EXPERIMENT

2

Instrumental Measurements

OBJECTIVES

- To obtain measurements of length, mass, volume, and temperature.
- To determine the mass and volume of an unknown rectangular solid.
- To gain proficiency in using the following instruments: metric rulers, balances, graduated cylinder, and thermometer.

DISCUSSION

The **metric system** uses a basic set of units and prefixes. The basic unit of length is the meter, the basic unit of mass is the gram, and the basic unit of volume is the liter. Metric prefixes make these basic units larger or smaller by powers of 10. For example, a kilometer is a thousand times longer than a meter, and a millimeter is a thousand times less than a meter. In the laboratory, the most common unit of length is **centimeter** (symbol **cm**), the most common unit of mass is **gram** (symbol **g**), and the most common unit of volume is **milliliter** (symbol **mL**).

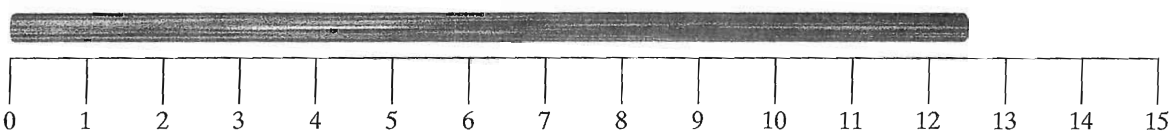
Scientific instruments have evolved to a high state of sensitivity. However, it is not possible to make an exact measurement. The reason is that all instruments possess a degree of **uncertainty**—no matter how sensitive. The uncertainty is indicated by the significant digits in the measurement. For example, a metric ruler may measure length to the nearest tenth of a centimeter (± 0.1 cm). A different metric ruler may measure length to the nearest five hundredths of a centimeter (± 0.05 cm). The measurement with least uncertainty (± 0.05 cm) is more precise.

In this experiment, we will use several instruments. We will make measurements of mass with balances having progressively greater sensitivity. A decigram balance is so named because the uncertainty is one-tenth of a gram (± 0.1 g). The uncertainty of a centigram balance is one-hundredth of a gram (± 0.01 g), and the uncertainty of a milligram balance is one-thousandth of a gram (± 0.001 g).

We will make length measurements using two metric rulers that differ in their uncertainty. METRIC RULER A is calibrated in 1-cm divisions and has an uncertainty of ± 0.1 cm. METRIC RULER B has 0.1-cm subdivisions and an uncertainty of ± 0.05 cm. Thus, METRIC RULER B has less uncertainty than METRIC RULER A. The following examples demonstrate measurement of length utilizing the two different metric rulers.

Example Exercise 2.1 • Measuring Length with Metric Ruler A

A copper rod is measured with the metric ruler shown below. What is the length of the rod?



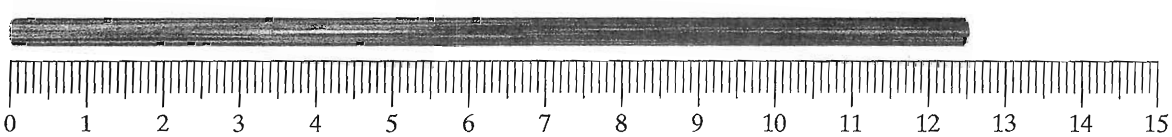
METRIC RULER A *(Estimate to a tenth of a division ±0.1 cm)*

Solution: Each division represents one centimeter. The end of the rod lies between the 12th and 13th divisions. We can estimate to a tenth of a division (± 0.1 cm). Since the end of the rod lies about five-tenths past 12, we can estimate the length as

$$12 \text{ cm} + 0.5 \text{ cm} = 12.5 \text{ cm}$$

Example Exercise 2.2 • Measuring Length with Metric Ruler B

The same copper rod is measured with the metric ruler shown below. What is the length of the rod?



METRIC RULER B *(Estimate to a half of a subdivision ±0.05 cm)*

Solution: Note that this ruler is divided into centimeters that are subdivided into tenths of centimeters. The end of the rod lies between the 12th and 13th divisions and between the 5th and 6th subdivisions. Thus, the length is between 12.5 cm and 12.6 cm.

We can estimate the measurement more precisely. A subdivision is too small to divide into ten parts but we can estimate to half of a subdivision (± 0.05 cm). The length is 12 cm + 0.5 cm + 0.05 cm = 12.55 cm.

We can measure the volume of a liquid using a graduated cylinder. If we carefully examine the 100-mL graduated cylinder shown in Figure 2.1, we notice that it is marked in 10-mL intervals, and each interval has ten subdivisions. Therefore, each subdivision equals one milliliter. If we estimate to half of a subdivision, the uncertainty is ± 0.5 mL.

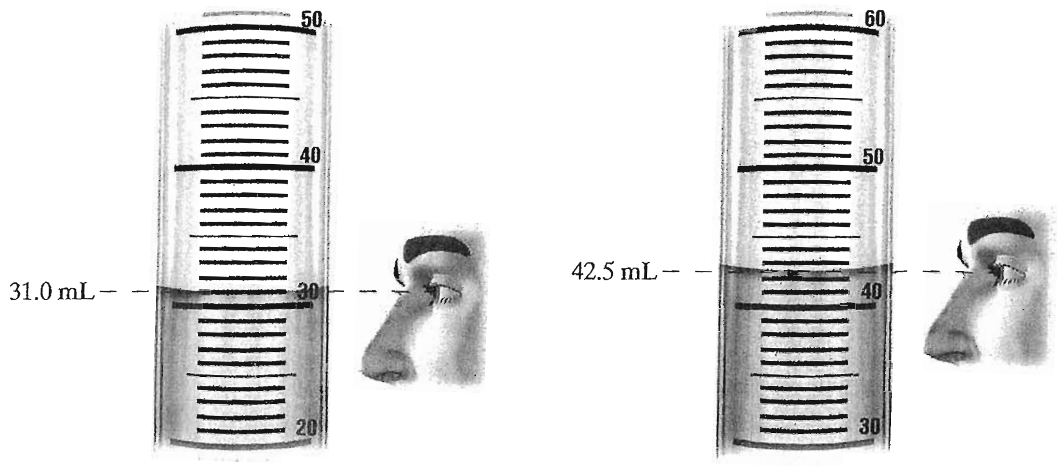


Figure 2.1 Graduated Cylinder Example readings using proper eye position and recording the bottom of the lens to half a subdivision (± 0.5 mL).

We can measure the temperature using a Celsius thermometer. If we examine the thermometer shown in Figure 2.2, we notice that it is marked in 10°C intervals that have ten subdivisions. Thus, each subdivision equals one degree Celsius. If we estimate to half of a subdivision, the temperature measurement has an uncertainty of ± 0.5°C.

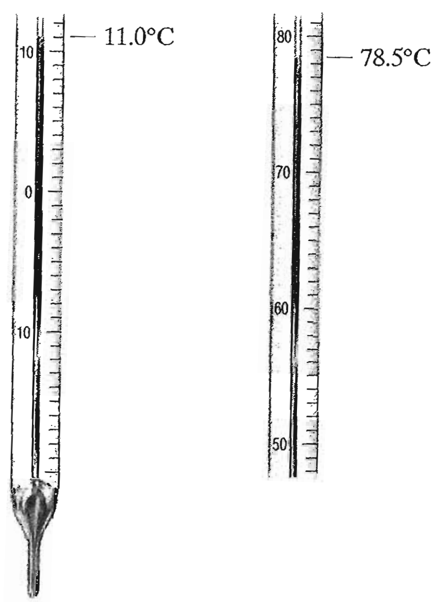


Figure 2.2 Celsius Thermometer Example readings obtained using a Celsius thermometer and recording the top of the liquid to half a subdivision (± 0.5°C).

To test your skill in making metric measurements, you will find the mass and volume of an unknown rectangular solid. The volume of a rectangular solid is calculated from its length, width, and thickness. The following examples will illustrate.

Example Exercise 2.3 • Calculating Volume of a Rectangular Solid

An unknown rectangular solid was measured with METRIC RULER A, which provided the following dimensions: 5.0 cm by 2.5 cm by 1.1 cm. What is the volume of the solid?

Solution: The volume of a rectangular solid equals length times width times thickness.

$$5.0 \text{ cm} \times 2.5 \text{ cm} \times 1.1 \text{ cm} = 13.75 \text{ cm}^3 = 14 \text{ cm}^3$$

When multiplying, the product is limited by the least number of significant digits. In this example, each dimension has two significant digits; thus, the volume is limited to two significant digits.

Example Exercise 2.4 • Calculating Volume of a Rectangular Solid

The unknown rectangular solid was also measured with METRIC RULER B, which gave the following: 5.00 cm by 2.45 cm by 1.15 cm. What is the volume of the solid?

Solution: The volume is once again found by multiplying the three dimensions.

$$5.00 \text{ cm} \times 2.45 \text{ cm} \times 1.15 \text{ cm} = 14.0875 \text{ cm}^3 = 14.1 \text{ cm}^3$$

In this example, each dimension has three significant digits; thus, the volume has three significant digits.

EQUIPMENT and CHEMICALS

- 13 × 100 mm test tubes (3)
- watchglass
- evaporating dish
- 250-mL beaker
- 125-mL Erlenmeyer flask
- crucible and cover
- 100-mL graduated cylinder
- dropper pipet
- 110 °C thermometer
- 150-mL beaker
- ring stand
- wire gauze
- decigram balance
- centigram balance
- milligram balance
- ice
- unknown rectangular solids

PROCEDURE

A. Length Measurement

1. Measure the length of a 13 × 100 mm test tube with each of the following: (a) METRIC RULER A, and (b) METRIC RULER B.

   Note: Refer to METRIC RULER A instructions in **Example Exercise 2.1**.
   Refer to METRIC RULER B instructions in **Example Exercise 2.2**.

2. Measure the diameter of a watchglass with each of the following: (a) METRIC RULER A, and (b) METRIC RULER B.

   Note: Refer to METRIC RULER A instructions in **Example Exercise 2.1**.
   Refer to METRIC RULER B instructions in **Example Exercise 2.2**.

3. Measure the diameter of an evaporating dish (not the spout) with each of the following: (a) METRIC RULER A, and (b) METRIC RULER B.

   Note: Refer to METRIC RULER A instructions in **Example Exercise 2.1**.
   Refer to METRIC RULER B instructions in **Example Exercise 2.2**.

B. Mass Measurement

1. Determine the mass of a 250-mL beaker on each of the following balances: (a) decigram balance, (b) centigram balance, and (c) milligram balance.
2. Determine the mass of a 125-mL Erlenmeyer flask on each of the following balances: (a) decigram balance, (b) centigram balance, and (c) milligram balance.
3. Determine the mass of a crucible and cover on each of the following balances: (a) decigram balance, (b) centigram balance, and (c) milligram balance.

   Note: Refer to balance instructions in **Appendices B**, **C**, and **D**.

C. Volume Measurement

1. Fill a 100-mL graduated cylinder with water. Adjust the bottom of the lens to the full mark with a dropper pipet. Record the volume as 100.0 mL.
2. Fill a 13 × 100 mm test tube with water from the graduated cylinder. Record the new volume in the graduated cylinder (± 0.5 mL).

   Note: Refer to the graduated cylinder instructions in **Figure 2.1**.

3. Fill a second test tube with water. Record the volume in the graduated cylinder.

D. Temperature Measurement

1. Record the temperature in the laboratory using a Celsius thermometer (± 0.5°C).

2. Half fill a 100-mL beaker with ice and water. Hold the thermometer in the ice water, and record the coldest observed temperature (± 0.5°C).

3. Half fill a 150-mL beaker with distilled water. Support the beaker on a ring stand with a wire gauze as shown in Figure 2.4. Heat the water to boiling and shut off the burner. Hold the thermometer in the boiling water and record the hottest temperature (± 0.5°C).

   Note: Refer to the laboratory burner instructions in **Appendix A**. You should not let the tip of the thermometer touch the bottom of the glass beaker.

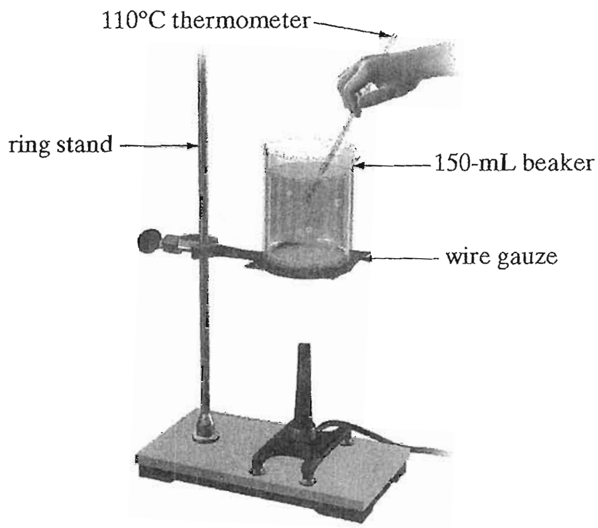


Figure 2.4 Temperature of Boiling Water To avoid breakage, do not allow the thermometer to touch the hot glass beaker.

E. Mass and Volume of an Unknown Solid

1. Obtain a rectangular solid, and record the unknown number in the Data Table. Find the mass of the unknown rectangular solid using each of the following: (a) a decigram balance, (b) a centigram balance, and (c) a milligram balance.

2. Measure the length, width, and thickness of the rectangular solid unknown using METRIC RULER A in Figure 2.3. Calculate the volume.

3. Measure the length, width, and thickness of the rectangular solid unknown using METRIC RULER B in Figure 2.3. Calculate the volume.

EXPERIMENT 2 NAME ______________________

DATE ______________ SECTION ______________________

*PRELABORATORY ASSIGNMENT**

1. In your own words, define the following terms:

   centimeter (cm)

   gram (g)

   metric system

   milliliter (mL)

   uncertainty

2. State the uncertainty in the following measuring instruments.

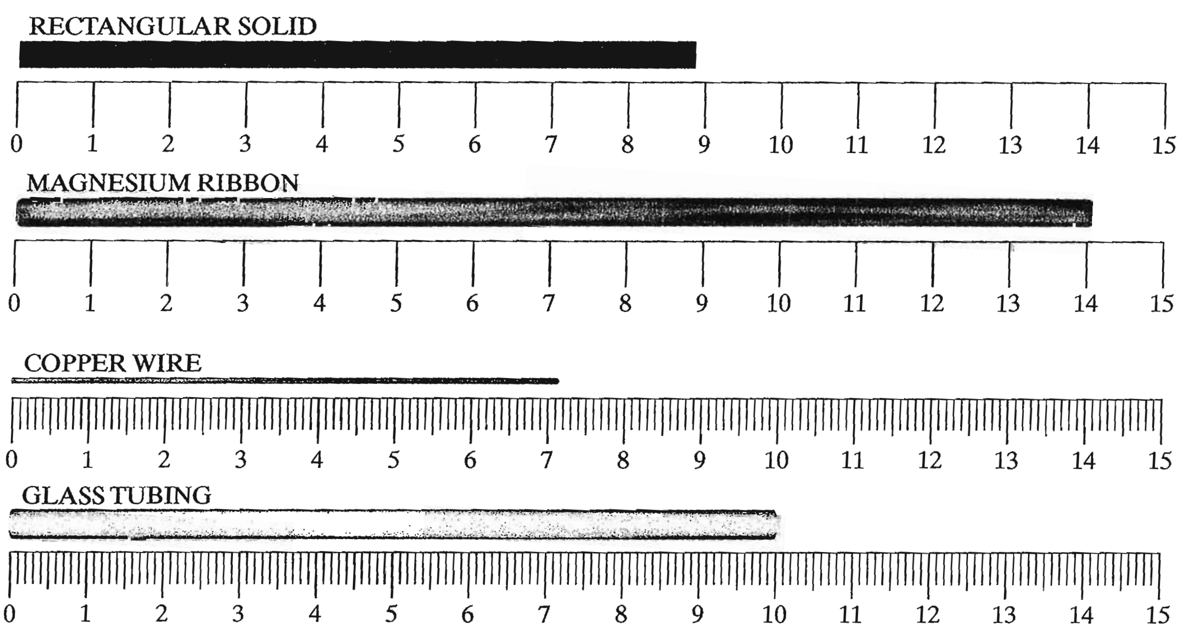
   (a) METRIC RULER A ________ (b) METRIC RULER B ________

   (c) decigram balance ________ (d) centigram balance ________

   (e) milligram balance ________ (f) graduated cylinder ________

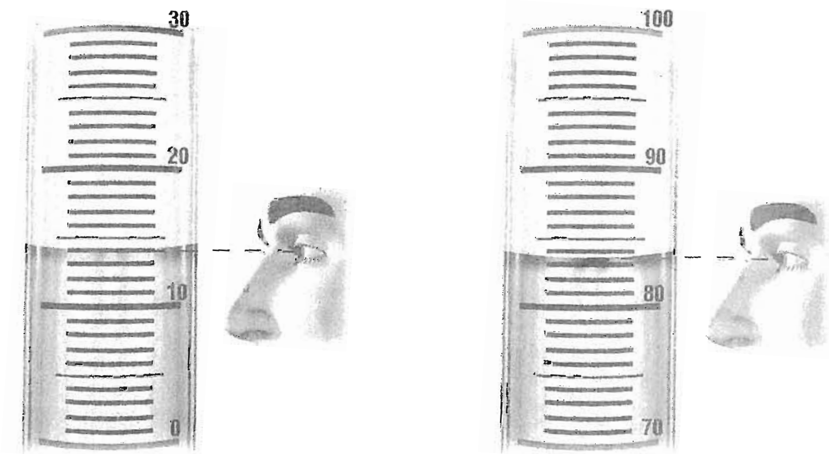
   (g) thermometer ________

3. Refer to Example Exercises 2.1 and 2.2 and record the measurement indicated by each of the following metric rulers.

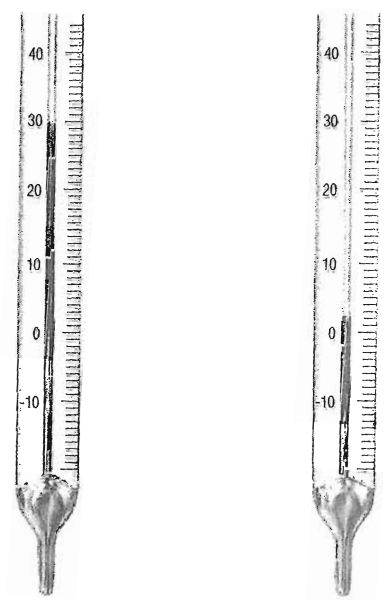


* *Answers in Appendix J*

4. Refer to Figure 2.1 and record the measurement indicated by each graduated cylinder.



5. Refer to Figure 2.2 and record the measurement indicated by each Celsius thermometer.



6. An unknown rectangular solid has the following measurements: 5.0 cm by 2.4 cm by 1.3 cm. Refer to Example Exercise 2.3 and calculate the volume in cubic centimeters.

7. An unknown rectangular solid has the following measurements: 5.00 cm by 2.45 cm by 1.25 cm. Refer to Example Exercise 2.4 and calculate the volume in cubic centimeters.

8. What safety precautions must be observed in this experiment?

EXPERIMENT 2 NAME ______________________

DATE ______________ SECTION ______________________

DATA TABLE

A. Length Measurement

length of a 13 × 100 mm test tube

METRIC RULER A ____________ cm

METRIC RULER B ____________ cm

diameter of a watchglass

METRIC RULER A ____________ cm

METRIC RULER B ____________ cm

diameter of an evaporating dish

METRIC RULER A ____________ cm

METRIC RULER B ____________ cm

B. Mass Measurement

mass of a 250-mL beaker

decigram balance ____________ g

centigram balance ____________ g

milligram balance ____________ g

mass of a 125-mL Erlenmeyer flask

decigram balance ____________ g

centigram balance ____________ g

milligram balance ____________ g

mass of a crucible and cover

decigram balance ____________ g

centigram balance ____________ g

milligram balance ____________ g

C. Volume Measurement

volume of water in a graduated cylinder ____________ mL

volume minus one test tube of water ____________ mL

volume minus two test tubes of water ____________ mL

D. Temperature Measurement

room temperature ____________ °C

melting point temperature of ice ____________ °C

boiling point temperature of water ____________ °C

E. Mass and Volume of an Unknown Solid **UNKNOWN #** _______

mass of unknown solid

decigram balance ____________ g

centigram balance ____________ g

milligram balance ____________ g

volume of unknown solid (METRIC RULER A)

length of solid ____________ cm

width of solid ____________ cm

thickness of solid ____________ cm

Show the calculation for the volume of the rectangular solid (see Example Exercise 2.3).

____________ cm^3

volume of unknown solid (METRIC RULER B)

length of solid ____________ cm

width of solid ____________ cm

thickness of solid ____________ cm

Show the calculation for the volume of the rectangular solid (see Example Exercise 2.4).

____________ cm^3

EXPERIMENT 2 NAME ______________________________

DATE ____________________ SECTION ______________________________

POSTLABORATORY ASSIGNMENT

1. State the basic unit and symbol in the metric system for each of the following quantities.

(a) length ____________ (b) mass ____________

(c) volume ____________ (d) temperature ____________

2. State a common metric unit and symbol obtained from each of the following instruments.

(a) metric ruler ____________ (b) balance ____________

(c) graduated cylinder ____________ (d) thermometer ____________

3. State a common laboratory instrument for measuring each of the following examples.

(a) diameter of beaker ____________ (b) mass of sugar ____________

(c) volume of alcohol ____________ (d) temperature of air ____________

4. Select the measurement that is consistent with the uncertainty of each instrument.

(a) METRIC RULER A: 10 cm, 10.0 cm, 10.00 cm ____________

(b) METRIC RULER B: 10 cm, 10.0 cm, 10.00 cm ____________

(c) decigram balance: 10.0 g, 10.00 g, 10.000 g ____________

(d) centigram balance: 10.0 g, 10.00 g, 10.000 g ____________

(e) milligram balance: 10.0 g, 10.00 g, 10.000 g ____________

(f) graduated cylinder: 10 mL, 10.0 mL, 10.00 mL ____________

(g) Celsius thermometer: 10 °C, 10.0 °C, 10.00 °C ____________

5. State the uncertainty (for example, ± 0.5 cm) in each of the following measurements.

(a) 10.00 cm ____________ (b) 10.000 g ____________

(c) 10.0 mL ____________ (d) 10.0 °C ____________

6. State the number of significant digits in each of the following measurements.

(a) 1.00 cm ________ (b) 0.05 cm ________

(c) 1.000 g ________ (d) 0.050 g ________

(e) 10.0 mL ________ (f) 50.0 mL ________

(g) 110.0 °C ________ (h) –20.0°C ________

7. Perform the indicated math operation and round off the answer to the proper significant digits.

(a)
50.55 g
+ 10.050 g

(b)
50.55 mL
– 10.5 mL

8. Perform the indicated math operation and round off the answer to the proper significant digits.

(a) (10.50 cm) (1.50 cm)

(b) $\frac{50.50 \text{ cm}^3}{15.0 \text{ cm}^2}$

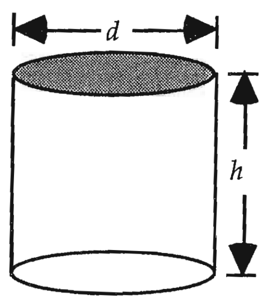
9. After recording a measurement using an instrument, do you round off experimental data?

YES / NO Explain:

10. After multiplying or dividing using a calculator, do you round off numbers in the display?

YES / NO Explain:

11. (optional) The original reference kilogram is a solid cylinder made of a platinum–iridium alloy. If the diameter and height are each 3.90 cm, what is the volume in cubic centimeters?



Note: The volume of a solid cylinder equals $\pi d^2h/4$, where π is 3.14, d is the diameter, and h is the height.