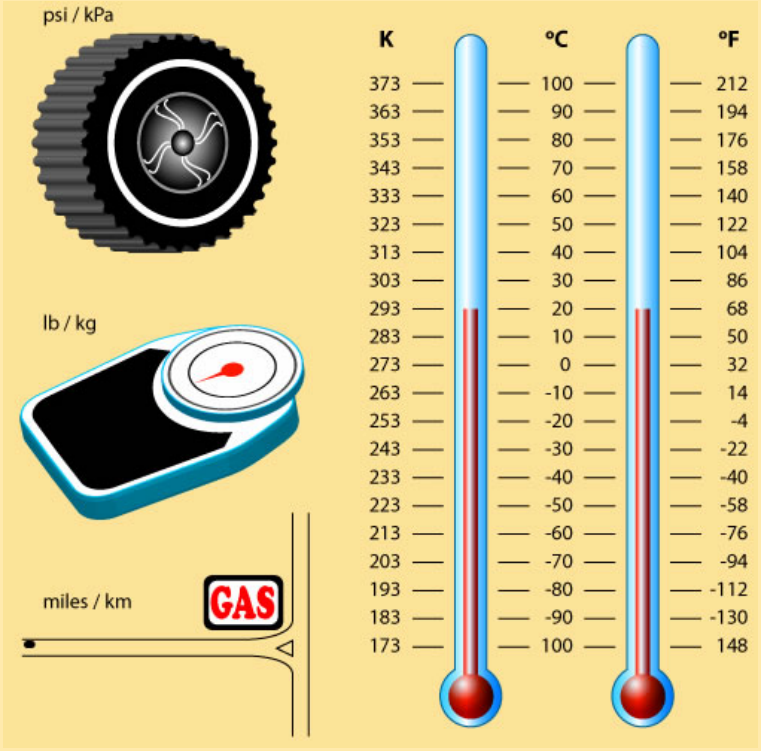
UNITS OF WEIGHTS AND MEASURES



Unit Overview

This unit provides information on the evolution of the current systems of weights and measures, and an overview of the International Standards of Units (SI) and metric system.

A strong foundation in weights and measure, an understanding of the units used in the metric system, and the ability to convert within the metric system and between systems is fundamental when working in micro and nanotechnologies. This information is needed in order to understand how MEMS (MicroElectroMechanical Systems) are used, how they work, how they are made, and how they are designed.

Objectives

- State two problems with the systems of weights and measures which led to the development of the metric system.
- Discuss the importance of an international standardized system of weights and measures.
- List the seven basic SI units of physical quantities.

What is a Unit of Weights and Measures?

When you think of "units" of weights and measures, what kind of "units" come to mind?

What is a Unit of Weights and Measure?

When you think of "units" of weights and measure, what do you think of?

- Feet, miles, meters
- Pounds, grams, kilograms
- Fahrenheit, centrigrade
- Feet per second, miles per hour
- Grams per cc^3

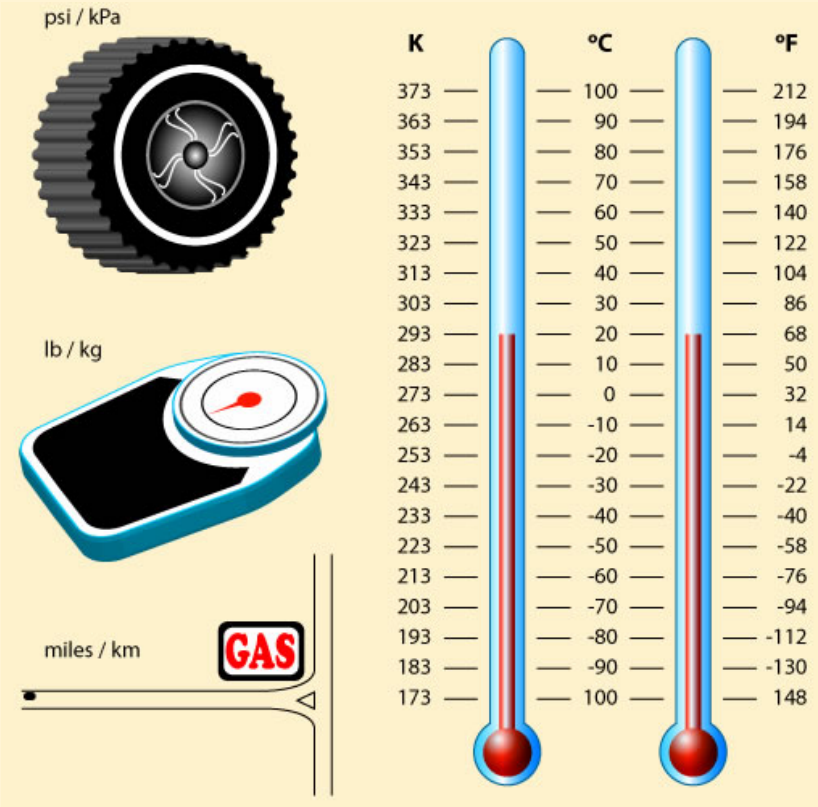
Are all of these units?

Introduction

A unit of measurement is a standardized quantity of a physical property: length, weight, time, temperature. Some of the first units were units of length, many of which were derived from the length of a body part.

Throughout history, the standards for units of weights and measures have continued to change creating the need for continuous conversion from one standard to another, one unit to another.

Today's a global standard is the International System of Units (SI), which is the current metric system.



Units for pressure, weight / mass, distance and temperature

First Units of Weights and Measures

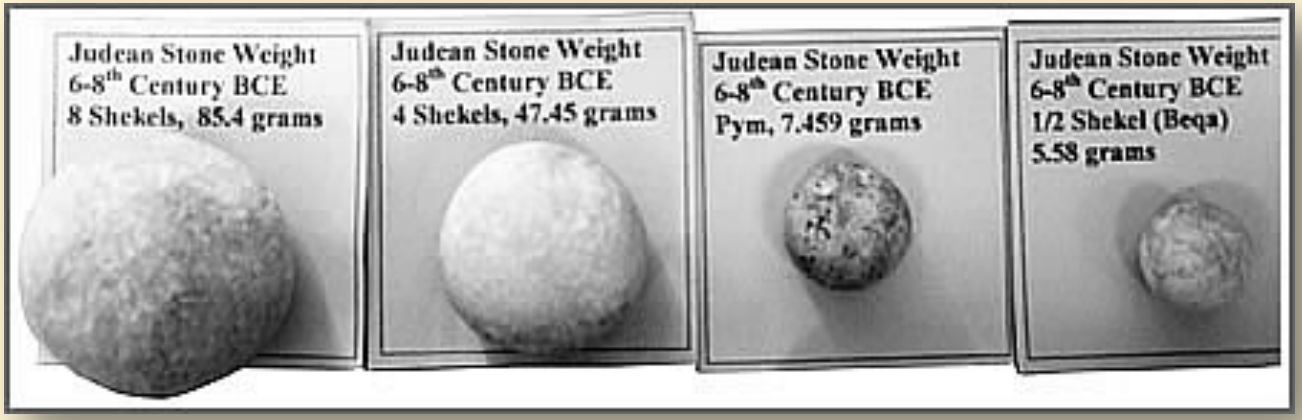
The cubit with close-up [Photo courtesy of and by Jon Bodsworth]

The earliest known units were developed in Egypt around 3000 BC. One of the first standardized units was the "cubit", the average length of a person's arm from the elbow to the outstretched fingertips (52.3 cm).

Grains of wheat and barley were used for weight measurements.

Over the centuries, the original units have been altered by different civilizations. For example, the original Royal Egyptian cubit was divided into 28 digits. Later it became 24 digits. The Roman cubit was 16 palms.

Commerce and Trade

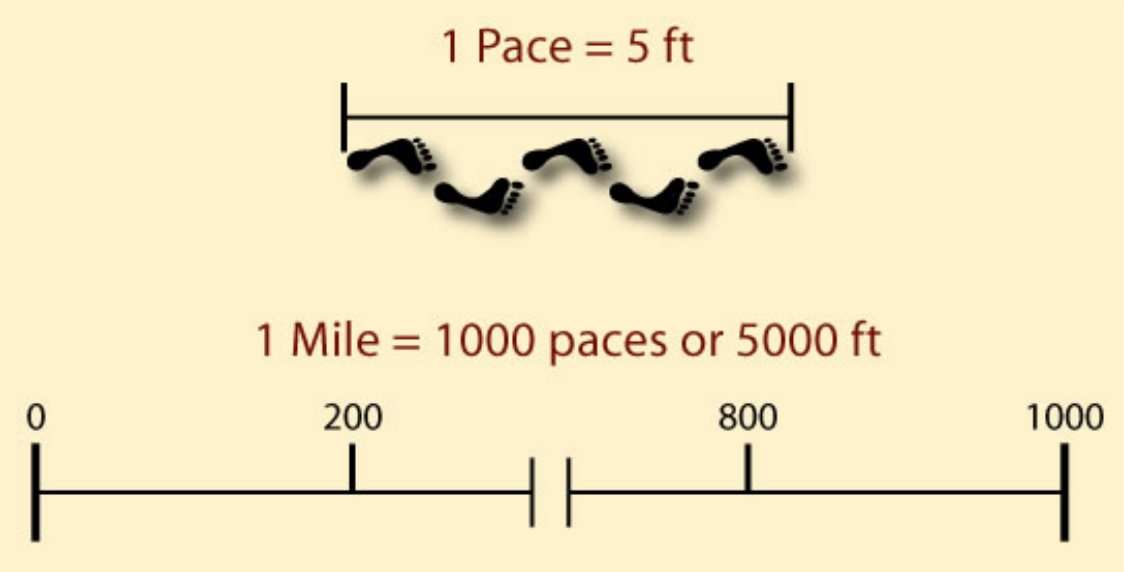


Ancient Stone Weight Standards (6 – 8th Century BC)
*[*From *Materials Evaluation*, Vol. 64, No. 10. Reprinted with permission of The American Society for Nondestructive Testing, Inc.*]*

As commerce and trade spread across countries, it became necessary to have more consistent representation of units.

Materials such as stone *(above)* and metal were used to produce exact units of weight and length, creating a standard for the trade market.

English Units of Measure



The Romans set the "pace" equal to five feet and the mile equal to 1000 paces or 5000 feet. In 1595, the Roman mile was changed 5280 feet.

English units of measurement, developed and standardized during the Roman Empire, divided both the foot and the pound into 12 equal parts. Both the Imperial System, used in the United Kingdom, and the US System were derived from the English units of weights and measures.

Systems of the US and UK

Through the years each country, the United States (US) and the United Kingdom (UK) working independently, continued to develop their respective standards for weights and measures. As a result, the differences between these two systems increased.

An example –

the US pint is defined as 16 ounces and the UK pint as 20 ounces.

The Origin of the Metric System

To complicate matters more,

- in 1790 the French Academy of Sciences was charged by the National Assembly of France to "deduce an invariable standard for all of the measures and all weights.“
- The outcome was the metric system.

The metric system attempted to reduce the existing conflicting and confusing units of measure to a few fundamental units.

Common multipliers (powers of 10) were developed to enable each unit to be expressed in larger and smaller quantities.

Treaty of the Meter

In Paris on May 20, 1875, an agreement referred to as the Treaty of the Meter was signed by 17 nations. Fifty-one nations have since signed this treaty, including all the major industrialized countries as well as the United States.

Two of the major outcomes of the Treaty of the Meter were

- the formation of the General Conference on Weights and Measures (CGPM), an intergovernmental treaty organization, and
- the creation of the International Bureau of Weights and Measures (BIPM).

International System of Units (SI)

At the 9th CGPM conference in 1948, the BIPM was instructed to conduct an international measurement requirements study of the scientific, technical, and educational communities.

The data from this study led to the adoption of the metric system as the International System of Units or Système International d'Unités (commonly referred to as *SI*) at the 11th CGPM conference in 1960.

The Seven Base Units of the SI

The SI replaces all traditional units of measurement (except for those used for time) with seven base units for seven physical quantities assumed to be mutually independent.

Physical Quantity	Unit of Measure	Unit Symbol
length	meter	m
mass	kilogram	k
temperature (absolute)	kelvin	K
amount of substance	mole	mol
electric current	ampere	A
luminous intensity	candela	cd
time	second	s

Derived Quantities

SI units derived from algebraic equations and the seven SI base units.

Derived quantity	**Name**	**Symbol**
area	square meter	m^2
volume	cubic meter	m^3
speed, velocity	meter per second	m/s
acceleration	meter per second squared	m/s^2
wave number	reciprocal meter	m^{-1}
mass density	kilogram per cubic meter	kg/m^3
specific volume	cubic meter per kilogram	m^3/kg
current density	ampere per square meter	A/m^2
magnetic field strength	ampere per meter	A/m
amount-of-substance concentration	mole per cubic meter	mol/m^3
luminance	candela per square meter	cd/m^2

Challenge

Write an algebraic equation for each of the following. Your answer should result in one of the derived units of the SI.

- The volume of a cube 3.5 m x 2 m x 6.3 m

- The speed of a car that traveled 88 km in 45 minutes

Challenge

Write an algebraic equation for each of the following. Your answer should result in one of the derived units of the SI.

- The volume of a cube 3.5 m x 2 m x 6.3 m
  - *Answer: 3.5 m x 2 m x 6.3 m = 44.1 m^3*

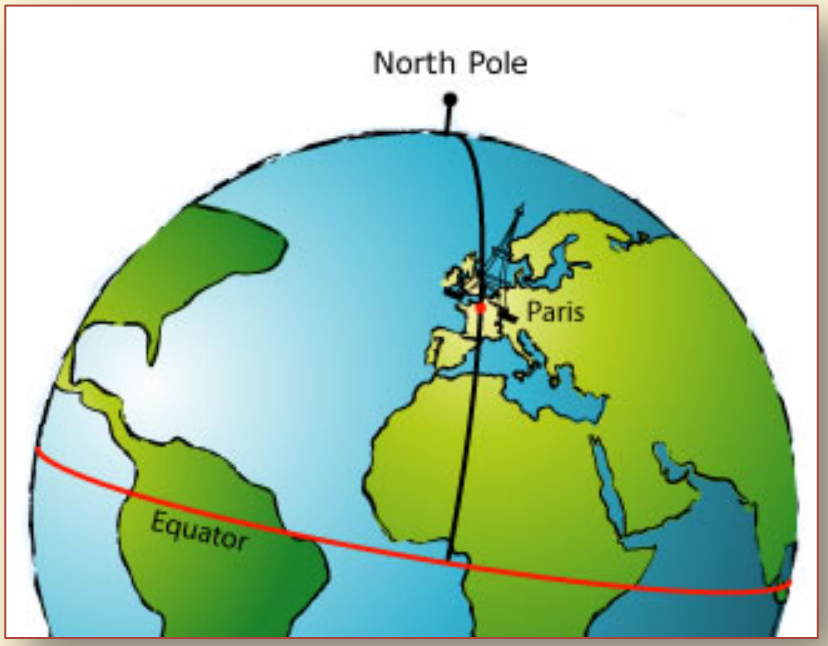
- The average speed of a car that traveled 88 km in 45 minutes in m/s?
  - *Answer: [88 km * (1000 m / 1km)] / [45 minutes *(60 s/1 minute)] = 32.6 m/s*

Defining the Seven Base Units

- As with most units of measurement, the official definitions for the seven base units of SI have changed through the years.
- The most current definitions are those established by the International Bureau of Weights and Measures (BIPM).
- These definitions and other aspects of SI are updated every four years at the CGPM.

The Meter

The meter was originally defined by the French Academy of Science as one ten-millionth (10^{-7}) of the distance from the equator to the North Pole. The meridian that was used was the one that goes through Paris. In 1983 the General Conference on Weights and Measures (CGPM), replaced this definition with the following:



Meridian used for the Original Meter Derivation

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 Kilogram

The kilogram was originally defined as “one thousand times the absolute weight of a volume of pure water equal to the cube of the hundredth part of a meter, and at the temperature of melting ice.” This was later changed to “the mass of a cubic decimeter of water at standard pressure and temperature.”

The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram.

Facsimile of the International Prototype of the kilogram [Photograph is reproduced with permission of the BIPM, which retains full internationally protected copyright.]

In 1889, the CGPM sanctioned the international prototype of the kilogram, and declared that "This prototype shall hence forth be considered to be the unit of mass."

SI Prefixes

Factor	Name	Symbol		Factor	Name	Symbol
10^{24}	yotta	Y		10^{-1}	deci	D
10^{21}	zetta	Z		10^{-2}	centi	C
10^{18}	exa	E		10^{-3}	milli	M
10^{15}	peta	P		10^{-6}	micro	μ
10^{12}	tera	T		10^{-9}	nano	N
10^{9}	giga	G		10^{-12}	pico	P
10^{6}	mega	M		10^{-15}	femto	F
10^{3}	kilo	K		10^{-18}	atto	A
10^{2}	hecto	H		10^{-21}	zepto	Z
10^{1}	deka	Da		10^{-24}	yocto	Y

Using the Prefixes

Examples of the prefixes with base units:

- 2000 meters = 2 kilometers or 2 km
- 0.005 meters = 5 millimeters or 5 mm
- 0.025 amperes = 25 milliamperes or 25 mA

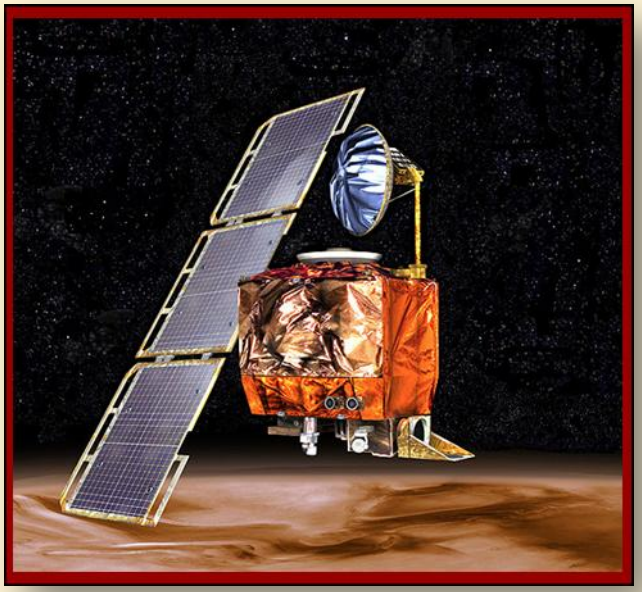
Since the kilogram already uses a prefix (kilo), smaller and larger values are based on the gram (10^0).

- 0.015 kilograms = 15×10^{-3} kg = 15 grams

Importance of a Standardized System

On September 23, 1999, NASA's Mars Climate Orbiter probe was lost after a 286-day journey. Upon its approach to Mars, the probe fired its engines to move into orbit. The firing brought it closer than planned to the planet's surface preventing the Orbiter's engines from functioning properly. The Orbiter fell deep into the planet's atmosphere and is believed to have burned up.

An investigation found that the loss of the $125 million Orbiter was due to the use of two different units of measurement. NASA used the metric system. The team that provided the thruster information used English units. No conversion was made when the data was entered into the computer.



Mars Climate Orbiter
[Created by and courtesy of NASA]

Food For Thought

Other than science and technologies, the US system of weights and measures is still used by the citizens of the United States. We still drive mph rather than km/hr. We still weigh ourselves in pounds rather than kilograms.

How do you feel about the United States' conversion to the SI?

What do you see as the biggest road block to converting to the SI?

Summary

- Since 3000 BC units of weights and measures have been derived, defined, redefined, replaced and evolved into an international quagmire.
- In 1790 the French Academy of Sciences developed the metric system.
- In 1960 the General Conference on Weights and Measures (CGPM) declared the modern metric system as the international standard of units (SI).

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