Measurements

As part of their daily work, scientists must carry out common laboratory procedures, take measurements, and report their results accurately and clearly. The system of measurement used in most modern scientific applications is the *metric system*. It is a decimal-based system, meaning that measurements of each type are related by factors of 10.

The metric system has one standard unit for each type of measurement: the standard unit for length measurement is the meter (m), the unit for mass measurement is the gram (g), and the unit for volume is the liter (L). When taking measurements of quantities that are significantly larger or smaller than the standard unit, prefixes are attached in front of the standard unit. Some of the more common prefixes are listed below.

Prefix	Symbol	Meaning
kilo	k	1×10^{3} (1000)
deci	d	1×10^{-1} (0.1)
centi	c	1×10^{-2} (0.01)
milli	m	1×10^{-3} (0.001)
micro	μ	1×10^{-6}

PROCEDURE

A. Preliminary Exercises

When taking measurements, it is essential that you report your answers to the correct decimal place. Determining that decimal place is a simple task. First, determine the quantity represented by the smallest markings on the device you are measuring with. You will report your answer with one more decimal place to the right than is represented by these smallest markings. For example, the smallest markings on the ruler in figure 1 are tenths of a centimeter:

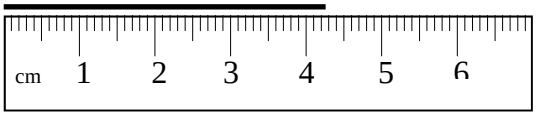


Figure 1

The decimal place to the right of the tenths place is the hundredths place. Therefore, *all* measurements determined with this ruler would be given to the hundredth of a centimeter. Using this information, we can correctly estimate the length of the line above the ruler. If you carefully compare the line to the ruler, you will see that the line is between 4.2 and 4.3 cm; in fact it is much closer to 4.3 than 4.2. I would estimate the length of the line as 4.28 cm. You would not be wrong had you said 4.27 cm or 4.29 cm, or even 4.30 cm, as you are making the best estimate possible with the device you are given. However, it would be incorrect for you to report the length as 4.3 cm; we have already established that any measurements (in centimeters) using this ruler must be reported to the hundredth's place.

We will use the same procedure to determine the length of the line using the ruler in Figure 2.

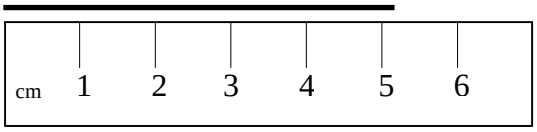


Figure 2

This ruler is not as detailed as the ruler in Figure 1. The smallest markings on the ruler in Figure 2 are whole centimeters, which corresponds to the ones' place. Therefore, we must always report our answer to the *tenth of a centimeter* when using this ruler. The length of the line in Figure 2 may be reported correctly as 5.2 cm. It should make sense to you that the ruler in figure 1 allowed us to measure one more decimal place than the ruler in figure 2.

For whatever reason, many students seem to report their answers incorrectly when a measurement appears to be "on the line". Consider the rulers in figures 1a and 2a below, which are exact copies of the rulers in figures 1 and 2, respectively:

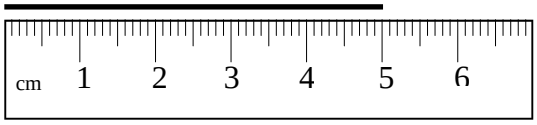


Figure 1a

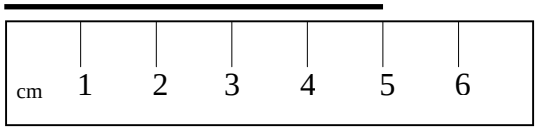


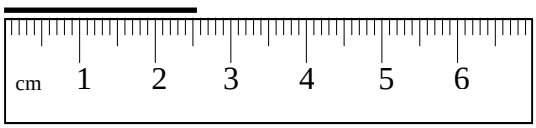
Figure 2a

Using the ruler in figure 1a, we would correctly report the length of the line as 5.00 cm. Recall that *all* measurements taken with this ruler are reported to the hundredths' place. We report the length of the line in figure 2a as 5.0 cm, since measurements with this ruler must always be reported to the tenths' place.

The procedure described here is to be used for all measurements taken in this class, regardless of the type of equipment being used (e.g. rulers, thermometers, graduated cylinders, etc.) or the type of measurement being taken (e.g. length, temperature, volume, etc.) These rules will not apply when using electronic devices, such as balances and stopwatches.

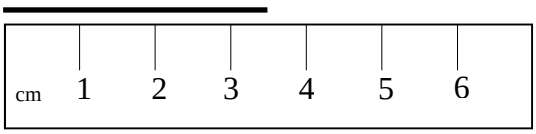
Determine the length of each line below. Copy your answers to the report sheet when you are done.

1.



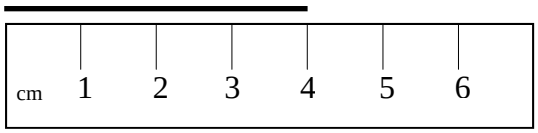
_____ cm

2.



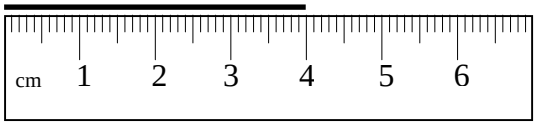
_____ cm

3.



_____ cm

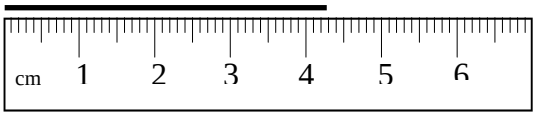
4.



_____ cm

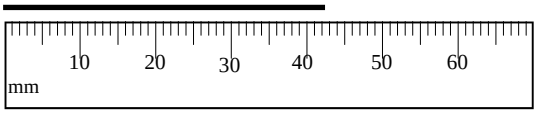
B. Measuring Length and Area

a. Obtain a ruler. In today's exercise we will <u>not</u> use the side labeled in inches. Observe the marked lines, and identify the lines that represent centimeters and those that represent tenths of a centimeter. Note that 1 millimeter is equivalent to 0.1 centimeters, so we may refer to lengths with this ruler using either unit:



4.23 centimeters

is the same as



42.3 millimeters

Note that the number of significant digits <u>does not change!</u>

b. Measure the length of each line below (i) in centimeters, and (ii) in millimeters.

Line 1

Line 2

_____ cm _____ cm

_____ mm _____ mm

Does each pair of measurements have the same number of significant digits? If not, you have not answered this problem correctly.

c. <u>Estimate</u> the length and width of this paper to the nearest *centimeter,* and record your estimate here:

<u>Estimated</u> length:_____cm width: _____cm

. Now, use a ruler to measure the length and width of this paper in cm. Be sure to report your answer with the correct number of decimal places.

<u>Actual</u> length:_____cm width: _____cm

d. Recall from geometry that the area of a rectangle can be found by multiplying the length by the width. Determine the area of the rectangle below in (i) cm^2 and (ii) mm^2

Area of the rectangle:_____ cm^2 _____ mm^2

How many times larger is your number value in mm^2 than the value in cm^2? Circle one.

10 times 100 times 1,000 times

e. Obtain a meter stick. Be careful that you do not poke other students with it, accidentally or otherwise. Use the meter stick to report each of the following distances *in centimeters:*.

i. the distance from the floor to the bottom of the handle of your lab drawer _____

ii. the width of the sink nearest to you _____

iii. the width of the other sink on your lab bench _____

iv. the length of one of the tiles on the floor _____

v. the width of the same tile used in the previous question _____

Did you remember to put units with your answers?

f. Use the information in part e to determine the area of a floor tile. Give your answer in cm^2.

C. Measuring Volume

The graduated cylinder is used to accurately measure the volume of liquids. Although beakers and Erlenmeyer flasks have markings on them indicating volumes, these values are only approximate and should not be used when accurate measurements are required. The rules for determining the number of decimal places a volume measurement should have are the same as those described in Part A for rulers.

Most liquids, when placed in a thin tube, form a curve at their surface. This curve is called a meniscus. The volume level in a liquid should be taken at the bottom of the meniscus.

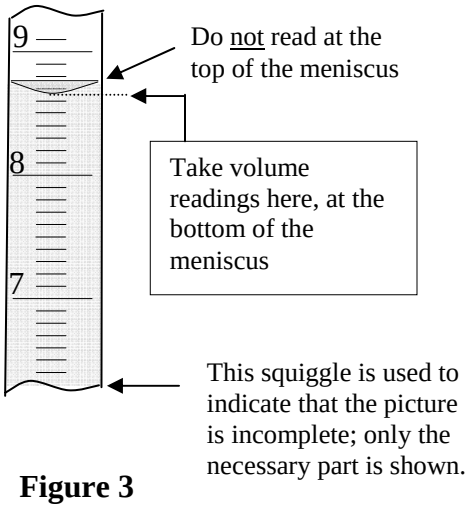


Figure 3

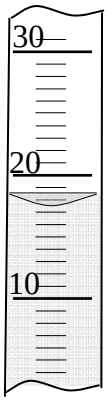


Figure 4

The correct volume reading in figure 3 is 8.65 mL. The reading is to taken to the hundredths place because the smallest marking represents tenths of a milliliter. In contrast, the volume in figure 4 should be read to the tenths place, at 17.5 mL.

The buret is an important piece of glassware which is used when great precision is required in determining the amount of liquid added. The scale on a buret may seem unusual, as the numbers increase from the top down. A correct volume reading for the buret represented in figure 5 is 16.62 mL.

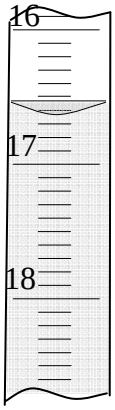


Figure 5

a. Remove a test tube from your drawer. Fill the tube with DI water to the rim (almost overflowing). Hold your large (100 mL) graduated cylinder next to the test tube. Estimate the volume of water in this test tube in milliliters (mL) using the graduated cylinder for comparison. *Estimate to the nearest whole milliliter.*

   Estimated volume _____mL

   Carefully pour the water into the large graduated cylinder. Record the volume.

   Actual volume _____mL (using 100 mL graduated cylinder)

b. Fill the test tube with DI water to the rim again. Pour the water into a medium (50 mL) sized graduated cylinder. Record the volume reading.

Actual volume _____mL (using 50 mL graduated cylinder)

c. Repeat this process using a small (10 mL) graduated cylinder. You must do this in several steps, by first transferring no more than 10 mL of water to the graduated cylinder at a time, and then pouring the water into the sink. When you are done, obtain the volume by adding the total volume measured. *Tip: pour about 9 mL of water into the cylinder, then use your dropper to transfer enough water to exactly match the 10 mL line. This will give you the most accurate results.*

Actual volume _____mL (using 10 mL graduated cylinder)

(Calculations)

d. Three test tubes have been prepared, each containing an unknown volume of water. A drop of food coloring has been added to each tube. Estimate the total volume of colored water in each test tube, basing your judgment on your experiences in parts a.-c. Report your answer *to the nearest milliliter.*

Estimated volume: Green water:_____ mL Red water:_____ mL

Yellow water: _____ mL

e. Obtain a plastic jug and a large 1L graduated cylinder from the cart. Completely fill the jug with tap water. Compare the jug to the graduated cylinder, estimate how many liters of water it contains, and write down this value. *Estimate to the tenth of a liter (one decimal place).*

Estimated volume _____L

f. Carefully pour the water from the jug into the graduated cylinder until you reach the top mark on the cylinder. Then, pour the water down the drain. Continue to refill the graduated cylinder with water from the jug until it is empty. From this, determine how many liters of water the jug will hold. *Report your value to three decimal places.*

Actual volume _____L

g. Locate the two demonstration burets in the classroom. One contains green water, the other red. Carefully read the volume on each buret. An index card with a black line drawn on it may be used to help you get a precise reading. *Record your answer to the hundredths' place.*

Buret reading: Green water:_____ mL Red water: _____ mL

D. Measuring Mass

Your instructor will show you how to use a laboratory balance. Always record all digits displayed on the balance; never round off unless you are specifically told to do so.

a. Determine the mass of (i.) a 50-mL beaker, (ii) a rubber stopper (on the cart), and a metal disk (also on the cart). Copy the number or letter on the disc to your report sheet. *Remember, you must always copy all of the digits from the balance reading on to your report sheet. Do not round off or drop any zeros!*

Mass of 50- mL beaker: _____g

Mass of stopper: _____g

Mass of disc# _____: _____g

b. Pour just enough salt into the beaker you weighed in the previous step to cover the bottom of the beaker. Then, estimate the mass and write down your estimation.

Estimated mass of salt: _____g

Use the balance to determine the mass of your salt, and record the value.

Mass of salt + beaker: _____g

Calculations

Mass of salt: _____g

c. Pour the salt into your evaporating dish. You will need it in a later part of the experiment.
d. You will be asked in later experiments to estimate the amounts of chemicals being used. This next exercise should improve your ability to do so.

i. *Without using the balance*, pour about 1 g of sugar into the 50-mL beaker.
ii. Weigh the beaker to see how close you were to 1 gram. If you were more than 0.25 grams off, repeat this step until you are within 0.25 grams (that is, between 0.750 grams and 1.250 grams).

Mass of sugar + beaker: _____g

Mass of sugar: _____g

iii. Three test tubes (labeled A, B, and C) containing an unidentified amount of salt will be provided on the cart. Carefully estimate the mass of salt in each *to the nearest gram*.

Mass of salt in test tube: A._____g B. _____g C. _____g

E. Measuring Temperature

Before you begin, take a careful look at your thermometer. Locate the following temperatures on it: 120.0 ^{o}C, 100.0 ^{o}C, 25.0 ^{o}C, 0.0 ^{o}C, and -10.0 ^{o}C. Also, determine the number of decimal places you should use in temperature readings with this thermometer, using the guidelines provided earlier.

a. Determine the temperature of the room by simply reading the value on your thermometer.

Temperature of room: _____^{o}C *This value should be close to 25 ^{o}C.*

b. Fill your 250-mL beaker about half way to the top with deionized (DI) water. Then, record the temperature of the water.

Temperature of water: _____^{o}C

c. Put a handful of ice into the beaker, and stir it for about a minute with your glass stirring rod (never stir with your thermometer!) Then, record the temperature of the slush you have made.

Temperature of ice-water: _____^{o}C

d. Pour the salt from Section D into the ice water, and stir it for about two minutes. Record the temperature of this mixture.

Temperature of ice water: _____^{o}C
with salt

Copy all values from these sheets over to the Report Sheet. Do not forget to copy all units! You will only turn in the Report Sheet when you are done. Save the remainder to assist you in further experiments.

Report Sheet **Name:_____**

MEASUREMENTS

A. Preliminary Exercises

a. Lengths of lines on ruler diagrams (p. 2-3)

1._____cm 2._____cm 3. _____cm 4._____cm

B. Measuring Length and Area

b. Lengths of two lines (p. 3)

Line 1	Line 2
_____cm	_____cm
_____mm	_____mm

c. Length and width of paper (p. 3)

Estimated length:_____cm width: _____cm

Actual length:_____cm width: _____cm

d. Area of rectangle (p. 4)

Area of the rectangle:_____ cm^2 _____ mm^2

How many times larger is your number value in mm^2 than the value in cm^2? Circle one.

10 times 100 times 1,000 times

e. Measurements with meter stick (<u>with units</u>)

i. floor to the bottom of the handle of your lab drawer _____

ii. the width of the sink nearest to you _____

iii. the width of the other sink on your lab bench _____

iv. the length of one of the tiles on the floor _____

v. the width of the same tile used in the previous question _____

f. Area of floor tile

Area:_____cm^2

C. Measuring Volume

a. Volume of test tube using 100. mL graduated cylinder (p. 5)

<u>Estimated volume</u> _____mL

<u>Actual volume</u> _____mL (using 100 mL graduated cylinder)

b. Volume of test tube using 50. mL graduated cylinder (p. 6)

<u>Actual volume</u> _____mL (using 50 mL graduated cylinder)

c. Volume of test tube using 10. mL graduated cylinder (p. 6)

<u>Actual volume</u> _____mL (using 10 mL graduated cylinder)

d. Estimation of volume in test tubes (p. 6)

<u>Estimated volume:</u> Green water:_____ mL Red water:_____ mL

Yellow water: _____ mL

e. Estimated volume of plastic jug (p. 6)

<u>Estimated volume</u> _____L

f. <u>Actual volume</u> _____L

g. Buret reading: Green water:_____ mL Red water: _____ mL

D. Measuring Mass

a. Mass of various lab equipment (p. 7)

Mass of 50- mL beaker: _____g

Mass of stopper: _____g

Mass of disc#_____: _____g

b. Estimated mass of salt: _____g

Mass of salt + beaker: _____g

Mass of salt: _____g

d.

ii. Mass of sugar + beaker: _____g

Mass of sugar: _____g

iii. Estimated mass of salt in test tube:

A._____g B. _____g C. _____g

E. Measuring Temperature

a. Temperature of the air in the room_____ºC

b. Temperature of the water_____ ºC

c. Temperature of the ice-water_____ ºC

d. Temperature of the salt/ice-water mixture_____

Questions

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1. Devise a way to measure the approximate thickness of a single sheet of paper in millimeters, using a ruler and paper (and maybe a calculator) as your only tools. (Only suggest a procedure; you do not need to carry it out.) Then, list the steps you would use clearly and in order.

2. Draw a diagonal line on the rectangle on page 4 from one corner across to the opposite corner. Determine the length of the line (in centimeters):

   a. Indirectly, using the Pythagorean theorem (treat the diagonal as the hypotenuse of a triangle and the length and width of the rectangle as the triangle's remaining sides.)

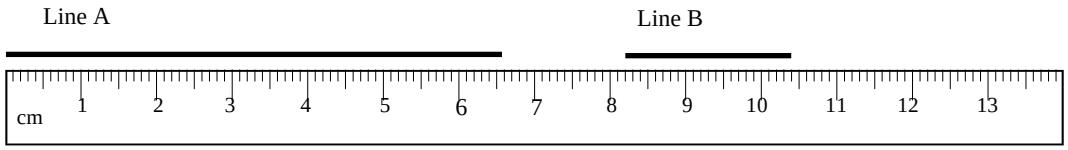
   $a^2 + b^2 = c^2$

   _____cm

   b. Directly, by measuring with a ruler.

   _____cm

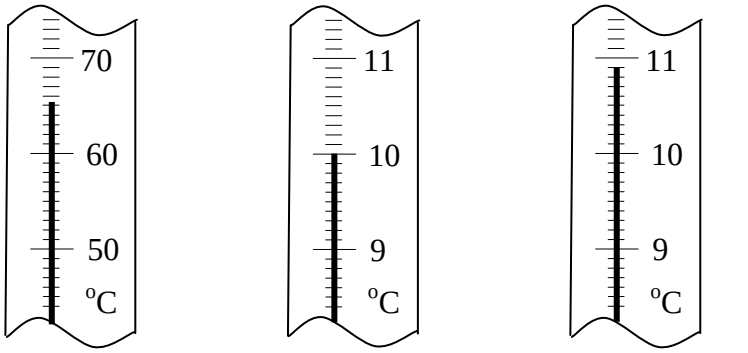
3. Record the correct value of each measurement represented in the pictures below. Be sure to give the correct number of decimal places for each.



Length of line A: in centimeters: _____cm in millimeters: _____mm

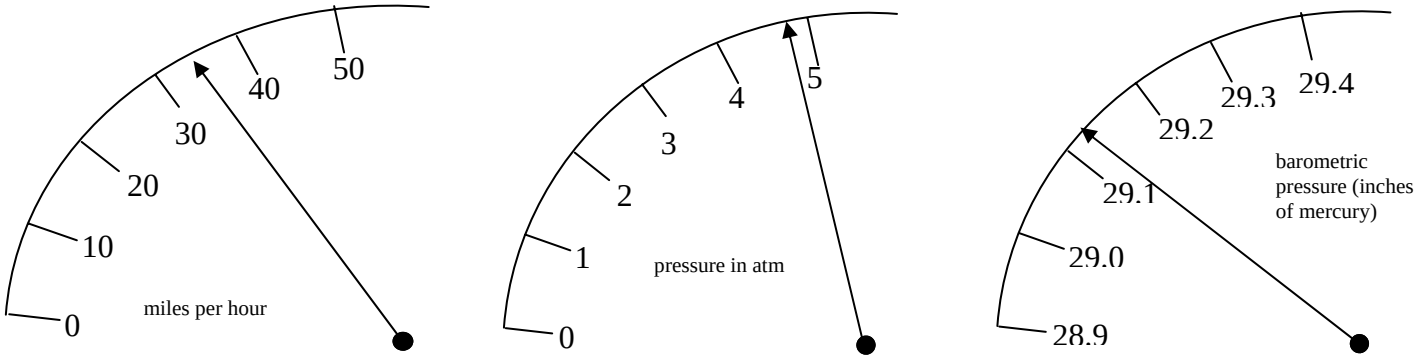
Length of line B: in centimeters: _____cm in millimeters: _____mm

Thermometers



_____°C _____°C _____°C

Gauges



_____mph _____atm _____in Hg

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