A Brief **HISTORY** *of Measurement Systems*

WITH A CHART OF THE MODERN METRIC SYSTEM

"Weights and measures may be ranked among the necessaries of life to every individual of human society. They enter into the economical arrangements and daily concerns of every family. They are necessary to every occupation of human industry; to the distribution and security of every species of property; to every transaction of trade and commerce; to the labors of the husbandman; to the ingenuity of the artificer; to the studies of the philosopher; to the researches of the antiquarian, to the navigation of the mariner, and the marches of the soldier; to all the exchanges of peace, and all the operations of war. The knowledge of them, as in established use, is among the first elements of education, and is often learned by those who learn nothing else, not even to read and write. This knowledge is riveted in the memory by the habitual application of it to the employments of men throughout life."

JOHN QUINCY ADAMS
Report to the Congress, 1821

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, and 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 that were then counted to measure the volumes. With the development of scales as a means for weighing, seeds and stones served as standards. For instance, the "carat," still used as a mass unit for gems, is derived from the carob seed.

As societies evolved, measurements became more complex. The invention of numbering systems and the science of mathematics made it possible to create whole systems of measurement units suited to trade and commerce, land division, taxation, and scientific research. For these more sophisticated uses, it was necessary not only to weigh and measure more complex things -- it was also necessary to do it accurately time after time and in different places. However, with limited international exchange of goods and communication of ideas, it is not surprising that different systems for the same purpose developed and became established in different parts of the world -- even in different parts of the same country.

THE ENGLISH SYSTEM

The measurement system commonly used in the United States today is nearly the same as that brought by the colonists from England. These measures had their origins in a variety of cultures -- Babylonian, Egyptian, Roman, Anglo-Saxon, and Norman French. The ancient "digit," "palm," "span," and "cubit" units of length slowly lost preference to the length units "inch," "foot," and "yard."

Roman contributions include the use of 12 as a base number (the foot is divided into 12 inches) and the words from which we derive many of our present measurement unit names. For example, the 12 divisions of the Roman "pes," or foot, were called unciae. Our words "inch" and "ounce" are both derived from that Latin word.

The "yard" as a measure of length can be traced back to early Saxon kings. They wore a sash or girdle around the waist that could be removed and used as a convenient measuring device. The word "yard" comes from the Saxon word "gird" meaning the circumference of a person's waist.

Standardizing various units and combining them into loosely related systems of measurement units sometimes occurred in fascinating ways. Tradition holds that King Henry I decreed that a yard should be the distance from the tip of his nose to the end of his outstretched thumb. The length of a furlong (or furrow-long) was established by early Tudor rulers as 220 yards. This led Queen Elizabeth I to declare, in the 16th century, that henceforth the traditional Roman mile of 5000 feet would be replaced by one of 5280 feet, making the mile exactly eight furlongs and providing a convenient relationship between the furlong and the mile.

Thus, through royal edicts, England by the 18th century had achieved a greater degree of standardization than other European countries. The English units were well suited to commerce and trade because they had been developed and refined to meet commercial needs. Through English colonization and its dominance of world commerce during the 17th, 18th, and 19th centuries, the English system of measurement units became established in many parts of the world, including the American colonies.

However, standards still differed to an extent undesirable for commerce, even among the 13 American colonies. The need for greater uniformity led to clauses in the Articles of Confederation (ratified by the original colonies in 1781) and the Constitution of the United States (ratified in 1790) that gave Congress the power to fix uniform standards for weights and measures. Today, standards supplied to all the states by the National Institute of Standards and Technology assure uniformity throughout the country.

THE METRIC SYSTEM

The need for a single worldwide coordinated measurement system was recognized over 300 years ago. Gabriel Mouton, Vicar of St. Paul's Church in Lyons and an astronomer, proposed in 1670 a comprehensive decimal measurement system based on the length of one minute of arc of a great circle of the Earth. Mouton also proposed the swing length of a pendulum with a frequency of one beat per second as the unit of length. A pendulum with this beat would have been fairly easily reproducible, thus facilitating the widespread distribution of uniform standards. Other proposals were made, but more than a century elapsed before any action was taken.

In 1790, in the midst of the French Revolution, the National Assembly of France requested the French Academy of Sciences to "deduce an invariable standard for all the measures and all the weights."

The Commission appointed by the Academy created a system that was, at once, simple and scientific. The unit of length was to be a portion of the Earth's circumference. Measures for capacity (volume) and mass were to be derived from the unit of length, thus relating the basic units of the system to each other and to nature. Furthermore, larger and smaller multiples of each unit were to be created by multiplying or dividing the basic units by 10 and its powers. This feature provided a great convenience to users of the system, by eliminating the need for such calculations as dividing by 16 (to convert ounces to pounds) or by 12 (to convert inches to feet). Similar calculations in the metric system could be performed simply by shifting the decimal point. Thus, the metric system is a "base-10" or "decimal" system.

The Commission assigned the name mètre -- meter -- to the unit of length. This name was derived from the Greek word metron, meaning "a measure." The physical standard representing the meter was to be constructed so that it would equal one ten-millionth of the distance from the North Pole to the equator along the meridian running near Dunkirk in France and Barcelona in Spain.

The initial metric unit of mass, the "gram," was defined as the mass of one cubic centimeter (a cube that is 0.01 meter on each side) of water at its temperature of maximum density. The cubic decimeter (a cube 0.1 meter on each side) was chosen as the unit for capacity. The fluid volume measurement for the cubic decimeter was given the name "liter."

Although the metric system was not accepted with enthusiasm at first, adoption by other nations occurred steadily after France made its use compulsory in 1840. The standardized structure and decimal features of the metric system made it well suited for scientific and engineering work. Consequently, it is not surprising that the rapid spread of the system coincided with an age of rapid technological development. In the United States, by Act of Congress in 1866, it became "lawful throughout the United States of America to employ the weights and measures of the metric system in all contracts, dealings or court proceedings."

By the late 1860s, even better metric standards were needed to keep pace with scientific advances. In 1875, an international agreement, known as the Meter Convention, set up well-defined metric standards for length and mass and established permanent mechanisms to recommend and adopt further refinements in the metric system. This agreement, commonly called the "Treaty of the Meter" in the United States, was signed by 17 countries, including the United States. As a result of the Treaty, metric standards were constructed and distributed to each nation that ratified the Convention. Since 1893, the internationally adopted-to metric standards have served as the fundamental measurement standards of the United States.

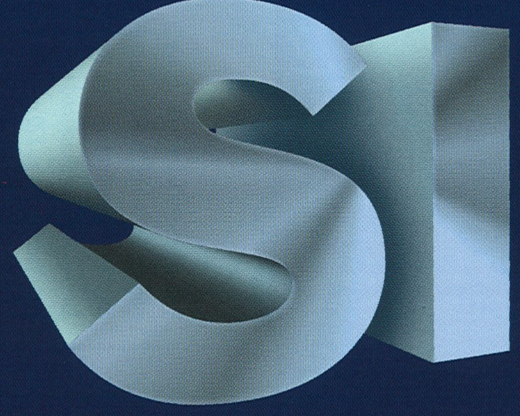
By 1900 a total of 35 nations -- including the major nations of continental Europe and most of South America -- had officially accepted the metric system.

In 1960, the General Conference on Weights and Measures, the diplomatic organization made up of the signatory nations to the Meter Convention, adopted an extensive revision and simplification of the system. Seven units -- the meter (for length), the kilogram (for mass), the second (for time), the ampere (for electric current), the kelvin (for thermodynamic temperature), the mole (for amount of substance), and the candela (for luminous intensity) -- were established as the base units for the system. The name Système International d'Unités (International System of Units), with the international abbreviation SI, was adopted for this modern metric system.

In 1971, the U.S. Secretary of Commerce, in transmitting to Congress the results of a 3-year study authorized by the Metric Study Act of 1968, recommended that the U.S. change to predominant use of the metric system through a coordinated 10-year national program. The Congress responded by enacting the Metric Conversion Act of 1975, calling for voluntary conversion. Amendments to the Act in 1988 designated the metric system as the "preferred system of weights and measures for United States trade and commerce."

Measurement science continues to develop more precise and easily reproducible ways of defining measurement units. The working organizations of the General Conference on Weights and Measures coordinate the exchange of information about the use and refinement of the metric system and make recommendations concerning improvements in the system and its related standards. The General Conference meets periodically to ratify improvements. Additions and improvements to SI were made by the General Conference in 1964, 1967-1968, 1971, 1975, 1979, 1983, 1991, and 1995.

NIST
U.S. DEPARTMENT OF COMMERCE
Technology Administration
National Institute of Standards and Technology



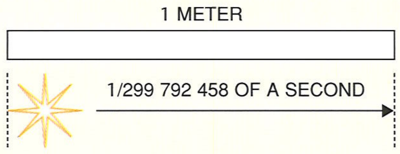
the modern metric system

The International System of Units (SI), the modern version of the metric system, is established by international agreement. It provides a logical and interconnected framework for all measurements in science, industry, and commerce. Officially abbreviated SI, the system is built upon a foundation of seven base units, shown on this chart along with their descriptions. All other SI units are derived from these units. Multiples and submultiples are expressed using a decimal system. Use of metric units was legalized in the United States in 1866. Since 1893 the yard and pound have been defined in terms of the meter and the kilogram. The base units for time, electric current, amount of substance, and luminous intensity are the same in both the inch-pound and metric systems.

length

METER m

The meter is the length of the path traveled by light in vacuum during a time interval of 1/299 792 458 of a second.

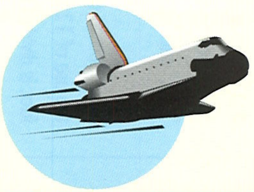


The SI unit of speed is the **meter per second** (m/s).

The speed of light in vacuum is 299 792 458 meters per second.

The SI unit of acceleration is the **meter per second per second** (m/s^2).

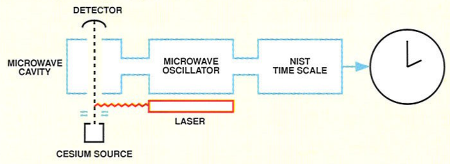
The SI unit of area is the **square meter** (m^2). The SI unit of volume is the **cubic meter** (m^3). The liter (1 cubic decimeter), although not an SI unit, is accepted for use with the SI and is commonly used to measure fluid volume.



time

SECOND s

The second is the duration of 9 192 631 770 cycles of the radiation associated with a specific transition of the cesium 133 atom. The second is realized by tuning an oscillator to the resonance frequency associated with the above definition. Just before entering a microwave cavity, cesium atoms are forced into the right atomic state by a laser beam. A detector registers a signal only when the oscillator delivers just the right frequency to the microwave cavity causing transitions and changing the state of the atoms. This change in state is sensed at the detector.



The number of periods or cycles per second is called frequency. The SI unit for frequency is the **hertz** (Hz). One hertz is the same as one cycle per second. Standard frequencies and the correct time are broadcast by radio stations WWV and WWVB in Colorado, and WWVH in Hawaii. NIST delivers digital timing signals by telephone and through the Internet.

COMMON CONVERSIONS
Accurate to Six Significant Figures

Symbol	When you know number of	Multiply by	To find number of	Symbol
in	inches	25.4[A]	millimeters[B]	mm
ft	feet	0.304 8[A]	meters	m
yd	yards	0.914 4[A]	meters	m
mi	miles	1.609 34	kilometers	km
yd^2	square yards	0.836 127	square meters	m^3
	acres	0.404 686	hectares	ha
yd^3	cubic yards	0.764 555	cubic meters	m^3
qt	quarts (lq)	0.946 353	liters	L
oz	ounces(avdp)	28.349 5	grams	g
lb	pounds(avdp)	0.453 592 37[A]	kilograms	kg
°F	degrees Fahrenheit	5/9[A] (after subtracting 32)	degrees Celsius	°C
mm	millimeters	0.039 370 1	inches	in
m	meters	3.280 84	feet	ft
m	meters	1.093 61	yards	yd
km	kilometers	0.621 371	miles	mi
m^2	square meters	1.195 99	square yards	yd^3
ha	hectares[C]	2.471 045	acres	
m^3	cubic meters	1.307 95	cubic yards	yd^3
L	liters	1.056 69	quarts (lq)	qt
g	grams	0.035 274 0	ounces (avdp)	oz
kg	kilograms	2.204 62	pounds (avdp)	lb
°C	degrees Celsius	9/5[A] (then add 32)	degrees Fahrenheit	°F

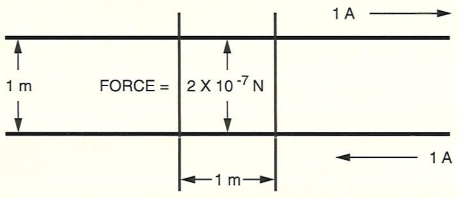
[A] exact
[B] for example: 1 in = 25.4 mm, so 3 inches would be (3 in)(25.4 $\frac{mm}{in}$) = 76.2 mm
Do not use more significant digits than justified by precision of original data.
[C] hectare is a common name for 10 000 square meters (1 hm^2)

Note: Most symbols are written with lower case letters; exceptions are L for liter and units named after persons for which the symbols are capitalized. Periods are not used with any symbols.

electric current

AMPERE A

The ampere is that current which, if maintained in each of two infinitely long parallel wires separated by one meter in free space, would produce a force between the two wires (due to their magnetic fields) of 2×10^{-7} newtons for each meter of length.



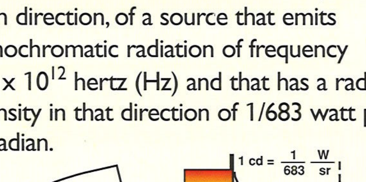
The SI unit of electric potential difference is the **volt** (V).
1 V = 1 W/A

The SI unit of electric resistance is the **ohm** (Ω).
1 Ω = 1 V/A

luminous intensity

CANDELA cd

The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz (Hz) and that has a radiant intensity in that direction of 1/683 watt per steradian.

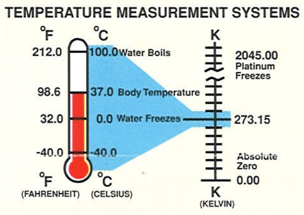


Radiation at frequencies other than 540×10^{12} Hz is also measured in candelas in accordance with the standard luminous efficiency, $V(\lambda)$, curve that peaks at 540×10^{12} Hz (yellow-green).

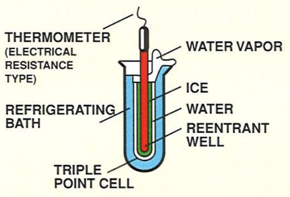
temperature

KELVIN K

The kelvin is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water. The temperature 0 K is commonly referred to as "absolute zero." On the widely used Celsius temperature scale, water freezes at 0 °C and boils at about 100 °C. One Celsius degree is an interval of 1 K, and zero degrees Celsius is 273.15 K. An interval of one Celsius degree corresponds to an interval of 1.8 Fahrenheit degrees on the Fahrenheit temperature scale.



The standard temperature at the triple point of water is provided by a special cell, an evacuated glass cylinder containing pure water. When the cell is cooled enough so that a mantle of ice forms around the reentrant well, the temperature at the interface of solid, liquid, and vapor is 273.16 K. Thermometers to be calibrated are placed in the reentrant well.



SI DERIVED UNITS WITH SPECIAL NAMES AND SYMBOLS

Derived quantity	Name	Symbol	Expression in terms of other SI units	Expression in terms of SI base units
plane angle	radian	rad		$m \cdot m^{-1} = 1$
solid angle	steradian	sr		$m^2 \cdot m^{-2} = 1$
frequency	hertz	Hz		s^{-1}
force	newton	N		$m \cdot kg \cdot s^{-2}$
pressure, stress	pascal	Pa	N/m^2	$m^{-1} \cdot kg \cdot s^{-2}$
energy, work,	joule	J	N·m	$m^2 \cdot kg \cdot s^{-2}$
power, radiant flux	watt	W	J/s	$m^2 \cdot kg \cdot s^{-3}$
electric charge	coulomb	C		s·A
electric potential difference	volt	V	W/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
capacitance	farad	F	C/V	$m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^2$
electric resistance	ohm	Ω	V/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$
electric conductance	siemens	S	A/V	$m^{-2} \cdot kg^{-1} \cdot s^3 \cdot A^2$
magnetic flux	weber	Wb	V·s	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$
magnetic flux density	tesla	T	Wb/m^2	$kg \cdot s^{-2} \cdot A^{-1}$
inductance	henry	H	Wb/A	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-2}$
Celsius temperature	degree Celsius	°C		K
luminous flux	lumen	lm	cd·sr	cd·sr
illuminance	lux	lx	lm/m^2	$m^{-2} \cdot cd \cdot sr$
radionuclide activity	becquerel	Bq		s^{-1}
absorbed dose	gray	Gy	J/kg	$m^2 \cdot s^{-2}$
dose equivalent	sievert	Sv	J/kg	$m^2 \cdot s^{-2}$

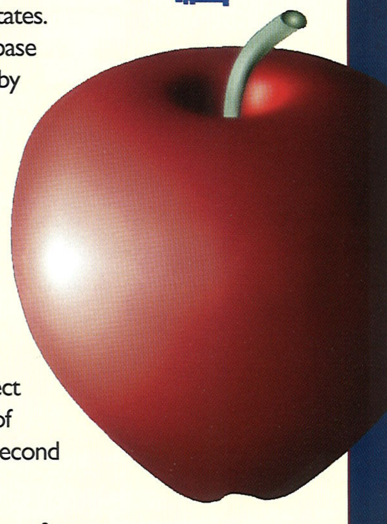
REFERENCES
NIST Special Publication 330, latest edition, "International System of Units (SI)," available by purchase from the Superintendent of Documents, U.S. Government Printing Office Mail Stop: SSOP, Washington, DC 20402-9328

IEEE/ASTM SI 10, latest edition, "Standard for Use of the International System of Units (SI): The Modern Metric System," available by purchase from:
IEEE, 345 East 47th Street, New York, NY 10017-2394
ASTM, 100 Bar Harbor Drive West Conshohocken, PA 19428-2959

mass

KILOGRAM kg

The standard for the unit of mass, the kilogram, is a cylinder of platinum-iridium alloy kept by the International Bureau of Weights and Measures near Paris. A duplicate in the custody of the National Institute of Standards and Technology serves as the mass standard for the United States. This is the only base unit still defined by an artifact.



The SI unit of force is the **newton** (N). One newton is a force that, applied to a one kilogram object, will give the object an acceleration of one meter per second per second.

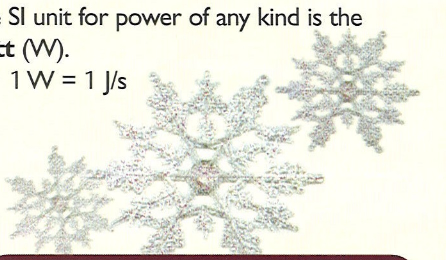
$1\ N = 1\ kg \cdot m/s^2$

The weight of an object is the force exerted on it by gravity. Gravity gives a mass a downward acceleration of about 9.8 m/s^2.

The SI unit for pressure is the **pascal** (Pa).
$1\ Pa = 1\ N/m^2$

The SI unit for work and energy of any kind is the **joule** (J).
1 J = 1 N·m

The SI unit for power of any kind is the **watt** (W).
1 W = 1 J/s



amount of substance

MOLE mol

The mole is the amount of substance of a system that contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12.

When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.

The SI unit of concentration (of amount of substance) is the **mole per cubic meter** (mol/m^3).

PREFIXES
May be Applied to All SI Units*

Multiples and Submultiples	Prefixes	Symbols
1000 000 000 000 000 000 000 000 = 10^{24}	yotta	Y
1000 000 000 000 000 000 000 = 10^{21}	zetta	Z
1000 000 000 000 000 000 = 10^{18}	exa	E
1000 000 000 000 000 = 10^{15}	peta	P
1000 000 000 000 = 10^{12}	tera	T
1000 000 000 = 10^{9}	giga	G
1000 000 = 10^{6}	mega	M
1000 = 10^{3}	kilo	k
100 = 10^{2}	hecto	h
10 = 10^{1}	deka	da
1 = 10^{0}		
0.1 = 10^{-1}	deci	d
0.01 = 10^{-2}	centi	c
0.001 = 10^{-3}	milli	m
0.000 001 = 10^{-6}	micro	µ
0.000 000 001 = 10^{-9}	nano	n
0.000 000 000 001 = 10^{-12}	pico	p
0.000 000 000 000 001 = 10^{-15}	femto	f
0.000 000 000 000 000 001 = 10^{-18}	atto	a
0.000 000 000 000 000 000 001 = 10^{-21}	zepto	z
0.000 000 000 000 000 000 000 001 = 10^{-24}	yocto	y

*apply to gram in case of mass

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