards. Since 1893 the avoirdupois pound has been defined in terms of the United States Prototype Kilogram 20 by the relation:

1 avoirdupois pound = 0.4535924277 kilogram.

Insofar as can be determined, these changes in definition have not made any change in the actual value of the pound.

The grain is 1/7000 of the avoirdupois pound and is identical in the avoirdupois, troy, and apothecaries systems. The troy ounce and the apothecaries ounce differ from the avoirdupois ounce but are equal to each other, and equal to 480 grains. The avoirdupois ounce is equal to 437 1/2 grains.

Distinction between Mass and Weight

The mass of a body, as used herein, is the quantity of material in the body. The weight of a body is defined as the force with which that body is attracted toward the earth. Confusion sometimes arises from the practice of referring to standards of mass as "weights" and from the fact that such standards are compared by "weighing" one against another by means of a balance. Standard "weights" are, in reality, standards of mass.

Another practice which tends to confusion is that of using the terms kilogram, gram, pound, etc., in two distinct senses; first, to designate units of mass, and second, to designate units of weight or force. For example, a body having a mass of one kilogram is called a kilogram (mass) and the force with which such a body is attracted toward the earth is also called a kilogram (force).

The International Kilogram and the U. S. Prototype Kilogram are specifically defined by the International Conference on Weights and Measures as standards of mass. The U. S. pound, which is derived from the International Kilogram, is, therefore, a standard of mass.

So long as no material is added to or taken from a body its mass remains constant. Its weight, however, varies with the acceleration of gravity "g". For example, a body would be found to weigh more at the poles of the earth than at the equator, and less at high elevations than at sea level. (Standard acceleration of gravity, adopted by the International Committee on Weights and Measures in 1901 is 980.665 cm/sec^2. This value corresponds nearly to the value at latitude 45° and sea level.)

Since standards of mass (or "weights"), are ordinarily calibrated and used on even-arm balances the effects of variations in the acceleration of gravity are self-eliminating and need not be taken into account. Two objects of equal mass will be affected in the same manner and by the same amount by any change in the value of the acceleration of gravity, and thus if they have the same weight, i.e., if they balance each other on an even-arm balance, under one value of "g" they will also balance each other under any other value of "g".

On a spring balance, however, the weight of the body is not balanced against the weight of another body, but against the elastic force of a spring. Therefore, using a very sensitive spring balance, the weight would be found to vary with the acceleration of gravity.

Effect of Air Buoyancy

Another point that must be taken into account in the calibration and use of standards of mass is the buoyancy or lifting effect of the air. A body immersed in any fluid is buoyed up by a force equal to the weight of the displaced fluid. Two bodies of equal mass, if placed one on each pan of an even-arm balance, will balance each other in a vacuum. If compared in air, however they will not balance each other unless they are of equal volume. If of unequal volume, the larger body will displace the greater volume of air and will be buoyed up by a greater force than will the smaller body, and the larger body will appear to be lighter in weight than the smaller body. The greater the difference in volume, and the greater the density of the air in which the comparison weighing is made, the greater will be the apparent difference in weight. For that reason, in assigning a precise numerical value of apparent mass to a standard, it is necessary to base this value on definite values for the air density and the density of the mass standard of reference.

At the National Bureau of Standards the corrections to be applied to high precision analytical weights are given on the basis of comparison in vacuum and also on the basis of comparisons in air of standard density, 1.2 mg per cm^3, and against brass weights having a density of 8.4 grams per cubic centimeter.

Commercial weights and weighing scales are usually adjusted on the basis of "apparent weight in air against brass weights". That is, commercial weights, regardless of their material, are so adjusted that they will balance a correct brass standard of mass of 8.4 density and of the same nominal value, when compared in air at standard atmospheric density. Weighing scales are so adjusted that they indicate the correct mass of a mass standard of 8.4 density when the standard is weighed in air of standard density, 1.2 mg per cm^3. In commercial weighing no correction need be made for variations in air density.

Tests of Standards of Mass

Weights regularly used in ordinary trade and industry should be tested by State or local weights and measures officials. The National Bureau of Standards tests standards but does not manufacture or sell them, and only in special circumstances does it correct those found inaccurate. Six regular classes of standard weights recognized by the National Bureau of Standards are indicated in references 12 and 13. Schedules of the present fees for tests may be had on application to the Bureau.

TIME

There is no physical standard of time corresponding to the standards of length and mass. Time is measured in terms of the motion of the earth; (a) on its axis, and (b) around the sun. The time it takes the earth to make a complete rotation on its axis is called a day, and the time it takes it to make a complete journey around the sun, as indicated by its position with reference to the stars, is called a year. The earth makes about 365 1/4 rotations on its axis (365.2422, more exactly) while making a complete journey around the sun. In other words, there are almost exactly 365 1/4 solar days in a tropical or solar year. As it would be inconvenient and confusing to have the year, as used in every-day life, contain a fractional part of a day, fractional days are avoided by making the calendar year contain 365 days in ordinary years and 366 days in leap-years. The frequency of occurrence of leap-years is such as to keep the average length of the calendar year as nearly as practicable equal to that of the tropical year, in order that calendar dates may not drift through the various seasons of the tropical year.

The earth, in its journey around the sun, does not move at a uniform speed, and the sun in its apparent motion does not move along the equator but along the ecliptic. Therefore the apparent solar days are not of exactly equal length. To overcome this difficulty time is measured in terms of the motion of a fictitious or "mean" sun the position of which, at all times, is the same as would be the apparent position of the real sun if the earth moved on its axis and in its journey around the sun at a uniform rate. Ordinary clocks and watches are designed and regulated to indicate time in terms of the apparent motion of this fictitious or "mean sun". It is "Mean noon" when this "mean sun" crosses the meridian, and the time between two successive crossings is a "mean solar day". The length of the mean solar day is equal to the average length of the apparent solar day.

The time used by astronomers is sidereal time. This is defined by the rotation of the earth with respect to the stars. A sidereal day is the interval between two successive passages of a star across a meridian. The sidereal day is subdivided into hours, minutes and seconds, the hours being numbered from 1 to 24. The sidereal year is 365.25636 solar days.

The mean solar day is divided into 24 hours, each hour into 60 minutes, and each minute into 60 seconds. Thus the mean solar second is 1/86400 of a mean solar day, and this mean solar second is the unit in which short time intervals are measured and expressed.

The time at which the "mean sun" crosses the meridian at any point on the earth is known as local mean noon. As it would be impracticable in these days of rapid communication and transportation to use local mean time at each locality, the surface of the earth, by international agreement, has been divided into standard time zones, each zone having a width of approximately 15 degrees of longitude, or 1/24 of the distance around the earth parallel to the equator. In each zone the time used is that corresponding to the meridian passing approximately through its center, and adjacent zones have a time difference of 1 hour.

The meridian passing through Greenwich, England, is taken as the standard, or prime meridian, and time throughout the world is reckoned with reference to the time at Greenwich. Each 15 degrees east or west from Greenwich corresponds to a time difference of 1 hour. There are a few exceptions to the above rule. East of Greenwich the time if faster, and west of Greenwich it is slower than at Greenwich.

The United States is divided into four time zones in which time is designated as Eastern, Central, Mountain, and Pacific. The time in these zones is slower than Greenwich time by 5, 6, 7, and 8 hours, respectively. For a more detailed description of standard time and its application, see reference (17).

In the United States time is determined at the U. S. Naval Observatory in Washington, D. C. Clocks of very high precision are regulated and compared by means of astronomical observations. Time signals sent out by the Naval Observatory are broadcast several times a day by Naval Radio Stations at Arlington, Va., and elsewhere. These radio time signals, which are very accurate, are used for checking clocks, watches, and other time measuring and time indicating devices all over this country and in many other parts of the world.

For use in the testing of clocks, watches, chronometers, and other time indicating devices, at the National Bureau of Standards, a clock of high precision, similar to some of those at the Naval Observatory, is maintained at that Bureau. This clock is checked daily by comparison with the time signals sent out by the Naval Observatory through the radio station at Arlington, Va., and its error is known at all times to within a few hundredths of a second. Tests of watches, clocks, etc., are made by comparison with this clock.

Tests are made for the Federal Government, for State Governments, and for the public. Fees are charged for tests made for the public, the amount of the fee depending upon the nature of the test.

REFERENCES

(General)

Government publications marked thus (*) are not for free distribution, but can be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., at the prices indicated (stamps not accepted). Many of the publications listed below will be found in some of the larger libraries.

* 1. National Bureau of Standards Research Paper No. 64, "History of the Standard Weights and Measures of the United States", by Louis A. Fischer, 15 cents.

2. William Hallock and Herbert T. Wade, "Outlines of the Evolution of Weights and Measures and the Metric System", Macmillan Co., New York, 1906. (Contains many references in the footnotes.)

3. Charles E. Guillaume, "La Creation du Bureau International des Poids et Mesures et son Oeuvre", Gautier-Villars et Cie., Paris 1927.

(Length)

* 4. National Bureau of Standards Circular No. 332, "Testing of Line Standards of Length". 10 cents

* 5. National Bureau of Standards Circular No. 329, "Calibration of a Divided Scale". 10 cents

* 6. National Bureau of Standards Scientific Paper No. 535, "A Fundamental Basis for Measurements of Length", by H. W. Bearce. 5 cents.

* 7. National Bureau of Standards Circular No. 328, "Testing of Measuring Tapes at the Bureau of Standards". 10 cents

* 8. National Bureau of Standards Reprint No. 1, "Recomparison of the United States Prototype Meter", by L. A. Fischer.

* 9. National Bureau of Standards Research Paper No. 743, "Calibrations of the Line Standards of Length of the National Bureau of Standards", by Lewis V. Judson and Benjamin L. Page. 5 cents

10. National Bureau of Standards Letter Circular LC 310, "Specifications, Standardization and Use of Steel Tapes".

11. National Bureau of Standards Letter Circular LC 313, "Nomographic Chart for Use with Steel Measuring Tapes".

(Mass)

* 12. National Bureau of Standards Circular No. 3, "Design and Test of Standards of Mass", 3rd Edition, 1918. (Contains detailed specifications and methods of test. Fees obsolete. New class, S2, and additional tests are given in reference 13.) 15 cents.

13. National Bureau of Standards Letter Circular LC 251, "Having Standard Weights Tested by the Bureau of Standards".

* 14. National Bureau of Standards Scientific Paper No. 527, "Short Tests for Sets of Laboratory Weights", by A. T. Pienkowsky. 10 cents

(Time)

* 15. National Bureau of Standards Circular No. 392, "Testing of Time Pieces". 10 cents.

* 16. National Bureau of Standards Circular No. 402, "Sundials". 5 cents

* 17. National Bureau of Standards Circular No. 406, "Standard Time Throughout the World". 10 cents.

* 18. National Bureau of Standards Miscellaneous Paper 84, "Standard Time Conversion Chart". 10 cents

* 19. National Bureau of Standards Miscellaneous Paper 111, "Time Zone Map of the United States". 10 cents

20. Hydrographic Office, Navy Department, Chart No. 5192, "Time Zone Chart of the World". 50 cents (For sale by the Hydrographic Office.

21. Hydrographic Office, Navy Department, H.O. No. 205, "Radio Aids to Navigation". 90 cents (For sale by the Hydrographic Office.

22. Young, Charles E. "General Astronomy". (Gives many definitions and explanations)

23. Milham, Willis I. "Time and Timepieces".

24. Bolton, L. "Time Measurement".

(The last two books treat of time in a general way.)