Units of Weights and Measures
Conversion Activity
Instructor Guide

Note to Instructor

Units of Weights and Measures Conversion Activity provides the participants with practice on converting units of weights and measures using both the metric and US systems. This activity can be assessed along with the Final Assessment.

Units of Weights and Measures Learning Module consists of 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 Post-Activity questions.

Description and Estimated Time to Complete

This activity provides process, examples, and practice for converting units of weights and measures. You will practice converting metric units to larger and smaller quantities and converting between metric and US units. This skill is vital to understanding almost every concept (design, fabrication, commercialization) associated with MEMS devices and components.

Estimated Time to Complete
Allow approximately 1 hour

Introduction

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 (abbreviated SI, after the French *Système International*), 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) [1]. It is universally recognized as the standard for science and technology.

This activity will provide examples and exercises for practicing conversion within the metric system and between the metric system and the US system of units.

Activity Objectives and Outcomes

<u>Activity Objectives</u>

- Convert at least three metric quantities to a larger or smaller quantity
- Convert at least three metric quantities to the US equivalents
- Convert at least three US units to the metric equivalents

<u>Activity Outcomes</u>

Upon completion of this activity you should be able to convert successfully within the metric system and between the metric and US systems.

Base Units of the Metric System

The following three tables can be used for this activity.

- Base Units of the Metric System
- Derived Quantities of the Metric System
- Metric Prefixes

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: Base Units of the Metric System

Derived Quantities of the Metric System

The derived quantities are derived algebraically from the 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

Table 2: Derived Quantities of the Metric System

Metric Prefixes

The metric prefixes are powers of ten and are used for all metric units when converting from smaller to larger quantities.

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: Metric Prefixes

Converting Units of Weights and Measures

$$\left(\frac{1yd}{3ft}\right)=1$$

$$346\cancel{ft}*\left(\frac{1yd}{3\cancel{ft}}\right)=\left(\frac{346yd}{3}\right)=115.3yd$$

$$25\cancel{yd}*\left(\frac{3ft}{1\cancel{yd}}\right)=(25*3ft)=75ft$$

Multiplication by "1"

Converting from one quantity to another of equal quantity in a different unit is easy as long as you remember this basic idea:

Multiplication by "1" or a fractional equivalent of 1 does not change the quantity.

A fraction is equal to "1" as long as the numerator and the denominator are of equal values. For example, 1 yard = 3 feet; therefore, using this equality as a fraction allows one to convert from yards to feet and feet to yards. The equations in "Multiplication by 1" show how to convert 346 ft to its equivalent in yds and 25 yds to its equivalent in ft.

Notice how the common units in the numerator and denominator cancel leaving the desired unit. When converting, if the cancellation of units does not yield the desired unit, then the fraction of 1 is set up incorrectly.

Metric to US equivalents

In order to convert between metric and the US system, you need to know the equivalents or conversion factor. The table "Metric and US Equivalents" provides some of the more common equivalents.

US Unit	**Metric Unit**
1 inch	2.54 centimeter
39.37 inches	1 meter
0.6 mile	1 kilometer
1.0567 quart	1 liter
1 pound	0.45 kilogram

Table 4: Metric and US Equivalents

Converting between Metric and the US System

$$\left(\frac{1in}{2.54cm}\right)=1$$

$$346\cancel{ft}*\left(\frac{12\cancel{in}}{1\cancel{ft}}\right)*\left(\frac{2.54cm}{1\cancel{in}}\right)=\left(\frac{346*12*2.54cm}{1}\right)=10546cm$$

$$\left(\frac{0.6mi}{1km}\right)=1$$

$$25\cancel{km}*\left(\frac{0.6mi}{1\cancel{km}}\right)=(25*0.6mi)=15mi$$

Converting between Systems

Following the same principle of "multiplication by 1 (or a fraction equal to 1)", one can easily convert from metric to US and from US to metric. Study the equations in "Converting between Systems". Notice that the equality 1 in = 2.54 cm is set up as a fraction equal to one. In the conversion equation, this fraction is set up so that the original unit cancels and leaves the desired unit.

Converting within Metric

$$\left(\frac{1m}{100cm}\right)=1$$

$$10546\cancel{cm}*\left(\frac{1m}{100\cancel{cm}}\right)=\left(\frac{10546m}{100}\right)=105.46m$$

$$\left(\frac{1km}{1000m}\right)=1$$

$$10546\cancel{cm}*\left(\frac{1\cancel{m}}{100\cancel{cm}}\right)*\left(\frac{1km}{1000\cancel{m}}\right)=0.10546km$$

Converting within Metric

To convert to larger or smaller quantities within the metric system, use the power of 10 for the respective metric prefix. You can apply the same system as demonstrated previously (setting up a fraction of 1). Study the equations in "Converting within Metric".

With practice, you can simply use the exponent of the desired prefix to know how many places to move the decimal point and in which direction. In the equations "Converting within Metric" 10546 cm was converted to meters and kilometers. Since the meter is 100 or 10^2 times larger than the cm, the decimal point moved *two places to the left* (10546 cm = 105.46 m). The kilometer is 10,000 or 10^5 times larger than the cm; therefore, the decimal point moved five places to the left (10546 cm = 0.10546 km).

When converting to a smaller quantity, the decimal point would move to the *right* the number of spaces defined by the power of ten. For example, 3 m is equal to 300 cm or 3,000 mm.

Conversion of Derived Quantities

$$\left(\frac{0.6mi}{1km}\right)=1$$

$$643\frac{\cancel{mi}}{hr}*\left(\frac{1km}{0.6\cancel{mi}}\right)=\left(\frac{643km}{0.6hr}\right)=1072\frac{km}{hr}$$

$$1072\frac{\cancel{km}}{\cancel{hr}}*\left(\frac{1000m}{1\cancel{km}}\right)*\left(\frac{1\cancel{hr}}{3600s}\right)=\frac{(1072*1000m)}{3600s}=297.8\frac{m}{s}$$

Conversion of Derived Quantities

Again, the same method applies when converting derived quantities. It also is used to convert derived quantities between systems, such as mph to km/hr or even to m/s. Study the equations in "Conversion of Derived Quantities." These equations convert 643 miles/hour to its equivalent in meters/second.

Activity: Units of Weights and Measures Conversion

Complete the Worksheet: Units of Weights and Measures Conversion for this activity. Show all of your conversion steps for each conversion.

Worksheet: Units of Weights and Measures Conversion (With Answers)

Description

Convert each of the following quantities to the unit(s) indicated. Show your work in the spaces provided.

1. **Convert 8,500 kg to lb**

   Solution

$$\left(\frac{1lb}{0.45kg}\right)=1$$

$$8{,}500kg*\left(\frac{1lb}{0.45kg}\right)=18{,}889lb$$

Answer: 18,889 lb

2. **Convert 889,300 m to mi**

   Solution

$$\left(\frac{1km}{0.6mi}\right)=1$$

$$889{,}300m*\left(\frac{1km}{1000m}\right)*\left(\frac{0.6mi}{1km}\right)=533.6mi$$

Answer: 533.6 mi

3. **Convert 9.25 km to m**

Solution

$$\left(\frac{1000m}{1km}\right)=1$$

$$9.25km*\left(\frac{1000m}{1km}\right)=9250m$$

Answer: 9250 m

4. **Convert 31.5 gal to liters**

Solution

$$\left(\frac{1.0567qt}{1liter}\right)=1$$

$$31.5gal*\left(\frac{4qt}{1gal}\right)*\left(\frac{1liter}{1.0567qt}\right)=119.24liters$$

Answer: 119.24 liters

5. **Convert 55 oz to kg**

Solution

$$\left(\frac{1lb}{0.45kg}\right)=1$$

$$55oz*\left(\frac{1lb}{16oz}\right)*\left(\frac{0.45kg}{1lb}\right)=1.55kg$$

Answer: 1.55kg

6. **Convert 925 km/h to mph**

   Solution

$$\left(\frac{0.6mi}{1km}\right)=1$$

$$925\frac{km}{h}*\left(\frac{0.6mi}{1km}\right)=555mph$$

Answer: 555 mph

7. **Convert 35 km/h to m/s**

   Solution

$$35\frac{km}{h}*\left(\frac{1h}{3600s}\right)*\left(\frac{1000m}{1km}\right)=9.72\frac{m}{s}$$

Answer: 9.72 m/s

8. **Convert 11,500 cm to km**

   Solution

$$\left(\frac{1m}{100cm}\right)=1$$

$$11{,}500cm*\left(\frac{1m}{100cm}\right)*\left(\frac{1km}{1000m}\right)=0.115km$$

Answer: 0.115 km

9. **Convert 628 in^2 to m^2**

Solution

$$\left(\frac{6.45cm^2}{1in^2}\right)=1$$

$$\left(\frac{10{,}000cm^2}{1m^2}\right)=1$$

$$628in^2 * \left(\frac{6.45cm^2}{1in^2}\right) * \left(\frac{1m^2}{10{,}000cm^2}\right)=0.405m^2$$

Answer: 0.405 m^2

10. **Convert 47 lbs/in^3 to kg/m^3**

Solution

$$\left(\frac{16.4cm^3}{1in^3}\right)=1$$

$$\left(\frac{100cm}{1m}\right)^3=1$$

$$47\frac{lbs}{in^3} * \left(\frac{1in^3}{16.4cm^3}\right) * \left(\frac{100^3cm^3}{1m^3}\right) * \left(\frac{0.45kg}{1lb}\right)=1{,}289{,}634\frac{kg}{m^3}$$

Answer: 1,289,634 kg/m^3

MEMS Applications

11. Hydrophobic (water fearing) coatings are deposited on microdevices to keep water from adhering to the device surface. These coatings are called "thin films" because they have microscopic thicknesses. An engineer has set up a process to deposit 50 angstroms (Å) of this coating with a tolerance specification of ±10 Å. In other words, the thickness specification is 50 ±10 Å. You are a metrology (measurement) technician that works with a thin film measurement tool set up to measure in nanometers.

What is the thin film specification in nanometers? Answer: 5.0 ± 1.0 nm

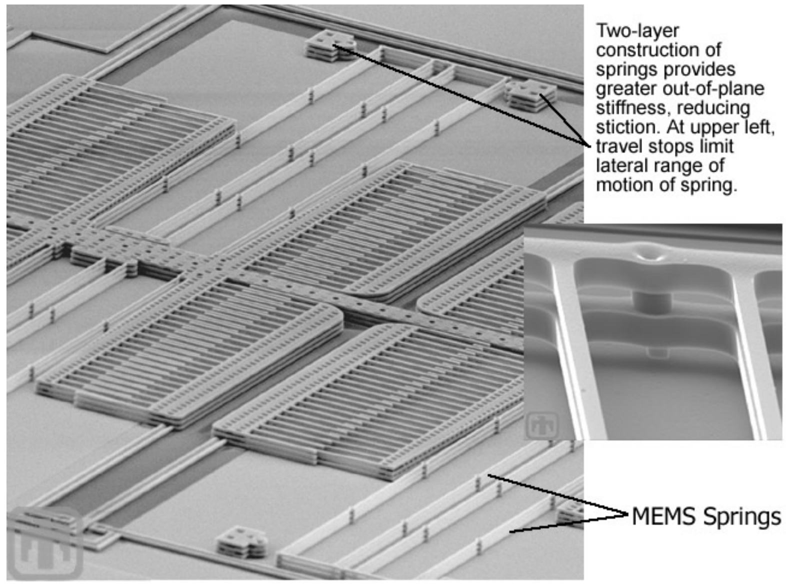
<u>Solution</u>
1 µm = 10,000 Å or 1 nm = 10 Å

$$50\text{Å} * \frac{1\ nm}{10\ \text{Å}} = 5\ nm$$

$$10\text{Å} * \frac{1\ nm}{10\ \text{Å}} = 1\ nm$$

Answer: 5.0 nm ± 1.0 nm

12. A particular MEMS device includes a thin spring. It is very important for that spring to have a consistent width from device to device. If the spring is too wide, it will be too stiff and if it is too narrow, it will be too compliant. Below is an image from a scanning electron microscope (SEM) of a MEMS comb drive and its springs (in the center). The springs provide the restoring force, returning the electrostatic comb teeth to their original position. The detail on the right shows a close-up of the two layer springs.



MEMS Comb Drive and Springs [Image source and text courtesy of Sandia National Laboratories. http://mems.sandia.gov/gallery/images_microengines.html]

You are a technician that works with a scanning electron microscope (SEM) which measures in nanometers. The engineering specifications are 0.55 ± 0.07um in width. The SEM indicates the spring's width to be 610nm. Does the measurement pass? (Show your work)

<u>Solution</u>

Determine specification range in microns (µm)

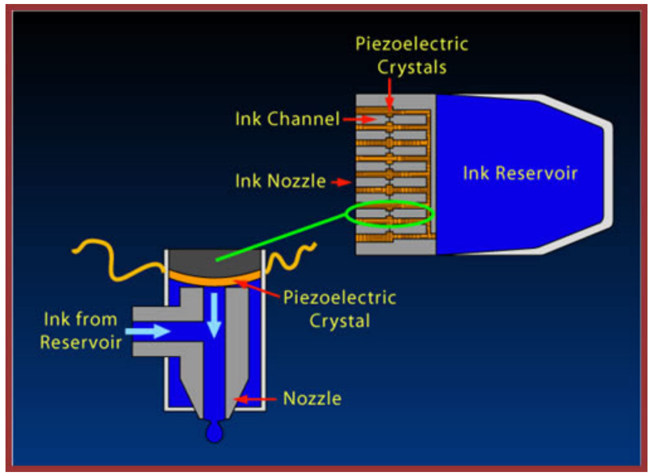
Specification Range = 0.480 µm to 0.620 µm

Convert 610 nm to microns: $610\ nm * \frac{1\ \mu m}{1000\ nm} = 0.610\ \mu m$

Answer: Yes, 0.610 µm is within specification; it is between 0.480 and 0.620 um

13. An inkjet print nozzle and pump system can produce 5 picoliter (pL) droplets.

The graphic shows a inkjet print head with a close-up of a nozzle. This particular nozzle uses a piezoelectric crystal that moves up and down acting as a "pump" pulling ink from the reservoir and pushing it through the nozzle.



a. A 1 milliliter (ml) eyedropper typically produces a 0.05 milliliter droplet or 20 drops. How many inkjet droplets are in a 1 milliliter eyedropper?

Solution

$$\frac{1\ x 10^{-3}}{5\ x\ 10^{-12}} = 0.2\ x\ 10^{9} = 200\ million\ droplets$$

Answer: 200 million droplets

b. If the inkjet nozzle/pump can print out 10,000, 5pL droplets per second, how long does it take to use 1ml of ink?

Solution

$$\frac{200\ x\ 10^{6}\ droplets}{10\ x\ 10^{3}\ droplets/\sec} = 20\ x\ 10^{3}\ seconds$$

$$20\ x\ 10^{3}\ seconds\ x \frac{1\ minute}{60\ seconds}\ x\ \frac{1\ hour}{60\ minutes} = 5.56\ hours!$$

Answer: 5.56 hours!

c. A typical large capacity cartridge has 42 ml. of ink, how many droplets can it produce?

Solution:

$$42\ ml * \frac{200\ million\ droplets}{1\ ml} = 8400\ million\ or\ 8.4\ billion\ droplets$$

Answer: 8.4 Billion droplets

d. The typical printed page has about 5% coverage – that is to say, 5% of the page is black and 95% of the page is white. The same 42 ml. cartridge above will let you print 833 pages at this 5% coverage rate.

i. How many drops per average page?

Solution: $\frac{8.4\ x\ 10^9\ droplets}{833\ pages} = 10.1\ x\ 10^6\ droplets/page$

Answer: approximately 10 million droplets per page

ii. How long does it take for one nozzle to print a page? (Assuming it is spraying at an average of 10,000 droplets/second since an actual inkjet nozzle turns on and off as the cartridge moves across the page)

Solution: $\frac{10\ x\ 10^6\ droplets/page}{10\ x\ 10^3\ droplets/sec} = 1\ x\ 10^3\ \frac{sec}{page}\ or\ 16.67\ \frac{minutes}{page}$

Answer: approximately 16.67 minutes/page or almost 4 pages per hour!

It will take over 15 minutes to print one page! Would you buy this? In reality, why do pages print so much faster?

Answer: There is more than one nozzle in a cartridge!!!!

iii. How many nozzles are in an inkjet cartridge for a printer that claims to print 30 black pages/minute?

Solution: $\frac{30\ pages}{minute} * \frac{16.67\ minutes}{page} = 500$

Answer: 500 nozzles

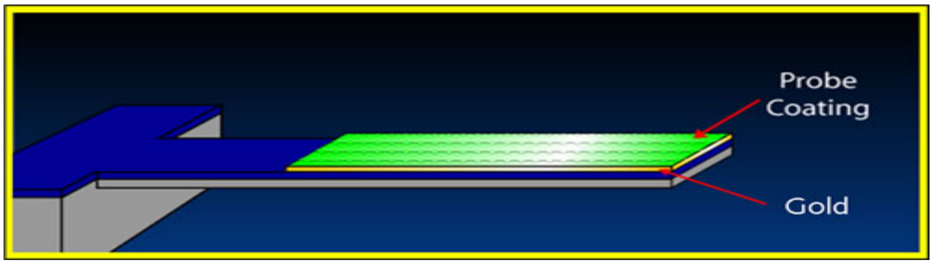
14. Density is a *physical property* of matter that describes the degree of compactness of a substance. The more closely packed together the individual particles of a substance, the higher the density of that substance. The ratio between the mass and volume of a substance defines its density:

Density (ϱ) = Mass/Volume

$$\rho = m/v$$

Mass (m) is the amount of matter contained in an object. Mass is measured in units of *grams (g)*. ***Volume (v)*** is the amount of space occupied by a quantity of matter. Volume is expressed in cubic centimeters *(cm^3)*.

Gold is a commonly used element in MEMS fabrication. It is used as a conductive layer, a reflective layer and a bonding layer *(see graphic below)*. The density of gold is 19.3 g/cm^3.



So just for fun, let's make a comparison of a couple of gold objects. Let's compare the mass of a gold bar to that of a gold MEMS layer.

Gold bar

The gold bars stored in the Federal Reserve Bank of 7" x 3.625" x 1.75".

a. What is the mass (in pounds) of one gold bar?

Solution

Volume = 7" * 3.625" * 1.75" = 44.4 in^3

Convert 44.4 in^3 to cm^3. $44.4\ in^3 * \frac{16.4\ cm3}{1\ in3} = 728\ cm^3$

Mass = $728\ cm^3 * \frac{19.3\ g}{cm3} = 14{,}050\ grams$

Answer: Pounds = $\mathbf{14{,}050\ grams * \frac{1\ pound}{454\ grams} = 30.9\ pounds}$!

b. What is the mass of a layer of gold 5 µm x 10 µm x 0.3 µm?

Solution

Volume = 5 µm * 10 µm * 0.3 µm = 15 µm^3

Convert volumes (15 µm^3 to cm^3) $15\ \mu m^3 * \frac{1\ cm^3}{1 \times 10^{12} \mu m^3} = 15 \times 10^{-12} cm^3$

Mass = $15 \times 10^{-12}\ cm^3 * \frac{19.3\ g}{cm3} = 0.29 \times 10^{-9}\ grams$

Answer: 0.29 nanograms

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 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.

The United States is one of three countries that has yet to adopt the metric system into common practice; therefore, conversion between metric and the US system is often required. For those in the science and technology fields, conversion within the metric system is required. Due to the current efforts of US metrication, converting between metric and the US system, and converting within the metric system are skills that everyone should acquire.

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