Bio 6 – Measurement in the Metric System

Overview

In this laboratory you will make a variety of measurements in metric units, and practice converting units within the metric system. You will also practice graphing data sets and making aqueous solutions.

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 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:

**LENGTH**

- **1 mile** = 8 furlongs = 1,760 yards = 5,280 feet = 63,360 inches

**VOLUME**

- **1 gallon** = 4 quarts = 8 pints = 16 cups = 128 ounces = 256 tablespoons

**MASS**

- **1 ton** = 2,000 pounds = 32,000 ounces = 2.24 x 10^8 grains

**TEMPERATURE**

- Fahrenheit - Water freezes at 32°F and boils at 212°F

Did you know how to do these conversions 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 most 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, °C) 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 pure water that is 1/1000th of a liter. [NOTE: 1/1000th of a liter = 1 milliliter = 1 cubic centimeter = 1 cm³ = 1 cc].

TEMPERATURE – The basic unit of temperature in the metric system is a degree Celsius (°C). Water freezes at 0°C and boils at 100°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>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mega</td>
<td>M</td>
<td>10⁶</td>
<td>1,000,000</td>
</tr>
<tr>
<td>Kilo</td>
<td>k</td>
<td>10³</td>
<td>1,000</td>
</tr>
<tr>
<td>No prefix</td>
<td></td>
<td>10⁰</td>
<td>1</td>
</tr>
<tr>
<td>Deci</td>
<td>d</td>
<td>10⁻¹</td>
<td>0.1 or 1/10 (i.e., tenths of a unit)</td>
</tr>
<tr>
<td>Centi</td>
<td>c</td>
<td>10⁻²</td>
<td>0.01 or 1/100 (i.e., hundredths of a unit)</td>
</tr>
<tr>
<td>Milli</td>
<td>m</td>
<td>10⁻³</td>
<td>0.001 or 1/1,000 (i.e., thousandths of a unit)</td>
</tr>
<tr>
<td>Micro</td>
<td>µ</td>
<td>10⁻⁶</td>
<td>0.000001 or 1/1,000,000 (i.e., millionths of a unit)</td>
</tr>
<tr>
<td>Nano</td>
<td>n</td>
<td>10⁻⁹</td>
<td>0.000000001 or 1/1,000,000,000 (i.e., billionths of a unit)</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 millionth of a liter? **a microliter (µl)**
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.

**DISTANCE in the Metric System**

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 is equal to 0.6 miles.

What are some other real-world examples of metric units of length? One micrometer (µm) is 1/1,000th the size of a millimeter or 1/1,000,000th 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 1/1,000th the size of a micrometer or 1/1,000,000,000th 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 1 – 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.

**VOLUME in the Metric System**

A variety of devices are used to measure volume in the metric system. In the next exercise you will familiarize yourself with measuring volumes greater than 1 ml using beakers, graduated cylinders and pipettes.
Exercise 2A – Measuring volumes larger than 1 ml

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. Repeat.

   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, use the graduated cylinder to measure the fluid in the flask labeled “A” to the nearest 0.5 ml. Record this volume on your worksheet.

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 yield the 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 moving 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. Record this volume on your worksheet.

To measure volumes less than 1 ml you will need a micropipettor like the one shown one the next page. Micropipettors will allow you to accurately measure volumes at the microliter (μl) level. While we don’t deal with microliter volumes in everyday life, in the laboratory measurements as little as 1 μl are used routinely. For this reason micropipettors are essential in any laboratory environment.
You should have at least four types of micropipettor at your table, each capable of measuring volumes in the indicated ranges:

- **P1000**: 100-1000 µl
- **P200**: 50-200 µl
- **P100**: 20-100 µl
- **P200**: 50-200 µl
- **P10**: 1-10 µl (not at all tables)

Let's first get acquainted with each part of a micropipettor and its corresponding function. Be sure to look at one of the micropipettors at your table as you read the next three paragraphs:

The end of the micropipettor labeled “tip attachment” is where you will attach a disposable plastic tip. The liquid you measure will be contained within the tip and thus will not make contact with the micropipettor itself. When you are finished measuring your liquid, you will discard the tip and use a new tip for the next measurement. This avoids contamination of your sample as well as the micropipettor. The **tip eject button** will move the **tip eject shaft** down to eject the disposable tip.

The **volume readout** shows the number of microliters (µl) the micropipettor is set to measure. The volume readout is adjusted by turning the **volume adjustment** knob. Each micropipettor has a range of volumes it is designed to measure which is indicated on the end of the plunger. **If you set the micropipettor to a volume outside this range you can damage the instrument’s internal mechanism which may destroy its accuracy.** Remember, you should never adjust the volume readout outside the range the micropipettor is designed to measure.
The plunger is pressed downward with your thumb and then released to draw liquid into the disposable tip. The measured liquid can then be expelled from the tip by depressing the plunger. If you press down on the plunger you will reach a point of resistance called the “first stop” as shown in the illustration. When depressed to the first stop, the plunger will draw in the volume indicated on the volume readout as it is released. To measure 20 µl for example, you would set the volume readout to “200” for the P20 or “020” for the P100, submerge the tip on the end of the micropipettor into the liquid to be measured, and slowly release the plunger to its rest position. The liquid can then be expelled from the tip by depressing the plunger to the first stop. If any liquid remains in the tip at this point, the plunger can be depressed beyond the first stop toward the “second stop” (see illustration). This will force any remaining liquid out of the tip. The only time you will concern yourself with the second stop is for this purpose.

**Exercise 2B – Measuring volumes less than 1 ml**

In addition to the micropipetters, you should have 3 racks of disposable micropipettor tips – large tips for the P1000, medium tips for the P200, P100 & P20, and small tips for the P10. You should also have a small microcentrifuge tube of blue liquid, five empty microcentrifuge tubes and a microcentrifuge tube rack. Everyone at your table should practice measuring and transferring the volumes indicated in the exercises below. Before you begin, be sure you are in a comfortable position with everything you will need in front of you or within comfortable reach.

Follow the instructions below when using each micropipettor to measure the desired volumes:

- adjust the volume readout of the micropipettor to the desired volume
- place the appropriate disposable tip snugly on the “tip attachment” end of the micropipettor by firmly inserting it into a tip in the rack
- open the small tube of blue liquid, depress the plunger to the first stop, immerse the end of the tip into the liquid, and slowly release the plunger (you can hold the tube in your opposite hand while doing this)
- hold the tube you want to transfer to in your opposite hand and insert the tip with your sample
- slowly depress the plunger to the first stop to expel the liquid into the tube, being sure to NOT release the plunger just yet!

**NOTE:** if necessary you can push the plunger toward the second stop to expel any remaining liquid

- move the tip out of the liquid, and then release the plunger (this is extremely important, you do NOT want to release the plunger before removing the tip from the liquid or else you will pull most of the sample back into the tip!)
- dispose of your used tip into the biohazard waste container at your table

1. Use the P1000 to transfer 500 µl of blue liquid to a tube labeled “500” (volume readout = 050).
2. Use the P200 to transfer 100 µl of blue liquid to a tube labeled “100” (volume readout = 100).
3. Using the P100, transfer 25 µl of blue liquid to a tube labeled “25” (volume readout = 025).
4. Using the P20, transfer 5 µl of blue liquid to a tube labeled “5” (volume readout = 050).
5. Using the P10, transfer 1 µl of blue liquid to a tube labeled “1” (volume readout = 010).
MASS in the Metric System

Mass is an inherent property of matter whereas weight refers to the mass of an object and the force of gravity acting upon it. For example, your mass is the same whether you are on earth or in outer space. Your weight, however, will be different on the earth vs outer space (where you can be essentially “weightless”). So technically you will be measuring the weight of various objects in the following exercise to illustrate the property of mass. To do so you will use a metric balance, much like the one shown on the left, to determine the mass/weight in grams.

Exercise 3 – Measuring mass

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.

NOTE: By definition, one gram is the mass of exactly 1.0 ml of pure 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.

TEMPERATURE in the Metric System

Temperature is a measure of the amount of heat a substance contains and can be measured in degrees Fahrenheit or degrees Celsius (also known as degrees Centigrade). The metric unit for temperature is °Celsius (°C), which is based on water freezing at 0 °C and boiling at 100 °C. Notice that this range of temperature is conveniently divided into 100 units. In the Fahrenheit system water freezes at 32 °F and boils at 212 °F, thus dividing the same range of temperature into 180 units.

Here in the United States we are more familiar with temperatures expressed in degrees Fahrenheit, however the scientific community and much of the rest of the world measures temperatures in degrees Celsius. Thus it is especially important here in the United States to be able to convert from one temperature system to the other. There are two simple formulas to do so which are shown on the following page. Instead of simply taking for granted that the formulas will convert temperatures correctly, let’s take moment to see how they are derived. In so doing you will not only learn the basis of each formula, but you will never have to remember the formulas since you can derive them yourself!
Recall that for every 100 degrees Celsius there are 180 degrees Fahrenheit. Thus a degree Fahrenheit is smaller than a degree Celsius by a factor of 100/180 or \( \frac{5}{9} \). Conversely, a degree Celsius is larger than a degree Fahrenheit by a factor of 180/100 or \( \frac{9}{5} \). When converting from Fahrenheit to Celsius or vice versa you must also consider that 0°C is the same temperature as 32°F. Thus the Fahrenheit system has an extra 32 degrees which must be taken into account. Keeping these facts in mind, let’s see how to convert temperatures between the two systems.

**Converting Celsius to Fahrenheit**

Since each degree Celsius is equal to 9/5 degrees Fahrenheit, simply multiply the degrees Celsius by 9/5 and then add 32. Note that the extra 32 degrees are added only after you have converted to degrees Fahrenheit, producing the following formula:

\[
\left( \frac{9}{5} \times ^\circ C \right) + 32 = ^\circ F
\]

**Converting Fahrenheit to Celsius**

Since each degree Fahrenheit is equal to 5/9 degrees Celsius, simply subtract 32 from the degrees Fahrenheit and then multiply by 5/9. Note that the extra 32 degrees are subtracted while still in degrees Fahrenheit, i.e., *before* you convert to degrees Celsius. This produces the following formula:

\[
(^\circ F - 32) \times \frac{5}{9} = ^\circ C
\]

**Exercise 4 – Measuring and converting temperature**

1. Use the thermometer at your table to measure the following in degrees Celsius:
   - the ambient temperature of the lab
   - a bucket of ice water
   - a beaker of boiling water
2. Convert the temperatures on your worksheet from Celsius to Fahrenheit or vice versa.

**Converting Units in the Metric System**

In science, numerical values are commonly represented using scientific notation. Scientific notation is a standardized form of exponential notation in which all values are represented by a number between 1 and 10 times 10 to some power. For example, 3500 in scientific notation would be \( 3.5 \times 10^3 \), and 0.0035 would be \( 3.5 \times 10^{-3} \). Scientific notation is much more practical when dealing with extremely large or small values. For example, consider the masses of the earth and a hydrogen atom:

- mass of the earth: \( 5.97 \times 10^{27} \) grams = 5,970,000,000,000,000,000,000,000,000,000 grams
- mass of a hydrogen atom: \( 1.66 \times 10^{-24} \) grams = 0.00000000000000000000000166 grams
In these examples scientific notation is clearly much more practical and also easier to comprehend. Instead of counting all those zeroes or decimal places, the factors of 10 associated with each value are clearly indicated in the exponent. Scientific notation is especially useful in the metric system since the various metric units represent different factors of 10. Therefore it is important to be able to convert between scientific and decimal notation as outlined below:

**Converting from decimal notation to scientific notation**

**STEP 1** – Convert the number to a value */between 1 and 10* by moving 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** – Multiply by a power of 10 (i.e., 10\(^n\)) to compensate for moving the decimal:

- the power will equal the number of places you moved the decimal
- the exponent is */negative* (-) if the original number is */less than 1*, and */positive* (+) if the original number is */greater than 1*

- e.g. 0.00105  =  1.05 \(\times 10^{-3}\)
  
  1,050  =  1.05 \(\times 10^3\)

**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 (e.g., 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 (e.g., .105 = 0.105)

**Exercise 5 – Converting decimal notation to exponential notation**

1. 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 is 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 is moved to the right:

\[
1.05 \times 10^3 = 1,050
\]
Exercise 6 – Converting exponential notation to decimal notation

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

Converting Units within the Metric System

Converting from one metric unit to another is simply a matter of changing a value by the appropriate factor of 10. With decimal numbers that means simply moving the decimal one place for every factor of 10 – to the right to increase the value or to the left to decrease. With exponential numbers you simply increase or decrease the exponent by 1 for every factor of 10. In other words, all you really need to figure out is A) whether the value should increase or decrease and B) by what factor of 10 to do so.

Although this seems fairly straightforward, many students struggle with such conversions and rely on various formulas to do them. This will work just fine, but oftentimes students end up with an answer that is wildly off the mark due to moving a decimal in the wrong direction or changing the exponent in the wrong way. One should immediately realize there is a problem with such errors, however when the process is divorced from intuition and common sense it is easy to make such a mistake and think nothing of it. So instead of focusing on a formula to follow, let’s approach this by appealing to common sense and common experience. Once your common sense has been engaged, converting from one metric unit to another should be easier than it seems.

When dealing with the metric system we usually talk about grams, meters and liters, however the metric system can be just as easily applied to something we are all familiar with and hold dear – money. The basic unit of money in this country is the dollar, with the smallest unit being the penny. We all know that 100 pennies equals a dollar, so a penny is clearly 1/100th of a dollar, or in metric terms, a centidollar ($10^{-2}$ dollars). We also know that 10 dimes equals 1 dollar, so a dime is actually a decidollar ($10^{-1}$ dollars). And if you’re fortunate enough to have 1000 dollars in the bank, you are the proud owner of a kilodollar ($10^{3}$ dollars). With this in mind, let’s do some conversions within this system.

If asked, “How many pennies is equal to ten dollars?” you should have little problem figuring this out. Since one dollar is equal to 100 pennies and there are 10 dollars total, it should be clear that 10 dollars is equal to 100 x 10 or 1000 pennies. Now let’s consider the same problem in metric terms:

\[ 10 \text{ dollars} = \underline{\text{_____ centidollars}} \]

Seeing the problem in this form may make the answer less intuitive. Nevertheless it is the same problem to which you can apply the same common sense – there should be 100 times more centidollars (pennies) than dollars. You should also realize that this is true for not only this problem, but for any problem involving dollars and centidollars. Let’s now consider the reverse in which you convert pennies (centidollars) to dollars:

\[ 1483 \text{ centidollars} = \underline{\text{_____ dollars}} \]

You know the answer immediately, right? The answer is 14.83 dollars since every 100 pennies (centidollars) is equal to one dollar. You intuitively knew to decrease 1483 by a factor of 100 to
arrive at the correct answer since there should be more of the smaller unit (pennies or centidollars) and less of the larger unit (dollars). This is all there is to metric conversions, realizing if the value should increase or decrease and by what factor of 10 to do so. Hopefully this has shown you that you already know how to do metric conversions intuitively, you just need to think of them in terms that are familiar to you. Let’s now try one that’s a bit more challenging:

\[
500 \text{ decidollars} = \underline{\quad} \text{ kilodollars}
\]

In this problem we are actually converting dimes to thousands of dollars. This may take a little more thinking, however you can probably figure out that a decidollar (dime) is 10,000 times smaller than a kilodollar (10 dimes per dollar x 1000 dollars per kilodollar). It should be clear now that 500 decidollars is equal to 10,000 times less kilodollars, thus you simply move the decimal 4 places to the left to arrive at the correct answer of 0.05 kilodollars. You can use a calculator if you like, but it really is not necessary since there is essentially no calculating involved.

Next we will do several sample problems involving more traditional metric units to show you how simple and straightforward this can be as long as you are familiar with the metric prefixes which are reproduced for you in the box below. Refer to this as needed and you should have little trouble.

<table>
<thead>
<tr>
<th>Basic Unit</th>
<th>Mega (M)</th>
<th>Kilo (k)</th>
<th>Deci (d)</th>
<th>CENTI (c)</th>
<th>Milli (m)</th>
<th>Micro (µ)</th>
<th>Nano (n)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>(10^6)</td>
<td>(10^3)</td>
<td>(10^1)</td>
<td>(10^{-2})</td>
<td>(10^{-3})</td>
<td>(10^{-6})</td>
<td>(10^{-9})</td>
</tr>
</tbody>
</table>

Before we do a few more sample problems, it is important to realize that this is really a two step process in which is outlined on the next page.

1. **Identify whether your value should increase or decrease.**
2. **Determine the factor of 10 by which the value should change.**

Once you have completed these two steps it’s simply a matter of adjusting your decimal or exponent accordingly.

As you realize from doing the problems involving money, there should always be a larger number of smaller units (e.g., pennies) and a smaller number of larger units (e.g., dollars). So the first step is easy. Let’s now do a problem similar to the ones you’ll find on your worksheet:
28 mg = _____ μg

You are converting larger mg (0.001 g) to smaller μg (0.000001 g), so clearly the value of 28 should increase. Since a μg is 1000 times smaller than a mg (0.001/0.000001 = 1000), the value of 28 should increase by a factor of 1000. Therefore:

\[ 28 \text{ mg} = 28 \times 1000 \text{ μg} = 28,000 \text{ μg} \]

If you prefer working with exponential numbers then the problem works out this way:

\[ 28 \text{ mg} = 28 \times 10^3 \text{ μg} = 2.8 \times 10^4 \text{ μg} \]

Let’s try one more problem which is presented in a slightly different way:

How many kilometers (km) is 3.7 centimeters (cm)?

This question can be expressed in the following problem:

\[ 3.7 \text{ cm} = _____ \text{ km} \]

In this problem, km (10^3 m) are clearly larger than cm (10^-2 m) so the value of 3.7 should decrease. A cm is 10^5 times larger than a cm (10^3/10^-2 = 10^5), so the value of 3.7 should decrease by a factor of 10^5. Therefore:

\[ 3.7 \text{ cm} = 3.7 \times 10^0 \text{ cm} = 3.7 \times 10^{-5} \text{ km} \]

In this problem it is more practical to use exponential notation, however the original value was in decimal form. Converting 3.7 to an exponential number (3.7 x 10^0) makes it easy to reduce the value by a factor of 10^5 by subtracting 5 from the exponent.

While this approach to making metric conversions is meant to engage your common sense, you may prefer a more traditional method. This involves multiplying the original metric value by a ratio of metric units equal to one that, due to cancellation, leaves you with an equivalent value in the desired units. To illustrate how this works, let’s consider the first problem on the previous page:

\[ 28 \text{ mg} = _____ \text{ μg} \]

In this problem you want to convert the units from mg to μg, so multiply 28 mg by a ratio equal to one that will cancel the mg and leave you with μg:

\[ 28 \text{ mg} \times 1000 \text{ μg/mg} = 28,000 \text{ μg} \]
Since 1000 $\mu$g equals 1 mg, a ratio of 1000 $\mu$g/mg is equal to one. The key to this method is determining how many of the new units ($\mu$g) equal one of the original units (mg). Once this is determined simply put the original unit on the bottom (to allow its cancellation) and the equivalent value in the desired units on top.

Let’s do one more example to make sure this is clear:

$$3.7 \text{ cm} = _____ \text{ km}$$

$$3.7 \text{ cm} \times 10^{-5} \text{ km/cm} = 3.7 \times 10^{-5} \text{ km}$$

Now that you see how to solve these conversion problems you are ready to complete the final exercise for this lab.

Exercise 7 – Metric conversions

1. Complete the metric conversions on your worksheet.

Working with Concentration

Units of Concentration

It is essential in biology to understand the concept of concentration – the amount of a substance per unit volume. The concentration of a substance can be expressed with a variety of units:

- Molarity (moles per liter)
- Mass concentrations (e.g., mg/ml)
- Percent solutions (g/100 ml)
- “X” concentrations (relative to the desired final concentration – e.g. 10X)

You will use all these units of concentration throughout the course so it is important that you are familiar with them and can use them in calculations.

Calculations Involving Concentration

Many biological experiments involve the use of concentrated stock solutions that need to be diluted to the correct concentration in a solution or biological reaction. A simple way to calculate the amount of concentrated stock solution to be added to a solution or reaction is to use the following formula:

$$\text{volume needed} = (\text{final concentration/stock concentration}) \times \text{total volume}$$
For example, if you have a 10X stock solution of something you want to add to a 50 μl total reaction volume such that its final concentration is 1X, you would need to add 5 μl of the stock solution to the reaction:

\[
\frac{1X}{10X} \times 50 \, \mu l = 5 \, \mu l
\]

In the next example the units are different, however the calculation is much the same. Assume you have a 500 mM stock solution of NaCl which you will use to make a 1 liter solution containing 10 mM NaCl. The amount of stock NaCl solution you will need to add is:

\[
\frac{10 \, mM}{500 \, mM} \times 1 \, \text{liter} = 0.02 \, \text{liters or 20 ml}
\]

In the following exercise you will practice making such calculations...

**Exercise 8 – Calculations involving concentration**

1. Complete the concentration problems on your worksheet.

---

**Making Solutions**

Another essential skill in the lab is making solutions. You should have already learned how to do this in your chemistry courses, nevertheless it will be good practice to make some solutions in this lab.

**Exercise 9 – Making solutions**

1. Make 1 liter of 1X TAE using a 50X TAE stock solution. The materials you will need can be found at the side of the lab near the window.

2. Make 50 ml of physiological saline solution which is 154 mM or 0.9%. The materials you will need can be found at the side of the lab near the window.

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**Graphing**

The previous lab (Morgan/Carter #1) addressed the graphing of data, however students typically need additional practice. Refer to the graphing guidelines in the previous lab to ensure you graph the data below properly.

**Exercise 10 – Graphing practice**

1. On your worksheet, use the grids provided to graph the three sets of data provided.
Metric System Lab Worksheet

Exercise 1 – 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 __________

Exercise 2A – Measurement of volume

Volume in Flask A = ____________ ml  
Volume in Test Tube B = ____________ ml

Exercise 3 – Measurement of mass

Mass of Graduated Cylinder = _____________ g

Mass of Graduated Cylinder with 50 ml of water = ____________ g

Mass of 50 ml of water (difference of the two numbers above): ____________ g

Difference between your measurement and actual weight of 50 ml of water (50 g): _______

Mass of Large Paper Clip = ____________ g
Exercise 4 – 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: 68°F = _______ °C
Body temperature 98.6°F = _______ °C
Cold day 8°C = _______ °F
Very hot day 40°C = _______ °F

Exercise 5 – Converting from decimal notation to exponential notation

Convert the following decimal numbers to exponential numbers:

243,000 = ____________    ____________  = 0.096
68.3 = ____________    ____________  = 0.00055
803.05 = ____________    ____________  = 0.0000019

Exercise 6 – Converting from exponential notation to decimal notation

Convert the following exponential numbers to decimal numbers:

2.7 x 10⁴ = ____________    ____________  = 10⁷
1.08 x 10⁶ = ____________    ____________  = 4.562 x 10³
4.0103 x 10⁻² = ____________    ____________  = 3 x 10⁵

Exercise 7 – Metric conversions

Convert the following measurements to the indicated unit:

335.9 g = ____________ mg    ____________ m = 0.00886 km
0.0939 μl = ____________ ml    ____________ kg = 894 mg
45.82 ng = ____________ μg    ____________ dl = 90.5 cl
20 kilotons = ____________ megatons    ____________ μm = 0.037 mm
12 megabase pairs (mbp) = ____________ kbp    ____________ mm = 110.5 nm
2.5 mg = ____________ g    ____________ μl = 0.0046 L
Exercise 8 – Calculations involving concentration

You are putting together a reaction in a total volume of 30 µl and stock solution A is 5 mM. What volume of stock solution do you need to add so that the final concentration of A in the reaction is 200 µM?

How many microliters of stock solution B do you need to add to a reaction if the stock concentration is 1 µM, the total volume of the reaction is 25 µl, and the final concentration of B needs to be 0.2 µM?

You are planning an enzymatic reaction and the buffer solution supplied with the enzyme is 5X.

a. How much of this 5X buffer will you add to the reaction if the total volume is 30 µl?

b. After adding what you thought was 5X buffer, you discover that it is actually a 10X buffer and there is none left so you can’t start over. How do you fix the problem so that you have a final concentration of 1X buffer in the reaction?

The enzyme you plan to use in a reaction is at a stock concentration of 10 units/µl. What volume of enzyme do you add if you want a total of 3 units of enzyme in the reaction?

You are responsible for preparing the 1X TAE needed for a Biology 6 laboratory session. The stock TAE solution is 50X and the class will be running a total of 8 samples, each requiring 500 ml of 1X TAE.

a. What total volume of 1X TAE will you need to make?

b. How much 50X TAE and how much water will you combine to make this volume of 1X TAE?
Exercise 9 – Making solutions

Have your instructor initial below to verify that your group has made the indicated solutions:

1X TAE _________    Physiological Saline _________

Exercise 10 – Graphing practice

Identify the independent and dependent variables for each data set, and graph each data set on the grids provided at the end of your worksheet:

1. Average monthly high and low temperatures in downtown Los Angeles from 1981 to 2010

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>average high (°F)</td>
<td>69</td>
<td>69</td>
<td>71</td>
<td>73</td>
<td>75</td>
<td>79</td>
<td>84</td>
<td>85</td>
<td>84</td>
<td>79</td>
<td>73</td>
<td>68</td>
</tr>
<tr>
<td>average low (°F)</td>
<td>50</td>
<td>51</td>
<td>53</td>
<td>55</td>
<td>59</td>
<td>62</td>
<td>65</td>
<td>66</td>
<td>65</td>
<td>60</td>
<td>54</td>
<td>49</td>
</tr>
</tbody>
</table>

Independent variable: ___________________  Dependent variable: ___________________

2. Average distance from sun and temperature data for the planets of the solar system

<table>
<thead>
<tr>
<th></th>
<th>Mercury</th>
<th>Venus</th>
<th>Earth</th>
<th>Mars</th>
<th>Jupiter</th>
<th>Saturn</th>
<th>Uranus</th>
<th>Neptune</th>
</tr>
</thead>
<tbody>
<tr>
<td>average distance from sun (millions of miles)</td>
<td>36</td>
<td>67</td>
<td>93</td>
<td>142</td>
<td>484</td>
<td>887</td>
<td>1784</td>
<td>2794</td>
</tr>
<tr>
<td>average surface temperature (°C)</td>
<td>179</td>
<td>453</td>
<td>12</td>
<td>-43</td>
<td>-153</td>
<td>-185</td>
<td>-214</td>
<td>-225</td>
</tr>
</tbody>
</table>

Independent variable: ___________________  Dependent variable: ___________________

3. National per capita CO₂ emissions for 2010

<table>
<thead>
<tr>
<th></th>
<th>Brazil</th>
<th>Canada</th>
<th>China</th>
<th>France</th>
<th>India</th>
<th>Japan</th>
<th>Mexico</th>
<th>Iran</th>
<th>Russia</th>
<th>U.S.</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ emissions per person (metric tons)</td>
<td>2.2</td>
<td>14.9</td>
<td>6.2</td>
<td>5.5</td>
<td>1.7</td>
<td>8.9</td>
<td>4.1</td>
<td>7.6</td>
<td>11.8</td>
<td>17.6</td>
</tr>
</tbody>
</table>

Independent variable: ___________________  Dependent variable: ___________________