EXERCISE 23

# The Metric System, Measurements, and Scientific Inquiry

Earth science, the study of Earth and its neighbors in space, involves investigations of natural objects that range in size from the very smallest divisions of atoms to the largest of galaxies (Figure 23.1). From atoms to galaxies, objects are each unique in their size, mass, and volume; and yet all are related when it comes to understanding the nature of Earth and its place in the universe.

Almost every scientific investigation requires accurate measurements. One important purpose of this exercise is to examine the metric system as a method of scientific measurement used in the Earth sciences. In addition, a few special units of measurement are also examined. The exercise concludes with an activity that focuses on the nature of scientific inquiry.

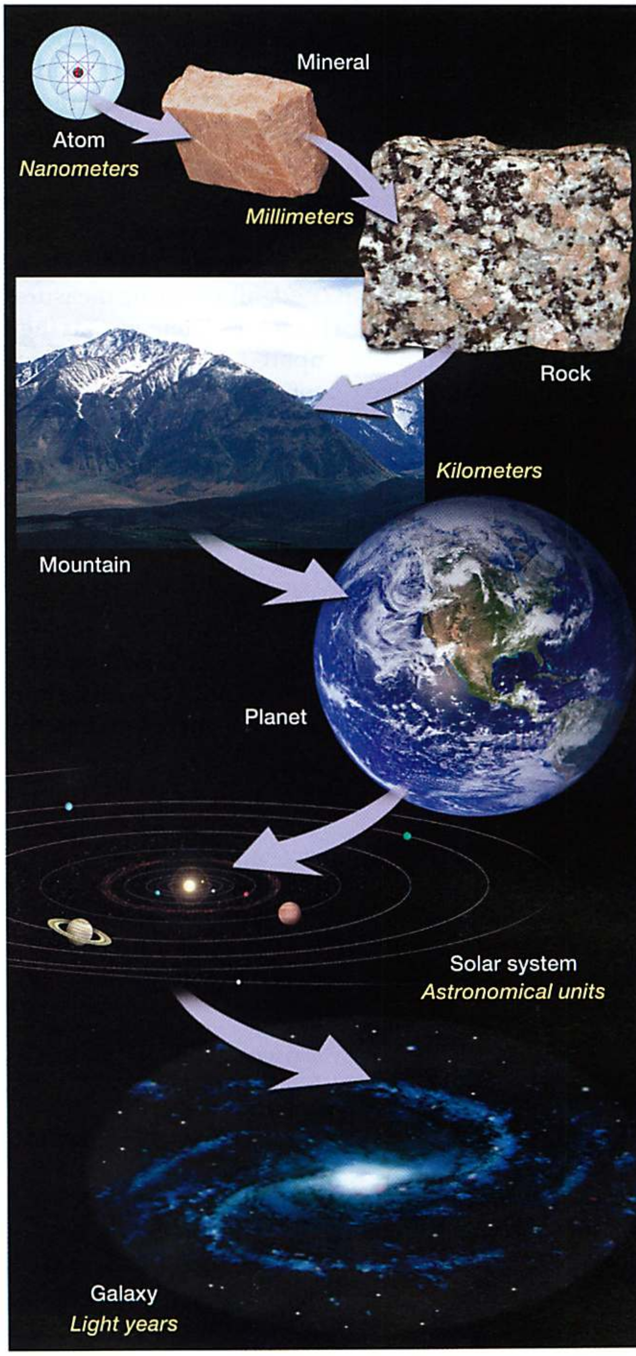


Figure 23.1 The range of Earth science measurements.

## Objectives

After you have completed this exercise, you should be able to:

1. List the units for length, mass, and volume that are used in the metric system.
2. Use the metric system for measurements.
3. Convert units within the metric system.
4. Understand and use the micrometer and nanometer for measuring very small distances as well as the astronomical unit and light-year for measuring large distances.
5. Determine the approximate density and specific gravity of a solid substance.
6. Conduct a scientific experiment using accepted methods of scientific inquiry.

## Materials

metric ruler
calculator

*Materials Supplied by Your Instructor*

metric tape measure or meterstick
metric balance
"bathroom" scale (metric)
paper clip
paper cup
thread
large graduated cylinder (marked in milliliters)
nickel coin
small rock

## Terms

| | | |
|---|---|---|
| metric system | micrometer (or micron) | light-year |
| meter | nanometer | density |
| liter | astronomical unit | specific gravity |
| gram | Kelvin degrees | hypothesis |
| Celsius degrees | | |

## Introduction

To describe objects, Earth scientists use units of measurement that are relative to the particular feature being studied. For example, centimeters or inches, instead of kilometers or miles, would be used to measure the width of this page; and kilometers or miles, rather than centimeters or inches, to measure the distance from New York to London, England.

Most areas of science have developed units of measurement that meet their particular needs. However, regardless of the unit used, all scientific measurements are defined within a broader system so that they may be understood and compared. In science, the fundamental units have been established by the *International System of Units* (SI, Système International d'Unités) (Table 23.1).

## The Metric System

The **metric system** is a decimal system (based on fractions or multiples of ten) that uses only one basic unit for each type of measurement: the **meter** (m) as the unit of length (Figure 23.2), the **liter** (l) as the unit of volume (One liter is equal to the volume of one kilogram of pure water at 4°C (39.2°F), about 1.06 quarts.), and the **gram** (g) as the unit of mass (Figure 23.3). In the English system, the units used to express the same relations are feet, quarts, and ounces.

**Table 23.1** Base units of the SI. From these base units, other units are derived to express quantities such as power (watt, W), force (newton, N), energy (joule, J), and pressure (pascal, Pa).

| Unit | Quantity measured | Symbol |
|---|---|---|
| meter | length | m |
| kilogram | mass | kg |
| second | time | s |
| kelvin | thermodynamic temperature | K |
| ampere | electric current | A |
| mole | quantity of a substance | mol |
| candela | luminous intensity | cd |

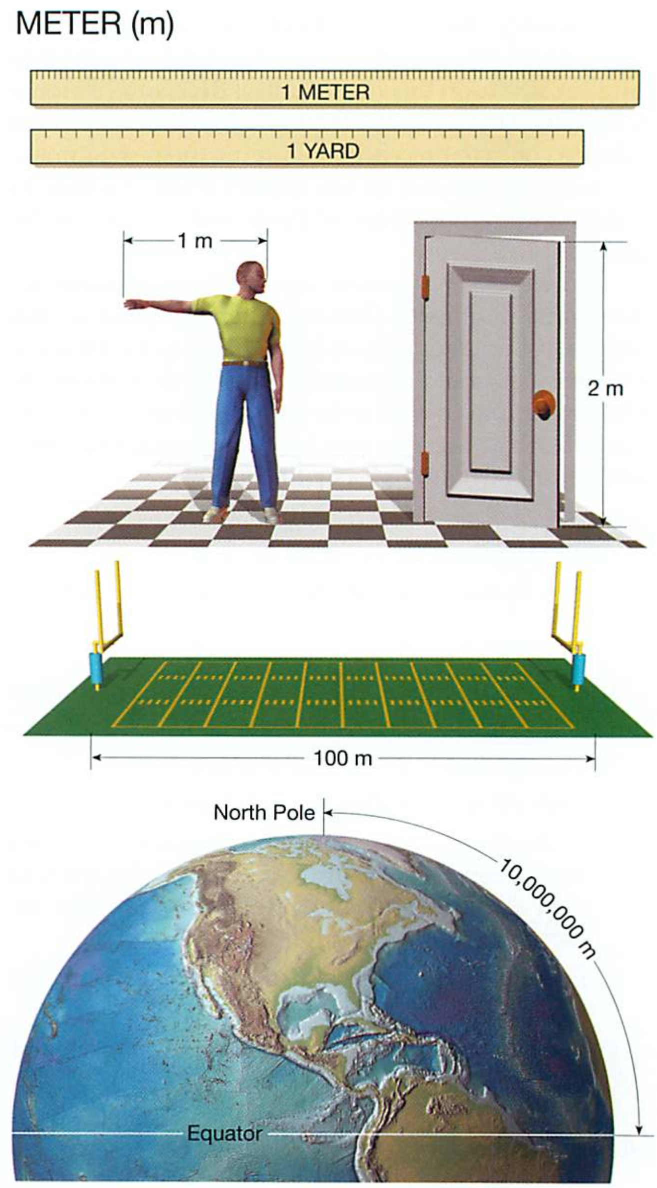


**Figure 23.2** The SI unit of length is the meter (m), which is slightly longer than a yard. Originally described as one ten-millionth of the distance from the equator to the North Pole, it is currently defined as the distance traveled by light in a vacuum in 0.0000000033 of a second.

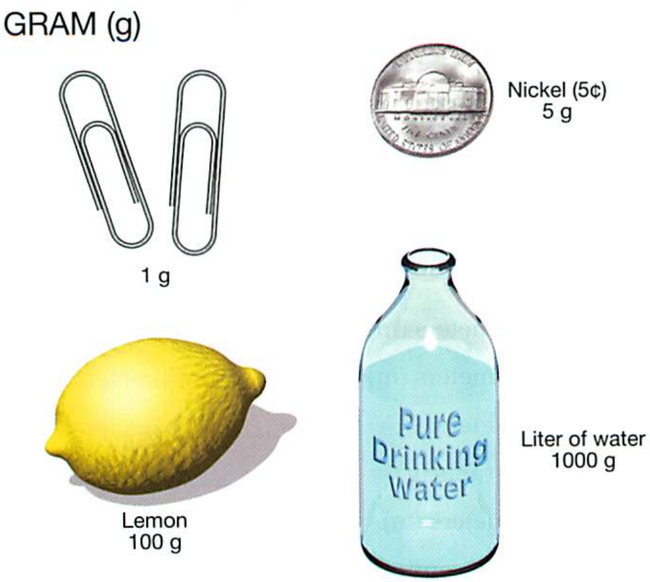


**Figure 23.3** The basic unit of mass in the metric system is the gram (g), approximately equal to the mass of one cubic centimeter of pure water at 4°C (39.2°F). A gram is about the weight of two paper clips, while an ounce is about the weight of 40 paper clips.

## Working with the Metric System

In the metric system the basic units of weights and measures are in "tens" relations to each other. It is similar to our monetary system where 10 pennies equal one dime and 10 dimes equal one dollar. However, in the English system of weights and measures no such regularity exists; for example, 12 inches equal a foot and 5,280 feet equal a statute mile. Thus, the advantage of the metric system is *consistency*.

Table 23.2 illustrates the prefixes that are used in the metric system to indicate how many times more (in multiples of 10) or what fraction (in fractions of ten) of the basic unit you have. Therefore, from the information in the table, a *kilo*gram (kg) means one thousand grams, while a *milli*gram (mg) is one one-thousandth of a gram.

To familiarize yourself with metric units, determine the following measurements using the equipment provided in the laboratory.

*Measuring length:*

1. Use a metric measuring tape (or meterstick) to measure your height as accurately as possible to the nearest hundredth of a meter (called a centimeter).

   _______ . _______ meters (m)

2. Use a metric ruler to measure the length of this page as accurately as possible to the nearest tenth of a centimeter (called a millimeter).

   _______ . _______ centimeters (cm)

3. Accurately measure the length of your shoe to the nearest millimeter.

   ________________ millimeters (mm)

*Measuring volume:*

4. Use a graduated measuring cylinder to measure the volume of the paper cup to the nearest milliliter.

   ________________ milliliters (ml)

**Table 23.2** Metric Prefixes and Symbols

| Prefix[1] | Symbol[2] | Meaning |
|---|---|---|
| giga- | G | one billion times base unit (1,000,000,000 × base) |
| mega- | M | one million times base unit (1,000,000 × base) |
| kilo- | k | one thousand times base unit (1000 × base) |
| hecto- | h | one hundred times base unit (100 × base) |
| deka- | da | ten times base unit (10 × base) |
| BASE UNIT | m (meter)–base unit of length<br>l (liter)–base unit of volume<br>g (gram)–base unit of mass | |
| deci- | d | one-tenth times base unit (.1 × base) |
| centi- | c | one-hundredth times base unit (.01 × base) |
| milli- | m | one-thousandth times base unit (.001 × base) |
| micro- | $\mu$ | one-millionth times base unit (.000001 × base) |
| nano- | n | one-billionth times base unit (.000000001 × base) |

[1]A prefix is added to the base unit to indicate how many times more, or what fraction of, the base unit is present. For example, a kilometer (km) means one thousand meters and a millimeter (mm) means one thousandth of a meter.
[2]When writing in the SI system, periods are not used after the unit symbols and symbols are not made plural. For example, if the length of a stick is 50 centimeters, it would be written as "50 cm" (not "50 cm." or "50 cms").

*Measuring mass:*

5. Weigh the following and record your results. (Follow the directions of your instructor for using a metric balance.)

   Sample of rock: ________ grams (g)

   Paper clip: ________ grams (g)

   Nickel coin: ________ grams (g)

(*Note:* Two terms that are often confused are *mass* and *weight*. Mass is a measure of the amount of matter an object contains. Weight is a measure of the force of gravity on an object. For example, the mass of an object would be the same on both Earth and the Moon. However, because the gravitational force of the Moon is less than that of Earth, the object would weigh less on the Moon. On Earth, mass and weight are directly related, and often the same units are used to express each.)

6. Use the metric "bathroom" scale. Weigh yourself as accurately as possible to the nearest tenth of a kilogram. (*Note:* If a metric scale is not available, convert your weight in pounds to kilograms by multiplying your weight (in pounds) by 0.45.)

   ________ . ________ kilograms (kg)

## Metric Conversions

As stated earlier, one important advantage of the metric system is that it is based on "tens." As shown on the metric conversion diagram, Figure 23.4, conversion from one unit to another can be accomplished simply by *moving the decimal point* to the left if going to larger units, or by moving the decimal point to the right if going to smaller units.

For example, if you measure the length of a piece of string and it is 1.43 decimeters long, in order to convert its length to millimeters, start with 1.43 on the "deci-" step of the diagram. Then move the decimal two places (steps) to the right (the "milli-" step). The length, in millimeters, becomes 143.0 millimeters.

7. Use the metric conversion diagram, Figure 23.4, to convert the following:

   a. 2.05 meters (m) = ________ centimeters (cm)

   b. 1.50 meters (m) = ________ millimeters (mm)

   c. 9.81 liters (l) = ________ deciliters (dl)

   d. 5.4 grams (g) = ________ milligrams (mg)

   e. 6.8 meters (m) = ________ kilometer (km)

   f. 4,214.6 centimeters = ________ meters (m)

   g. 321.50 grams = ________ kilogram (kg)

   h. 70.73 hectoliters = ________ dekaliters (dal)

8. Use a metric tape measure (or meterstick) to determine the length of your laboratory table as accurately as possible to the nearest hundredth of a meter. Then convert the length to each of the units in question 8b.

   a. Length of table: ________ . ________ meters

   b. Length of table equals:

      ________ millimeters (mm)

      ________ centimeters (cm)

      ________ km

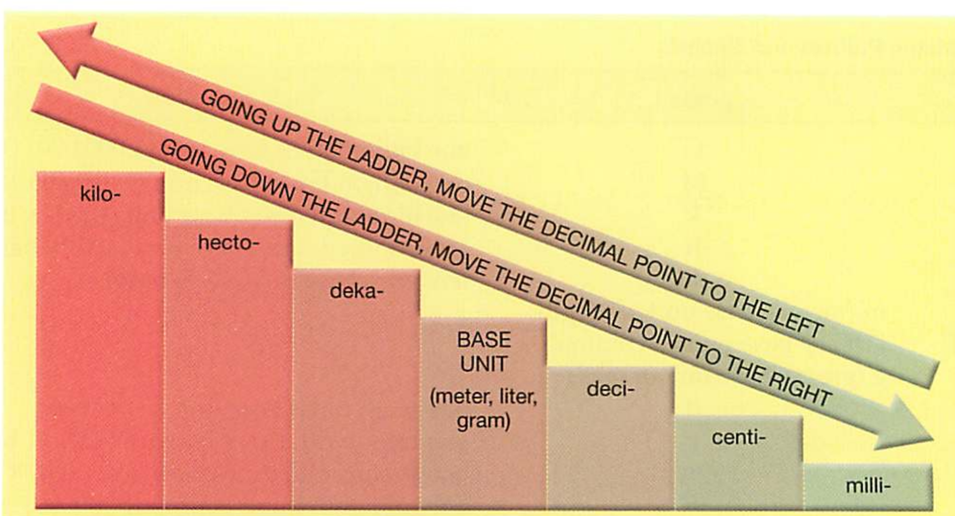


**Figure 23.4** Metric conversion diagram. Beginning at the appropriate step, if going to larger units (left), move the decimal to the left for each step crossed. When going to smaller units (right), move the decimal to the right for each step crossed. For example, 1.253 meters (base unit step) would be equivalent to 1,253.0 millimeters (decimal moved three steps to the right, the milli- step).

## Metric–English Conversions

Because the change to the metric system will occur gradually over the next few decades, we will be forced to use both systems simultaneously. If we are not able to convert from one system to the other, we will occasionally be inconvenienced or mildly frustrated.

By using the conversion tables on the inside back cover of this manual, show the metric equivalent for each of the following units.

*Length conversion:*

9. 1 inch = __________ centimeters
10. 1 meter = __________ feet
11. 1 mile = __________ kilometers

*Volume conversion:*

12. 1 gallon = __________ liters
13. 1 cubic centimeter = __________ cubic inch

*Mass conversion:*

14. 1 gram = __________ ounce
15. 1 pound = __________ kilogram

## Temperature

Temperature represents one relatively common example of using different systems of measurement. On the Fahrenheit temperature scale, 32°F is the melting point of ice and 212°F marks the boiling point of water (at standard atmospheric pressure). On the **Celsius scale**, ice melts at 0°C and water boils at 100°C. On the **Kelvin scale**, ice melts at 273 K.

Conversion from one temperature scale to the other can be accomplished using either an equation or graphic comparison scale. To convert Celsius degrees to Fahrenheit degrees, the equation is $°F = (1.8)°C + 32°$. To convert Fahrenheit degrees to Celsius degrees, the equation is $°C = (°F - 32°)/1.8$. To convert Kelvins (K) to Celsius degrees, subtract 273 and add the degree symbol.

16. Convert the following temperatures to their equivalents. Do the first four conversions using the appropriate equation, and the others using the temperature comparison scale on the inside-back cover of this manual.
    a. On a cold day it was 8°F = __________ °C
    b. Ice melts at 0°C = __________ °F
    c. Room temperature is 72°F = __________ °C
    d. A hot summer day was 35°C = __________ °F
    e. Normal body temperature is 98.6°F = __________ °C
    f. A warm shower is 27°C = __________ °F
    g. Hot soup is 72°C = __________ °F
    h. Water boils at 212°F = __________ K
17. Using the temperature comparison scale, answer the following:
    a. The thermometer reads 28°C. Will you need your winter coat? __________
    b. The thermometer reads 10°C. Will the outdoor swimming pool be open today? __________
    c. If your body temperature is 40°C, do you have a fever? __________
    d. The temperature of a cup of cocoa is 90°C. Will it burn your tongue? __________
    e. Your bath water is 15°C. Will you have a scalding, warm, or chilly bath? __________
    f. "Who's been monkeying with the thermostat? It's 37°C in this room." Are you shivering or perspiring? __________

## Metric Review

Use what you have learned about the metric system to determine whether or not the following statements are *reasonable*. Write "yes" or "no" in the blanks. *Do not* convert these units to English equivalents, only *estimate* their value.

18. A man weighs 90 kilograms. _______
19. A fire hydrant is a meter tall. _______
20. A college student drank 3 kiloliters of coffee last night. _______
21. The room temperature is 295 K. _______
22. A dime is 1 millimeter thick. _______
23. Sugar will be sold by the milligram. _______
24. The temperature in Paris today is 80°C. _______
25. The bathtub has 80 liters of water in it. _______
26. You will need a coat if the outside temperature is 30°C. _______
27. A pork roast weighs 18 grams. _______

# Special Units of Measurement

Scientists often use special units to measure various phenomena. Most of them are defined using the units of the International System of Units. Throughout this course you will encounter several of these units in your reading and laboratory studies. Only a few are introduced here.

## Very Small Distances

Two units commonly used to measure very small distances are the **micrometer** (symbol, $\mu$m), also known as the **micron**, and the **nanometer** (symbol, nm).

By definition, one micrometer equals .000001 m (one millionth of a meter). There are one million micrometers in one meter and 10,000 micrometers in a centimeter. A nanometer equals .000000001 m (one billionth of a meter).

28. There are (10, 100, 1,000) nanometers in a micrometer. Circle your answer.

29. What would be the length of a 2.5 centimeter line expressed in micrometers and nanometers?

    ________________ micrometers in a 2.5 cm line

    ________________ nanometers in a 2.5 cm line

30. Some forms of *radiation* (e.g. light) travel in very small waves with distances from crest to crest of about 500 nanometers (0.5 $\mu$m). How many of these waves would it take to equal one centimeter?

    ________________ waves in one centimeter

## Very Large Distances

On the other extreme of size, astronomers must measure very large distances, such as the distances between planets or to the stars and beyond. To simplify their measurements, they have developed special units including the **astronomical unit** (symbol, AU) and the **light-year** (symbol, LY).

The astronomical unit is a unit for measuring distance within the solar system. One astronomical unit is equal to the average distance of Earth from the Sun. This average distance is 150 million kilometers, which is approximately equal to 93 million miles.

31. The planet Saturn is 1,427 million kilometers from the Sun. How many AUs is Saturn from the Sun?

    ____________ AUs from the Sun

The light-year is one unit for measuring distances to the stars and beyond. One light-year is defined as the distance that light travels in a vacuum in one year. This distance is about 6 trillion miles (6,000,000,000,000 miles).

32. Approximately how many kilometers will light travel in one year?

    ______________________ kilometers per year

33. The nearest star to Earth, excluding our Sun, is named Proxima Centauri. It is about 4.27 light-years away. What is the distance of Proxima Centauri from Earth in both miles and kilometers?

    ________________________________ miles

    ______________________________ kilometers

## Density and Specific Gravity

Two important properties of a material are its **density** and **specific gravity.** Density is the mass of a substance per unit volume, usually expressed in grams per cubic centimeter ($g/cm^3$) in the metric system. The specific gravity of a solid is the *ratio* of the mass of a given volume of the substance to the mass of an equal volume of some other substance taken as a standard (usually water at 4°C). Because specific gravity is a ratio, it is expressed as a pure number and has no units. For example, a specific gravity of 6 means that the substance has six times more mass than an equal volume of water. Because the density of pure water at 4°C is 1 $g/cm^3$, the specific gravity of a substance will be numerically equal to its density.

The approximate density and specific gravity of a rock, or other solid, can be arrived at using the following steps:

**Step 1:** Determine the mass of the rock using a metric balance.

**Step 2:** Fill a graduated cylinder that has its divisions marked in milliliters approximately two-thirds full with water. Note the level of the water in the cylinder in milliliters.

**Step 3:** Tie a thread to the rock and immerse the rock into the water in the graduated cylinder. Note the new level of the water in the cylinder.

**Step 4:** Determine the difference between the beginning level and after-immersion level of the water in the cylinder.

**Step 5:** Calculate the density and specific gravity using the following information and appropriate equations.

*A milliliter of water has a volume approximately equal to a cubic centimeter* (*$cm^3$*). Therefore, the difference between the beginning water level and the after-immersion water level in the cylinder equals the volume of the rock in cubic centimeters. Furthermore, *a cubic centimeter (one milliliter) of water has a mass of approximately one gram.* (*Note:* Using the equipment already present in the lab, you may want to devise a simple experiment to confirm this fact.) Therefore, the difference between the beginning water level and the after-immersion water level in the cylinder is the mass of a volume of water equal to the volume of the rock.

Using the steps listed above for determining density and specific gravity, complete questions 34 and 35.

34. Determine the density and specific gravity of a small rock sample by completing questions 34a–34f.

    a. Mass of rock sample: ______________ grams

    b. After-immersion level of water: ________ ml

       Beginning level of water in cylinder: _____ ml

       ________________

       Difference: _______ ml

    c. Volume of rock sample: ________ $cm^3$

d. Mass of a volume of water equal to the volume of the rock: ________ g

e. Density of rock:

$$\text{Density} = \frac{\text{mass of rock (g)}}{\text{volume of rock (cm}^3\text{)}}$$

$$= \_\_\_\_\_\_\_ \text{ g/cm}^3$$

f. Specific gravity of rock:

Specific gravity

$$= \frac{\text{mass of rock (g)}}{\text{mass of an equal volume of water (g)}}$$

$$= \_\_\_\_\_$$

35. As a means of comparison, your instructor may require that you determine the density and/or specific gravity of other objects. If so, record your results in the following spaces.

a. Object: ______________________________

Density: ______________________________ $g/cm^3$

Specific gravity: ______________________________

b. Object: ______________________________

Density: ______________________________ $g/cm^3$

Specific gravity: ______________________________

36. If you have investigated the densities and/or specific gravities of several objects, write a brief paragraph comparing the objects.

______________________________

______________________________

______________________________

## Methods of Scientific Inquiry

Scientists use many methods in an attempt to understand natural phenomena. Some scientific discoveries represent purely theoretical ideas, while others may occasionally occur by chance. However, scientific knowledge is often gained by following a sequence of steps which involve

**Step 1:** Establishing a **hypothesis**—a tentative, or untested, explanation.

**Step 2:** Gathering data and conducting experiments to validate the hypothesis.

**Step 3:** Accepting, modifying, or rejecting the hypothesis on the basis of extensive data gathering or experimentation.

The following simple inquiry should help you understand the process.

### Step 1—Establishing a Hypothesis

Observe all the people in the laboratory and pay particular attention to each individual's height and shoe length.

37. Based on your observations, write a hypothesis that relates a person's height to their shoe length.

Hypothesis: ______________________________

______________________________

______________________________

### Step 2—Gathering Data

Previously, in questions 1 and 3 of the exercise, each person in the laboratory measured his or her height using a metric tape measure (or meterstick) and shoe length.

38. Gather your data by asking ten or fifteen people in the lab for their height and shoe length measurements. Enter your data in Table 23.3 by recording height to the nearest hundredth of a meter and shoe length to the nearest millimeter.

### Step 3—Evaluating the Hypothesis Based Upon the Data

Plot all your data from Table 23.3 on the Height versus Shoe Length graph, Figure 23.5, by locating a person's height on the vertical axis and his or her shoe length on the horizontal axis. Then place a dot on the graph where the two intersect.

39. Describe the pattern of the data points (dots) on the Height versus Shoe Length graph, Figure 23.5. For example, are the points scattered all over the graph, or do they appear to follow a line or curve?

______________________________

______________________________

40. Draw a single line on the graph that appears to average, or best fit, the pattern of the data points.

41. Describe the relation of height to shoe length that is illustrated by the line on your graph.

______________________________

______________________________

______________________________

42. Ask several people, whose height and shoe length you have not used to prepare the graph, for their height. Then see how accurately your line predicts what their shoe length should be. Do this by marking each person's height on the vertical axis and then follow a line straight across to the right until you intersect the line on the

**Table 23.3 Data Table for Recording Height and Shoe Length Measurements of People in the Lab**

| Person | Height (nearest hundredth of a meter) | Shoe Length (nearest millimeter) |
|---|---|---|
| 1 | ______ . ______ m | ______ mm |
| 2 | ______ . ______ m | ______ mm |
| 3 | ______ . ______ m | ______ mm |
| 4 | ______ . ______ m | ______ mm |
| 5 | ______ . ______ m | ______ mm |
| 6 | ______ . ______ m | ______ mm |
| 7 | ______ . ______ m | ______ mm |
| 8 | ______ . ______ m | ______ mm |
| 9 | ______ . ______ m | ______ mm |
| 10 | ______ . ______ m | ______ mm |
| 11 | ______ . ______ m | ______ mm |
| 12 | ______ . ______ m | ______ mm |
| 13 | ______ . ______ m | ______ mm |
| 14 | ______ . ______ m | ______ mm |
| 15 | ______ . ______ m | ______ mm |

graph. Read the predicted shoe length from the axis directly below the point of intersection.

43. Summarize how accurately your graph predicts a person's shoe length, knowing only his or her height.

______________________________

______________________________

______________________________

44. Using your graph's ability to make predictions as a guide, do you think you should accept, reject, or modify your original hypothesis? Give the reason(s) for your choice.

______________________________

______________________________

______________________________

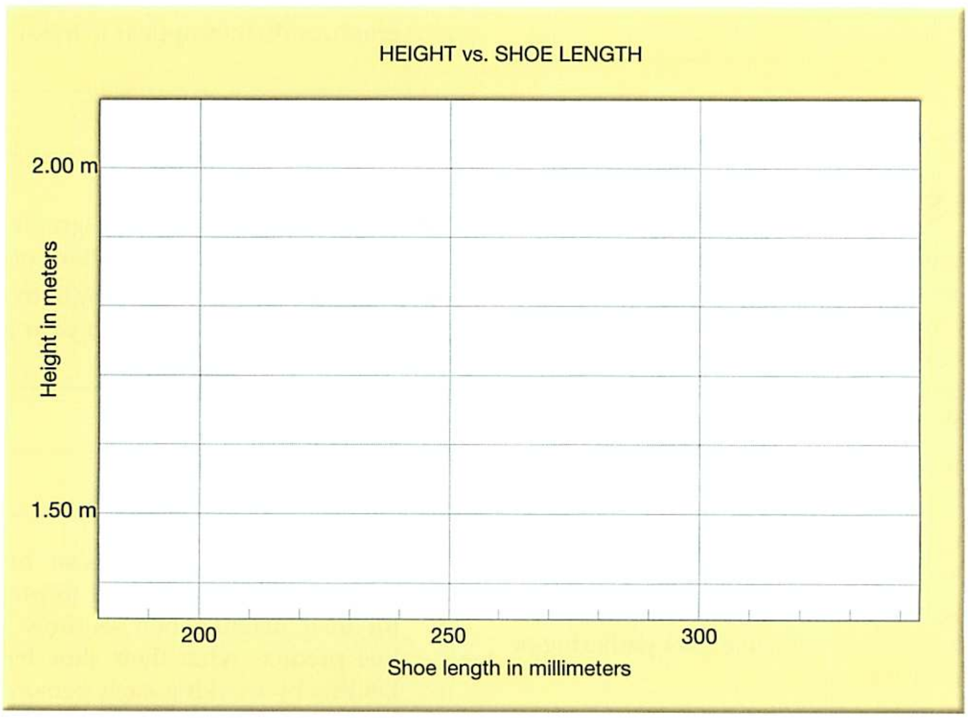


**Figure 23.5** Height versus Shoe Length graph.

Your study has been restricted to people in your laboratory.

45. Why would your ability to make predictions have been more accurate if you had used the heights and shoe lengths of ten thousand people to construct your graph?

_______________________________________________

_______________________________________________

_______________________________________________

Drawing hasty conclusions with limited data can often cause problems. In science you can never have too much data. Experiments are repeated many times by many different people before the results are accepted by the scientific community.

## The Metric System on the Internet

Continue your analyses of the topics presented in this exercise by completing the corresponding online activity on the *Applications & Investigations in Earth Science* website at http://prenhall.com/larthsciencelab

**Notes and calculations.**

# The Metric System, Measurements, and Scientific Inquiry

Date Due: ____________________

Name: ____________________

Date: ____________________

Class: ____________________

After you have finished Exercise 23, complete the following questions. You may have to refer to the exercise for assistance or to locate specific answers. Be prepared to submit this summary/report to your instructor at the designated time.

1. List the basic metric unit and symbol used for these measurements:

   Length: ____________________

   Mass: ____________________

   Volume: ____________________

2. Convert the following units:

   a. 2 liters = __________ deciliters

   b. 600 millimeters = __________ meter

   c. 72°F = __________ °C

   d. 0.32 kilograms = __________ grams

   e. 12 grams = __________ milligrams

3. Indicate by answering "yes" or "no" whether or not the following statements are reasonable:

   a. A person is 600 centimeters tall.

   b. A bag of groceries weighs 5 kilograms. ______

   c. It took 52 liters of gasoline to fill the car's empty gasoline tank. ______

4. List your height and shoe length using the metric system.

   a. Height: ______ . ______ meters

   b. Shoe length: ______ millimeters

5. How many micrometers are there in 3.0 centimeters?

   __________ micrometers in 3.0 centimeters

6. How many waves, each 500 nanometers wide, would fit along a two centimeter line?

   __________ waves along a two centimeter line

7. What would be the distance in kilometers of a star that is 6.5 light-years from Earth?

   ____________________ kilometers from Earth

8. Uranus, one of the most distant planets, is 2,870 million kilometers from the Sun. What is its distance from the Sun in astronomical units?

   __________ astronomical units from the Sun

9. Explain the difference between the two terms, *density* and *specific gravity*.

   ____________________

   ____________________

   ____________________

10. At the conclusion of your height–shoe length experiment, in question 44 you (accepted, rejected, modified) your original hypothesis. Circle your answer and give the reason for this decision.

    ____________________

    ____________________

    ____________________

# Appendix