NBS CIRCULAR 570

Units and Systems of Weights and Measures

Their Origin, Development, and Present Status

UNITED STATES DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

PERIODICALS OF THE NATIONAL BUREAU OF STANDARDS

(Published monthly)

The National Bureau of Standards is engaged in fundamental and applied research in physics, chemistry, mathematics, and engineering. Projects are conducted in fifteen fields: electricity and electronics, optics and metrology, heat and power, atomic and radiation physics, chemistry, mechanics, organic and fibrous materials, metallurgy, mineral products, building technology, applied mathematics, data processing systems, cryogenic engineering, radio propagation, and radio standards. The Bureau has custody of the national standards of measurement and conducts research leading to the improvement of scientific and engineering standards and of techniques and methods of measurement. Testing methods and instruments are developed; physical constants and properties of materials are determined; and technical processes are investigated.

Journal of Research

The Journal presents research papers by authorities in the specialized fields of physics, mathematics, chemistry, and engineering. Complete details of the work are presented, including laboratory data, experimental procedures, and theoretical and mathematical analyses. Annual subscription: domestic, $4.00; $1.25 additional for foreign mailing.

Technical News Bulletin

Summaries of current research at the National Bureau of Standards are published each month in the Technical News Bulletin. The articles are brief, with emphasis on the results of research, chosen on the basis of their scientific or technologic importance. Lists of all Bureau publications during the preceding month are given, including Research Papers, Handbooks, Applied Mathematics Series, Building Materials and Structures Reports, Miscellaneous Publications, and Circulars. Each issue contains 12 or more two-column pages; illustrated. Annual subscription: domestic, $1.00; 35 cents additional for foreign mailing.

Basic Radio Propagation Predictions

The Predictions provide the information necessary for calculating the best frequencies for communication between any two points in the world at any time during the given month. The data are important to all users of long-range radio communications and navigation, including broadcasting, airline, steamship, and wireless services, as well as to investigators of radio propagation and ionosphere. Each issue, covering a period of one month, is released three months in advance and contains 16 large pages, including pertinent charts, drawings, and tables. Annual subscription: domestic, $1.00; 25 cents additional for foreign mailing.

CATALOG OF NBS PUBLICATIONS

National Bureau of Standards Circular 460 and its Supplement list all Bureau publications from 1901 through June 1952, including Applied Mathematics Series, Building Materials and Structures Reports, Circulars, Handbooks, Research Papers, and Miscellaneous Publications. Brief abstracts for the publications issued after January 1, 1942, are also included.

National Bureau of Standards Circular 460, 375 pages, $1.25. Supplement to Circular 460, 223 pages, 75 cents. (A free mimeographed list of publications issued since June 1952 is available on request to the National Bureau of Standards.)

UNITED STATES DEPARTMENT OF COMMERCE • Sinclair Weeks, *Secretary*
NATIONAL BUREAU OF STANDARDS • A. V. Astin, *Director*

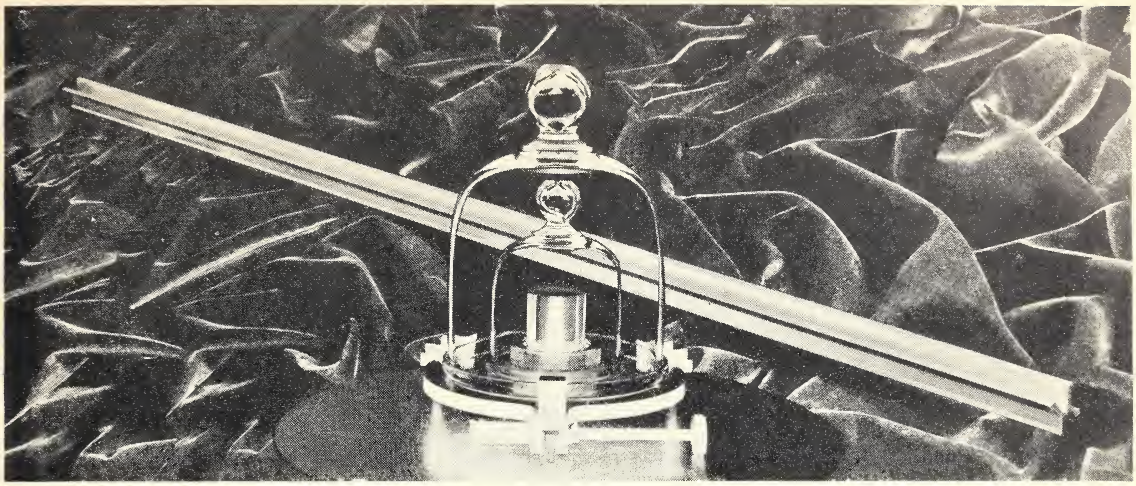
Units and Systems of Weights and Measures

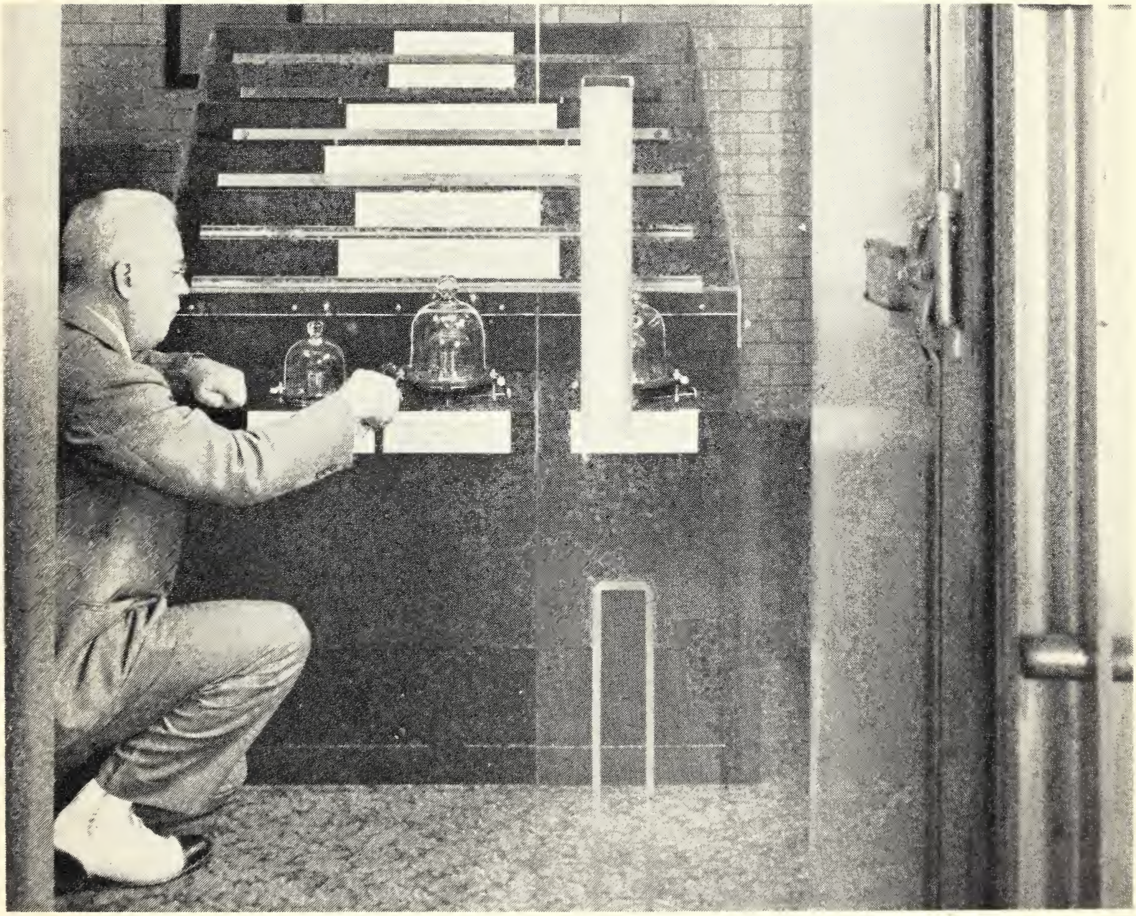
Their Origin, Development, and Present Status

Lewis V. Judson

National Bureau of Standards Circular 570
Issued May 21, 1956

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.
Price 25 cents





The National Standards of Length and Mass, U. S. Prototype Meter 27 and U. S. Prototype Kilogram 20, are kept in this Standards Vault. Made of a stable alloy containing 90 percent of platinum and 10 percent of iridium, these standards are basic to all length and weight measurements in the United States. On daily display, the standards are safeguarded by a heavy alarm-protected glass door. View shows final inspection before standards were put on exhibition.

Preface

The subject of weights and measures is of universal interest. Millions of daily industrial operations and commercial transactions depend on a uniform and convenient system of weights and measures.

In its broadest sense the subject of weights and measures covers much more than the units used in the sale and purchase of commodities. Our high standard of living depends in large part on our ability to measure accurately everything from a loaded railroad car to the diameter of a submicroscopic particle. In fact, almost everyone makes daily use of an accepted system of measurement—from the school child who studies arithmetic to the machinist who measures to a ten-thousandth of an inch, from the housewife who purchases a pound of butter to the manufacturer of automotive engines.

The National Bureau of Standards receives many requests for information on both the customary and metric systems of weights and measures. It is to serve this need—for teachers, students, and the general public—that this Circular has been prepared. It brings together much of the information that was previously available in separate mimeographed leaflets. For scientists and industrialists who want more extensive information on the subject, the Bureau has published *Units and Systems of Weights and Measures*, Miscellaneous Publication 214.

A. V. Astin, *Director*.

Contents

Units and Systems of Weights and Measures

Their Origin, Development, and Present Status

Lewis V. Judson

This Circular brings together in a convenient form information about weights and measures that experience has shown is of interest to the general public. Much of it has been issued previously by the National Bureau of Standards in temporary and scattered form. The Circular discusses the origin and early history of units and standards, gives general information about the metric system, and states and explains the present status of standards of length, mass, time, and capacity in the United States and in Great Britain. It discusses for the benefit of the general reader such matters as the distinction between units and standards, and that between mass and weight. Two items of everyday life relating to weights and measures are considered in some detail: The weight of coal, and the definitions and usages of the terms "ton" and "tonnage." The Circular concludes with tables of weights and measures, prepared for the benefit of those requiring such tables for occasional ready reference. School teachers will find in this Circular considerable material to supplement their textbooks.

1. Introduction

The National Bureau of Standards was established by act of Congress in 1901 to serve as a National scientific laboratory in the physical sciences and to provide fundamental measurement standards for science and industry. In carrying out these related functions the Bureau conducts research and development in many fields of physics, mathematics, chemistry, and engineering. At the time of its founding, the Bureau had custody of two primary standards—the meter bar for length and the kilogram cylinder for mass (or weight). With the phenomenal growth of science and technology over the past half century, the Bureau has become a major research institution concerned not only with everyday weights and measures but also with hundreds of other scientific and engineering standards that have become necessary to the industrial progress of the Nation. Nevertheless, the country still looks to the Bureau for information on the units of weights and measures, particularly their definitions and equivalents.

The subject of weights and measures can be treated from several different standpoints. Scientists and engineers are interested in the methods by which precision measurements are made; State weights and measures officials are interested in laws and regulations on the subject and in methods of verifying commercial weighing and measuring devices. But a vastly larger group of people are interested in some general knowledge of the origin and development of weights and measures, of the present status of units and standards, and of miscellaneous facts that will be useful in everyday life. This Circular has been prepared to supply that information on weights and measures that experience has shown to be the common subject of inquiry.

2. Units and Systems of Weights and Measures

The expression "weights and measures" is used in this Circular in its basic sense of referring to measurements such as length, mass, and capacity, thus excluding such topics as electrical measurements and thermometry. This section on units and systems of weights and measures presents some fundamental information to clarify thinking on this subject and to eliminate erroneous and misleading use of terms.

2.1. Origin and Early History of Units and Standards

a. Units and Standards

It is essential that there be established and kept in mind the distinction between the terms "units" and "standards."

A *unit* is a value, quantity, or magnitude in terms of which other values, quantities, or magnitudes are expressed. In general, a unit is fixed by definition and is independent of such physical conditions as temperature. Examples: The yard, the pound, the gallon, the meter, the liter, the gram.

A *standard* is a physical embodiment of a unit. In general it is not independent of physical conditions, and it is a true embodiment of the unit only under specified conditions. For example, a yard standard has a length of one yard when at some definite temperature and supported in a certain manner. If supported in a different manner, it might have to be at a different temperature in order to have a length of 1 yard.

b. General Survey of Early History of Weights and Measures

The beginnings of the development of weights and measures go back to primitive man in prehistoric times. Hence, there is a great deal of uncertainty about the origin and early history of weights and measures. Many believe that the units first used by primitive man were those of length and weight and that units of area, volume, and capacity were of much later origin. Units of length may have been the earliest. These were derived from the limbs of the human body, and included the length of the foot, the width of the palm, the length of the forearm, etc. Units of weight included weights of kernels of grain and weights of shells.

At first these units were not very definitely defined. Later they became somewhat more definite when, for example, the foot became the length of the foot of a tribal chief or other ruler. At a much later date physical standards were made and deposited for safekeeping in a temple or other place of security. These early physical standards were usually very crude; it is generally considered, however, that they were as satisfactory for the needs of the people at that time as our most modern standards are for our own needs.

Our present knowledge of early weights and measures comes from many sources. Some rather early standards have been recovered by archeologists and preserved in museums. The comparison of the dimensions of buildings with the descriptions of contemporary writers is another source of information. An interesting example of this is the comparison of the dimensions of the Greek Parthenon with the description given by Plutarch from which a fairly accurate idea of the size of the Attic foot is obtained. In some cases we have only plausible theories and we must sometimes decide on the interpretation to be given to the evidence. For example, does the fact that the length of the double-cubit of early Babylonia was equal (within two parts in a thousand) to the length of the seconds pendulum at Babylon indicate a scientific knowledge of the pendulum at a very early date, or do we merely have a curious coincidence? By studying the evidence given by all available sources, and by correlating the relevant facts, we obtain some idea of the origin and development of the units. We find that they have changed more or less gradually with the passing of time in a complex manner because of a great variety of modifying influences. We find the units modified and grouped into systems of weights and measures: The Babylonian system, the Phileterian system of the Ptolemaic age, the Olympic system of Greece, the Roman system, and the British system, to mention only a few.

c. Origin and Development of Some Common Units

The origin and development of units of weights and measures has been investigated in considerable detail and a number of books have been written on the subject. It is only possible to give here somewhat sketchily the story about a few units.

One of the earliest units was the *foot*. This was first the length of the human foot without further specification or modification, then the length of the foot of various rulers of tribes and groups of people. Later, by gradual evolution, it was the foot as used in succession by the

Egyptians, Greeks, and Romans, brought to Britain by the Romans, modified with the passing of time, and finally defined in Great Britain as 1/3 of the British Imperial Yard and in this country as 1/3 of the U. S. yard.

A very interesting and important unit of length used by many ancient peoples was the *cubit*, originally defined as the distance from the point of the elbow to the end of the middle finger. This unit was about 18 inches long, but there were important variations in the length of a cubit.

The *inch* was originally a thumb's breadth. In the Roman duodecimal system it was defined as 1/12 foot, and was introduced into Britain during Roman occupation, where it became a part of the English system of weights and measures.

The *mile* was defined by the Romans as 1 000 paces* or double steps, the pace being equal to 5 Roman feet. This Roman mile of 5 000 Roman feet was introduced into Britain, became 5 000 English feet, and in Tudor times (probably in the reign of Henry VII, 1485 to 1509, but definitely by a statute of Queen Elizabeth, who reigned 1558 to 1603) was changed to 5 280 feet in order to make the furlong of 1/8 mile equal to the rood of 660 feet, or 220 yards (40 rods of 16½ feet, or 5½ yards each).

The *yard* as a unit of length is apparently of much later origin than the units previously discussed. It appears to have had a double origin: (1) as the length of an Anglo-Saxon gird or girdle, and (2) as the length of the double cubit. There is an old tradition, often stated as a fact, that Henry I decreed that the yard should thenceforth be the distance from the tip of his nose to the end of his thumb.

The *point* is the basic unit for measuring type. This unit originated with Pierre Simon Fournier in 1737. It was modified and developed by the Didot brothers, Francois Ambroise and Pierre Francois, in 1755. It was first put into effect in the United States by a Chicago type foundry (Marder, Luse, and Company) in 1878. As adopted in 1886 by the American Type Founders' Association and now defined in the United States, Canada, and Great Britain, it is 0.013 837 inch, a value only slightly less than 1/72 inch.

Of units of weight, one of the earliest is the *grain*, which was originally the weight of a grain of wheat or of some specified seed native to some particular locality.

The Roman *pound* (libra) was the hundredth part of an older weight, the talent, which is believed to have been originally the weight of an Egyptian royal cubic foot of water. The Roman pound was divided into 12 ounces (unciae, meaning twelfth parts) of 437 grains each. This system was introduced into Britain where the pound was increased so as to have 16 of the original ounces. This pound became known as the avoirdupois pound, the word avoirdupois meaning "goods of weight." The idea of a pound divided into 16 parts was not a new one, as the Greeks had divided their pound into 16 parts, as well as into 12 parts. The pound, which in England had long been used for mint purposes and called the troy pound, consisted of 5 760 grains (12 ounces of 480 grains each). The origin of this troy pound and troy ounce is very uncertain. One theory is that the troy pound came from Troyes, France, but there seems to be a serious question whether even the name had its origin in that place. Sometime prior to 1600 A. D., the avoirdupois pound was increased by 8 grains so that it would consist of 7 000 grains instead of 6 992 grains and thus the number of grains in the avoirdupois pound would have a more simple ratio to the number of grains in the troy pound, which, being used for mint purposes, it was considered advisable to keep unchanged.

That the *ton* was the weight of a certain volume of some material is highly probable. Among the Anglo-Saxons it may have been the weight of a quantity of wheat in 32 bushels, that is, in 1 chaldron.

The *stone* was an early unit of weight in the British Isles. At one time it appears to have been 16 pounds in the system: 16 pounds=1 stone, 16 stones=1 wey, 16 weys=1 last, and ½ last=1 ton (not the present ton). The stone is still used to a considerable extent in Great Britain, being now equal to 14 pounds except in special cases. (8 stones=1 hundredweight=112 lb; 20 hundredweights=1 ton=2 240 lb. This ton is commonly referred to as the long ton in the United States.)

*It should be noted that a space has been inserted instead of commas in all of the numerical values given in this Circular, following a growing practice originating in tabular work to use the space to separate large numbers into groups of three digits.

A unit of antiquity which has survived without change is the *degree of arc*. The early Babylonians reckoned the year as 360 days. They therefore divided the circle into 360 parts, or degrees. They knew that a chord equal to the radius subtends an arc of 60°. The number 60 became the basis of their sexagesimal number system and is an explanation of the division of the degree into 60 minutes and of the minute into 60 seconds. This is also the basis of the relation between longitude and time. Since the earth makes one complete rotation (360°) on its axis in 24 hours, a time change of 1 hour is represented by each 15° of longitude (360/24=15).

2.2. The Metric System

a. The Metric System: Definition, Origin, and Development

The metric system is the international decimal system of weights and measures based on the meter and the kilogram. The essential features of the system were embodied in a report made to the French National Assembly by the Paris Academy of Sciences in 1791. The definitive action taken in 1791 was the outgrowth of recommendations along similar lines dating back to 1670. The adoption of the system in France was slow, but its desirability as an international system was recognized by geodesists and others. On May 20, 1875, an international treaty known as the International Metric Convention was signed providing for an International Bureau of Weights and Measures, thus insuring "the international unification and improvement of the metric system." The metric system is now either obligatory or permissive in every civilized country of the world.

Although the metric system is a decimal system, the words "metric" and "decimal" are not synonymous, and care should be taken not to confuse the two terms.

b. Units and Standards of the Metric System

In the metric system the fundamental units are the meter and the kilogram. The other units of length and mass, as well as all units of area, volume, and capacity, also compound units, such as pressure, are derived from these two fundamental units.

The meter was originally intended to be 1 ten-millionth part of a meridional quadrant of the earth. The Meter of the Archives, the platinum end-standard which was the standard for most of the 19th century, at first was supposed to be exactly this fractional part of the quadrant. More refined measurements over the earth's surface showed that this supposition was not correct. The present international metric standard of length, the International Prototype Meter, a graduated line standard of platinum-iridium, was selected from a group of bars because it was found by precise measurements to have the same length as the Meter of the Archives. The meter is now defined as the distance under specified conditions between the lines on the International Prototype Meter without reference to any measurements of the earth or to the Meter of the Archives, which it superseded. The kilogram was originally intended to be the mass of one cubic decimeter of water at its maximum density, but it is now defined as the mass of the International Prototype Kilogram without reference to the mass of a cubic decimeter of water or to the Kilogram of the Archives. Each of the countries which subscribed to the International Metric Convention was assigned one or more copies of the international standards; these are known as National Prototype Meters and Kilograms. The liter is a unit of capacity based on the mass standard and is defined as the volume occupied, under standard conditions, by a quantity of pure water having a mass of 1 kilogram. This volume is very nearly equal to 1 000 cubic centimeters or 1 cubic decimeter; the actual metric equivalent is, 1 liter=1 000.028 cubic centimeters. (The change in this equivalent from the previously published value of 1 000.027 is based on a recomputation of earlier data carried out at the International Bureau of Weights and Measures.) Thus the milliliter and the liter are larger than the cubic centimeter and the cubic decimeter, respectively, by 28 parts in 1 000 000; except for determinations of high precision, this difference is so small as to be of no consequence.

The metric system, by itself, is not a complete system covering all physical measurements. A complete system requires certain additional units such, for example, as units of temperature and time.

FIGURE 1. *International Bureau of Weights and Measures.*
Founded in accordance with Treaty of May 20, 1875. Located on international territory in Sèvres ,near Paris , France

c. The International Bureau of Weights and Measures

The International Bureau of Weights and Measures (fig. 1) was established at Sèvres, a suburb of Paris, France, in accordance with the International Metric Convention of May 20, 1875. At the Bureau there are kept the International Prototype Meter and the International Prototype Kilogram, many secondary standards of all sorts, and equipment for comparing standards and making precision measurements. The Bureau, maintained by assessed contributions of the signatory governments, is truly international.

In recent years the scope of the work at the International Bureau has been considerably broadened. It now carries on researches in the fields of electricity and photometry in addition to its former work in weights and measures with which were included such allied fields as thermometry and the measurement of barometric pressures.

d. Present Status of the Metric System in the United States

The use of the metric system in this country was legalized by Act of Congress in 1866, but was not made obligatory.

The United States Prototype Meter No. 27 and United States Prototype Kilogram No. 20 are recognized as the primary standards of length and mass for both the metric and the customary systems of measurement in this country because these standards are the most precise and reliable standards available. Obviously it is not possible to accept both a meter and a yard, and both a kilogram and a pound as "primary" standards, unless there is willingness to accept the possibility of continually changing the ratio between the corresponding units. In each case one must be accepted as the primary standard and the other derived therefrom by means of an accepted relation. In the United States the yard is defined in terms of the meter, and the pound in terms of the kilogram. There is in the United States no primary standard either of length or mass in the customary system.

The use of metric units in certain athletic events in this country is undoubtedly of considerable interest to many people. Initial action by the Amateur Athletic Union was taken in November 1932, when it adopted metric distances for track events to be run in athletic meets held under the jurisdiction of that organization. Metric units for track and field events were adopted by various athletic organizations but this movement soon began to lose ground. In 1951 the use of metric distances in track and field events on national championship programs held under AAU auspices was restricted to Olympic years.

e. Arguments For and Against the Metric System

That there are arguments for and against the metric system is evidenced by the rather voluminous literature on the subject.

The National Bureau of Standards neither advocates nor opposes the compulsory adoption of the metric system. Those desiring arguments in favor of its more general adoption are referred to the Metric Association, J. T. Johnson, President, 2025 Silver Tip Lane, Long Beach, Michigan City, Ind. Those desiring arguments against it are referred to The American Institute of Weights and Measures, W. R. Ingalls, President, Georgetown, Mass.

The book compiled by Julia Emily Johnson entitled "Metric System" and published in 1926 by The H. W. Wilson Co., New York, N. Y., contains a bibliography and other material useful for debates.

2.3. British and United States Systems of Weights and Measures

The implication is sometimes made that the systems of weights and measures in general use in the British Empire and those in general use in the United States are identical. It is true that the difference between the U. S. and the British inch is not significant except in a few cases of the most refined measurements, that the British and the U. S. pound may be considered practically identical, and that many tables such as 12 inches=1 foot, 3 feet=1 yard, and 1 760 yards=1 mile are the same in both countries; but there are some very important differences.

In the first place, the U. S. bushel and the U. S. gallon, and their subdivisions differ from the corresponding British units. Also the British ton is 2 240 pounds, whereas the ton generally used in the United States is the short ton of 2 000 pounds. The American colonists adopted the English wine gallon of 231 cubic inches. The English of that period used this wine gallon and they also had another gallon, the ale gallon of 282 cubic inches. In 1824 these two gallons were abandoned by the British when they adopted the British Imperial gallon, which is defined as the volume of 10 pounds of water, at a temperature of 62° F which, by calculation, is equivalent to 277.42 cubic inches. At the same time, the bushel was redefined as 8 gallons. In the British system the units of dry measure are the same as those of liquid measure. In the United States these two are not the same, the gallon and its subdivisions being used in the measurement of liquids, while the bushel, with its subdivisions, is used in the measurement of certain dry commodities. The U. S. gallon is divided into 4 liquid quarts and the U. S. bushel into 32 dry quarts. All the units of capacity mentioned thus far are larger in the British system than in the U. S. system. But the British fluid ounce is smaller than the U. S. fluid ounce, because the British quart is divided into 40 fluid ounces whereas the U. S. quart is divided into 32 fluid ounces.

From the foregoing it is seen that in the British system an avoirdupois ounce of water at 62° F has a volume of 1 fluid ounce, because 10 pounds is equivalent to 160 avoirdupois ounces, and 1 gallon is equivalent to 4 quarts, or 160 fluid ounces. This convenient relation does not exist in the U. S. system because a U. S. gallon of water at 62° F weighs about 8⅓ pounds, or 133⅓ avoirdupois ounces, and the U. S. gallon is equivalent to 4×32, or 128 fluid ounces.

1 U. S. fluid ounce =1.040 8 British fluid ounces.
1 British fluid ounce=0.960 8 U. S. fluid ounce.

Among other differences between the British and the American systems of weights and measures it should be noted that the use of the troy pound was abolished in England January 6, 1879, only the troy ounce and its subdivisions being retained, whereas the troy pound is still legal in the United States, although it is not now greatly used. The common use in England of the stone of 14 pounds should be mentioned, this being a unit now unused in the United States, although its influence was shown in the practice until World War II of selling flour by the barrel of 196 pounds (14 stones). In the apothecaries system of liquid measure the British insert a unit, the fluid scruple, equal to one third of a fluid drachm (spelled *dram* in the United States) between their minim and their fluid drachm. In the United States the general practice now is to sell dry commodities, such as fruits and vegetables, by weight.

2.4. Subdivision of Units

In general, units are subdivided by one of three systems: (a) decimal, that is into tenths; (b) duodecimal, into twelfths; or (c) binary, into halves. Usually the subdivision is continued by the use of the same system. Each method has its advantages for certain purposes and it cannot properly be said that any one method is "best" unless the use to which the unit and its subdivisions are to be put is known.

For example, if we are concerned only with measurements of length to moderate precision, it is convenient to measure and to express these lengths in feet, inches, and binary fractions of an inch, thus 9 feet $4\frac{3}{8}$ inches. If, however, these measured lengths are to be subsequently used in calculations of area or volume, that method of subdivision at once becomes extremely inconvenient. For that reason civil engineers, who are concerned with areas of land, volumes of cuts, fills, excavations, etc., instead of dividing the foot into inches and binary subdivisions of the inch, divide it decimally, that is, into tenths, hundredths, and thousandths of a foot.

The method of subdivision of a unit is thus largely made on the basis of convenience to the user. The fact that units have commonly been subdivided into certain subunits for centuries does not preclude these units also having another mode of subdivision in some frequently used cases where convenience indicates the value of such other method. Thus the gallon is usually subdivided into quarts and pints, but the majority of gasoline-measuring pumps of the price-computing type are graduated to show tenths of a gallon. Although the mile has for centuries been divided into rods, yards, feet, and inches, the odometer part of an automobile speedometer indicates tenths of a mile. Although our dollar is divided into 100 parts, we habitually use and speak of halves and quarters. An illustration of rather complex subdividing is found on the scales used by draftsmen. These scales are of two types: (a) architects, which are commonly graduated with scales in which $\frac{3}{32}$, $\frac{3}{16}$, $\frac{1}{8}$, $\frac{1}{4}$, $\frac{3}{8}$, $\frac{1}{2}$, $\frac{3}{4}$, 1, $1\frac{1}{2}$, and 3 inches, respectively, represent 1 foot full scale, as well as having a scale graduated in the usual manner to $\frac{1}{16}$ inch; and (b) engineers, which are commonly subdivided to 10, 20, 30, 40, 50, and 60 parts to the inch.

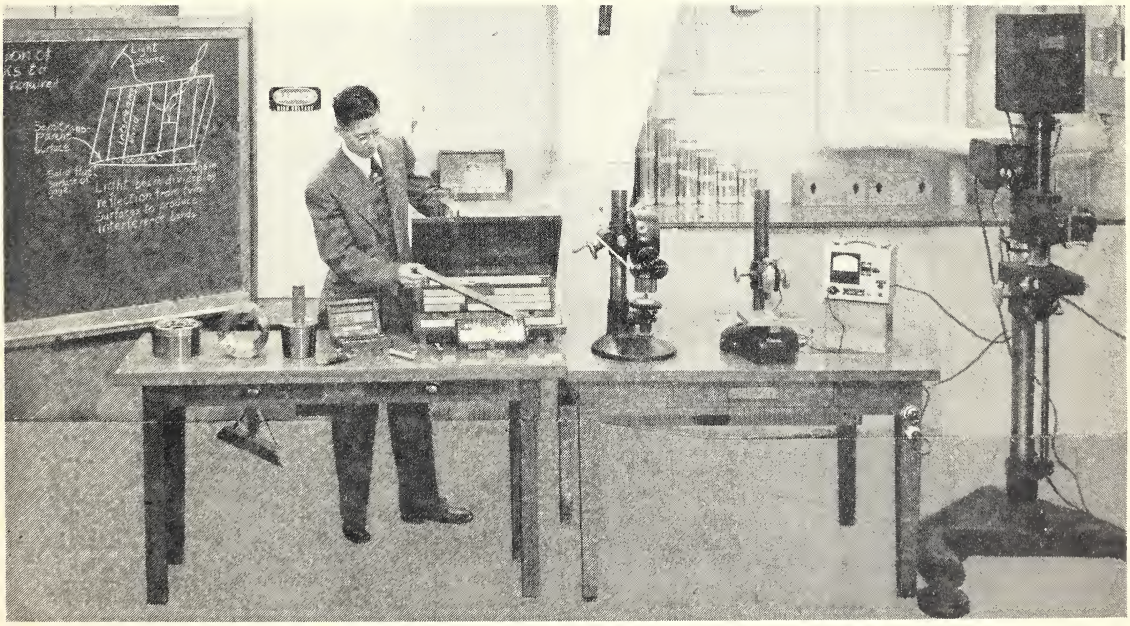


FIGURE 2. *Gage block testing*

Proper fitting and functioning of interchangeable mechanical parts depend upon precisely calibrated gage blocks. The NBS checks master gage blocks of industry. Shown on the table are various gage blocks and ring gages used by industry along with some of the equipment used by NBS for this calibration (see page 8).

The dictum of convenience applies not only to subdivisions of a unit but also to multiples of a unit. Elevations of land above sea level are given in feet even though the height may be several miles; the height of aircraft above sea level as given by an altimeter is likewise given in feet, no matter how high it may be.

On the other hand, machinists, toolmakers, gage makers, scientists, and others who are engaged in precision measurements of relatively small distances, even though concerned with measurements of length only, find it convenient to use the inch, instead of the tenth of a foot, but to divide the inch decimally to tenths, hundredths, thousands, etc., even down to millionths of an inch. Verniers, micrometers, and other precision measuring instruments are usually graduated in this manner. Machinist scales are commonly graduated decimally along one edge and are also graduated along another edge to binary fractions as small as 1/64 inch. The scales with binary fractions are used only for relatively rough measurements.

It is seldom convenient or advisable to use binary subdivisions of the inch that are smaller than 1/64. In fact, 1/32-, 1/16-, or 1/8-inch subdivisions are usually preferable for use on a scale to be read with the unaided eye.

2.5. Arithmetical Systems of Numbers

The subdivision of units of measurement is closely associated with arithmetical systems of numbers. The systems of weights and measures used in this country for commercial and scientific work, having many origins as has already been shown, naturally show traces of the various number systems associated with their origins and developments. Thus (a) the binary subdivision has come down to us from the Hindus, (b) the duodecimal system of fractions from the Romans, (c) the decimal system from the Chinese and Egyptians, some developments having been made by the Hindus, and (d) the sexagesimal system (division by 60), now illustrated in the subdivision of units of angle and of time, from the ancient Babylonians.

The suggestion is made from time to time that we should adopt a duodecimal number system and a duodecimal system of weights and measures. Another suggestion is for an octonary number system (a system with 8 as the basis instead of 10 in our present system or 12 in the duodecimal) and an octonary system of weights and measures. Such suggestions have certain theoretical merits, but are very impractical because it is now too late to modify our number system and unwise to have arbitrary enforcement of any single system of weights and measures. It is far better for each branch of science, industry, and commerce to be free to use whatever system has been found by experience best to suit its needs. The prime requisite of any system of weights and measures is that the units be definite. It is also important that the relations of these units to the units of other systems be definite, convenient, and known, in order that conversion from one system to another may be accurately and conveniently made.

3. Standards of Length, Mass, Time, and Capacity

3.1. Standards of Length

The primary standard of length in the United States is the United States Prototype Meter 27, a platinum-iridium (90% platinum, 10% 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 at the International Bureau of Weights and Measures at Sèvres, near Paris, France.

The U. S. yard is defined, following the policy stated in the Mendenhall Order [1] of April 5, 1893, as follows:

$$1 \text{ U. S. yard} = \frac{3\ 600}{3\ 937} \text{ meter.}$$

[1] This order stated that the Office of Weights and Measures, with the approval of the Secretary of the Treasury, would in the future regard the International Prototype Meter and Kilogram as fundamental standards, and that the customary units would be derived therefrom in accordance with the Act of July 28, 1866.

The relation 1 U. S. yard $=\frac{3\ 600}{3\ 937}$ meter, derived from the Law of 1866 that made the use of the metric system legal in the United States, was confirmed by later comparisons of copies of the British yard with the U. S. national copies of the meter. Since the Mendenhall Order it has been used as an exact relation. From this it follows that 1 U. S. inch is slightly larger than 0.025 400 05 meter, or 25.400 05 millimeters.

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

1 inch=25.4 millimeters (exactly), that is, 0.025 4 meter (exactly),

from which 1 yard=0.914 4 meter (exactly), or 914.4 millimeters (exactly).

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 desirable step in the direction of international uniformity in precision length measurements.

In Great Britain the Imperial Yard is represented by a yard bar made of bronze in 1844. The relation between that yard and the meter according to the most recent published determinations is

$$1 \text{ British Imperial Yard} = \frac{3\ 600\ 000}{3\ 937\ 014} \text{ meter.}$$

Although opinions about the British yard standard are conflicting, there is substantial evidence that the British yard has shortened by a few parts in a million during the past century. Uncertainties in some of the measurements and in the thermometric scale of the early compari-

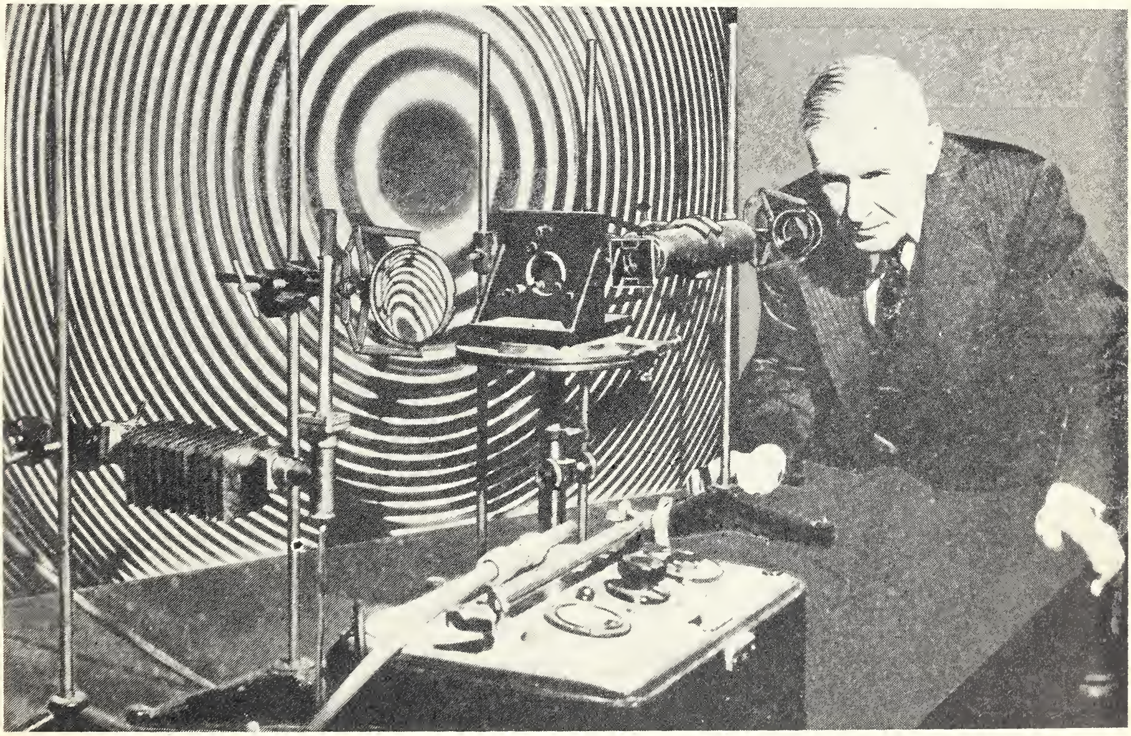


FIGURE 3. *Mercury 198 lamp.*

William F. Meggers positions the eyepiece of an optical train prior to observation of the circular interference fringes of the green light from a mercury 198 lamp. This electrodeless lamp contains about 1 milligram of mercury of atomic weight 198. The lamp is excited in a radiofrequency field (left foreground). The interference pattern portrayed in the background enables researchers to make accurate length measurements. The NBS-Meggers Mercury 198 lamp is one of the light sources proposed for use in defining length by reference to a specified wavelength of light.

sons, however, make it impossible to state the difference between the U. S. and the British yards a century ago or to be certain of the amount that the British Imperial Yard has changed since that date.

In 1927 the Seventh General (International) Conference on Weights and Measures approved a resolution stating the wavelength of the red cadmium radiation under standard conditions of temperature, pressure, and humidity to be 0.000 643 846 96 millimeter. From this the length of the meter in terms of the wavelength of light was provisionally expressed as equal to 1 553 164.13 wavelengths of cadmium light under the specified conditions.

With the advances made in physics in recent years better sources of monochromatic radiation for use as wavelength standards of length have been developed. The National Bureau of Standards has proposed that the wavelength of the green radiation of the 198 isotope of mercury (fig. 3) be adopted as the fundamental standard of length instead of the International Prototype Meter. The change proposed is in the standard; the unit would not be altered. Other laboratories have proposed other radiations, and investigations are now in progress in a number of national laboratories in various countries to determine what length standard will be the most stable and the most suitable for the purpose. It is believed that a natural phenomenon such as monochromatic radiation will be more unchangeable than a metal standard, even though no change in length of the international platinum-iridium bar seems to be detectable.

a. Tests and Calibrations of Length Standards

The National Bureau of Standards tests standards of length including meter bars, yard bars, miscellaneous precision line standards, steel tapes, invar geodetic tapes (see fig. 4), 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. 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. 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 carpenters rules, machinists scales, draftsmans scales, and the like. Such apparatus, if test is required, should be submitted to State or local weights and measures officials. NBS Circular 572, Calibration of Line Standards of Length and Measur-

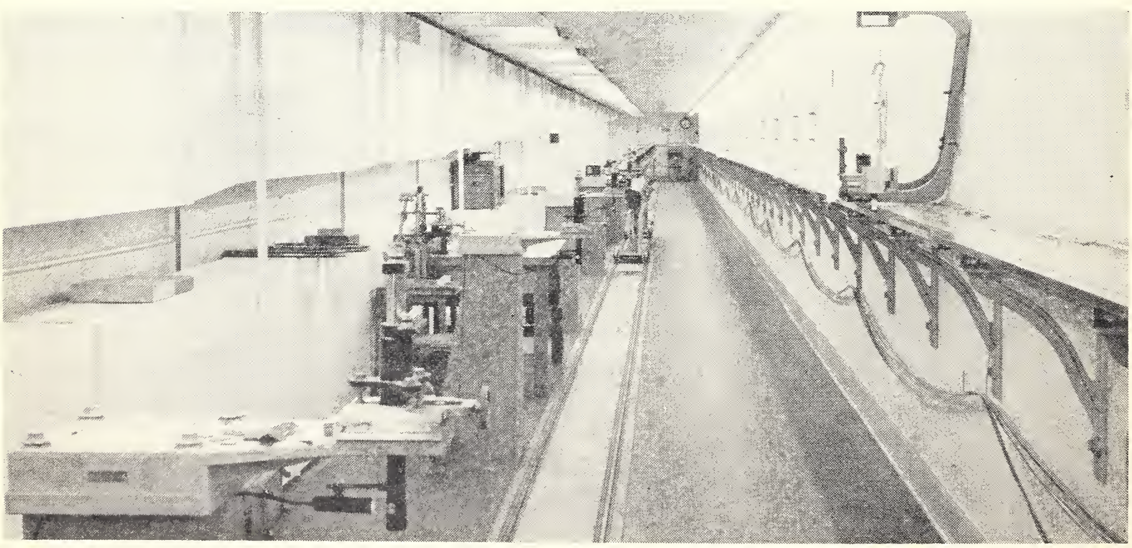


FIGURE 4. *NBS Tape Calibration Laboratory.*

In this laboratory the Bureau calibrates steel tapes used by surveyors and engineers and the more precise base-line tapes used by the U. S. Coast and Geodetic Survey.

ing Tapes at the National Bureau of Standards, by Lewis V. Judson (in press) contains additional information on this subject.

3.2. Standards of 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 U. S. 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=0.453 592 427 7 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 1/7 000 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 437½ grains.

In Great Britain the Imperial Pound, an avoirdupois pound, is represented by a physical standard made in 1845. According to the most recent published determination

1 British Imperial Pound=0.453 592 34 kilogram.

There is substantial evidence that the British standard has diminished by about 1 part in 5 million since 1883 in relation to the kilogram, and is therefore smaller than the U. S. pound by that amount.

a. Distinction Between Mass and Weight

The *mass* of a body is a measure of 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.)

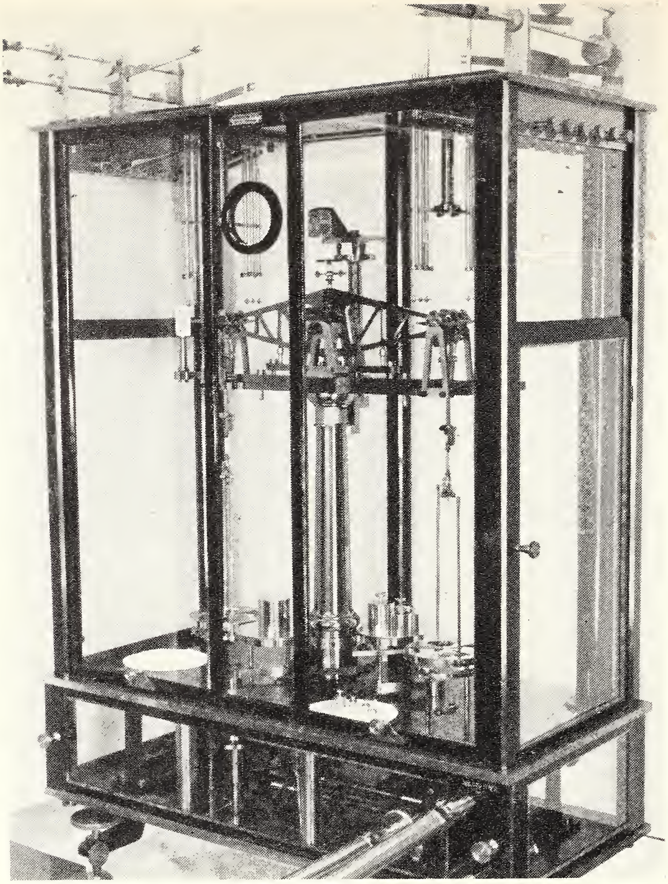


FIGURE 5. *Precision balance.*

The most accurate of the precision balances at NBS is used to compare secondary and laboratory standards of mass with the national prototype kilogram. This balance is operated by remote control in order to avoid errors caused by the heat given off by the body of the observer. By means of rods (above and lower right) the balance pan is arrested and released, the loads on the pans are interchanged, and sensitivity weights are added. A precision better than 1 part in 100 000 000 is obtained.

Because standards of mass (or "weights") are ordinarily calibrated and used on equal-arm balances (fig. 5), 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 equal-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 resistance of a spring. Therefore, using a very sensitive spring balance, the weight of a body would be found to change if the spring balance and the body were moved from one locality to another locality with a different acceleration of gravity. But a spring balance is usually used in one locality and is adjusted to indicate mass at that locality.

b. 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 equal-arm balance, will balance each other in a vacuum. A comparison in a vacuum against a known mass standard gives "true mass." If compared in air, however, they will not balance each other unless they are of equal volume. If of unequal volume, the

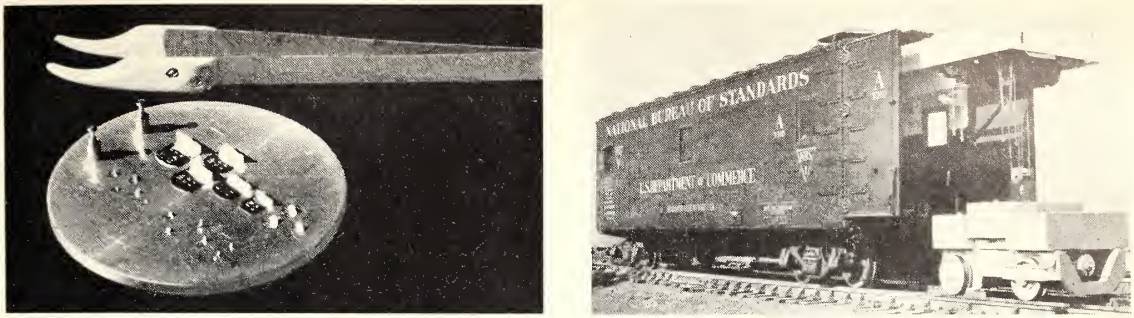


FIGURE 6. *Calibration of weights by NBS.*

These two illustrations indicate extremes of weights routinely calibrated by NBS. The one on left shows the small weights (down to 0.05 mg) for use with microbalances. The illustration on right shows 1 of 2 standard test weight cars, owned and operated by NBS for calibrating and adjusting the master railway track scales of the Nation's railroads. The largest individual weight of these cars is 10 000 pounds. A total test load of 80 000 pounds is carried by each car.

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.

The corrections furnished by the National Bureau of Standards for the more precise mass standards are given both (a) on the basis of comparison in vacuum, and (b) on the basis of comparison against normal brass standards in air under standard conditions, with no correction applied for the buoyant effect of the air. Normal brass standards are defined as having a density of 8.4 grams per cubic centimeter at 0° C and a coefficient of cubical thermal expansion of 0.000 054 per deg C. Standard conditions are defined as air of 1.2 milligrams per cubic centimeter and temperature of 20° C. The corrections to be used with precise analytical weights are ordinarily given only in terms of apparent mass against normal brass standards.

c. 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 calibrates and certifies the values of weights submitted but it does not manufacture or sell weights. Information regarding the various classes of weights, the requirements for each class, the weight-calibration service of the Bureau and the regulations governing the submission of weights to NBS for test are contained in NBS Circular 547, section 1, Precision Laboratory Standards of Mass and Laboratory Weights, by T. W. Lashof and L. B. Macurdy (for sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., at 25 cents a copy).

3.3. Standards of 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 365¼ rotations on its axis (365.242 2, more exactly) while making a complete journey around the sun. In other words, there are almost exactly 365¼ solar days in a tropical or solar year. As it would be inconvenient and confusing to have the year, as used in everyday 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 motion 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.

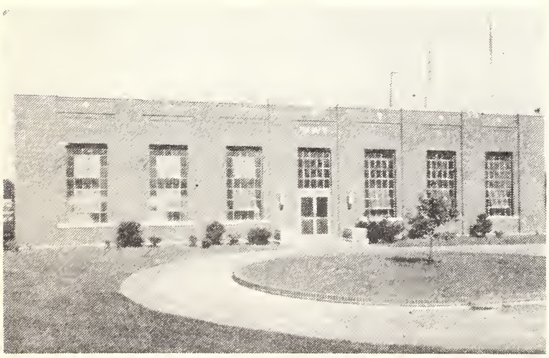
In observing on the stars, the time generally used by astronomers is sidereal time. This is defined by the rotation of the earth with respect to the stars. A sidereal day is the interval between two successive passages of a star across a meridian. The sidereal day is subdivided into hours, minutes, and seconds, the hours being numbered from 1 to 24. The sidereal year is 365.256 36 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 1/864 00 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 to use local mean time at each locality, the surface of the earth, by international agreement, has been divided into 24 standard time zones, each zone having a width of approximately 15 degrees of longitude. 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 is 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,



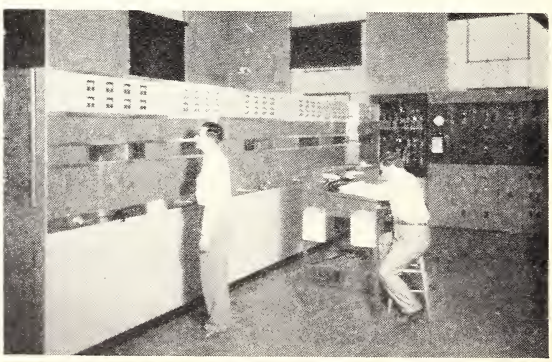


FIGURE 7. *Radio station WWV in Beltsville, Md.*

NBS broadcasts various standard radiofrequency and time signals, day and night, from station WWV. These signals—accurate to 1 part n 50 000 000—are used by utilities to control 60-cycle generators, by manufacturers of electronic equipment to calibrate oscillators, by radio stations to keep their signals within assigned channels, by aircraft and ships, and by scientists and engineers in experimental work. WWV services—including the standard musical pitch (440 cycles per second), precise time intervals (seconds), and time announcements in voice—can be picked up by shortwave receiver at 5, 10, 15, 20, and 25 megacycles per second.

6, 7, and 8 hours, respectively. For further information see NBS Circular 496, Standard Time Throughout the World, by R. E. Gould (for sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., at 15 cents a copy).

The U. S. Naval Observatory has elaborate transit equipment with which it measures the time of rotation of the earth with respect to various heavenly bodies. The average time of rotation over a period of several days is used as a standard interval to which is compared the interval indicated by extremely accurate crystal clocks owned by the National Bureau of Standards. The time difference between these two intervals is published as a correction to the crystal clock time signals transmitted continuously by the National Bureau of Standards broadcasting station WWV (fig. 7) on 2.5, 5, 10, 15, 20, and 25 megacycles per second. The National Bureau of Standards time signal is accurate to one-millionth of a second over a 1-second interval, and accurate to 1 part in 50 million for intervals of 1 minute or longer. This signal provides an indispensable standard time interval for purposes of physical measurements, for quick and accurate calibration of timing devices, and for adjustment of very low frequency oscillators.

3.4. Standards of Capacity

Units of capacity, being derived units, in this country defined in terms of linear units, are not represented by fundamental standards. Laboratory standards have been constructed and are maintained at the National Bureau of Standards. These have validity only by calibration with reference either directly or indirectly with the linear standards. Similarly, standards of capacity have been made and distributed to the several States. Other standards of capacity have been verified by calibration for a wide variety of uses in science, technology, and commerce.

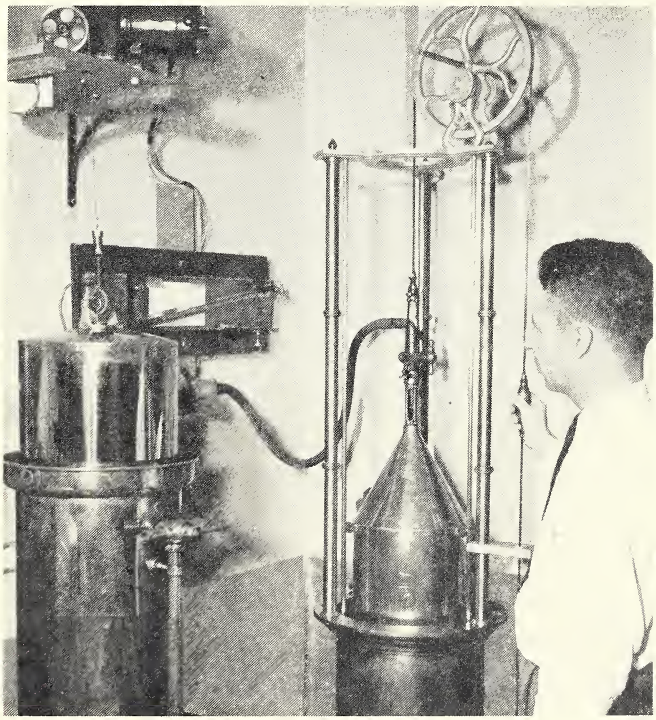


Figure 8. *Calibration of a capacity standard at NBS.*

A portable cubic foot standard of volume (left) for field use in the fuel gas industry is being calibrated under laboratory conditions at NBS by comparison with a laboratory standard immersion-type cubic-foot bottle (right center).

a. Tests of Standards of Capacity

Calibrations are made by the Bureau on capacity standards that are in the customary units of trade, that is the gallon, its multiples, and submultiples, or in metric units. Furthermore the Bureau calibrates precision grade volumetric glassware which is normally in metric units. Tests are made in accordance with test-fee schedules, copies of which may be obtained by application to the Bureau.

3.5. Maintenance and Preservation of Fundamental Standards of Length and Mass

There is considerable interest in the maintenance and preservation of the national standards of length and mass at the National Bureau of Standards. In 1955, a special glass door, fully protected by an alarm system, was installed so that during the regular working hours of the Bureau the vault can be viewed by those interested. At other times the steel outer doors are locked. All measurements made with these standards are conducted in special air-conditioned laboratories to which the standards are taken a sufficiently long time before the observations to ensure that the standards will be in a state of equilibrium under standard conditions when the measurements or comparisons are made. Hence it is not necessary to maintain the vault at standard conditions, but care is taken to prevent large changes of temperature. More important is the care to prevent any damage to the standards because of careless handling.

4. Weights and Measures in Everyday Life

As weighing and measuring are important factors in our everyday lives, it is quite natural that questions arise about the use of various units and terms and about the magnitude of quantities involved. Only two items will be considered here, first the weight of coal, and second the definitions and usages of the terms "ton" and "tonnage."

4.1. Weight of Coal

Questions are frequently asked about the weight per unit volume of coal. As there are large variations in the weight per cubic foot of coal, the reader is cautioned that the figures presented herein are only approximate values, and that in the case of any particular delivery of coal, the actual number of cubic feet per ton (of 2 000 pounds), may differ materially from the values given here.

The following values may, however, be satisfactory for use in calculating the approximate size of bin required to contain a given number of tons of coal, the approximate number of tons of coal that a given bin will contain, and the approximate weight of a measured amount of coal. Relatively large shortages can be detected by computing the weights of deliveries, and computed weights may properly be used by a purchaser as a basis of complaint to the weights and measures official; such evidence alone, however, probably would not be accepted by a court, and satisfactory evidence can be procured only by actually weighing the coal comprising a delivery.

The weight per cubic foot of anthracite (hard coal) varies with the size into which the coal is broken, and with the kind of coal or the vein from which the coal comes. According to information published by the Anthracite Institute, "frequently used average weight and volume figures for all sizes of anthracite are 37 cubic feet per ton and 54 lbs per cubic feet." This corresponds to 67 pounds per stricken bushel (2 150.42 cubic inches). Variations from these averages as high as 10 percent may be expected.

The weight of bituminous (common soft) coal also varies according to the locality from which the coal comes. Such weights range from 47 to 55 pounds per cubic foot. These values correspond to 42.6 to 36.4 cubic feet per 2 000-pound ton; and to 58.5 to 68.4 pounds per stricken bushel.

4.2. Definitions and Usages of the Terms "Ton" and "Tonnage"

Because the words "ton" and "tonnage" are used in widely different senses, a great deal of confusion has arisen regarding the application of these terms.

a. Definitions and Uses of "Ton"

The ton is used as a unit of measure in two distinct senses: (1) as a unit of weight, and (2) as a unit of capacity or volume.

In the first sense the term has the following meanings:

(a). The *short*, or *net* ton of 2 000 pounds.

(b). The *long*, *gross*, or *shipper's* ton of 2 240 pounds.

(c). The *metric* ton of 1 000 kilograms, or 2 204.6 pounds.

In the second sense (capacity) it is usually restricted to uses relating to ships and has the following meaning:

(a). The *register* ton of 100 cubic feet.

(b). The *measurement* ton of 40 cubic feet.

(c). The *English water* ton of 224 British Imperial gallons.

In the United States and Canada the ton (weight) most commonly used is the *short* ton, in Great Britain it is the *long* ton, and in countries using the metric system it is the *metric* ton. The *register* ton and the *measurement* ton are capacity units used in expressing the tonnage of ships. The *English water* ton is used, chiefly in Great Britain, in statistics dealing with petroleum products.

There have been many other uses of the term ton such as the timber ton of 40 cubic feet and the wheat ton of 20 bushels, but their use has been local and the meanings have not been consistent from one place to another.

b. Definitions and Uses of "Tonnage"

Properly, the word "tonnage" is used as a noun only in respect to the capacity and dimensions of ships, and to the amount of the ship's cargo. There are two distinct kinds of tonnage, namely, *vessel tonnage* and *cargo tonnage* and each of these is used in various meanings.

The several kinds of *vessel tonnage* are as follows:

Gross tonnage, or *gross register tonnage*, is the total cubical capacity of a ship expressed in *register* tons of 100 cubic feet, or 2.83 cubic meters, less such space as hatchways, bakeries, galleys, etc., as are exempted from measurement by different governments. There is some lack of uniformity in the gross tonnages as given by different nations on account of lack of agreement on the spaces that are to be exempted.

Official merchant marine statistics of most countries are published in terms of the *gross register tonnage*. Press references to *ship tonnage* are usually to the *gross tonnage*.

The *net tonnage*, or *net register tonnage*, is the *gross tonnage* less the different spaces specified by maritime nations in their measurement rules and laws. The spaces that are deducted are those totally unavailable for carrying cargo, such as the engine room, coal bunkers, crews quarters, chart and instrument room, etc.

The *net tonnage* is used in computing the amount of cargo that can be loaded on a ship. It is used as the basis for wharfage and other similar charges.

The *register under-deck tonnage* is the cubical capacity of a ship under her tonnage deck expressed in register tons. In a vessel having more than one deck the tonnage deck is the second from the keel.

There are several variations of *displacement tonnage*.

The *dead weight tonnage* is the difference between the "loaded" and "light" *displacement tonnages* of a vessel. It is expressed in terms of the long ton of 2 240 pounds, or the metric ton of 2 204.6 pounds, and is the weight of fuel, passengers, and cargo that a vessel can carry when loaded to her maximum draft.

The second variety of tonnage, *cargo tonnage*, refers to the weight of the particular items making up the cargo. In overseas traffic it is usually expressed in long tons of 2 240 pounds or metric tons of 2 204.6 pounds. The short ton is only occasionally used. The *cargo tonnage* is therefore very distinct from *vessel tonnage*.

5. General Tables of Weights and Measures

These tables have been prepared for the benefit of those requiring tables of weights and measures for occasional ready reference. In section 5.4 the tables are carried out to a large number of decimal places and exact values are indicated by boldface type. In most of the other tables only a limited number of decimal places are given, thus making the tables better adapted to the average user. More extensive tables will be found in Miscellaneous Publication M214 of the National Bureau of Standards, Units of Weight and Measure—Definitions and Tables of Equivalents (sold by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., at 40 cents a copy).

5.1. Tables of United States Customary Weights and Measures

LINEAR MEASURE

12 inches (in.)	=1 foot (ft).
3 feet	=1 yard (yd).
5½ yards	=1 rod (rd), pole, or perch=16½ feet.
40 rods	=1 furlong (fur.)=220 yards=660 feet.
8 furlongs	=1 statute mile (mi)=1 760 yards=5 280 feet.

6 076.103 33 . . . feet (1 852 meters)=1 international nautical mile. This value was adopted effective July 1, 1954, for use in the United States. The value formerly used in the United States was 6 080.20 feet=1 nautical (geographical or sea) mile.

AREA MEASURE [a]

144 square inches (sq in.)	=1 square foot (sq ft).
9 square feet	=1 square yard (sq yd)=1 296 square inches.
30¼ square yards	=1 square rod (sq rd)=272¼ square feet.
160 square rods	=1 acre=4 840 square yards=43 560 square feet.
640 acres	=1 square mile (sq mi).
1 mile square	=1 section of land.
6 miles square	=1 township=36 sections=36 square miles.

CUBIC MEASURE [a]

1 728 cubic inches (cu in.)	=1 cubic foot (cu ft).
27 cubic feet	=1 cubic yard (cu yd).

GUNTER'S OR SURVEYORS CHAIN MEASURE

7.92 inches (in.)	=1 link (li).
100 links	=1 chain (ch)=4 rods=66 feet.
80 chains	=1 statute mile (mi)=320 rods=5 280 feet.

LIQUID MEASURE [b]

4 gills (gi)	=1 pint (pt)=28.875 cubic inches.
2 pints	=1 quart (qt)=57.75 cubic inches.
4 quarts	=1 gallon (gal)=231 cubic inches=8 pints=32 gills.

[a] Squares and cubes of units are sometimes abbreviated by using "superior" figures. For example, ft^2 means square foot, and ft^3 means cubic foot.

[b] When necessary to distinguish the *liquid* pint or quart from the *dry* pint or quart, the word "liquid" or the abbreviation "liq" should be used in combination with the name or abbreviation of the *liquid* unit.

APOTHECARIES FLUID MEASURE

60 minims (min or ♏)	=1 fluid dram (fl dr or *f* ʒ) = 0.225 6 cubic inch.
8 fluid drams	=1 fluid ounce (fl oz or *f* ℥) = 1.804 7 cubic inches.
16 fluid ounces	=1 pint (pt or O) = 28.875 cubic inches = 128 fluid drams.
2 pints	=1 quart (qt) = 57.75 cubic inches = 32 fluid ounces = 256 fluid drams.
4 quarts	=1 gallon (gal) = 231 cubic inches = 128 fluid ounces = 1 024 fluid drams.

DRY MEASURE [c]

2 pints (pt)	=1 quart (qt) = 67.200 6 cubic inches.
8 quarts	=1 peck (pk) = 537.605 cubic inches = 16 pints.
4 pecks	=1 bushel (bu) = 2 150.42 cubic inches = 32 quarts.

AVOIRDUPOIS WEIGHT [d]

[The "grain" is the same in avoirdupois, troy, and apothecaries weight.]

27 11/32 grains	=1 dram (dr).
16 drams	=1 ounce (oz) = 437½ grains.
16 ounces	=1 pound (lb) = 256 drams = 7 000 grains.
100 pounds	=1 hundredweight (cwt).[e]
20 hundredweights	=1 ton = 2 000 pounds.[e]

In "gross" or "long" measure, the following values are recognized:

112 pounds	=1 gross or long hundredweight.[e]
20 gross or long hundredweights	=1 gross or long ton = 2 240 pounds.[e]

TROY WEIGHT

[The "grain" is the same in avoirdupois, troy, and apothecaries weight.]

24 grains	=1 pennyweight (dwt).
20 pennyweights	=1 ounce troy (oz t) = 480 grains.
12 ounces troy	=1 pound troy (lb t) = 240 pennyweights = 5 760 grains.

APOTHECARIES WEIGHT

[The "grain" is the same in avoirdupois, troy, and apothecaries weight.]

20 grains	=1 scruple (s ap or ℈).
3 scruples	=1 dram apothecaries (dr ap or ʒ) = 60 grains.
8 drams apothecaries	=1 ounce apothecaries (oz ap or ℥) = 24 scruples = 480 grains.
12 ounces apothecaries	=1 pound apothecaries (lb ap or ℔) = 96 drams apothecaries = 288 scruples = 5 760 grains.

5.2. Notes on British Weights and Measures Tables

In Great Britain, the yard, the avoirdupois pound, the troy pound, and the apothecaries pound, are, for all commercial purposes, identical with the units of the same names used in the United States. The tables of British linear measure, troy weight, and apothecaries weight are the same as the corresponding United States tables, except for the British spelling "drachm"

[c] When necessary to distinguish the *dry* pint or quart from the *liquid* pint or quart, the word "dry" should be used in combination with the name or abbreviation of the dry unit.

[d] When necessary to distinguish the *avoirdupois* dram from the *apothecaries* dram, or to distinguish the *avoirdupois* dram or ounce from the *fluid* dram or ounce, or to distinguish the *avoirdupois* ounce or pound from the *troy* or *apothecaries* ounce or pound, the word "avoirdupois" or the abbreviation "avdp" should be used in combination with the name or abbreviation of the *avoirdupois* unit.

[e] When the terms "hundredweight" and "ton" are used unmodified, they are commonly understood to mean the 100-pound hundredweight and the 2 000-pound ton, respectively; these units may be designated "net" or "short" when necessary to distinguish them from the corresponding units in *gross* or *long* measure.

in the table of apothecaries weight. The table of British avoirdupois weight is the same as the United States table up to 1 pound; above that point the table reads:

14 pounds	=1 stone.
2 stones	=1 quarter=28 pounds.
4 quarters	=1 hundredweight=112 pounds.
20 hundredweight	=1 ton=2 240 pounds.

The present British gallon and bushel, known as the "Imperial gallon" and "Imperial bushel" are, respectively, about 20 percent and 3 percent larger than the United States gallon and bushel. The Imperial gallon is defined as the volume of 10 avoirdupois pounds of water under specified conditions, and the Imperial bushel is defined as 8 Imperial gallons. Also, the subdivision of the Imperial gallon as presented in the table of British apothecaries fluid measure differs in two important respects from the corresponding United States subdivision, in that the Imperial gallon is divided into 160 fluid ounces (whereas the United States gallon is divided into 128 fluid ounces), and a "fluid scruple" is included. The full table of British measures of capacity (which are used alike for liquid and for dry commodities) is as follows:

4 gills	=1 pint.
2 pints	=1 quart.
4 quarts	=1 gallon.
2 gallons	=1 peck.
8 gallons [4 pecks]	=1 bushel.
8 bushels	=1 quarter.

The full table of British apothecaries measure is as follows:

20 minims	=1 fluid scruple.
3 fluid scruples	=1 fluid drachm=60 minims.
8 fluid drachms	=1 fluid ounce.
20 fluid ounces	=1 pint.
8 pints	=1 gallon=160 fluid ounces.

5.3. Tables of Metric Weights and Measures

In the metric system of weights and measures, designations of multiples and subdivisions of any unit may be arrived at by combining with the name of the unit the prefixes *deka*, *hecto*, and *kilo*, meaning, respectively, 10, 100, and 1 000, and *deci*, *centi*, and *milli*, meaning, respectively, one-tenth, one-hundredth, and one-thousandth. In some of the following metric tables, some such multiples and subdivisions have not been included for the reason that these have little, if any, currency in actual usage.

In certain cases, particularly in scientific usage, it becomes convenient to provide for multiples larger than 1 000 and for subdivisions smaller than one-thousandth. Accordingly, the following prefixes have been introduced and these are now generally recognized:

myria, meaning 10 000,
mega, meaning 1 000 000,
micro, meaning one-millionth.

A special case is found in the term "micron" (abbreviated as μ, the Greek letter mu), a coined word meaning one-millionth of a meter (equivalent to one-thousandth of a millimeter); a millimicron (abbreviated as $m\mu$) is one-thousandth of a micron (equivalent to one-millionth of a millimeter), and a micromicron (abbreviated as $\mu\mu$) is one-millionth of a micron (equivalent to one-thousandth of a millimicron or to 0.000 000 001 millimeter.)

LINEAR MEASURE

10 millimeters (mm)	=1 centimeter (cm).
10 centimeters	=1 decimeter (dm)=100 millimeters.
10 decimeters	=1 meter (m)=1 000 millimeters.
10 meters	=1 dekameter (dkm).
10 dekameters	=1 hectometer (hm)=100 meters.
10 hectometers	=1 kilometer (km)=1 000 meters.

AREA MEASURE

100 square millimeters (mm^2)	=1 square centimeter (cm^2).
10 000 square centimeters	=1 square meter (m^2)=1 000 000 square millimeters.
100 square meters	=1 are (a).
100 ares	=1 hectare (ha)=10 000 square meters.
100 hectares	=1 square kilometer (km^2)=1 000 000 square meters.

VOLUME MEASURE

10 milliliters (ml)	=1 centiliter (cl).
10 centiliters	=1 deciliter (dl)=100 milliliters.
10 deciliters	=1 liter [f]=1 000 milliliters.
10 liters	=1 dekaliter (dkl).
10 dekaliters	=1 hectoliter (hl)=100 liters.
10 hectoliters	=1 kiloliter (kl)=1 000 liters.

CUBIC MEASURE

1 000 cubic millimeters (mm^3)	=1 cubic centimeter (cm^3).
1 000 cubic centimeters	=1 cubic decimeter (dm^3)=1 000 000 cubic millimeters.
1 000 cubic decimeters	=1 cubic meter (m^3)=1 stere=1 000 000 cubic centimeters= 1 000 000 000 cubic millimeters.

WEIGHT

10 milligrams (mg)	=1 centigram (cg).
10 centigrams	=1 decigram (dg)=100 milligrams.
10 decigrams	=1 gram (g)=1 000 milligrams.
10 grams	=1 dekagram (dkg).
10 dekagrams	=1 hectogram (hg)=100 grams.
10 hectograms	=1 kilogram (kg)=1 000 grams.
1 000 kilograms	=1 metric ton (t).

---

[f] The liter is defined as the volume occupied, under standard conditions, by a quantity of pure water having a mass of 1 kilogram. This volume is very nearly equal to 1 000 cubic centimeters or 1 cubic decimeter; the actual metric equivalent is, 1 liter=1 000.028 cubic centimeters. (The change in this equivalent from the previously published value of 1 000.027 is based on a recomputation of earlier data, carried out at the International Bureau of Weights and Measures.) Thus the milliliter and the liter are larger than the cubic centimeter and the cubic decimeter, respectively, by 28 parts in 1 000 000; except for determinations of high precision, this difference is so small as to be of no consequence.

5.4. TABLES OF INTERRELATION

UNITS OF

Units	Inches	Links	Feet	Yards	Rods
1 inch =	1	0.126 263	0.083 333 3	0.027 777 8	0.005 050 51
1 link =	7.92	1	0.66	0.22	0.04
1 foot =	12	1.515 152	1	0.333 333	0.060 606 1
1 yard =	36	4.545 45	3	1	0.181 818
1 rod =	198	25	16.5	5.5	1
1 chain =	792	100	66	22	4
1 mile =	63 360	8000	5280	1760	320
1 centimeter =	0.3937	0.049 709 60	0.032 808 33	0.010 936 111	0.001 988 384
1 meter =	39.37	4.970 960	3.280 833	1.093 611 1	0.198 838 4

UNITS OF

Units	Square inches	Square links	Square feet	Square yards	Square rods	Square chains
1 square inch =	1	0.015 942 3	0.006 944 44	0.000 771 605	0.000 025 507 6	0.000 001 594 23
1 square link =	62.7264	1	0.4356	0.0484	0.0016	0.0001
1 square foot =	144	2.295 684	1	0.111 111 1	0.003 673 09	0.000 229 568
1 square yard =	1296	20.6612	9	1	0.033 057 85	0.002 066 12
1 square rod =	39 204	625	272.25	30.25	1	0.0625
1 square chain =	627 264	10 000	4356	484	16	1
1 acre =	6 272 640	100 000	43 560	4840	160	10
1 square mile =	4 014 489 600	64 000 000	27 878 400	3 097 600	102 400	6400
1 square centimeter =	0.154 999 69	0.002 471 04	0.001 076 387	0.000 119 598 5	0.000 003 953 67	0.000 000 247 104
1 square meter =	1549.9969	24.7104	10.763 87	1.195 985	0.039 536 7	0.002 471 04
1 hectare =	15 499 969	247 104	107 638.7	11 959.85	395.367	24.7104

UNITS OF

Units	Cubic inches	Cubic feet	Cubic yards
1 cubic inch =	1	0.000 578 704	0.000 021 433 47
1 cubic foot =	1728	1	0.037 037 0
1 cubic yard =	46 656	27	1
1 cubic centimeter =	0.061 023 38	0.000 035 314 45	0.000 001 307 94
1 cubic decimeter =	61.023 38	0.035 314 45	0.001 307 943
1 cubic meter =	61 023.38	35.314 45	1.307 942 8

UNITS OF CAPACITY

Units	Minims	Fluid drams	Fluid ounces	Gills	Liquid pints
1 minim =	1	0.016 666 7	0.002 083 33	0.000 520 833	0.000 130 208
1 fluid dram =	60	1	0.125	0.031 25	0.007 812 5
1 fluid ounce =	480	8	1	0.25	0.0625
1 gill =	1920	32	4	1	0.25
1 liquid pint =	7680	128	16	4	1
1 liquid quart =	15 360	256	32	8	2
1 gallon =	61 440	1024	128	32	8
1 milliliter =	16.2311	0.270 518	0.033 814 8	0.008 453 69	0.002 113 42
1 liter =	16 231.1	270.518	33.8148	8.453 69	2.113 42
1 cubic inch =	265.974	4.432 90	0.554 113	0.138 528	0.034 632 0
1 cubic foot =	459 603.1	7660.052	957.506 5	239.376 6	59.844 16

LENGTH

Chains	Miles	Centimeters	Meters	Units
0. 001 262 63	0. 000 015 782 8	2. 540 005	0. 025 400 05	=1 inch
0.01	**0.000 125**	20. 116 84	0. 201 168 4	=1 link
0. 015 151 5	0. 000 189 393 9	30. 480 06	0. 304 800 6	=1 foot
0. 045 454 5	0. 000 568 182	91. 440 18	0. 914 401 8	=1 yard
0.25	**0.003 125**	502. 9210	5. 029 210	=1 rod
1	**0.0125**	2011. 684	20. 116 84	=1 chain
80	**1**	160 934. 72	1609. 3472	=1 mile
0. 000 497 096 0	0. 000 006 213 699	**1**	**0.01**	=1 centimeter
0. 049 709 60	0. 000 621 369 9	**100**	**1**	=1 meter

AREA

Acres	Square miles	Square centimeters	Square meters	Hectares	Units
0. 000 000 159 423	0. 000 000 000 249 1	6. 451 626	0. 000 645 162 6	0. 000 000 064 516	=1 square inch
0.000 01	**0.000 000 015 625**	404. 6873	0. 040 468 73	0. 000 004 046 87	=1 square link
0. 000 022 956 8	0. 000 000 035 870 1	929. 0341	0. 092 903 41	0. 000 009 290 34	=1 square foot
0. 000 206 612	0. 000 000 322 831	8361. 307	0. 836 130 7	0. 000 083 613 1	=1 square yard
0.006 25	**0.000 009 765 625**	252 929. 5	25. 292 95	0. 002 529 295	=1 square rod
0.1	**0.000 156 25**	4 046 873	404. 6873	0. 040 468 7	=1 square chain
1	**0.001 562 5**	40 468 726	4046. 873	0. 404 687	=1 acre
640	**1**	25 899 984 703	2 589 998	258. 9998	=1 square mile
0.000 000 024 710 4	0. 000 000 000 038 610 06	**1**	**0.0001**	**0.000 000 01**	=1 square centimeter
0. 000 247 104	0. 000 000 386 100 6	**10 000**	**1**	**0.0001**	=1 square meter
2. 471 04	0. 003 861 006	**100 000 000**	**10 000**	**1**	=1 hectare

VOLUME

Cubic centimeters	Cubic decimeters	Cubic meters	Units
16. 387 162	0. 016 387 16	0. 000 016 387 16	=1 cubic inch
28 317. 016	28. 317 016	0. 028 317 016	=1 cubic foot
764 559. 4	764. 5594	0. 764 559 4	=1 cubic yard
1	**0.001**	**0.000 001**	=1 cubic centimeter
1 000	**1**	**0.001**	=1 cubic decimeter
1 000 000	**1000**	**1**	=1 cubic meter

LIQUID MEASURE

Liquid quarts	Gallons	Milliliters	Liters	Cubic inches	Cubic feet	Units
0. 000 065 104	0. 000 016 276	0. 061 610 2	0. 000 061 610 2	0. 003 759 77	0. 000 002 175 79	=1 minim
0.003 906 25	0. 000 976 562	3. 696 61	0. 003 696 61	0. 225 586	0. 000 130 547	=1 fluid dram
0.031 25	**0.007 812 5**	29. 5729	0. 029 572 9	1. 804 69	0. 001 044 38	=1 fluid ounce
0.125	**0.031 25**	118. 292	0. 118 292	**7.218 75**	0. 004 177 52	=1 gill
0.5	**0.125**	473. 166	0. 473 166	**28.875**	0. 016 710 1	=1 liquid pint
1	**0.25**	946. 332	0. 946 332	**57.75**	0. 033 420 1	=1 liquid quart
4	**1**	3785. 329	3. 785 329	**231**	0. 133 680 6	=1 gallon
0. 001 056 71	0. 000 264 178	**1**	**0.001**	0. 061 025 1	0. 000 035 315 4	=1 milliliter
1. 056 71	0. 264 178	**1000**	**1**	61. 025 1	0. 035 315 4	=1 liter
0. 017 316 0	0. 004 329 00	16. 3867	0. 016 386 7	**1**	0. 000 578 703 7	=1 cubic inch
29. 922 08	7. 480 519 5	28 316. 22	28. 316 22	**1728**	**1**	=1 cubic foot.

UNITS OF CAPACITY

Units	Dry pints	Dry quarts	Pecks	Bushels
1 dry pint =	**1**	**0.5**	**0.0625**	**0.015 625**
1 dry quart =	**2**	**1**	**0.125**	**0.031 25**
1 peck =	**16**	**8**	**1**	**0.25**
1 bushel =	**64**	**32**	**4**	**1**
1 liter =	1.816 21	0.908 103	0.113 513	0.028 378
1 dekaliter =	18.1621	9.081 03	1.135 13	0.283 78
1 cubic inch =	0.029 761 6	0.014 880 8	0.001 860 10	0.000 465 025
1 cubic foot =	51.428 093	25.714 047	3.214 255 8	0.803 563 95

UNITS OF MASS NOT GREATER

Units	Grains	Apothecaries scruples	Pennyweights	Avoirdupois drams	Apothecaries drams	Avoirdupois ounces
1 grain =	**1**	**0.05**	0.041 666 67	0.036 571 43	0.016 666 7	0.002 285 71
1 apoth. scruple =	**20**	**1**	0.833 333 3	0.731 428 6	0.333 333	0.045 714 3
1 pennyweight =	**24**	**1.2**	**1**	0.877 714 3	**0.4**	0.054 857 1
1 avdp. dram =	**27.343 75**	**1.367 187 5**	1.139 323	**1**	0.455 729 2	**0.0625**
1 apoth. dram =	**60**	**3**	**2.5**	2.194 286	**1**	0.137 142 9
1 avdp. oz. =	**437.5**	**21.875**	18.229 17	**16**	7.291 67	**1**
1 apoth. or troy oz. =	**480**	**24**	**20**	17.554 28	**8**	1.097 142 9
1 apoth. or troy lb. =	**5760**	**288**	**240**	210.6514	**96**	13.165 714
1 avdp. lb. =	**7000**	**350**	291.6667	**256**	116.6667	**16**
1 milligram =	0.015 432 356	0.000 771 618	0.000 643 014 8	0.000 564 383 3	0.000 257 205 9	0.000 035 273 96
1 gram =	15.432 356	0.771 618	0.643 014 85	0.564 383 3	0.257 205 9	0.035 273 96
1 kilogram =	15 432.356	771.6178	643.014 85	564.383 32	257.205 94	35.273 96

UNITS OF MASS NOT LESS

Units	Avoirdupois ounces	Avoirdupois pounds	Short hundred-weights	Short tons
1 avoirdupois ounce =	**1**	**0.0625**	**0.000 625**	**0.000 031 25**
1 avoirdupois pound =	**16**	**1**	**0.01**	**0.0005**
1 short hundredweight =	**1600**	**100**	**1**	**0.05**
1 short ton =	**32 000**	**2000**	**20**	**1**
1 long ton =	**35 840**	**2240**	**22.4**	**1.12**
1 kilogram =	35.273 957	2.204 622 34	0.022 046 223	0.001 102 311 2
1 metric ton =	35 273.957	2204.622 34	22.046 223	1.102 311 2

DRY MEASURE

Liters	Dekaliters	Cubic inches	Cubic feet	Units
0.550 598	0.055 059 8	**33.600 312 5**	0.019 444 63	=1 dry pint
1.101 197	0.110 119 7	**67.200 625**	0.038 889 25	=1 dry quart
8.809 57	0.880 957	**537.605**	0.311 114	=1 peck
35.2383	3.523 83	**2150.42**	1.244 456	=1 bushel
1	**0.1**	61.0251	0.035 315 4	=1 liter
10	**1**	610.251	0.353 154	=1 dekaliter
0.016 386 7	0.001 638 67	**1**	0.000 578 703 7	=1 cubic inch
28.316 22	2.831 622	**1728**	**1**	=1 cubic foot

THAN POUNDS AND KILOGRAMS

Apothecaries or troy ounces	Apothecaries or troy pounds	Avoirdupois pounds	Milligrams	Grams	Kilograms	Units
0.002 083 33	0.000 173 611 1	0.000 142 857 1	64.798 918	0.064 798 918	0.000 064 798 9	=1 grain
0.041 666 7	0.003 472 222	0.002 857 143	1295.9784	1.295 978 4	0.001 295 978	=1 apoth. scruple
0.05	0.004 166 667	0.003 428 571	1555.1740	1.555 174 0	0.001 555 174	=1 pennyweight
0.056 966 146	0.004 747 178 8	**0.003 906 25**	1771.8454	1.771 845 4	0.001 771 845	=1 avdp. dram
0.125	0.010 416 667	0.008 571 429	3887.9351	3.887 935 1	0.003 887 935	=1 apoth. dram
0.911 458 3	0.075 954 861	**0.0625**	28 349.527	28.349 527	0.028 349 53	=1 avdp. ounce
1	0.083 333 33	0.068 571 43	31 103.481	31.103 481	0.031 103 48	=1 apoth. or troy ounce
12	**1**	0.822 857 1	373 241.77	373.241 77	0.373 241 77	=1 apoth. or troy pound
14.583 333	1.215 277 8	**1**	**453 592.4277**	**453.592 4277**	**0.453 592 427 7**	=1 avdp. pound
0.000 032 150 74	0.000 002 679 23	0.000 002 204 62	**1**	**0.001**	**0.000 001**	=1 milligram
0.032 150 74	0.002 679 23	0.002 204 62	**1000**	**1**	**0.001**	=1 gram
32.150 742	2.679 228 5	2.204 622 341	**1 000 000**	**1000**	**1**	=1 kilogram

THAN AVOIRDUPOIS OUNCES

Long tons	Kilograms	Metric tons	Units
0.000 027 901 79	0.028 349 53	0.000 028 349 53	=1 avoirdupois ounce
0.000 446 428 6	**0.453 592 427 7**	0.000 453 592 43	=1 avoirdupois pound
0.044 642 86	45.359 243	0.045 359 243	=1 short hundredweight
0.892 857 1	907.184 86	0.907 184 86	=1 short ton
1	1016.047 04	1.016 047 04	=1 long ton
0.000 984 206 4	**1**	**0.001**	=1 kilogram
0.984 206 40	**1000**	**1**	=1 metric ton

5.5. Tables of Equivalents

When the name of a unit is enclosed in brackets (thus, [1 hand] ----), this indicates (1) that the unit is not in general current use in the United States, or (2) that the unit is believed to be based on "custom and usage" rather than on formal authoritative definition.

Equivalents involving decimals are, in most instances, rounded off to the third decimal place except where they are exact, in which cases these exact equivalents are so designated.

LENGTHS

1 angstrom (A)[g]	0.1 millimicron. 0.000 1 micron. 0.000 000 1 millimeter. 0.000 000 004 inch.
1 cable's length	120 fathoms. 720 feet. 219.456 meters.
1 centimeter (cm)	0.393 7 inch (exactly).
1 chain (ch) (Gunter's or surveyors)	66 feet. 20.117 meters.
[1 chain] (engineers)	100 feet. 30.480 meters.
1 decimeter (dm)	3.937 inches (exactly).
1 dekameter (dkm)	32.808 feet.
1 fathom	6 feet. 1.829 meters.
1 foot (ft)	0.305 meter.
1 furlong (fur.)	10 chains (surveyors). 660 feet. 220 yards. ⅛ statute mile. 201.168 meters.
[1 hand]	4 inches.
1 inch (in.)	2.540 centimeters.
1 kilometer (km)	0.621 mile.
1 league (land)	3 statute miles. 4 828 kilometers.
1 link (li) (Gunter's or surveyors)	7.92 inches (exactly). 0.201 meter.
[1 link (li) (engineers)]	1 foot. 0.305 meter.
1 meter (m)	39.37 inches (exactly). 1.094 yards.
1 micron (μ [the Greek letter mu])	0.001 millimeter (exactly). 0.000 039 37 inch (exactly).
1 mil	0.001 inch (exactly). 0. 025 4 millimeter.
1 mile (mi) (statute or land)	5 280 feet. 1.609 kilometers.
[1 mile (mi) (nautical, geographical, or sea, U. S.)] [h]	1.152 statute miles. 6 080.20 feet. 1.853 kilometers. 1.001 international nautical mile.
1 mile (mi) (nautical, international)[h]	1.852 kilometers (exactly). 1.151 statute miles. 0.999 U. S. nautical miles.
1 millimeter (mm)	0.039 37 inch (exactly).

[g] The angstrom is basically defined in terms of the wavelength of the red radiation of cadmium under specified conditions by the relation 1 wavelength=6 438.469 6 angstroms.

[h] The international nautical mile of 1 852 meters (6 076.103 33 . . . feet) was adopted effective July 1, 1954 for use in the United States. The value formerly used in the United States was 6 080.20 feet=1 nautical (geographieal or sea) mile

1 millimicron (mμ [the English letter m in combination with the Greek letter mu])	0.001 micron (exactly). 0.000 000 039 37 inch (exactly).
1 point (typography)	0.013 837 inch (exactly). 1/72 inch (approximately). 0.351 millimeter.
1 rod (rd), pole, or perch	16½ feet. 5½ yards. 5.029 meters.
1 yard (yd)	0.914 meter.

AREAS OR SURFACES

1 acre [i]	43 560 square feet. 4 840 square yards. 0.405 hectare.
1 are	119.596 square yards. 0.025 acre.
1 hectare	2.471 acres.
[1 square (building)]	100 square feet.
1 square centimeter (cm^2)	0.155 square inch.
1 square decimeter (dm^2)	15.500 square inches.
1 square foot (sq ft)	929.034 square centimeters.
1 square inch (sq in.)	6.452 square centimeters
1 square kilometer (km^2)	247.104 acres. 0.386 square mile.
1 square meter (m^2)	1.196 square yards. 10.764 square feet.
1 square mile (sq mi)	259.000 hectares.
1 square millimeter (mm^2)	0.002 square inch.
1 square rod (sq rd), sq pole, or sq perch	25.293 square meters.
1 square yard (sq yd)	0.836 square meter.

CAPACITIES OR VOLUMES

1 barrel (bbl), liquid	31 to 42 gallons.[j]
1 barrel (bbl), standard for fruits, vegetables, and other dry commodities except cranberries	7 056 cubic inches. 105 dry quarts. 3.281 bushels, struck measure.
1 barrel (bbl), standard, cranberry	5 826 cubic inches. 86 45/64 dry quarts. 2.709 bushels, struck measure.
1 bushel (bu) (U. S.) struck measure	2 150.42 cubic inches (exactly). 35.238 liters.
[1 bushel, heaped (U. S.)]	2 747.715 cubic inches. 1.278 bushels, struck measure.[k]
[1 bushel (bu) (British Imperial) (struck measure)]	1.032 U. S. bushels, struck measure. 2 219.36 cubic inches.
1 cord (cd) (firewood)	128 cubic feet.
1 cubic centimeter (cm^3)	0.061 cubic inch.
1 cubic decimeter (dm^3)	61.023 cubic inches.
1 cubic foot (cu ft)	7.481 gallons. 28.317 cubic decimeters.
1 cu inch (cu in.)	0.554 fluid ounce. 4.433 fluid drams. 16.387 cubic centimeters.
1 cubic meter (m^3)	1.308 cubic yards.
1 cubic yard (cu yd)	0.765 cubic meter.

[i] The question is often asked as to the length of a side of an acre of ground. An acre is a unit of area containing 43 560 square feet. It is not necessarily square, or even rectangular. But, if it is square then the length of a side is equal to $\sqrt{43\ 560}=208.710+$ feet.

[j] There are a variety of "barrels" established by law or usage. For example, Federal taxes on fermented liquors are based on a barrel of 31 gallons; many State laws fix the "barrel for liquids" as 31½ gallons; one State fixes a 36-gallon barrel for cistern measurement; Federal law recognizes a 40-gallon barrel for "proof spirits"; by custom, 42 gallons comprise a barrel of crude oil or petroleum products for statistical purposes, and this equivalent is recognized "for liquids" by four States.

[k] Frequently recognized as 1¼ bushels, struck measure.

1 cup, measuring	8 fluid ounces. ½ liquid pint.
1 dram, fluid (or liquid) (fl dr or f℥) (U. S.)	⅛ fluid ounce. 0.226 cubic inch. 3.697 milliliters. 1.041 British fluid drachms.
[1 drachm, fluid (fl dr) (British)]	0.961 U. S. fluid dram. 0.217 cubic inch. 3. 552 milliliters.
1 dekaliter (dkl)	2.642 gallons. 1.135 pecks.
1 gallon (gal) (U. S.)	231 cubic inches. 3.785 liters. 0.833 British gallon. 128 U. S. fluid ounces.
[1 gallon (gal) (British Imperial)]	277.42 cubic inches. 1.201 U. S. gallons. 4.546 liters. 160 British fluid ounces.
1 gill (gi)	7.219 cubic inches. 4 fluid ounces. 0.118 liter.
1 hectoliter (hl)	26.418 gallons. 2.838 bushels.
1 liter	1.057 liquid quarts. 0.908 dry quart. 61.025 cubic inches.
1 milliliter (ml)	0.271 fluid dram. 16.231 minims. 0.061 cubic inch.
1 ounce, fluid (or liquid) (fl oz or f℥) (U. S.)	1.805 cubic inches. 29.573 milliliters. 1.041 British fluid ounces.
[1 ounce, fluid (fl oz) (British)]	0.961 U. S. fluid ounce. 1.734 cubic inches. 28.412 milliliters.
1 peck (pk)	8.810 liters.
1 pint (pt), dry	33.600 cubic inches. 0.551 liter.
1 pint (pt), liquid	28.875 cubic inches (exactly). 0.473 liter.
1 quart (qt), dry (U. S.)	67.201 cubic inches. 1.101 liters. 0.969 British quart.
1 quart (qt), liquid (U. S.)	57.75 cubic inches (exactly). 0.946 liter. 0.833 British quart.
[1 quart (qt) (British)]	69.354 cubic inches. 1.032 U. S. dry quarts. 1.201 U. S. liquid quarts.
1 tablespoon	3 teaspoons.[1] 4 fluid drams. ½ fluid ounce.
1 teaspoon	⅓ tablespoon.[1] 1⅓ fluid drams.[1]
1 water ton (English)	270.91 U. S. gallons. 224 British Imperial gallons (exactly).

[1] The equivalent "1 teaspoon=1⅓ fluid drams" has been found by the Bureau to correspond more closely with the actual capacities of "measuring" and silver teaspoons than the equivalent "1 teaspoon=1 fluid dram," which is given by a number of dictionaries.

1 assay ton [m] (AT)	29.167 grams.
1 carat (c)	200 milligrams. 3.086 grains.
1 dram, apothecaries (dr ap or ƒʒ)	60 grains. 3.888 grams.
1 dram, avoirdupois (dr avdp)	$27^{11}/_{32}$ (=27.344) grains. 1.772 grams.
gamma, *see* microgram.	
1 grain	64.799 milligrams.
1 gram (g)	15.432 grains. 0.035 ounce, avoirdupois.
1 hundredweight, gross or long [n] (gross cwt)	112 pounds. 50.802 kilograms.
1 hundredweight, net or short (cwt or net cwt)	100 pounds. 45.359 kilograms.
1 kilogram (kg)	2.205 pounds.
1 microgram (μg [the Greek letter mu in combination with the letter g]) [o]	0.000 001 gram (exactly).
1 milligram (mg)	0.015 grain.
1 ounce, avoirdupois (oz avdp)	437.5 grains (exactly). 0.911 troy or apothecaries ounce. 28.350 grams.
1 ounce, troy or apothecaries (oz t or oz ap or ƒ℥)	480 grains. 1.097 avoirdupois ounces. 31.103 grams.
1 pennyweight (dwt)	1.555 grams.
1 point	0.01 carat. 2 milligrams.
1 pound, avoirdupois (lb avdp)	7 000 grains. 1.215 troy or apothecaries pounds. 453.592 grams.
1 pound, troy or apothecaries (lb t or lb ap)	5 760 grains. 0.823 avoirdupois pound. 373.242 grams.
1 scruple (s ap or ℈)	20 grains. 1.296 grams.
1 ton, gross or long [p]	2 240 pounds. 1.12 net tons (exactly). 1.016 metric tons.
1 ton, metric (t)	2 204.622 pounds. 0.984 gross ton. 1.102 net tons.
1 ton, net or short	2 000 pounds. 0.893 gross ton. 0.907 metric ton.

[m] Used in assaying. The assay ton bears the same relation to the milligram that a ton of 2 000 pounds avoirdupois bears to the ounce troy; hence the weight in milligrams of precious metal obtained from one assay ton of ore gives directly the number of troy ounces to the net ton.

[n] The gross or long ton and hundredweight are used commercially in the United States to only a very limited extent, usually in restricted industrial fields. These units are the same as the British "ton" and "hundredweight."

[o] The symbol γ [the Greek letter gamma] is also used.

[p] The gross or long ton and hundredweight are used commercially in the United States to a limited extent only, usually in restricted industrial fields. These units are the same as the British "ton" and "hundredweight."

WASHINGTON, May 31, 1955.

U. S. GOVERNMENT PRINTING OFFICE: 1956

SELECTED WEIGHTS AND MEASURES PUBLICATIONS OF THE NATIONAL BUREAU OF STANDARDS

NBS Handbook 37	Testing of Weighing Equipment	$1.25
NBS Handbook 44—2d Edition—1955	Specifications, Tolerances, and Regulations for Commercial Weighing and Measuring Devices	
	Bound	2.00
	Loose Leaf (does not include binder)	1.00
NBS Handbook 45	Testing of Measuring Equipment	1.50
NBS Circular 434	Testing of Glass Volumetric Apparatus	.15
NBS Circular 501	Federal and State Weights and Measures Laws	6.50
NBS Circular 540	Weights and Measures Case Reference Book	1.25
NBS Circular 547	Precision Laboratory Standards of Mass and Laboratory Weights—Section 1	.25
NBS Circular 572	Calibration of Line Standards of Length and Measuring Tapes at the National Bureau of Standards	(In press)
NBS Misc. Pub. 214	Units of Weight and Measure—Definitions and Tables of Equivalents	.40

AVAILABLE REPORTS OF THE NATIONAL CONFERENCE ON WEIGHTS AND MEASURES

1947	Miscellaneous Publication 189	40¢
1950	Miscellaneous Publication 199	50¢
1951	Miscellaneous Publication 202	50¢
1952	Miscellaneous Publication 206	40¢
1953	Miscellaneous Publication 209	40¢
1954	Miscellaneous Publication 212	50¢
1955	Miscellaneous Publication 216	70¢

Index to the Reports of the National Conference on Weights and Measures from the First to the Thirty-sixth, 1905 to 1951, Miscellaneous Publication 203 — 20¢

ORDER ALL PUBLICATIONS, WITH REMITTANCE, FROM THE SUPERINTENDENT OF DOCUMENTS, GOVERNMENT PRINTING OFFICE, WASHINGTON 25, D. C.

DEPARTMENT OF COMMERCE
UNITED STATES OF AMERICA