



Purpose

The purpose of this experiment is to make measurements using correct number of significant figures and to use measurements appropriately in calculations.

Learning Objectives

State the name and symbol for the SI and metric units of mass, length, time, volume, temperature and amount of substance.

Explain the difference between fundamental and derived units in the SI system.

State the name, symbol and power of ten for the metric prefixes commonly used in chemistry (kilo, deci, centi, milli, micro, nano).

Apply the significant figure rules to report the results of calculations.

Calculate area and volume by measuring dimensions of a solid object and applying the appropriate mathematical formula.

Convert between metric and other units for mass using the appropriate conversion factors.

Laboratory Skills

Use a metric ruler.

Equipment

- Meter stick or metric ruler (rectangular solid or cylinder)
- Solid object (cube,

Chemicals

- none

Background

Measurements are a constant part of life. For example, people use a thermometer to measure the outside temperature or a kitchen scale to measure the mass of an ingredient. Measurements play an important role in laboratory experiments, almost always using the metric system.

Measurements involve two parts: the number and the unit. The unit reflects what property is being measured. For example, the unit, *grams*, indicates a *mass* measurement. The number in the measurement primarily indicates the magnitude or quantity of the measurement units. The number also reflects how precisely the measurement is known, based on how many digits are included in the measurement. In chemistry, measurements are made using the SI system and the metric system.

The SI System

The SI system is an international system of measurements used by scientists and as the official system of measurement of almost all the nations of the world, with the only exceptions being the United States, Myanmar, and Liberia. The SI system, which encompasses the metric system, consists of carefully defined base units that can be modified by prefixes equal to specific multiples of 10. Together, the metric system and scientific notation provide a means to report measurements that range from amazingly small (the mass of an electron, $9.10938356 \times 10^{-31}$ kilograms) to amazingly large (the mass of the sun, 1.9891×10^{30} kilograms), using the same units.

The SI system consists of seven fundamental units, shown in Table CF.1, which also shows the units more commonly used in the chemistry laboratory. In addition, there are derived units, such as volume (cm^3) and density (g/cm^3), which are defined using combinations of the fundamental units. Another commonly used volume unit, the milliliter, is defined as follows: $1 \text{ mL} = 1 \text{ cm}^3$.

The metric/SI system includes a series of prefixes that multiply the base unit by a specific power of ten. The prefixes most commonly used in chemistry, along with their powers of ten are given in Table CF.2.

Table CF.1: SI Fundamental Units

Property	SI Unit (Symbol)	Common Metric Unit (Symbol)
Length	meter (m)	centimeter (cm)
Time	second (s)	second (s)
Mass	kilogram (kg)	gram (g)
Temperature	kelvin (K)	degree Celsius (°C)
Amount of substance	mole (mol)	mole (mol)
Electric current	ampere (A)	ampere (A)
Luminous intensity	candela (cd)	candela (cd)

Table CF.2: Common Metric Prefixes

Prefix	Symbol	Power of ten
giga	G	$\times 10^9$
mega	M	$\times 10^6$
kilo	k	$\times 10^3$
(base unit)	-	$\times 10^0$ (1)
deci	d	$\times 10^{-1}$
centi	c	$\times 10^{-2}$
milli	m	$\times 10^{-3}$
micro	μ	$\times 10^{-6}$
nano	n	$\times 10^{-9}$

Rounding

Because the number of digits in a measurement is important, any calculations using the measurement need to maintain the same level of precision. Calculations need to be rounded to the proper number of digits, which means that not all numbers from a calculator should be reported. Once the correct number of digits to report is

known, the student counts the number of allowed digits starting from the left. The next digit is the first digit to be dropped. If the value of the first digit to be dropped is less than 5, retain the previous digit without changing it and drop the following digits. If the first digit to be dropped is equal to 5 or greater, increase the previous digit by 1 and drop all following digits.

Example CF.1

Round the measurement 17.62 mL to two digits.

The first digit to drop is a 6 so the last retained digit, 7, gets increased to an 8 and the other digits are dropped.

The measurement 17.62 mL rounds to 18 mL when reporting two digits.

Note that some large numbers need placeholder zeros when digits are dropped in order maintain the correct magnitude. When the measurement 6541 g is rounded to three digits, it becomes 6540 g, with the last zero holding the place of the dropped digit.

Significant Figures in Calculations

The digits in a measured number are called significant figures. The result of any calculation using measured numbers must take into account the number of significant figures in the measurements and the mathematical operation involved.

Identifying Significant Figures

The first step in working with significant figures is being able to recognize how many are present in a given measurement. Table CF.3 provides the guidelines for determining significant figures and an example of each.

Table CF.3: Guidelines for Counting Significant Figures

Guideline	Example Measurement	# of Significant Figures
Non-zero digits are ALWAYS significant	1.23 cm	3
Zeros between non-zero digits (sandwich zeros) are ALWAYS significant	4.062 g	4
Zeros to the left of all non-zero digits (preceding zeros) are NEVER significant	0.98 dL	2
Zeros to the right of all non-zero digits (trailing zeros) are ONLY significant with a decimal point	5.60 mL 560 s	3 2

Multiplication and Division

If a calculation uses multiplication and/or division, the result can have no more significant figures than the measurement with the fewest significant figures. That is, the result can only be as precise as the *least* precise measurement used in the calculation.

Example CF.2

Report the result of the calculation with the correct number of significant figures.

$$\frac{560 \text{ mL} \times 0.098 \text{ g}}{1.230 \text{ mL}} =$$

Both 560 and 0.098 have two significant figures while 1.230 has four significant figures. The calculator result is 44.61788618, but that needs to be rounded to two significant figures.

The result reported with the correct number of significant figures is 45 g.

Addition and Subtraction

If a calculation uses addition and/or subtraction, the result should have the same number of digits past the decimal point as the measurement with the fewest digits past the decimal point. This is another way of saying that the result can only be as precise as the least precise measurement used in the calculation.

Example CF.3

Report the result of the calculation with the correct number of significant figures.

$$4.062 \text{ g} + 1.23 \text{ g} + 560. \text{ g} =$$

The measurement with the fewest digits past the decimal point is 560. with zero digits past the decimal point and it has a decimal point, making the zero in the ones place significant. The calculator result is 565.292, but that needs to be rounded to the ones place, with zero digits past the decimal point.

The result reported with the correct number of significant figures is 565 g.

Conversion Factors

Any measured property can be measured in different units. For example, length can be measured in units of meters or yards. Units that measure the same property have a direct equality (conversion factor) that allows them to be interconverted.

Metric Conversions

Metric units for the same property are all related by powers of ten and represented by the prefix of the unit. For example, both grams (g) and milligrams (mg) measure mass. The difference between the units is the prefix milli-, which indicates the power of 10 that relates them, 10^{-3} . Specifically, the equality for these units is $1 \text{ mg} = 10^{-3} \text{ g}$. Another way to write this equation is $1 \text{ g} = 1000 \text{ mg}$. The equality between two units defines the conversion factor, or ratio of the two values, necessary for a conversion.

Example CF.4

Write the equality and two conversion factors between grams and milligrams.

Equality $1 \text{ g} = 1000 \text{ mg}$

Conversion factors $\frac{1 \text{ g}}{1000 \text{ mg}}$ and $\frac{1000 \text{ mg}}{1 \text{ g}}$

The correct conversion factor depends on the starting unit of the measurement.

Note that the values involved in metric equalities are exact and do not limit the significant figures in any calculation using them.

Conversions between Metric and U.S. Units

As stated, any units that measure the same property have a relationship or equality between them. This is true even if the units come from different systems, such as between metric and U.S. units. For example, both centimeters (cm), a metric unit, and inches (in), a U.S. unit, measure length, so there is an equality that $2.54 \text{ cm} = 1 \text{ in}$ that allows conversion between them. The relationship between cm and in is defined as being exact. However, most equalities between units from different systems include a measured, rounded value. For example, the equality between grams (g) and pounds (lb) is $454 \text{ g} = 1 \text{ lb}$. The 454 g value has been measured and reported to three significant figures as the grams in exactly 1 pound. See Table CF.4 for some common relationships between units.

Table CF.4: Common Equalities and Conversion Factors

Property	Metric–Metric		Metric–U.S.	
	Equality	Conversion Factors	Equality	Conversion Factors
Length	$1 \text{ m} = 100 \text{ cm}$	$\frac{1 \text{ m}}{100 \text{ cm}}$ and $\frac{100 \text{ cm}}{1 \text{ m}}$	$1 \text{ in} = 2.54 \text{ cm}$	$\frac{1 \text{ in}}{2.54 \text{ cm}}$ and $\frac{2.54 \text{ cm}}{1 \text{ in}}$
Mass	$1 \text{ kg} = 1000 \text{ g}$	$\frac{1 \text{ kg}}{1000 \text{ g}}$ and $\frac{1000 \text{ g}}{1 \text{ kg}}$	$1 \text{ lb} = 454 \text{ g}$	$\frac{1 \text{ lb}}{454 \text{ g}}$ and $\frac{454 \text{ g}}{1 \text{ lb}}$
Volume	$1 \text{ L} = 1000 \text{ mL}$	$\frac{1 \text{ L}}{1000 \text{ mL}}$ and $\frac{1000 \text{ mL}}{1 \text{ L}}$	$1 \text{ qt} = 946 \text{ mL}$	$\frac{1 \text{ qt}}{946 \text{ mL}}$ and $\frac{946 \text{ mL}}{1 \text{ qt}}$

Using Conversion Factors in Problem Solving

Many of the calculations in chemistry can be summarized in the following steps and are shown in the example below:

- Identify the starting measurement and the desired unit or related property.
- Identify the equality or equalities that relate the starting measurement and desired property.
- Multiply the starting measurement by the conversion factor or factors.
- Round the result to the correct number of significant figures.

Example CF.5

What is the length of a bed that is 1.91 m long in cm?

1. **Identify the given and desired values and units.**

Given: 1.91 meters Desired: length in centimeters.

2. **Plan out the connections needed.**

Is there a direct connection (one equality) or are multiple steps needed? There is a direct equality between m and cm, so only one step is needed.

3. **State the equalities and conversion factors from your plan.** Equality: 1 m = 100 cm

Conversion factors: $\frac{1\text{ m}}{100\text{ cm}}$ and $\frac{100\text{ cm}}{1\text{ m}}$

4. **Set up calculation to cancel starting units and give desired units.** Start by writing the given value. Then, select the conversion factor that has the desired units on the top and starting units on the bottom. Finally, multiply the given, starting value by the selected conversion factor.

$$1.91\text{ m} \times \frac{100\text{ cm}}{1\text{ m}} = 191\text{ cm}$$

5. **Review the magnitude and precision of your answer.** Check that the relative size of your answer makes physical sense and that the answer is reported with the correct significant figures. Magnitude: A centimeter is a smaller unit of length than a meter, so there are more cm than m in the same length. Precision: The starting measurement was reported with 3 significant figures in a multiplication/division calculation with an exact metric conversion factor, so the answer is reported with three significant figures.

Procedure

Comments

- For each measurement tool, note the smallest unit of measurement.
- Include an estimated digit in each recorded measurement.
- *Check with TA or Instructor for any other supplies you may need.*

Safety Precautions

Safety goggles are required!

Rounding

1. See Report Table CF.1 for values rounded by a student to three significant figures.
2. For each value, determine if the rounding was done correctly.
3. If not, write the correctly rounded value.

Significant Figures in Calculations

Multiplication and Division

Solve the multiplication and division problems, reporting the answer with the correct number of significant figures.

Addition and Subtraction

Solve the addition and subtraction problems, reporting the answer with the correct number of significant figures.

Area

1. Use the virtual metric rule to measure the length and width, in centimeters (cm), of the rectangle drawn on the report sheet.
2. Calculate the area (in cm^2) of the rectangle using your measurements and the equation $\text{area} = \text{length} \times \text{width}$.
3. You will be provided with another student's measurements for the same rectangle.
4. Calculate the area of the rectangle using the other student's measurements.

Volume of a Solid

1. Record the shape of the solid object and which dimensions need to be measured from Table CF.5.
2. Use the meter stick or metric ruler to measure the dimensions of the solid object in centimeters (cm).
3. Calculate the volume of the solid object using the equation from Table CF.5.

Table CF.5: Calculating the Surface Area and Volume of Common 3D Shapes

Shape	Dimensions to measure	Surface area equation	Volume equation
Cube	length (l)	$6l^2$	l^3
Rectangular solid (box)	length (l), width (w), and height (h)	$2lw + 2wh + 2lh$	$l \times w \times h$
Sphere	circumference ($2\pi r$)	$4\pi r^2$	$\frac{4}{3}\pi r^3$
Cylinder	diameter ($2r$) and height (h)	$2\pi r h + 2\pi r^2$	$\pi r^2 h$

Using Conversion Factors in Problem Solving

Conversions with Metric Prefixes

For each metric conversion, select the correct conversion factor(s) to use and then complete the conversion.

Conversions with Non-Metric Units

Complete each conversions using non-metric units. Report your answer to each conversion with the correct number of significant figures.

Problem Solving – Calculating Your Metric Height

1. Record your height in inches. Use the yardstick if needed.
2. Use the appropriate conversion factor to calculate your height in centimeters. Write out your work for each calculation, striking through units as they cancel.
3. Use the appropriate conversion factor to calculate your height in meters. Write out your work for each calculation, striking through units as they cancel.



Name: _____

Section: _____ Date: _____

Report Sheet:

Conversion Factors and Problem Solving

Rounding

Report Table CF.1: Rounding Measurements to Three Significant Figures

	Initial Value	Student's Rounded Value	Correct Rounding (yes/no)	Correct Rounded Value
Value 1	243.6193 g	244 g	_____	_____
Value 2	654900 mL	655 mL	_____	_____
Value 3	0.00731582 m	0.007 m	_____	_____
Value 4	3 g/mL	3.00 g/mL	_____	_____

Significant Figures in Calculations

Multiplication and Division

Report your answers for the calculations below in your Labflow report with the correct number of significant figures.

1. $0.1184 \text{ cm} \times 8.00 \text{ cm} \times 0.0345 \text{ cm}$

2.
$$\frac{(42.4 \text{ mL})(15.6 \text{ g})}{1.265 \text{ mL}}$$

3.
$$\frac{(35.56 \text{ g})(1.45 \text{ mL})}{(4.8 \text{ mL})(0.56 \text{ min})}$$



Addition and Subtraction

Report your answers for the calculations below in your Labflow report with the correct number of significant figures.

1. $13.45 \text{ mL} + 0.4552 \text{ mL}$

2. $145.5 \text{ m} + 86.58 \text{ m} + 1045 \text{ m}$

3. $245.625 \text{ g} - 80.2 \text{ g}$

4. $4.62 \text{ cm} - 0.885 \text{ cm}$

Area

Report your answers for the calculations below in your Labflow report with the correct number of significant figures.

Your Measurements

Length of the rectangle (cm) _____

Width of the rectangle (cm) _____

Calculate the area (in cm^2) of the rectangle using your measurements.

Another Student's Measurements

Length of the rectangle (cm) _____

Width of the rectangle (cm) _____

Calculate the area (in cm^2) of the rectangle using the other student's measurements.

Volume of a Solid

Shape of the solid _____

Dimensions to measure _____

Height (cm) _____

Length (cm) _____

Width (cm) _____

Diameter (cm) _____

Calculate the volume of the solid object.

Show your work:

Using Conversion Factors in Problem Solving

Conversions with Metric Prefixes

1.
 - a. What conversion factor(s) can you use to convert m to km?

 - b. Complete the conversion of the number in Labflow from m to km.

2.
 - a. What conversion factor(s) can you use to convert g to μg ?

 - b. Complete the conversion of the number in Labflow from g to μg .

3.
 - a. What conversion factor(s) can you use to convert ng to mg?

 - b. Complete the conversion of the number in Labflow from ng to mg.

4.
 - a. What conversion factor(s) can you use to convert kg to Mg?

 - b. Complete the conversion of the number in Labflow from kg to Mg.

Conversions with Non-Metric Units

If $2.54 \text{ cm} = 1 \text{ in}$, convert the number in Labflow from m to inches.

If $1 \text{ mile} = 1.609 \text{ km}$, convert the number in Labflow from miles to kilometers.

If $1 \text{ liter} = 1.0567 \text{ quarts}$, convert the number in Labflow from mL to quarts.

Knowing that $1 \text{ mile} = 1.609 \text{ km}$ and there are 60 minutes in 1 hour, convert the number in Labflow from miles per hour to kilometers per minute.

Calculating your Metric Height

Height (in) _____

Height (cm) _____

Height (m) _____

Show your work, striking through units as they cancel.