LAB 1B: THE METRIC SYSTEM OF MEASUREMENT

How many teaspoons are in a cup? How many inches are in a mile? How many ounces are in a pound? If you know the answers to all of these questions, you are one of the few people in the world who can completely understand the English System of Measurement. The United States is one of the few countries of the 186 members of the United Nations that still uses the English System of Measurement (not even England uses it!).

The English System was developed over many centuries by the kings and noblemen of the Roman and British empires. In fact, the foot was literally the length of the actual foot of an English king, which happens to be 12 inches (each inch being the length of three seeds of barley).

The following are units used in the English System today:

<table>
<thead>
<tr>
<th>LENGTH</th>
<th>1 mile = 8 furlongs = 1,760 yards = 5,280 feet = 63,360 inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>VOLUME</td>
<td>1 gallon = 4 quarts = 8 pints = 16 cups = 128 ounces = 256 tablespoons</td>
</tr>
<tr>
<td>MASS</td>
<td>1 ton = 2,000 pounds = 32,000 ounces = 2.24 x 10^8 grains</td>
</tr>
<tr>
<td>TEMPERATURE</td>
<td>Fahrenheit - Water freezes at 32 ºF and boils at 212 ºF</td>
</tr>
</tbody>
</table>

How do you convert from one unit to the next using this system? Watch:

A person has 5 gallons of water. How many ounces of water does this equal?

\[
5 \text{ gallons} \times 128 \text{ ounces/gallon} = 640 \text{ ounces}
\]

Did you know how to do this already? Probably not. Very few scientists, much less everyday citizens, can remember how to convert units within this system, even though they’ve used it their entire lives. Basically, the English system is so difficult to work with that most countries in the world, and all scientists, have adopted a much easier system called the Metric System of Measurement.

The metric system of measurement has been adopted by 99% of the countries in the world and all scientists for two primary reasons: 1) there is a single, basic unit for each type of measurement (meter, liter, gram, ºC) and 2) each basic unit can have prefixes that are based on powers of 10 making conversions much easier. Once you learn the basic units and the multiples of 10 associated with each prefix, you will have the entire system mastered.
Basic Units of the Metric System

**LENGTH** - The basic unit of length in the metric system is the **meter**, abbreviated by the single letter **m**. A meter was originally calculated to be one ten-millionth of the distance from the north pole to the equator, and is ~3 inches longer than a yard.

**VOLUME** – The basic unit of volume in the metric system is the **liter**, abbreviated by the single letter **l** or **L**. A liter is defined as the volume of a box that is 1/10 of a meter on each side. A liter is just a little bit larger than a quart (1 liter = 1.057 quarts).

**MASS** – The basic unit of mass in the metric system is the **gram**, abbreviated by the single letter **g**. A gram is defined as the mass of a volume of water that is 1/1000\textsuperscript{th} of a liter. (Note: 1/1000\textsuperscript{th} of a liter = 1 milliliter = 1 cubic centimeter = 1 cm\textsuperscript{3} = 1 cc).

**TEMPERATURE** – The basic unit of temperature in the metric system is a degree Celsius (\(^\circ\)C). Water freezes at 0 \(^\circ\)C and boils at 100 \(^\circ\)C.

Prefixes used in the Metric System

Unlike the English System, the metric system is based on the meter (m), liter (L or l) and gram (g), and several prefixes that denote various multiples of these units. Specifically, each basic unit can be modified with a prefix indicating a particular “multiple of 10” of that unit. Here are the more commonly used prefixes and what they mean:

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Symbol</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mega</td>
<td>M</td>
<td>(10^6)</td>
</tr>
<tr>
<td>Kilo</td>
<td>k</td>
<td>(10^3)</td>
</tr>
<tr>
<td>Basic</td>
<td></td>
<td>(10^0)</td>
</tr>
<tr>
<td>Deci</td>
<td>d</td>
<td>(10^{-1})</td>
</tr>
<tr>
<td>Centi</td>
<td>c</td>
<td>(10^{-2})</td>
</tr>
<tr>
<td>Milli</td>
<td>m</td>
<td>(10^{-3})</td>
</tr>
<tr>
<td>Micro</td>
<td>(\mu)</td>
<td>(10^{-6})</td>
</tr>
<tr>
<td>Nano</td>
<td>n</td>
<td>(10^{-9})</td>
</tr>
</tbody>
</table>

Here is how simple the metric system is using the basic units and the prefixes:

What is one thousandth of a meter? **a millimeter** (mm)
What is one one-millionth of a liter? **a microliter** (\(\mu\)l)
What is 1,000 grams? **a kilogram** (kg)
Let us now examine these units more closely by using them to make actual measurements and converting from one metric unit to another.

**Exercise A – Measuring distance**

1. Obtain a wooden meter stick. If you look on the back of the meter stick, one meter is approximately 39 inches or about 3 inches longer than one yard (36 inches). Using the meter stick, estimate the size of the laboratory by measuring its width and length to the nearest **meter**.

2. Observe that the meter is divided into 100 equal units called centimeters. A centimeter is about the width of a small finger. Using the meter stick, estimate the dimensions of a regular piece of notebook paper to the nearest **centimeter**.

3. How tall are you? Go over to the medical weight and height scale to measure how tall you are to the nearest **centimeter**.

4. Next, obtain a small plastic metric rule. Observe that each centimeter is divided into 10 small units called millimeters. A millimeter is about the thickness of a fingernail. Using the small plastic ruler, estimate the diameter of a hole on a regular piece of notebook paper to the nearest **millimeter**.

In the United States, when we travel by car, distances are measured in miles. For example, from the Mission College to downtown Los Angeles is about 20 miles. In almost every other country, such distances are measured in **kilometers**. One kilometer is exactly 1,000 meters and approximately 0.6 miles. Thus, 1 km = 0.6 miles.

How does one convert miles to kilometers? How many kilometers are in 20 miles?

\[
\frac{20 \text{ miles}}{0.6 \text{ miles}} \times 1 \text{ km} \approx 33 \text{ km}
\]

Do the following distance conversions for practice:

Distance from Los Angeles to San Diego: 145 miles \( \times \) \( \approx \) ______ km
Distance from Los Angeles to New York: 2,500 miles \( \times \) \( \approx \) ______ km

What are some real-world examples of other metric units of length?

One **micrometer (µm)** is 1/1,000\(^{th}\) the size of a millimeter or 1/1,000,000\(^{th}\) of a meter. When you observe a cheek cell under the microscope in a future lab, it is about 40 µm in diameter. Typical bacteria are about 5-10 µm in diameter.

One **nanometer (nm)** is 1/1,000\(^{th}\) the size of a micrometer or 1/1,000,000,000\(^{th}\) of a meter. Objects this small are far too tiny to observe even in a light microscope. If you line up five water molecules side-by-side, the length would be about 1 nanometer.
Exercise B – Measuring volume

1. Obtain a one liter (L or l) beaker. One liter is equal to 1,000 cubic centimeters (cc = cm³ = milliliter = ml). Fill the beaker with one liter of water. To do this, add water until the meniscus (top level of the water) reaches the 1 liter marker on the beaker. Pour the water into a 2 liter soda bottle.

Once again, fill the beaker with one liter of water by adding water until the meniscus reaches the 1 liter mark. Pour the water into the 2 liter soda bottle.

Once again, fill the beaker with one liter of water by adding water until the meniscus reaches the 1 liter mark. Over the sink, add the 1 liter of water to the 1 quart container provided. Notice that 1 liter is just a little bit more than 1 quart. In fact, 1 liter = 1.057 quarts.

2. One way to measure the volume of a fluid in a laboratory is to use a graduated cylinder. Whereas beakers are generally used to hold fluids, graduated cylinders are used to accurately measure volumes.

Obtain a 50 milliliter (ml) graduated cylinder. Fill the graduated cylinder with water until the meniscus reaches the 50 ml mark. Add the water to a 1 liter (1,000 ml) beaker. Notice that 50 ml is equal to 1/20th of a liter. Next, measure the fluid in the flask labeled “A” to the nearest 0.1 ml.

3. Pipettes are used to measure smaller liquid volumes whereas graduated cylinders are used to measure larger volumes. Obtain a 10 ml glass pipette and attach it snugly to a pipette pump.

Notice whether or not the pipette is a delivery or blowout pipette. Blowout pipettes are designed for measuring fluids all the way to the end of the pipette so that the liquid measured can be completely “blown out” of the pipette. Delivery pipettes have a gap at the end of the pipette and are designed to “deliver” the liquid down to the desired marking only. The remainder is discarded or returned to the original container. (NOTE: blowing out a delivery pipette will give a wrong volume)

Using the roller on the pipette pump, gradually suck up some water until the meniscus reaches the 0 ml mark. Measure 10 ml of the water into the sink by rolling the roller in the opposite direction. Next, measure the amount of fluid in the test tube labeled B to the nearest 0.1 ml using the 10 ml pipette.
**Exercise C – Measuring mass**

A balance scale is used to measure the mass of a sample in grams (g).

1. Place an empty 50 ml graduated cylinder on the balance and determine its mass in grams.

2. Next, fill the graduated cylinder with 50 ml of water and measure the mass of both the cylinder and the water. From this value subtract the mass of the cylinder to get the mass of the water.

By definition, one gram is the mass of exactly 1.0 ml of water, thus 50 ml of water has a mass of 50.0 grams. How far off was your measured mass from the true mass of 50 ml of water?

3. Next, take a large paper clip and place it on the balance and determine its mass in grams.

**Exercise D – Measuring temperature**

The metric unit for temperature is °Celsius (°C). Water freezes at 0 °C and boils at 100 °C. Note that this is much easier to remember than the corresponding values of 32 °F and 212 °F.

1. Use a thermometer to measure the following in degrees Celsius:
   
   A) the ambient temperature of the lab  
   B) a bucket of ice water  
   C) a beaker of boiling water

2. Convert the temperatures on your worksheet from °C to °F or °F to °C with the following formulas:

\[ °C = \frac{5}{9} (°F - 32) \]

\[ °F = \frac{9}{5} °C + 32 \]
Converting Units in the Metric System

Since numerical values for any metric unit can be represented as a decimal number (e.g. 375.2) or an exponential number (e.g. 3.752 x 10^2), it is important that you first know how to convert from decimal notation to exponential notation (also known as scientific notation), and vice versa, as outlined below:

Converting from decimal notation to exponential notation

STEP 1 – move the decimal point to the right of the 1st non-zero digit:

- e.g. 0.00105 OR 1.050
  - 1.05
  - 1.05

STEP 2 – determine the power to which 10 is raised (i.e., 10^n) to compensate for moving the decimal:

The power is going to be equal to the number of places you moved the decimal (10^3 in the examples above). You need only to determine the sign (+ or -) of the exponent. This can be determined in 2 ways, whatever works best for you:

1) If the original number is less than 1, the exponent is negative (-), if the original number is greater than 1, the exponent is positive (+).

Examples:

- 0.00105 = 1.05 x 10^{-3}
- 1.050 = 1.05 x 10^{0}

Some things to remember about the conventions of writing numbers in decimal notation:

- if there is no decimal in the number, it is after the last digit (1,050 = 1050.0)
- zeroes after the last non-zero digit to the right of the decimal can be dropped (e.g., 1.050 = 1.05)
- all simple numbers less than 1 are written with a zero to the left of the decimal (.105 = 0.105)

Exercise E – Converting decimal notation to exponential notation

Complete the conversions of simple numbers to exponential numbers on your worksheet.
Converting from exponential notation to decimal notation

You simply move the decimal a number of places equal to the exponent. If the exponent is negative, the number is less than one and the decimal should be moved to the left:

\[ 1.05 \times 10^{-3} = 0.00105 \]

If the exponent is positive, the number is greater than one and the decimal should be moved to the right:

\[ 1.05 \times 10^{3} = 1,050 \]

Exercise F – Converting exponential notation to decimal notation

Complete the conversions of exponential numbers to simple numbers on your worksheet.

Converting Units within the Metric System

Once you are familiar with the units and prefixes in the metric system, converting from one unit to another requires two simple steps:

1) divide the value associated with the prefix of the original unit by the prefix of the unit you are converting to
2) multiply this value by the number in front of the original unit

To illustrate this let’s look at an example:

\[ 2.4 \text{ kg} = \underline{\quad} \text{ mg} \]

In this case you’re converting from \textbf{kilo}grams to \textbf{milli}grams. Since the prefix \textit{kilo}- refers to 1000 and the prefix \textit{milli}- refers to 1/1000 or 0.001 (see page 7), divide 1000 by 0.001. This gives a value of 1,000,000 which is multiplied by 2.4 to get the mass in milligrams:

\[ 2.4 \text{ kg} = 2.4 \times 1,000,000 \text{ mg} = 2,400,000 \text{ mg} \]

You may find it simpler to associate each metric prefix with an exponential number. With this approach \textbf{kilo}- refers to \(10^3\) and \textbf{milli}- refers to \(10^{-3}\), so \(10^3/10^{-3}\) equals \(10^6\) (when dividing exponential numbers simply subtract the first exponent minus the second), and thus:

\[ 2.4 \text{ kg} = 2.4 \times 10^6 \text{ mg} = 2,400,000 \text{ mg} \]
Whether or not you represent your answer as an exponential number is up to you, either way the values are the same. To ensure that you’ve done the problem correctly, remember that any given distance, mass or volume should contain more of a smaller unit and less of a larger unit. This is simply common sense if you think about it. As you can see in the example above, there are a lot more of the smaller milligrams than there are the larger kilograms, even though both represent the exact same mass. So each time you do a metric conversion look at your answer to be sure that you have more of the smaller unit and less of the larger unit.

One more thing to remember is that a basic unit without a prefix (m, g or l) is one or $10^0$ of that unit. Here are a couple more examples just to be sure everything is clear:

\[
\begin{align*}
643 \text{ m} &= \quad \text{km} & 1 \text{ divided by } 1000 \text{ (kilo-)} &= 0.001 \times 643 &= \bf{0.643 \text{ km}} \\
\quad \text{l} &= 50 \text{ ml} & 10^{-3} \text{ (milli-)} \text{ divided by } 10^0 &= 10^{-3} \times 50 &= \bf{5.0 \times 10^{-2} \text{ l}}
\end{align*}
\]

**Exercise G – Metric Conversions**

Complete the metric conversions on your worksheet.
LABORATORY 1B WORKSHEET  
Name ________________________  
Section_______________________  

Exercise A – Measurement of distance  
Laboratory width: _________ m  
Laboratory length: _________ m  
Calculate approximate area: width _____ m  x  length _____ m  =   _________ m$^2$  
Paper width: _______ cm  
Paper length: _______ cm  
Calculate approximate area: width _____ cm  x  length _____ cm  =   _________ cm$^2$  
Paper hole diameter: ________ mm  
Your height: ________ cm, which is equal to ________ m  

*Indicate which metric unit of length you would use to measure the following:*  
length of a fork __________  
width of a plant cell __________  
size of a small pea __________  
length of your car __________  
height of a refrigerator __________  
distance to the beach __________  
diameter of an apple __________  
size of a dust particle __________  

Exercise B – Measurement of volume  
Volume of fluid in Beaker A = ____________ ml  
Volume of fluid in Test Tube B = ____________ ml  

Exercise C – Measurement of mass  
Mass of Graduated Cylinder = _____________ g  
Mass of Graduated Cylinder with 50 ml of water = _____________ g  
Mass of 50 ml of water: _____________ g  
Difference between calculated and actual mass of 50 ml of water: ____________  
Mass of 1 ml of water based on your measurements: ________ g/50 ml = ________ g/ml  
Mass of Large Paper Clip = _____________ g
Exercise D – Measurement of temperature

Ambient temperature in lab ______°C  ice water ______°C boiling water ______ °C

Convert the following temperatures using the formulas on page 10 of the lab exercises:

Mild temperature: 72 °F = ______°C Body temperature 98.6 °F = ______ °C
Cold day 10 °C = ______°F Very hot day 34 °C = ______°F

Exercise E – Converting from decimal notation to exponential notation

Convert the following decimal numbers to exponential numbers:

186,000 = ___________ ___________ = 0.00018
32.9 = ___________ ___________ = 0.0369
700.02 = ___________ ___________ = 0.0000025

Exercise F – Converting from exponential notation to decimal notation

Convert the following exponential numbers to decimal numbers:

3.7 x 10³ = ___________ ___________ = 10⁶
1.01 x 10⁷ = ___________ ___________ = 2.818 x 10⁻³
4.0103 x 10⁻¹ = ___________ ___________ = 8 x 10⁵

Exercise G – Metric conversions

Convert the following measurements to the indicated unit:

335.9 g = ________________ kg ________________ m = 0.0886 km
0.00939 μl = ________________ ml ________________ kg = 89 mg
456.82 ng = ________________ μg ________________ dl = 900.5 cl
20 megabytes = ____________ kilobytes ________________ μm = 0.37 mm
8 megabase pairs (mbp) = __________ kbp ________________ mm = 11.5 nm
95 °C = ________________ °F ________________ °C = 100 °F