November 1985

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
GAITHERSBURG, MD 20899

LETTER CIRCULAR
LC 1035

UNITS AND SYSTEMS OF WEIGHTS AND MEASURES
THEIR ORIGIN, DEVELOPMENT, AND PRESENT STATUS

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 concerned with laws and regulations on the subject and with methods for verifying commercial weighing and measuring devices. But a vastly larger group of people is 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 material 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 herein in its basic sense of referring to measurements of length, mass, and capacity, thus excluding such topics as electrical and time 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.

2.1.1. UNITS AND STANDARDS.- It is essential that there be established and kept in mind the distinction between the terms "units" and "standards" of weights and measures.

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.

2.1.2. GENERAL SURVEY OF EARLY HISTORY OF WEIGHTS AND MEASURES. Weights and measures were among the earliest tools invented by man. Primitive societies needed rudimentary measures for many tasks: constructing dwellings of an appropriate size and shape, fashioning clothing, or bartering food or raw materials.

Man understandably turned first to parts of his body and his natural surroundings for measuring instruments. Early Babylonian and Egyptian records and the Bible indicate that length was first measured with the forearm, hand, or finger and that time was measured by the periods of the sun, moon, and other heavenly bodies. When it was necessary to compare the capacities of containers such as gourds or clay or metal vessels, they were filled with plant seeds which were then counted to measure the volumes. When means for weighing were invented, seeds and stones served as standards. For instance, the "carat," still used as a unit for gems, was derived from the carob seed.

Our present knowledge of early weights and measures comes from many sources. Some rather early standards have been recovered by archaeologists 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 of 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 Egyptian 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.

2.1.3. ORIGIN AND DEVELOPMENT OF SOME COMMON CUSTOMARY 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.

Units of length: The cubit was the first recorded unit used by ancient peoples to measure length. There were several cubits of different magnitudes that were used. The common cubit was the length of the forearm from the elbow to the tip of the middle finger. It was divided into the span of the hand (one-half cubit), the palm or width of the hand (one sixth), and the digit or width of a finger (one twenty-fourth). The Royal or Sacred Cubit, which was 7 palms or 28 digits long, was used in constructing buildings and monuments and in surveying. The inch, foot, and yard evolved from these units through a complicated transformation not yet fully understood. Some believe they evolved from cubic measures; others believe they were simple proportions or multiples of the cubit. In any case, the foot was inherited from the Egyptians by the Greeks and Romans.

The Roman foot was divided into both 12 unciae (inches) and 16 digits. The Romans also introduced the mile of 1 000* paces or double steps, the pace being equal to 5 Roman feet. The Roman mile of 5 000 feet was introduced into England during the occupation. Queen Elizabeth, who reigned from 1558 to 1603, changed by statute the mile to 5 280 feet or 8 furlongs, a furlong being 40 rods of 5-1/2 yards each.

The introduction of the use of the yard as a unit of length came later, but its origin is not definitely known. Some believe the origin is the double cubit, others believe that it originated from cubic measure. Regardless of its origin, the early yard was divided by the binary system into 2, 4, 8, and 16 parts called the half-yard, span, finger, and nail. The association of the yard with the "gird" or circumference of a person's waist or with the distance from the tip of the nose to the end of the thumb of Henry I are probably standardizing actions, since several yards were in use in Great Britain.

The point, which is a unit for measuring type, is recent. It originated with Pierre Simon Fournier in 1737. It was modified and developed by the Didot brothers, Francois Ambroise and Pierre Francois, in 1755. The point was first used in the United States in 1878 by a Chicago type foundry (Marder, Luse, and Company). Since 1886, a point is 0.013 837 inch, or about 1/72 inch.

Units of mass: The grain was the earliest unit of mass and is the smallest unit in the apothecary, avoirdupois, Tower, and Troy systems. The early unit was a grain of wheat or barleycorn used to weigh the precious metals silver and gold. Larger units preserved in stone standards were developed that were used as both units of mass and of monetary currency. The pound was derived from the mina used by ancient civilizations. A smaller unit was the shekel and a larger unit was the talent. The magnitude of these units varied from place to place. The Babylonians and Sumerians had a system in which there were 60 shekels in a mina and 60 minas in a talent. The Roman talent consisted of 100 libra (pound) which was smaller in magnitude than the mina. The Troy pound used in England and the United States for monetary purposes, like the Roman pound, was divided into 12 ounces, but the Roman uncia (ounce) was smaller. The carat is a unit for measuring gemstones that had its origin in the carob seed, which later was standardized at 1/144 ounce and then 0.2 gram.

Goods of commerce were originally traded by number or volume. When weighing of goods began, units of mass based on a volume of grain or water were developed. For example, the talent in some places was approximately equal to the mass of one cubic foot of water. Was this a coincidence or by design? The diverse magnitudes of units having the same name, which still appear today in our dry and liquid measures, could have arisen from the various commodities traded. The larger avoirdupois pound for goods of commerce might have been based on volume of water which has a higher bulk density than grain. For example, the Egyptian hon was a volume unit about 11 percent larger than a cubic palm and corresponded to one mina of water. It was almost identical in volume to the present U.S. pint.

---

* It should be noted that a space has been inserted instead of a comma in all of the numerical values given in this document, following a growing practice originating in tabular work to use the space to separate large numbers into groups of three digits. This practice avoids conflict with the practice of those countries that use the comma for a decimal marker.

The stone, quarter, hundredweight, and ton are larger units of mass still used in Great Britain. The present stone is 14 pounds, but an earlier unit appears to have been 16 pounds. The other units are multiples of 2, 8, and 160 times the stone, or 28, 112, and 2 240 pounds. The hundredweight is approximately equal to 2 talents. In the U.S. the ton of 2 240 pounds is known as the long ton. The short ton is equal to 2 000 pounds.

Units of time and angle: The division of the circle into 360 degrees and the day into hours, minutes, and seconds can be traced to the Babylonians who had a sexagesimal system of numbers. The 360 degrees may have been related to a year of 360 days.

2.2. THE METRIC SYSTEM.

2.2.1. DEFINITION, ORIGIN, AND DEVELOPMENT.- The metric system is the international 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 permissible throughout 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.

2.2.2. UNITS AND STANDARDS OF THE METRIC SYSTEM.- In the metric system the fundamental units of length and mass are the meter and the kilogram. The other units of length and mass, as well as all units of area, volume, and compound units such as density 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. In 1889, a new 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 was then 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. From 1960 to 1983 the meter was defined as the length equal to 1 650 763.73 wavelengths in vacuum of the radiation corresponding to the transition between the levels 2 p_{10} and 5 d_5 of the krypton 86 atom. Since 1983 the meter has been defined as the length of the path traveled by light in vacuum during a time interval of 1/299 792 458 of a second.

The kilogram previously defined as the mass of one cubic decimeter of water at the temperature of maximum density was known as the Kilogram of the Archives. It was replaced after the International Metric Convention in 1875 by the International Prototype Kilogram which became the unit of mass without reference to the mass of a cubic decimeter of water or to the Kilogram of the Archives. Each of the countries that 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. In 1964 the 12th General Conference on Weights and Measures redefined the liter as being one cubic decimeter. By its previous definition as being the volume occupied, under standard conditions, by a quantity of pure water having a mass of 1 kilogram, the liter was larger than the cubic decimeter 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 modernized metric system includes "base" units such, for example, as units of temperature and time, as well as many "derived" units such, for example, as units of force and work. For details, see NBS Special Publication 330 (latest edition), The International System of Units (SI) (available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402).

2.2.3. THE INTERNATIONAL BUREAU OF WEIGHTS AND MEASURES.- The International Bureau of Weights and Measures was established at Sevres, 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 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, photometry and radiometry, and ionizing radiations, 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.

2.2.4. 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 speed of light in vacuum and U.S. Prototype Kilogram No. 20 are recognized as the primary standards of length and mass for both the metric and the inch-pound 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, since 1893, the yard has been 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 inch-pound system.

From 1893 until 1959, the yard was defined as being equal exactly to 3600/3937 meter. In 1959 a small change was made in the definition of the yard to resolve discrepancies both in this country and abroad. Since 1959 the yard is defined as being equal exactly to 0.9144 meter; the new yard is shorter than the old yard by exactly two parts in a million. At the same time it was decided that any data expressed in feet derived from geodetic surveys within the U.S. would continue to bear the relationship as defined

in 1893 (one foot equals 1200/3937 meter). This foot is called the U.S. survey foot, while the foot defined in 1959 is called the international foot. Measurements expressed in U.S. statute miles, survey feet, rods, chains, links, or the squares thereof, and also acres should therefore be converted to the corresponding metric values by using pre-1959 conversion factors where more than five significant figure accuracy is involved.

In 1971 the National Bureau of Standards completed a three-year study of the impact of increasing worldwide metric use on the United States. The study ended with a report to the Congress entitled "A Metric America--A Decision Whose Time Has Come." In the last few years metric use has been increasing rapidly in the U.S., principally in the manufacturing and educational sectors. Public Law 93-380 enacted August 21, 1974, states that it is the policy of the United States to encourage educational agencies and institutions to prepare students to use the metric system of measurement with ease and facility as a part of the regular education program. On December 23, 1975, President Ford signed Public Law 94-168, the "Metric Conversion Act of 1975." This act declares a national policy to coordinate the increasing use of the metric system in the United States, and to establish a United States Metric Board to coordinate the voluntary conversion to the metric system. Since 1982 this function of the Board has been assumed by the Office of Metric Programs of the U.S. Department of Commerce.

2.3. BRITISH AND UNITED STATES SYSTEMS OF WEIGHTS AND MEASURES.- The implication is sometimes made that the customary system of weights and measures in the British Commonwealth countries and that in the United States are identical. It is true that the U.S. and the British inch are defined identically for scientific work, that they are identical in commercial usage, that a similar situation exists for the U.S. and the British pound, and that many relationships, such as 12 inches = 1 foot, 3 feet = 1 yard, and 1760 yards = 1 international 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 ^{o}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 ^{o}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 ^{o}F weighs about 8-1/3 pounds, or 133-1/3 avoirdupois ounces, and the U.S. gallon is equivalent to 4 x 32, or 128 fluid ounces.

1 U.S. fluid ounce	= 1.041 British fluid ounces.
1 British fluid ounce	= 0.961 U.S. fluid ounce.
1 U.S. gallon	= 0.833 British Imperial gallon.
1 British Imperial gallon	= 1.201 U.S. gallons.

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 4-3/8 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 their 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 3/32, 3/16, 1/8, 1/4, 3/8, 1/2, 3/4, 1, 1-1/2, and 3 inches, respectively, represent 1 foot full scale, as well as having a scale graduated in the usual manner to 1/16 inch; and (b) engineers, which are commonly subdivided to 10, 20, 30, 40, 50, and 60 parts to the inch.

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, gauge 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, thousandths, 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, AND CAPACITY

3.1. STANDARDS OF LENGTH.- The speed of light in vacuum is the international standard on which all length measurements are based.

The yard is defined* as follows:

1 yard = 0.914 4 meter

The inch is therefore exactly equal to 25.4 millimeters.

---

* See Federal Register for July 1, 1959. See also next to last paragraph of 2.2.4.

3.1.1. 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, precision gauge blocks, micrometers, and limit gauges. 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.

3.2. STANDARDS OF MASS.- The primary standard of mass for this country is United States Prototype Kilogram 20, which is a platinum-iridium cylinder 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. The avoirdupois pound is defined* in terms of the kilogram by the relation:

1 avoirdupois pound = 0.453 592 37 kilogram.

These changes in definition have not made any appreciable change in the 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 437 1/2 grains.

3.2.1. MASS AND WEIGHT.- The mass of a body is a measure of its inertial property. The weight of a body is used at times to designate its mass and at other times to designate a force that is related to gravitational attraction. These two concepts of weight are incompatible, and have therefore resulted in confusion. In this document as throughout the Weights and Measures community, the term "weight" is considered to be synonymous with mass.

Standards of mass (or "weights") are ordinarily calibrated and used on equal-arm balances. If two objects balance each other on an equal-arm balance, they have the same mass. What are balanced are the forces of gravity on the two objects. Even though the value of the acceleration of gravity, g, is different from location to location, because the two objects of equal mass will be affected in the same manner and by the same amount by any change in the value of g, the two objects will balance each other under any value of g.

* See Federal Register for July 1, 1959.

On a spring balance, however, the weight of a body is not balanced against the weight of another body. Instead, the force of gravity on the body is balanced by the restoring force of a spring. Therefore, if a very sensitive spring balance is used, the indicated mass of the 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.

3.2.2. 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 force of gravity on 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 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 of less mass 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 mass. For that reason, in assigning a precise numerical value of 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. By definition brass standards have a density of 8 400 kilograms per cubic meter at 0 ^{o}C and a coefficient of cubical thermal expansion of 0.000 054 per ^{o}C. Standard conditions are defined as air of 1.2 kilograms per cubic meter and temperature of 20 ^{o}C. The corrections to be used with precise analytical weights are ordinarily given only in terms of apparent mass against normal brass standards.

A full discussion of this topic is given in NBS Monograph 133, Mass and Mass Values, by Paul E. Pontius (for sale by the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161 (COM 7450309)).

3.2.3. TESTS OF STANDARDS OF MASS.- Standards of mass regularly used in ordinary trade should be tested by State or local weights and measures officials. The National Bureau of Standards calibrates mass standards submitted, but it does not manufacture or sell them. Information regarding the weight calibration service of the Bureau and the regulations governing the submission of weights to NBS for test are contained in NBS Special Publication 250, Calibration and Related Measurement Services of the National Bureau of Standards, latest edition.

3.3. STANDARDS OF CAPACITY.- Units of capacity, being derived units, are in this country defined in terms of linear units and 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 to 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.

3.3.1. 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.

3.4. MAINTENANCE AND PRESERVATION OF FUNDAMENTAL STANDARD OF MASS.There is considerable interest in the maintenance and preservation of the national standard of mass at the National Bureau of Standards. It is fully protected by an alarm system. During the regular working hours of the Bureau it can be viewed by those interested. All measurements made with this standard are conducted in special air-conditioned laboratories to which the standard is taken a sufficiently long time before the observations to ensure that the standard 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 standard at standard conditions, but care is taken to prevent large changes of temperature. More important is the care to prevent any damage to the standard because of careless handling.

4. SPECIALIZED USE OF WEIGHTS

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

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.

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 its 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 underlining. 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.

5.1. TABLES OF METRIC WEIGHTS AND MEASURES

In the metric system of weights and measures, designations of multiples and submultiples 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 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:

exa, (E), meaning 10^{18}	deci, (d), meaning 10^{-1}
peta, (P), meaning 10^{15}	centi, (c), meaning 10^{-2}
tera, (T), meaning 10^{12}	milli, (m), meaning 10^{-3}
giga, (G), meaning 10^{9}	micro, (μ), meaning 10^{-6}
mega, (M), meaning 10^{6}	nano, (n), meaning 10^{-9}
kilo, (k), meaning 10^{3}	pico, (p), meaning 10^{-12}
hecto, (h), meaning 10^{2}	femto, (f), meaning 10^{-15}
deka, (da), meaning 10^{1}	atto, (a), meaning 10^{-18}

Thus a kilometer is 1 000 meters and a millimeter is 0.001 meter.

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 (dam).
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).
100 square centimeters = 1 square decimeter (dm^2).
100 square decimeters = 1 square meter (m^2).
100 square meters = 1 square dekameter (dam^2) = 1 are.
100 square dekameters = 1 square hectometer (hm^2) = 1 hectare (ha),
100 square hectometers = 1 square kilometer (km^2).

General Tables

FLUID VOLUME MEASURE

10 milliliters (mL)	= 1 centiliter (cL).
10 centiliters	= 1 deciliter (dL) = 100 milliliters.
10 deciliters	= 1 liter* = 1 000 milliliters.
10 liters	= 1 dekaliter (daL).
10 dekaliters	= 1 hectoliter (hL) = 100 liters.
10 hectoliters	= 1 kiloliter (kL) = 1 000 liters.

SOLID VOLUME 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)
	= 1 000 000 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 (dag).
10 dekagrams	= 1 hectogram (hg) = 100 grams.
10 hectograms	= 1 kilogram (kg) = 1 000 grams.
1 000 kilograms	= 1 megagram (Mg) or 1 metric ton (t).

5.2. TABLES OF THE UNITED STATES CUSTOMARY WEIGHTS AND MEASURES

In these tables where foot or mile is underlined, it is survey foot or U.S. statute mile rather than international foot or mile that is meant (see Section 2.2.4.).

LINEAR MEASURE

12 inches (in)	= 1 foot (ft).
3 feet	= 1 yard (yd).
16-1/2 feet	= 1 rod (rd), pole, or perch.
40 rods	= 1 furlong (fur) = 660 feet.
8 furlongs	= 1 U.S. statute mile (mi) = 5 280 feet.
1 852 meters	= 6 076.115 49 feet (approximately)
	= 1 international nautical mile.

*By action of the 12th General Conference on Weights and Measures (1964) the liter is a special name for the cubic decimeter.

AREA MEASURE*

144 square inches (in^2)	= 1 square foot (ft^2).
9 square feet	= 1 square yard (yd^2)
	= 1 296 square inches.
272-1/4 square feet	= 1 square rod (sq rd).
160 square rods	= 1 acre = 43 560 square feet.
640 acres	= 1 square mile (mi^2).
1 mile square	= 1 section of land.
6 miles square	= 1 township
	= 36 sections = 36 square miles.

CUBIC MEASURE*

1 728 cubic inches (in^3)	= 1 cubic foot (ft^3).
27 cubic feet	= 1 cubic yard (yd^3).

GUNTER'S OR SURVEYORS CHAIN MEASURE

0.66 foot (ft)	= 1 link (li).
100 links	= 1 chain (ch)
	= 4 rods = 66 feet.
80 chains	= 1 U.S. statute mile (mi)
	= 320 rods = 5 280 feet.

LIQUID MEASURE**

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.

APOTHECARIES FLUID MEASURE

60 minims (min or ♏)	= 1 fluid dram (fl dr or ƒ℥)
	= 0.225 6 cubic inch.
8 fluid drams	= 1 fluid ounce (fl oz or ƒ℥)
	= 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.

*Squares and cubes of customary but not of metric units are sometimes expressed by the use of abbreviations rather than symbols. For example, sq ft means square foot, and cu ft means cubic foot.

**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.

DRY MEASURE*

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**

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

27-11/32 grains	= 1 dram (dr).	
16 drams	= 1 ounce (oz)	
	= 437-1/2 grains.	
16 ounces	= 1 pound (lb)	= 256 drams
		= 7 000 grains.
100 pounds	= 1 hundredweight (cwt).***	
20 hundredweights	= 1 ton	= 2 000 pounds.***

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

112 pounds	= 1 gross or long hundredweight.***	
20 gross or long hundredweights	= 1 gross or long ton	
	= 2 240 pounds.	

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.	

*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.

**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.

***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.

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.

5.3. NOTES ON BRITISH WEIGHTS AND MEASURES TABLES

In Great Britain, the yard, the avoirdupois pound, the troy pound, and the apothecaries pound are 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" 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.

5.4. TABLES OF WEIGHTS AND MEASURES

UNITS OF LENGTH INTERNATIONAL MEASURE*

Units	Inches	Feet	Yards	Miles	Centimeters	Meters
1 inch =	$\frac{1}{}$	0.083 333 33	0.027 777 78	0.000 015 782 83	$\frac{2.54}{}$	$\frac{0.025\ 4}{}$
1 foot =	$\frac{12}{}$	$\frac{1}{}$	0.333 333 3	0.000 189 393 9	$\frac{30.48}{}$	$\frac{0.304\ 8}{}$
1 yard =	$\frac{36}{}$	$\frac{3}{}$	$\frac{1}{}$	0.000 568 181 8	$\frac{91.44}{}$	$\frac{0.914\ 4}{}$
1 mile =	$\frac{63\ 360}{}$	$\frac{5280}{}$	$\frac{1760}{}$	$\frac{1}{}$	$\frac{160\ 934.4}{}$	$\frac{1609.344}{}$
1 centimeter =	0.393 700 8	0.032 808 40	0.010 936 13	0.000 006 213 712	$\frac{1}{100}$	$\frac{0.01}{}$
1 meter =	39.370 08	3.280 840	1.093 613	0.000 621 371 2		$\frac{1}{}$

UNITS OF LENGTH SURVEY MEASURE*

Units	Links	Feet	Rods	Chains	Miles	Meters
1 link =	$\frac{1}{}$	$\frac{0.66}{}$	$\frac{0.04}{}$	$\frac{0.01}{}$	$\frac{0.000\ 125}{}$	0.201 168 4
1 foot =	1.515 152	$\frac{1}{}$	0.060 606 06	0.015 151 52	0.000 189 393 9	0.304 800 6
1 rod =	$\frac{25}{}$	$\frac{16.5}{}$	$\frac{1}{}$	$\frac{0.25}{}$	$\frac{0.003\ 125}{}$	5.029 210
1 chain =	$\frac{100}{}$	$\frac{66}{}$	$\frac{4}{}$	$\frac{1}{}$	$\frac{0.0125}{}$	20.116 84
1 mile =	$\frac{8000}{}$	$\frac{5280}{}$	$\frac{320}{}$	$\frac{80}{}$	$\frac{1}{}$	1609.347
1 meter =	4.970 960	3.280 833	0.198 838 4	0.049 709 60	0.000 621 369 9	$\frac{1}{}$

*One international foot = 0.999 998 survey foot (exactly)
One international mile = 0.999 998 statute mile (exactly)

Note: 1 survey foot = 1200/3937 meter (exactly)
1 international foot = 12 x 0.0254 meter (exactly)
∴ 1 international foot = 0.0254 x 39.37 survey foot (exactly)

All underlined figures are exact.

UNITS OF AREA INTERNATIONAL MEASURE*

Units	Square Inches	Square Feet	Square Yards
1 square inch =	1	0.006 944 444	0.000 771 604 9
1 square foot =	144	1	0.111 111 1
1 square yard =	1296	9	1
1 square mile =	4 014 489 600	27 878 400	3 097 600
1 square centimeter =	0.155 000 3	0.001 076 391	0.000 119 599 0
1 square meter =	1550.003	10.763 91	1.195 990

Units	Square Miles	Square Centimeters	Square Meters
1 square inch =	0.000 000 000 249 097 7	6.451 6	0.000 645 16
1 square foot =	0.000 000 035 870 06	929.030 4	0.092 903 04
1 square yard =	0.000 000 322 830 6	8361.273 6	0.836 127 36
1 square mile =	1	25 899 881 103.36	2 589 988.110 336
1 square centimeter =	0.000 000 000 038 610 22	1	0.000 1
1 square meter =	0.000 000 386 102 2	10 000	1

UNITS OF AREA SURVEY MEASURE*

Units	Square Feet	Square Rods	Square Chains	Acres
1 square foot =	1	0.003 673 095	0.000 229 568 4	0.000 022 956 84
1 square rod =	272.25	1	0.062 5	0.006 25
1 square chain =	4 356	16	1	0.1
1 acre =	43 560	160	10	1
1 square mile =	27 878 400	102 400	6400	640
1 square meter =	10.763 87	0.039 536 70	0.002 471 044	0.000 247 104 4
1 hectare =	107 638.7	395.367 0	24.710 44	2.471 044

Units	Square Miles	Square Meters	Hectares
1 square foot =	0.000 000 035 870 06	0.092 903 41	0.000 009 290 341
1 square rod =	0.000 009 765 625	25.292 95	0.002 529 295
1 square chain =	0.000 156 25	404.687 3	0.040 468 73
1 ecre =	0.001 562 5	4 046.873	0.404 687 3
1 square mile =	1	2 589 998	258.999 8
1 square meter =	0.000 000 386 100 6	1	0.000 1
1 hectare =	0.003 861 006	10 000	1

*One square survev foot = 1.000 004 square international feet
One square statute mile = 1.000 004 square international miles

All underlined figures are exact.

General Tables

UNITS OF VOLUME

Units	Cubic Inches	Cubic Feet	Cubic Yards
1 cubic inch =	$\frac{1}{}$	0.000 578 703 7	0.000 021 433 47
1 cubic foot =	$\frac{1728}{}$	$\frac{1}{}$	0.037 037 04
1 cubic yard =	$\frac{46\ 656}{}$	$\frac{27}{}$	$\frac{1}{}$
1 cubic centimeter =	0.061 023 74	0.000 035 314 67	0.000 001 307 951
1 cubic decimeter =	61.023 74	0.035 314 67	0.001 307 951
1 cubic meter =	61 023.74	35.314 67	1.307 951

Units	Milliliters (Cubic Centimeters)	Liters (Cubic Decimeters)	Cubic Meters
1 cubic inch =	$\frac{16\ 387\ 064}{}$	$\frac{0.016\ 387\ 064}{}$	$\frac{0.000\ 016\ 387\ 064}{}$
1 cubic foot =	$\frac{28\ 316.846\ 592}{}$	$\frac{28.316\ 846\ 592}{}$	$\frac{0.028\ 316\ 846\ 592}{}$
1 cubic yard =	$\frac{764\ 554.857\ 984}{}$	$\frac{764.554\ 857\ 984}{}$	$\frac{0.764\ 554\ 857\ 984}{}$
1 cubic centimeter =	$\frac{1}{}$	$\frac{0.001}{}$	$\frac{0.000\ 001}{}$
1 cubic decimeter =	$\frac{1\ 000}{}$	$\frac{1}{}$	$\frac{0.001}{}$
1 cubic meter =	$\frac{1\ 000\ 000}{}$	$\frac{1000}{}$	$\frac{1}{}$

UNITS OF CAPACITY DRY MEASURE

Units	Dry Pints	Dry Quarts	Pecks	Bushels
1 dry pint =	$\frac{1}{}$	$\frac{0.5}{}$	$\frac{0.062\ 5}{}$	$\frac{0.015\ 625}{}$
1 dry quart =	$\frac{2}{}$	$\frac{1}{}$	$\frac{0.125}{}$	$\frac{0.031\ 25}{}$
1 peck =	$\frac{16}{}$	$\frac{8}{}$	$\frac{1}{}$	$\frac{0.25}{}$
1 bushel =	$\frac{64}{}$	$\frac{32}{}$	$\frac{4}{}$	$\frac{1}{}$
1 cubic inch =	0.029 761 6	0.014 880 8	0.001 860 10	0.000 465 025
1 cubic foot =	51.428 09	25.714 05	3.214 256	0.803 563 95
1 liter =	1.816 166	0.908 083 0	0.113 510 4	0.028 377 59
1 cubic meter =	1 816.166	908.083 0	113.510 4	28.377 59

Units	Cubic Inches	Cubic Feet	Liters	Cubic Meters
1 dry pint =	$\frac{33.600\ 312\ 5}{}$	0.019 444 63	0.550 610 5	0.000 550 610 5
1 dry quart =	$\frac{67.200\ 625}{}$	0.038 889 25	1.101 221	0.001 101 221
1 peck =	$\frac{537.605}{}$	0.311 114	8.809 768	0.008 809 768
1 bushel =	$\frac{2\ 150.42}{}$	1.244 456	35.239 07	0.035 239 07
1 cubic inch =	$\frac{1}{}$	0.000 578 703 7	0.016 387 06	0.000 016 387 06
1 cubic foot =	$\frac{1728}{}$	$\frac{1}{}$	28.316 85	0.028 316 85
1 liter =	61.023 74	0.035 314 67	$\frac{1}{}$	$\frac{0.001}{}$
1 cubic meter =	61 023.74	35.314 67	$\frac{1000}{}$	$\frac{1}{}$

All underlined figures are exact.

UNITS OF CAPACITY LIQUID MEASURE

Units	Minims	Fluid Drams	Fluid Ounces	Gills
1 minim =	$\frac{1}{}$	0.016 666 67	0.002 083 333	0.000 520 833 3
1 fluid dram =	$\frac{60}{}$	$\frac{1}{}$	$\frac{0.125}{}$	$\frac{0.031\ 25}{}$
1 fluid ounce =	$\frac{480}{}$	$\frac{8}{}$	$\frac{1}{}$	$\frac{0.25}{}$
1 gill =	$\frac{1920}{}$	$\frac{32}{}$	$\frac{4}{}$	$\frac{1}{}$
1 liquid pint =	$\frac{7680}{}$	$\frac{128}{}$	$\frac{16}{}$	$\frac{4}{}$
1 liquid quart =	$\frac{15\ 360}{}$	$\frac{256}{}$	$\frac{32}{}$	$\frac{8}{}$
1 gallon =	$\frac{61\ 440}{}$	$\frac{1024}{}$	$\frac{128}{}$	$\frac{32}{}$
1 cubic inch =	265.974 0	4.432 900	0.554 112 6	0.138 528 1
1 cubic foot =	459 603.1	7660.052	957.506 5	239.376 6
1 milliliter =	16.230 73	0.270 512 2	0.033 814 02	0.008 453 506
1 liter =	16 230.73	270.512 2	33.814 02	8.453 506

Units	Liquid Pints	Liquid Quarts	Gallons	Cubic Inches
1 minim =	0.000 130 208 3	0.000 065 104 17	0.000 016 276 04	0.003 759 766
1 fluid dram =	$\frac{0.007\ 812\ 5}{}$	$\frac{0.003\ 906\ 25}{}$	$\frac{0.000\ 976\ 562\ 5}{}$	0.225 585 94
1 fluid ounce =	$\frac{0.062\ 5}{}$	$\frac{0.031\ 25}{}$	$\frac{0.007\ 812\ 5}{}$	$\frac{1.804\ 687\ 5}{}$
1 gill =	$\frac{0.25}{}$	$\frac{0.125}{}$	$\frac{0.031\ 25}{}$	$\frac{7.218\ 75}{}$
1 liquid pint =	$\frac{1}{}$	$\frac{0.5}{}$	$\frac{0.125}{}$	$\frac{28.875}{}$
1 liquid quart =	$\frac{2}{}$	$\frac{1}{}$	$\frac{0.25}{}$	$\frac{37.75}{}$
1 gallon =	$\frac{8}{}$	$\frac{4}{}$	$\frac{1}{}$	$\frac{231}{}$
1 cubic inch =	0.034 632 03	0.017 316 02	0.004 329 004	$\frac{1}{}$
1 cubic foot =	59.844 16	29.922 08	7.480 519	$\frac{1728}{}$
1 milliliter =	0.002 113 376	0.001 056 688	0.000 264 172 1	0.061 023 74
1 liter =	2.113 376	1.056 688	0.264 172 1	61.023 74

Units	Cubic Feet	Milliliters	Liters
1 minim =	0.000 002 175 790	0.061 611 52	0.000 061 611 52
1 fluid dram =	0.000 130 547 4	3.696 691	0.003 696 691
1 fluid ounce =	0.001 044 379	29.573 53	0.029 573 53
1 gill =	0.004 177 517	118.294 1	0.118 294 1
1 liquid pint =	0.016 710 07	473.176 5	0.473 176 5
1 liquid quart =	0.033 420 14	946.352 9	0.946 352 9
1 gallon =	0.133 680 6	3785.412	3.785 412
1 cubic inch =	0.000 578 703 7	16.387 06	0.016 387 06
1 cubic foot =	$\frac{1}{}$	28 316.85	28.316 85
1 milliliter =	0.000 035 314 67	$\frac{1}{1000}$	$\frac{0.001}{}$
1 liter =	0.035 314 67		$\frac{1}{}$

All underlined figures are exact.

UNITS OF MASS NOT LESS THAN AVOIRDUPOIS OUNCES

Units	Avoirdupois Ounces	Avoirdupois Pounds	Short Hundred-weights	Short tons
1 avoirdupois ounce =	$\frac{1}{}$	$\frac{0.0625}{}$	$\frac{0.000\ 625}{}$	$\frac{0.000\ 031\ 25}{}$
1 avoirdupois pound =	$\frac{16}{}$	$\frac{1}{}$	$\frac{0.01}{}$	$\frac{0.000\ 5}{}$
1 short hundredweight =	$\frac{1\ 600}{}$	$\frac{100}{}$	$\frac{1}{}$	$\frac{0.05}{}$
1 short ton =	$\frac{32\ 000}{}$	$\frac{2\ 000}{}$	$\frac{20}{}$	$\frac{1}{}$
1 long ton =	$\frac{35\ 840}{}$	$\frac{2\ 240}{}$	$\frac{22.4}{}$	$\frac{1.12}{}$
1 kilogram =	35.273 96	2.204 623	0.022 046 23	0.001 102 311
1 metric ton =	35 273.96	2204.623	22.046 23	1.102 311

Units	Long Tons	Kilograms	Metric Tons
1 avoirdupois ounce =	0.000 027 901 79	$\frac{0.028\ 349\ 523\ 125}{}$	$\frac{0.000\ 028\ 349\ 523\ 125}{}$
1 avoirdupois pound =	0.000 446 428 6	$\frac{0.453\ 592\ 37}{}$	$\frac{0.000\ 453\ 592\ 37}{}$
1 short hundredweight =	0.044 642 86	$\frac{45.359\ 237}{}$	$\frac{0.045\ 359\ 237}{}$
1 short ton =	0.892 857 1	$\frac{907.184\ 74}{}$	$\frac{0.907\ 184\ 74}{}$
1 long ton =	$\frac{1}{}$	$\frac{1016.046\ 908\ 8}{}$	$\frac{1.016\ 046\ 908\ 8}{}$
1 kilogram =	0.000 984 206 5	$\frac{1}{}$	$\frac{0.001}{}$
1 metric ton =	0.984 206 5	$\frac{1\ 000}{}$	$\frac{1}{}$

All underlined figures are exact.

UNITS OF MASS NOT GREATER THAN POUNDS AND KILOGRAMS

Units	Grains	Apothecaries Scruples	Pennyweights	Avoirdupois Drams
1 grain =	1	0.05	0.041 666 67	0.036 571 43
1 apoth. scruple =	20	1	0.833 333 3	0.731 428 6
1 pennyweight =	24	1.2	1	0.877 714 3
1 avdp. dram =	27.343 75	1.367 187 5	1.139 323	1
1 apoth. dram =	60	3	2.5	2.194 286
1 avdp. ounce =	437.5	21.875	18.229 17	16
1 apoth. or troy ounce =	480	24	20	17.554 29
1 apoth. or troy pound =	5 760	288	240	210.651 4
1 avdp. pound =	7 000	350	291.666 7	256
1 milligram =	0.015 432 36	0.000 771 617 9	0.000 643 014 9	0.000 564 383 4
1 gram =	15.432 36	0.771 617 9	0.643 014 9	0.564 383 4
1 kilogram =	15432.36	771.617 9	643.014 9	564.383 4

Units	Apothecaries Drams	Avoirdupois Ounces	Apothecaries or Troy Ounces	Apothecaries or Troy Pounds
1 grain =	0.016 666 67	0.002 285 714	0.002 083 333	0.000 173 611 1
1 apoth. scruple =	0.333 333 3	0.045 714 29	0.041 666 67	0.003 472 222
1 pennyweight =	0.4	0.054 857 14	0.05	0.004 166 667
1 avdp. dram =	0.455 729 2	0.062 5	0.056 966 15	0.004 747 179
1 apoth. dram =	1	0.137 142 9	0.125	0.010 416 67
1 avdp. ounce =	7.291 667	1	0.911 458 3	0.075 954 86
1 apoth. or troy ounce =	8	1.097 143	1	0.083 333 333
1 apoth. or troy pound =	96	13.165 71	12	1
1 avdp. pound =	116.666 7	16	14.583 33	1.215 278
1 milligram =	0.000 257 206 0	0.000 035 273 96	0.000 032 150 75	0.000 002 679 229
1 gram =	0.257 206 0	0.035 273 96	0.032 150 75	0.002 679 229
1 kilogram =	257.206 0	35.273 96	32.150 75	2.679 229

Units	Avoirdupois Pounds	Milligrams	Grams	Kilograms
1 grain =	0.000 142 857 1	64.798 91	0.064 798 91	0.000 064 798 91
1 apoth. scruple =	0.002 857 143	1295.978 2	1.295 978 2	0.001 295 978 2
1 pennyweight =	0.003 428 571	1555.173 84	1.555 173 84	0.001 555 173 84
1 avdp. dram =	0.003 906 25	1771.846 195 312 5	1.771 845 195 312 5	0.001 771 845 195 312 5
1 apoth. dram =	0.008 571 429	3887 934 6	3.887 934 6	0.003 887 934 6
1 avdp. ounce =	0.062 5	28 349.523 125	28.349 523 125	0.028 349 523 125
1 apoth. or troy ounce =	0.068 571 43	31 103.476 8	31.103 476 8	0.031 103 476 8
1 apoth. or troy pound =	0.822 857 1	373 241.721 6	373.241 721 6	0.373 241 721 6
1 avdp. pound =	1	453 592.37	453 592 37	0.453 592 37
1 milligram =	0.000 002 204 623	1	0 001	0 000 001
1 gram =	0.002 204 623	1000	1	0.001
1 kilogram =	2.204 623	1 000 000	1 000	1

All underlined figures are exact.

5. TABLES OF EQUIVALENTS

In these tables it is necessary to differentiate between the "international foot" and the "survey foot" (see Section 2.2.4.); the survey foot is underlined.

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. The equivalents of the imprecise units "tablespoon" and "teaspoon" are rounded to the nearest milliliter.

LENGTHS

1 angstrom (Å)*	0.1 nanometer (exactly). 0.000 1 micrometer (exactly). 0.000 000 1 millimeter (exactly). 0.000 000 004 inch.
1 cable's length	120 fathoms (exactly). 720 feet (exactly). 219 meters.
1 centimeter (cm)	0.393 7 inch.
1 chain (ch) (Gunter's or surveyors)	66 feet (exactly). 20.116 8 meters.
1 decimeter (dm)	3.937 inches.
1 dekameter (dam)	32.808 feet.
1 fathom	6 feet (exactly). 1.828 8 meters.
1 foot (ft)	0.304 8 meter (exactly).
1 furlong (fur)	10 chains (surveyors) (exactly). 660 feet (exactly). 1/8 U.S. statute mile (exactly). 201.168 meters.
[1 hand]	4 inches.
1 inch (in)	2.54 centimeters (exactly).
1 kilometer (km)	0.621 mile.
1 league (land)	3 U.S. statute miles (exactly). 4.828 kilometers.
1 link (li) (Gunter's or surveyors)	0.66 foot (exactly). 0.201 168 meter.
1 meter (m)	39.37 inches. 1.094 yards.
1 micrometer	0.001 millimeter (exactly). 0.000 039 37 inch.

*The angstrom is basically defined as 10^{-10} meter.

1 mil	0.001 inch (exactly). 0.025 4 millimeter (exactly).
1 mile (mi) (U.S. statute)*	5 280 feet (exactly). 1.609 kilometers.
1 mile (mi) (international)	5 280 feet (exactly).
1 mile (mi) (international nautical)**	1.852 kilometers (exactly). 1.151 survey miles.
1 millimeter (mm)	0.039 37 inch.
1 nanometer (nm)	0.001 micrometer (exactly). 0.000 000 039 37 inch.
1 point (typography)	0.013 837 inch (exactly). 1/72 inch (approximately). 0.351 millimeter.
1 rod (rd), pole, or perch	16 1/2 feet (exactly). 5.029 2 meters.
1 yard (yd)	0.914 4 meter (exactly).

AREAS OR SURFACES

1 acre***	43 560 square feet (exactly). 0.405 hectare.
1 are	119.599 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 (ft^2)	929.030 square centimeters.
1 square inch (in^2)	6.451 6 square centimeters (exactly).
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 (mi^2)	258.999 hectares.
1 square millimeter (mm^2)	0.002 square inch.
1 square rod (rd^2), sq pole, or sq perch	25.293 square meters.
1 square yard (yd^2)	0.836 square meter.

*The term statute mile originated with Queen Elizabeth I who changed the definition of the mile from the Roman mile of 5000 feet to the statute mile of 5280 feet (see 2.1.3). The international mile and the U.S. statute mile differ by about 3 millimeters although both are defined as being equal to 5280 feet. The international mile is based on the international foot (0.3048 meter) whereas the U.S. statute mile is based on the survey foot (1200/3937 meter).

**The international nautical mile of 1 852 meters (6 076.115 49...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 (geographical or sea) mile.

***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.

CAPACITIES OR VOLUMES

1 barrel (bbl), liquid	31 to 42 gallons.*
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). 35.239 liters.
[1 bushel, heaped (U.S.)]	2 747.715 cubic inches. 1.278 bushels, struck measure.**
[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 (exactly).
1 cubic centimeter (cm^3)	0.061 cubic inch.
1 cubic decimeter (dm^3)	61.024 cubic inches.
1 cubic foot (ft^3)	7.481 gallons. 28.316 cubic decimeters.
1 cu inch (in^3)	0.554 fluid ounce. 4.433 fluid drams. 16.387 cubic centimeters.
1 cubic meter (m^3)	1.308 cubic yards.
1 cubic yard (yd^3)	0.765 cubic meter.
1 cup, measuring	8 fluid ounces (exactly). 237 milliliters. 1/2 liquid pint (exactly).
1 dekaliter (daL)	2.642 gallons. 1.135 pecks.
1 dram, fluid (or liquid) (fl dr or $\mathfrak{f}3$)(U.S.)	1/8 fluid ounce (exactly). 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.

*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 31-1/2 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.

**Frequently recognized as 1 1/4 bushels, struck measure.

1 gallon (gal) (U.S.)	231 cubic inches (exactly). 3.785 liters. 0.833 British gallon. 128 U.S. fluid ounces (exactly).
[1 gallon (gal) (British Imperial)]	277.42 cubic inches. 1.201 U.S. gallons. 4.546 liters. 160 British fluid ounces (exactly).
1 gill (gi)	7.219 cubic inches. 4 fluid ounces (exactly). 0.118 liter.
1 hectoliter (hL)	26.418 gallons. 2.838 bushels.
1 liter (1 cubic decimeter exactly)	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 $f\bar{3}$) (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, measuring	3 teaspoons (exactly). 15 milliliters 4 fluid drams. 1/2 fluid ounce (exactly).
1 teaspoon, measuring	1/3 tablespoon (exactly). 5 milliliters 1 1/3 fluid drams.*

*The equivalent "1 teaspoon = 1 1/3 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 water ton (English)	270.91 U.S. gallons. 224 British Imperial gallons (exactly).

WEIGHTS OR MASSES

1 assay ton* (AT)	29.167 grams.
1 carat (c)	200 milligrams (exactly). 3.086 grains.
1 dram, apothecaries (dr ap or ℥)	60 grains (exactly). 3.888 grams.
1 dram avoirdupois (dr avdp)	27-11/32 (= 27.344) grains. 1.772 grams.
1 gamma (γ)	1 microgram (exactly).
1 grain	64.798 91 milligrams (exactly).
1 gram (g)	15.432 grains. 0.035 ounce, avoirdupois.
1 hundredweight, gross or long** (gross cwt)	112 pounds (exactly). 50.802 kilograms.
1 hundredweight, net or short (cwt or net cwt)	100 pounds (exactly). 45.359 kilograms.
1 kilogram (kg)	2.205 pounds.
1 microgram (μg [the Greek letter mu in combination with the letter g])	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 ℥)	480 grains (exactly). 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 (exactly). 1.215 troy or apothecaries pounds. 453.592 37 grams (exactly).
1 pound, troy or apothecaries (lb t or lb ap)	5 760 grains (exactly). 0.823 avoirdupois pound. 373.242 grams.
1 scruple (s ap or ℈)	20 grains (exactly). 1.296 grams.

*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.

**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."

1 ton, gross or long*	2 240 pounds (exactly). 1.12 net tons (exactly). 1.016 metric tons.
1 ton, metric (t)	2 204.623 pounds. 0.984 gross ton. 1.102 net tons.
1 ton, net or short	2 000 pounds (exactly). 0.893 gross ton. 0.907 metric ton.

*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."

Prepared by: Lewis V. Judson
Office of Weights and Measures
National Bureau of Standards
1960

Revised by: Louis E. Barbrow
Office of Weights and Measures
National Bureau of Standards
1976 and 1985