Units of Weights and Measures
Primary Knowledge (PK)
Instructor Guide

Note to Instructor

Units of Weights and Measure Learning Module is an introduction to units of weights and measures and is supported by two related activities and an assessment.

This learning module includes the following:
- Knowledge Probe (KP) or Pre-Quiz
- **Units of Weights and Measures Primary Knowledge (PK)**
- Research Activity
- Conversion Activity
- Final Assessment

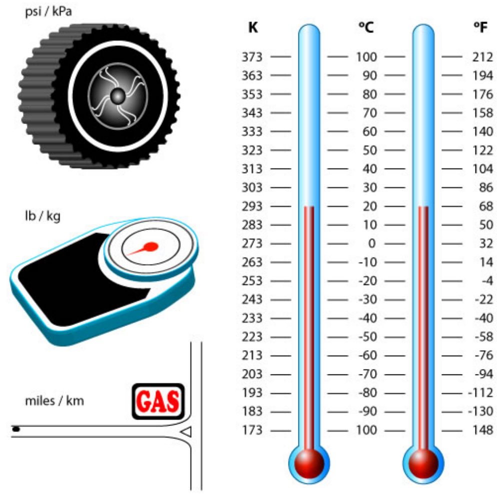
The companion Instructor Guide (IG) contains all of the information in the PG as well as answers to the coaching and review questions at the end of the unit.

Unit Description

This primary knowledge unit provides information on the evolution of the current systems of weights and measures and an overview of the International Standards of Units 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 with MEMS Technology. This information is needed in order to understand how MEMS are used, how they work, how they are made, how they are designed and how they are marketing.

<u>Estimated Time to Complete</u>
Allow approximately 30 minutes

Introduction



Units for pressure, weight / mass, distance and temperature

How many pounds of pressure do car tires require?
How much does the average person weigh?
What is the temperature?
How far is it to the nearest gas station?

What do all of these questions have in common?
All of the answers require a "unit of measurement".

A unit of measurement is a standardized quantity of a physical property, such as length, weight, time, and temperature. Some of the first units of measurement were units of length, many of which were derived from the length of a body part. For example, by 2500 BC the cubit was the standard unit for length. It was derived from the length of an average person's arm from the elbow to the outstretched fingertip.

Throughout history, the standards for units of weights and measures have continued to change. Different standards have been used by different countries and at times, within the same country. These factors have created the need for continuous conversion from one standard to another, from one unit to another. Today there is a global standard, the International System of Units (SI), which is the current metric system. As of 2007, the SI standard has been adopted by all but three countries: United States, Liberia, and Myanmar (Burma). It is universally recognized as the standard for science and technology. [1]

This unit will provide a brief history on units of weights and measures, and a review of the International System of Units (SI).

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.

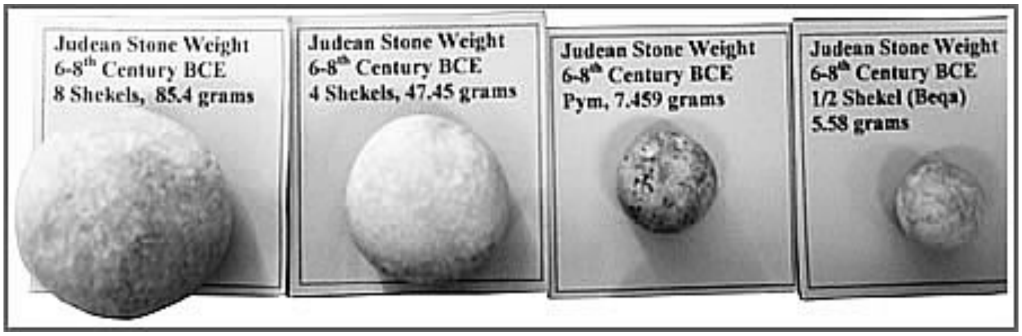
First Units of Weights and Measures

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

The earliest known units of weights and measures were developed in Egypt around 3000 BC. Most of these units were derived from the human body or the natural surroundings. One of the first standardized units was the "cubit". By 2500 BC the Egyptian cubit was standardized as the length of an average person's arm from the elbow to the outstretched fingertips (52.3 cm). The Egyptian shekel became the standard unit for weight. It was defined by 180 grains of barley corn (8.33 grams). Grains of wheat were also used for weight measurements. The conversion due to size differences was three barleycorns to four wheat grains.

Over the centuries, the original units of weights and measures were altered by different civilizations. The Royal Egyptian cubit (see figure), which was originally divided into 28 digits (the width of a finger), was later divided into 24 digits or 6 palms (width of the hand) of 4 digits. The Roman cubit was 16 palms. The number of grams in a shekel ranged from 8.5 to as high as 17 grams that is not surprising considering the fact that there are variations in weight among the grains of barleycorn. Subsequent units, such as the foot and pound, were eventually derived from these original units of length and weight.

Commerce and Trade



Ancient Stones used as Standards for various weights
[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 and metal were used to produce exact units of weight and length, creating a standard for the trade market. Larger quantities such as the yard, mile or pound were based on multiples of these smaller units.

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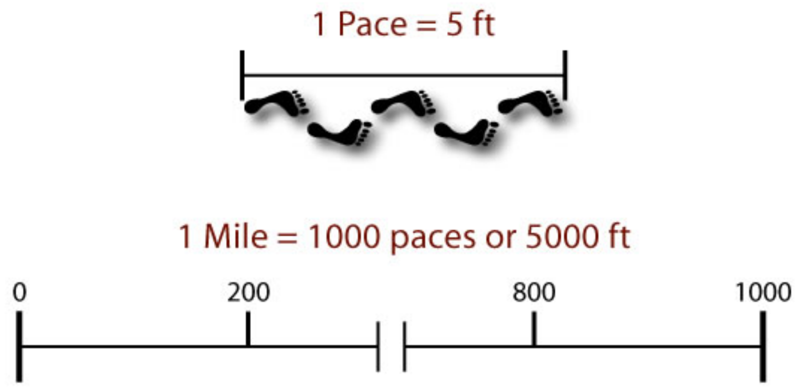
English Units of Measurements

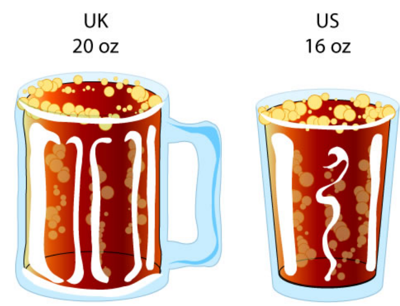


One Pace = 5 feet

The English units of measurement were derived from the base-12 system developed and standardized during the Roman Empire (510 BC – 476 AD). This system divided both the foot and the pound into 12 equal parts (inches and ounces). The Romans established the "pace" equal to five feet and the mile equal to 1000 paces or 5000 feet.[2] In 1595, under the reign of Queen Elizabeth I, the Roman mile was changed from 5000 feet to 5280 feet or 8 furlongs. (The furlong is equal to 220 yards. It was derived in the Middle Ages as a "furrow long," the length of a plowed strip of land in the English open field system). Both the Imperial System, used in the United Kingdom (UK), and the US System were derived from the English units of weights and measures.

Systems of the US and the 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. For example, the US pint was defined as 16 ounces and the UK pint as 20 ounces. The US wine-gallon was defined as 231 cubic inches and the UK wine-gallon as 277 cubic inches.



The Origin of the Metric System

To complicate matters even 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." [3] 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 (Convention du Mètre), 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. [3]

Two of the major outcomes of the Treaty of the Meter were the formation of the General Conference on Weights and Measures (CGPM, Conference Generale des Poids et Mesures), an intergovernmental treaty organization, and the creation of the International Bureau of Weights and Measures (BIPM, Bureau International des Poids et Mesures). The CGPM meets every four years and remains the basis of all international agreements on units of measurement.

International System of Units (SI)

Since the original metric system of 1791, several variations have evolved. Countries around the globe began replacing their traditional systems of weights and measures with the French metric system or slight variations of it.

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 International System of Units or Système International d'Unités (commonly referred to as *SI*) at the 11th CGPM conference in 1960.[3] All systems of weights and measures, metric and non-metric, are linked through a network of international agreements supporting the International System of Units (SI).

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. The table shows the basic units and the physical quantities they represent.

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

Table 1: Seven Base Units of SI

Derived Quantities

Other quantities, called **derived quantities**, are derived algebraically in terms of the seven base quantities. The SI units for these derived quantities are derived from these algebraic equations and the seven SI base units. The table shows some of these derived quantities.

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

Table 2: Derived Quantities of SI

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

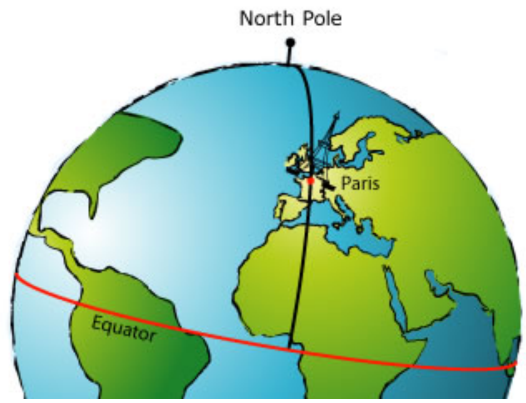
Defining the Seven Base Units

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:

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.[3]



Meridian used for the Original Meter Derivation

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 definition was later changed to the mass of a cubic decimeter of water at standard pressure and temperature. In 1889, the CGPM sanctioned the international prototype of the kilogram, made of platinum-iridium, and declared "This prototype shall hence forth be considered to be the unit of mass." This prototype is kept at the International Bureau of Weights and Measures (BIPM). In 1901, the CGPM redefined the kilogram:

The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram.[3]

To learn the historical derivation of the other base units of SI, complete the Unit of Weights and Measures Activity.

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

SI Prefixes

To represent smaller and larger quantities of the fundamental units, the SI established a system of prefixes based on powers of 10.

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

Table 3: SI Prefixes

Using the Prefixes

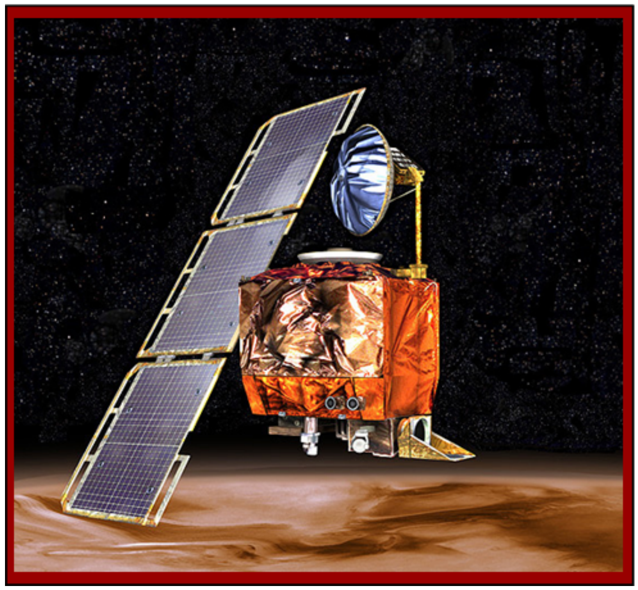
Examples of the prefixes with base units:

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 x 10^{-3} kg = 15 grams

Importance of a Standardized System[5]



Mars Climate Orbiter
[Created by and courtesy of NASA]

On September 23, 1999, NASA's Mars Climate Orbiter probe was lost after a 286-day journey to Mars. Upon its approach, the probe fired its engines to move into orbit. The firing brought it to within 60 km (36 miles) of the planet's surface. This was 100 km (60 miles) closer than planned and about 25 km (15 miles) beneath the level at which the Orbiter's engines could properly function. As a result, the probe's propulsion system overheated and was disabled. The Orbiter fell deep into the planet's atmosphere and possibly burned up, or "continued out beyond Mars and now could be orbiting the sun" (Frank O'Donnell, spokesperson for NASA's Jet Propulsion Laboratory).

After a thorough investigation it was discovered that the loss of the $125 million Orbiter was due to the use of two different units of measurement. NASA and other project teams used the metric system; however, one lone engineering team was using the English system. It was this team that provided the thruster information in English units of pound-force-seconds rather than the metric unit of Newton-second which was being used by the Orbiter programs. This simple unit of measurement resulted in a very costly mistake.

Summary

Since 3000 BC units of weights and measures have been derived, defined, redefined, replaced and evolved into an international quagmire. Through the years, this has created many problems with international communication and commerce. 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). The SI consists of seven fundamental units and additional derived units each of which use common multipliers (powers of 10) to represent smaller and larger quantities.

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 roadblock to converting to the SI?

References (You may need to cut and paste the URL into your browser.)

[1] The World Factbook. Appendix G – Weights and Measures. https://www.cia.gov/library/publications/the-world-factbook/appendix/appendix-g.html

[2] "Measurement: Wrestling the mother of all nonstandards", Kenneth Holladay. InTech: Control Fundamental. August 1998.

[3] The NIST Reference on Constants, Units, and Uncertainty. http://physics.nist.gov/cuu/Units/current.html

[4] Facsimile of the international prototype of the kilogram kept at the BIPM. http://www.bipm.org/en/scientific/mass/prototype.html

[5] Mars Climate Orbiter Website. https://solarsystem.nasa.gov/missions/mco/indepth

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