Quantitative Measurements

Introduction

Bill Cosby once joked about the imperial system of measurement. Using artistic license, he retold the Biblical story of Noah and the Ark, including the following exchange:

[The Lord:] Noah...I want you to build an Ark.

[Noah:] Right! What's an Ark?

[The Lord:] Get some wood. Build it 300 cubits by 80 cubits by 40 cubits.

[Noah:] Right! What's a cubit?

[The Lord:] Let's see...a cubit...I used to know what a cubit was.

Systems of measurement have a long and diverse history. In the United States, we typically use the United States Customary System, which evolved from a common ancestor to the imperial units currently used in Great Britain. This system merged components of the Anglo-Saxon and Roman systems of measurement. The Anglo-Saxon system had an agrarian foundation of barleycorns. Legally, an inch was defined as three barleycorns.

So what is a cubit? A cubit is equal to three shaftments or two spans. A shaftment is equal to two palms and a span is equal to 3 palms. A palm is equal to three inches and, as stated before, an inch is equal to three barleycorns. Needless to say, the system is a bit confusing and the barleycorn standard led to some measurement differences. While the imperial system is now standardized, conversion between units can still be a bit awkward (e.g., 12 inches make 1 foot and 3 feet make 1 yard).

Although the United States continues to hold on to the US Customary System, most nations have converted to the International System of Units (SI), which is based in the metric system. Science has adopted this system as well. This facilitates comparison of data throughout space and time. In this course, we will only use the metric system.

Quantitative measurements are important in science because they allow for greater precision and improve our ability to communicate information. For example, the terms ``tall'' and ``taller'' mean little; however, ``29.6 meters tall'' and ``5.6 centimeters taller'' convey more information. The purpose of this lab exercise is to familiarize you with the system of quantitative measurement that you will be using throughout this and future science courses.

Objectives

Having completed the laboratory exercise pertaining to the metric system, the student should be able to:

1. State the metric units of measurement for length, volume, and mass.

2. Use and estimate metric units.
3. Calculate the diameter of low and high power fields of view.
4. State the relationship between length, volume, and mass in metric units.
5. State the relationship between the degree of magnification and the size of the field of view.
6. Convert between metric units of measure.

The Metric System

Introduction

The metric system is based on units of 10. The base units of measure in the metric system are meter (m) for length, the liter (L) for volume, the gram (g) for mass and Kelvin (K) for temperature. More common for temperature, however, are degrees Celsius ($^{\circ}$C), which is equivalent to K -273.15.

Whether measuring length, volume, or mass, the prefixes listed below are used to designate the relationship of a unit of measure to the base unit (i.e., m, L, or g).

Table 1: Prefixes for metric system units commonly used in biology.

Prefix	Abbrev.	Meaning
kilo-	k	1,000
deci-	d	1/10 or 0.1
centi-	c	1/100 or 0.01
milli-	m	1/1,000 or 0.001
micro-	μ	1/1,000,000 or 0.000001
nano-	n	1/1,000,000,000 or
		0.000000001

Example conversion factors for length

1 km = 1,000 m or 1 m = 0.001 km
1 meter (m) = 10 decimeters (dm)
1 meter (m) = 100 centimeters (cm)
1 meter (m) = 1,000 millimeters (mm)
1 meter (m) = 1,000,000 micrometers (μ m)
1 meter (m) = 1,000,000,000 nanometers (nm)

Converting between units of measure

Many students try to jump into unit conversions by moving the decimal place to the left or right. If you are familiar with the metric system, this may work for you. However, common mistakes are moving the decimal in the wrong direction and converting to the base unit of measure rather than the unit needed.

A more reliable method for unit conversion is the use of conversion factors and unit cancellation. For example, if you are asked to convert 2 kL to mL, begin by considering the conversion factors that you know.

1. (k) kilo- means 1000. There are 1000 L in 1 kL.
2. (m) milli- means 1/1000. There are 1000 mL in 1 L.
3. If starting with 2 kL, we need to multiply by a conversion factor to eliminate the `kL'. We need to divide kL by kL to eliminate this unit (kL divided by kL equals 1). Therefore, the multiplier is the conversion factor between kL and L in fraction form:

$$\frac{1000\ \mathrm{L}}{1\ \mathrm{kL}}$$

with kL in the denominator. So, we can multiply our original measure by the conversion factor

$$2\ \not{\mathrm{k}}\mathrm{L} \times \frac{1000\ \mathrm{L}}{1\ \not{\mathrm{k}}\mathrm{L}} = 2000\ \mathrm{L}$$

which cancels out the kL and leaves us with L in the numerator.

4. But we're not done! We wanted to convert to mL, not L. Therefore, we need another conversion factor. We now have L and need mL. One L is equal to 1000 mL. This conversion factor needs to be arranged to eliminate L. In fraction form, we need to divide by L, so our conversion factor becomes

$$\frac{1000\text{ mL}}{1\text{ L}}.$$

Multiplying our new measure by this conversion factor leaves us with mL,

$$2000\ \not{\text{L}} \times \frac{1000\text{ mL}}{1\ \not{\text{L}}} = 2000000\text{ mL}.$$

5. Steps 3 and 4 could be combined as follows:

$$2\ \not{\text{k}}\text{L} \times \frac{1000\ \not{\text{L}}}{1\ \not{\text{k}}\text{L}} \times \frac{1000\text{ mL}}{1\ \not{\text{L}}} = 2000000\text{ mL}.$$

While perhaps tedious, using conversion factors for unit cancellation can help prevent mistakes when converting between units of measure.

Units of Length

Materials

Small metric ruler and a microscope slide.

Procedure

1. Examine a small metric ruler and note the subdivisions. What is the smallest subdivision appearing on the metric ruler?

2. Measure the length and width of a microscope slide in millimeters:

   Length: Width:

3. Convert the length of the microscope slide into the following units:

   meters (m):

   centimeters (cm):

   micrometers (μm):

   nanometers (nm):

   kilometers (km):

4. Measure the length of this page in centimeters and make the following conversions:

   centimeters (cm):

   millimeters (mm):

   meters (m):

   kilometers (km):

Units of Volume

Materials

Shell vial, graduated pipette, pipette bulb, metric ruler, beaker, water

Procedure

1. Using a pipette graduated in milliliters (mL), determine the volume of water required to fill the shell vial.

   mL:

2. Calculate the volume of the shell vial using measurements of length. To calculate the volume of a cylinder, measure the height and radius of the shell vial in centimeters (cm). Use the following formula: $V = \pi r^2 h$ ($\pi = 3.14$)
   Because the measurements were taken in centimeters the volume will be cubic centimeters (cm^3)

Measurements:

r= cm; h= cm

Calculations:

Volume = $\underline{\quad cm^3}$

3. Compare the measured volume (mL) with the calculated volume ($\underline{cm^3}$). Did you find that the measured volume (mL) was very nearly the same as you calculated volume ($\underline{cm^3}$)?

4. What explanations can you state to explain, if there was a difference between your calculated volume and measured volume.

Units of Mass

Materials

Digital balance, shell vial, water

Procedure

1. Mass may be measured with a digital balance.
2. To measure the mass of water that the shell vial holds, complete these steps:
    1. Make sure that the platform of the balance is clear of debris and liquid.
    2. Turn on the digital balance.
    3. Make sure that the units of measure are set to grams (g), not ounces (oz).
    4. Place a shell vial on the balance. Note that its mass should register. However, we are interested in the mass of water that the vial will hold, excluding the mass of the vial itself.
    5. Exclude mass of the vial by ``taring'' the balance. Push the button labeled either ``zero'' or ``tare.'' The balance should now read ``0.0 g''.

6. Remove the shell vial from the platform of the balance and fill it with water. Make sure that there are no drops adhering to the outside of the vial.
7. Place the vial back on the balance. Wait a few seconds for the number to stabilize and record the mass to the greatest precision allowed by the balance.

Mass of water = g

3. Compare your mass (g) with your measured volume (mL). Are these two values very nearly the same?

4. Compare your mass (g) with your calculated volume (cm^3) Are these two values very nearly the same?

5. For water, the numbers above should be nearly the same. This is because a gram was originally defined as the mass of one mL of water at 4 °C. Furthermore, a mL was defined as a cm^3. If there are any differences in numbers for mass and the two measures of volume, explain why.

Note: The term weight was avoided in the above discussion because mass is a quantity of matter, while weight depends on the gravitational field in which the matter is located. Thus, if you were on the moon you would weigh less, but your mass would be the same as on earth. Although it is technically incorrect, mass and weight are often used interchangeably.

Temperature Measurement

Materials

Thermometer marked in degrees Celsius, distilled water, ice, hot plate, and beakers.

Procedure

1. Record the room temperature in degrees Celsius:

2. Using a hot plate and beaker of distilled water record the temperature of boiling water:

3. Record the temperature of ice water:

4. Estimate the outside temperature in degrees Celsius:

Size and Measurement of Microscopic Materials

Calculating the Magnification of the Microscope

Introduction

The magnification of your microscope can be calculated by multiplying the magnification of the ocular by the magnification of the objective used.

Example:

An ocular of $10\times$ with an objective of $5\times$ would give a total magnification of $50\times$.

Materials

Compound microscope and dissection microscope

Procedure

1. Refer to the introduction above and calculate the total magnification of your microscope at the different powers.

   Scanning power:

   Low power:

   High power:

   Oil Immersion:

2. Calculate the lowest and highest magnifications of the dissection microscope. To do this, multiply the magnification of the ocular by number on the magnification change dial.

Lowest power:

Highest power:

The Microscopic Field

Introduction

As the magnification of the objective lens increases, the diameter of the field of view is reduced. The rate of reduction is proportional to the increase in magnification.

Materials

Compound microscope, dissection microscope, plastic metric ruler-length of slide, prepared slide of Paramecium.

Procedure: Compound Microscope

1. With the compound microscope measure the diameter of the low power field ($10\times$) by placing the plastic millimeter rule on the stage of the microscope and focusing on it. What is the diameter of the field in millimeters?

2. Convert this measurement to micrometers (μm):

   This is the diameter of the low power field of your microscope in μm.

3. To calculate the diameter of high power field ($40\times$) complete these two steps:

    1. divide the magnification of the high power field by the magnification of the low power field:

2. then divide the diameter of the low power field (μm) (Answer in question 2) by the quotient found above in step 3(a)

This is the diameter of the high power field of your microscope in μm. Why did you need to calculate this diameter, rather than measuring it directly?

4. Using a prepared slide of Paramecium, focus on these organisms which are stained pink/purple. Estimate the length and width of one Paramecium in micrometers (μm) using the diameters of the microscopic fields calculated above. (Hint: Estimates will be more accurate on high power.)

   Length: μm

   Width: μm

Procedure: Dissection Microscope

1. Using the dissection microscope measure the diameter of the field with the lowest magnification using a millimeter ruler. What is the maximum diameter of the field of view in millimeters (mm)?

2. Focus on one of your finger nails using the dissection microscope. With the ruler, measure the width in millimeters (mm) of your finger nail at the widest point.

3. Focus on your thumb nail using the dissection microscope. With the ruler, measure the width in millimeters (mm) of your thumb at the widest point of your nail.

Review questions:

1. If a beaker contains 150 mL of water, give the mass (weight) and the volume of the water.

   Mass: grams

   Volume: cm^3

2. If your field of view is 2 mm with a $10\times$ objective, what would be your field of view using a $5\times$ objective?

3. If your field of view is 2 mm with a $10\times$ objective, what would be your field of view using a $50\times$ objective?

Reference information for other labs:

1. Diameter of low power field of view of your compound microscope:

   μm

2. Diameter of high power field of view of your compound microscope:

   μm

About this document ...

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