Name ______________________________

POGIL ACTIVITY 2

Units of Measurement and Dimensional Analysis

A. Units of Measurement- The SI System and Metric System

There are myriad units for measurement. For example, length is reported in miles or kilometers; mass is measured in pounds or kilograms and volume can be given in gallons or liters. To avoid confusion, scientists have adopted an international system of units commonly known as the **SI System**. Standard units are called **base units**.

Table A1. SI System
(Systéme Internationale d'Unités)

Measurement	Base Unit	Symbol
mass	gram	g
length	meter	m
volume	liter	L
temperature	Kelvin	K
time	second	s
energy	joule	j
pressure	atmosphere	atm

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The **metric system** combines the powers of ten and the base units from the SI System. Powers of ten are used to derive larger and smaller units, multiples of the base unit. Multiples of the base units are defined by a **prefix**. When metric units are attached to a number, the **letter symbol** is used to abbreviate the prefix and the unit. For example, 2.2 kilograms would be reported as 2.2 **kg**. Plural units, i.e., (kgs) are incorrect.

Table A2. Common Metric Units

Power Of Ten	Decimal equivalent	Prefix (symbol)	Name of metric unit (and symbol)		
			length	volume	mass
10^3	1000	kilo (k)	kilometer (km)	**B**	kilogram (kg)
10^0	1	**Base Unit**	**meter (m)**	**Liter (L)**	**gram (g)**
10^{-1}	0.1	deci (d)	**A**	deciliter (dL)	**D**
10^{-2}	0.01	centi (c)	centimeter (cm)	**C**	**E**
10^{-3}	0.001	milli (m)	millimeter (mm)	milliliter (mL)	milligram (mg)
10^{-6}	0.000 001	micro (μ)	micrometer (μm)	microliter (μL)	microgram (μg)

Critical Thinking Questions

CTQ 1

Consult Table A2. The labels, **A, B, C, D** and **E** represent units that are not frequently encountered. Write the name and the (symbol) for each of these.

A __________________________ (   ) C _________________________ (   )

B __________________________ (   ) D _________________________ (   )

E __________________________ (   )

CTQ 2

Identify by name the metric unit and the prefix that use the same abbreviation.

CTQ 3

Identify by name the two SI units that do not use a lower-case abbreviation.

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CTQ 4

Match each prefix (symbol) with its corresponding power of ten by placing an X in the appropriate box.

	10^{-6}	10^{-3}	10^{-2}	10^{-1}	10^{1}	10^{2}	10^{3}	10^{6}
d =								
m =								
k =								
μ =								
c =								

Mathematical Equivalency- A Useful Table of Metric Units

There exists a mathematical equivalency between the multiples of each base unit; equivalency is based on some power of ten. For example, since a kilogram is one-thousand times bigger than a gram, we could say that **one kilogram is equal to one-thousand grams**, and the mathematical equivalency is written as:

$$1\ \text{kg} = 1000\ \text{g} = 10^3\ \text{g}$$

Or, we could say that **one gram is equal to one-thousandth of a kilogram** and write the equivalency as:

$$1\ \text{g} = 0.001\ \text{kg} = 10^{-3}\ \text{kg}$$

Another unit of volume is cubic centimeter ($cm^{3.}$) In the health science professions, cubic centimeter is frequently abbreviated with (cc). Since **one cubic centimeter is equal to one milliliter**, the equivalency is:

$$1\ \text{mL} = 1\ \text{cm}^3 = 1\ \text{cc}$$

CTQ 5

Complete the Table of Metric Equivalents below:

Table A3. Metric Equivalents		
Length	**Volume**	**Mass**
1 km = m	1 L = mL	1 kg = g
1 m = cm	1 L = dL	1 g = mg
1 m = mm	1 mL = μL	1 mg = μg
1 mm = μm	1 mL = cm^3 = cc	

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CTQ 6

The Table of Metric Equivalents does not include an equivalency between kilometers (km) and centimeters (cm). How do we convert (km) into (cm)? Your answer must be in the form of one or two grammatically correct sentences.

CTQ 7

Explain why The Table of Metric Equivalents, as completed, is sufficient to derive an equivalency between any two mass units, any two volume units or any two length units.

B. Conversion Factors

A conversion factor is a ratio (fraction) of equivalent values that have different units. The mathematical equivalency between any two units can be used to derive a conversion factor between the units. For example, this equivalency **1 kg = 1000 g**, can be expressed as two different, but equivalent quotients or fractions. Notice the fractions are reciprocals:

$$\frac{1\ \text{kg}}{1000\ \text{g}} \quad \text{or} \quad \frac{1000\ \text{g}}{1\ \text{kg}}$$

These conversion factors say, **"one kilogram is equal to one thousand grams"** or **"one thousand grams is equal to 1 kg"**. Every equality in The Table of Metric Equivalents can be expressed as reciprocal fractions; in other words, two equivalent conversion factors can be derived from any equality.

Conversion factors are not restricted to metric units. Consider this equivalency of U.S. units: **twelve inches = 1 foot**. The conversion factors are derived in the same manner:

$$\frac{1\ \text{ft}}{12\ \text{in}} \quad \text{or} \quad \frac{12\ \text{in}}{1\ \text{ft}}$$

Notice that every conversion factor contains a <u>number and a unit</u> in the numerator as well as a <u>number and a unit</u> in the denominator.

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Critical Thinking Questions

CTQ 8

Using the Table of Metric Equivalents, write two reciprocal conversion factors for each pair of units. You may use decimal numbers or a power of ten for numerical values. Be sure each quotient contains a number and a unit in both numerator and denominator.

m and km			m and μm		
m and mm			m and cm		
L and dL			L and μL		
L and mL			mL and μL		
L and cc			cm^3 and μL		
g and mg			mg and μg		
g and μg			mg and kg		

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CTQ 9

Derive reciprocal conversion factors based on the following. Be sure each quotient contains a number and a unit in both the numerator and denominator.

One inch (in) equals 2.54 cm		
One kg equals 2.2 pounds (lb)		
One liter equals 1.06 qt		
Your car burns one gallon (gal) of gas every 18 miles (mi)		
One milliliter of mercury (Hg) has a mass of 13.6 grams		
There are 12 eggs in one dozen		

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C. Unit Conversions or Dimensional Analysis

A **unit conversion** is a simple algebraic calculation used to switch a quantity in one particular unit into another unit. For example, mass units can be expressed in grams or milligrams. We can switch between units by choosing the appropriate conversion factor:

$$\frac{1\ \text{g}}{1000\ \text{mg}} \quad \text{or} \quad \frac{1000\ \text{mg}}{1\ \text{g}}$$

Which conversion factor to use depends on which unit we want in our final answer, grams or milligrams. For example, to convert 325 mg into grams, we need to set up an equation so that the given unit of (mg) is **algebraically canceled** and the desired unit of (g) remains:

$$325\ \cancel{\text{mg}} \times \left(\frac{1\ \text{g}}{1000\ \cancel{\text{mg}}}\right) = 0.325\ \text{g}$$

Conversely, to switch grams into milligrams, we use the reciprocal conversion factor. For example, 2.59 g is equal to 2590 mg:

$$2.59\ \cancel{\text{g}} \times \left(\frac{1000\ \text{mg}}{1\ \cancel{\text{g}}}\right) = 2590\ \text{mg}$$

Dimensional analysis is a technical term for unit conversion, often implying that a particular unit may undergo sequential conversions. For example, to express 525 mg in units of kilograms, one approach uses a two-step process to convert milligrams to grams followed by conversion of grams into kilograms.

Step 1 (mg into g) $\quad 525\ \cancel{\text{mg}} \times \left(\frac{1\ \text{g}}{1000\ \cancel{\text{mg}}}\right) = 0.525\ \text{g}$

Step 2 (g into kg) $\quad 0.525\ \cancel{\text{g}} \times \left(\frac{1\ \text{kg}}{1000\ \cancel{\text{g}}}\right) = 0.000525\ \text{kg}$

A more efficient approach to dimensional analysis makes use of the rules of algebra to combine both steps into a single equation:

$$\underbrace{525\ \cancel{\text{mg}}}_{\text{starting unit}} \times \underbrace{\left(\frac{1\ \cancel{\text{g}}}{1000\ \cancel{\text{mg}}}\right)\left(\frac{1\ \text{kg}}{1000\ \cancel{\text{g}}}\right)}_{\text{conversion factor(s)}} = 0.000525\ \underbrace{\text{kg}}_{\text{final unit}}$$

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Notice the **three elements of dimensional analysis**: a starting quantity, a desired quantity and conversion factors. The starting quantity and desired quantity are stated (or implied) in the word problem. The conversion factors must be derived base on knowledge of the units of measurement. The **key** to dimensional analysis is proficiency in recognizing these three elements.

When two or more conversion factors are needed, the rules of algebra are followed:	$x \bullet \frac{a}{b} \bullet \frac{c}{d} = \frac{(x \bullet a \bullet c)}{(b \bullet d)} =$

Critical Thinking Questions

CTQ 10

What are the three elements needed to set up a calculation for dimensional analysis?

CTQ 11

For each calculation below, draw a **square** around the starting units, draw a **circle** around the conversion factor(s) and draw a **triangle** around the final unit.

a. $22.4 \text{ L} \quad \frac{1000 \text{ mL}}{1 \text{ L}} = 22400 \text{ mL}$

b. $0.78 \text{ cm} \quad \frac{1 \text{ m}}{100 \text{ cm}} = 0.0078 = 7.8 \times 10^{-3} \text{ m}$

c. $2.5 \text{ ft} \quad \frac{12 \text{ in}}{1 \text{ ft}} \quad \frac{2.54 \text{ cm}}{1 \text{ in}} \quad \frac{10 \text{ mm}}{1 \text{ cm}} = 762 = 7.62 \times 10^{2} \text{ mm}$

CTQ 12

In all unit conversions, every number **must** include ______________________.

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CTQ 13

Read the word problems carefully. **Do not bother to calculate answers**. Instead, for each problem, **identify the three elements**: starting quantity, the desired (final) unit and the conversion factor(s). Be sure to include proper units with the starting quantity.

Word problem	starting quantity	final unit	conversion factor(s)
Convert 100 centimeters into millimeters.			
How many dL in 15 mL?			
Calculate the mg of gold in a wedding ring that has a mass of 17.5 g			
A 5.0 L vessel containing salt water is cooled to 10°C and the solution is transferred into a holding tank. How many mL of salt water are in the tank?			
Gas mileage for a late model truck is reported as 14 miles per gallon. What is this mileage in km per liter?			
Superman is faster than a speeding bullet which travels at 2700 feet per second. How fast is this in miles per hour?			
A doctor prescribes 1 L of saline solution to be administered intravenously over a two-hour period. How many mL per second is this?			

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D. More About Dimensional Analysis and Conversion Factors

There are a number of ways to solve any word problem. In the previous example:

$$525\ \cancel{mg} \times \left(\frac{1\ \cancel{g}}{1000\ \cancel{mg}}\right)\left(\frac{1\ kg}{1000\ \cancel{g}}\right) = 0.000525\ kg$$

This calculation required two conversion factors, one quotient for (mg and g) and another for (g and kg) based on the equalities (1000 mg = 1g) and (1000 g = 1 kg), respectively.

However, if one recognizes this equality (1 kg = 1,000,000 mg), then the calculation can be done in a single step with one conversion factor:

$$525\ \cancel{mg}\ \frac{1\ kg}{10^{6}\ \cancel{g}} = 0.00525\ kg = 5.25 \times 10^{-3}\ kg$$

Notice the use of scientific notation which eliminates all place-holder zeros.

Both approaches to the word problem are correct since both calculations render the same answer. With complex, multi-step problems, it is recommended to do all calculations in a step-wise fashion unless you know your conversion facts are correct.

CTQ 17

Write a grammatically correct definition of a place-holder zero.

CTQ 18

Convert 2459 km into micrometers. For each calculation, complete each conversion factor(s) and solve the equation.

a. $$2459\ km \times \frac{\underline{\qquad}\ m}{km} \times \frac{\underline{\qquad}\ cm}{m} \times \frac{\underline{\qquad}\ mm}{cm} \times \frac{\underline{\qquad}\ \mu m}{mm} =$$

b. $$2459\ km \times \frac{\underline{\qquad}\ \mu m}{km} =$$

c. Write each answer above in scientific notation.

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Exercises

Show calculations and fill in the blank after converting answer to scientific notation.

a. 97.5 m = _______________μm

b. 345 m = _______________cm

c. 2.3×10^{-1} L = _______________μL

d. 1.05 km = _______________mm

e. 24.2 cm^3 = _______________μL

f. 8.89×10^{-6} mg = _______________μg

g. 7.34 mg = _______________kg

h. 75 mL = _______________L

i. 6.53×10^{4} mL = _______________μL

j. 3.5×10^{-4} mg = _______________g

k. 0.25 dL = _______________cc (mL)

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NOTES