3.1 Using and Expressing Measurements

**Essential Understanding** In science, measurements must be accurate, precise, and written to the correct number of significant figures.

**Reading Strategy**

**Venn Diagram** A Venn diagram is a useful tool in visually organizing related information. A Venn diagram shows which characteristics the concepts share and which characteristics are unique to each concept.

Use the Venn diagram to compare **accuracy** and **precision**.

---

**EXTENSION** Add the term **error** in the correct location in your Venn diagram. Then explain why you placed this term where you did.

---

**Lesson Summary**

**Scientific Notation** Scientific notation is a kind of shorthand to write very large or very small numbers.

- Scientific notation always takes the form \((a \text{ number } \geq 1 \text{ and } < 10) \times 10^x\).
Accuracy, Precision, and Error

Accuracy, precision, and error help determine the reliability of measurements.

- The accuracy of a measurement is determined by how close the measured value is to the actual value.
- The precision of a measurement is determined by how close repeated measurements are to one another.
- Error is the difference between the measured value and the accepted value.

Significant Figures

Significant figures include all known digits plus one estimated digit.

- The number of significant figures reflects the precision of reported data.
- In calculations, the number of significant figures in the least precise measurement is the number of significant figures in the answer.

<table>
<thead>
<tr>
<th>Significant Figures</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sample number: 0.024050 (5 significant figures)</strong></td>
</tr>
<tr>
<td>Not significant</td>
</tr>
<tr>
<td>Significant</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Scientific Notation

1. Why are numbers used in chemistry often expressed in scientific notation?

2. Circle the letter of each sentence that is true about numbers expressed in scientific notation.
   a. A number expressed in scientific notation is written as the product of a coefficient and 10 raised to a power.
   b. The power of 10 is called the exponent.
   c. The coefficient is always a number greater than or equal to one and less than ten.
   d. For numbers less than one, the exponent is positive.

3. Circle the letter of the answer in which 503,000,000 is written correctly in scientific notation.
   a. $5.03 \times 10^{-7}$
   b. $503 \times 10^6$
   c. $5.03 \times 10^8$
   d. 503 million
Accuracy, Precision, and Error

4. Is the following sentence true or false? To decide whether a measurement has good precision or poor precision, the measurement must be made more than once.

5. Four of five repetitions of a measurement were numerically identical, and the fifth varied from the others in value by less than 1%.

6. Eight measurements were spread over a wide range.

7. A single measurement is within 1% of the correct value.

8. On a dartboard, darts that are closest to the bull’s-eye have been thrown with the greatest accuracy. On the second target, draw three darts to represent three tosses of lower precision, but higher accuracy than the darts on the first target.

9. What is the meaning of “accepted value” with respect to an experimental measurement?

10. Complete the following sentence. For an experimental measurement, the experimental value minus the accepted value is called the_______________________.

11. Is the following sentence true or false? The value of an error must be positive.

12. Relative error is also called _______________________.

13. The accepted value of a length measurement is 200 cm, and the experimental value is 198 cm. Circle the letter of the value that shows the percent error of this measurement.
   a. 2%
   b. −2%
   c. 1%
   d. −1%
Significant Figures

14. If a thermometer is calibrated to the nearest degree, to what part of a degree can you estimate the temperature it measures? ______________________

15. Circle the letter of the correct digit. In the measurement 43.52 cm, which digit is the most uncertain?
   a. 4
   b. 3
   c. 5
   d. 2

16. Circle the letter of the correct number of significant figures in the measurement 6.80 m.
   a. 2
   b. 3
   c. 4
   d. 5

17. List two situations in which measurements have an unlimited number of significant figures.
   a. ______________________________________________________
   b. ______________________________________________________

18. Circle the letter of each sentence that is true about significant figures.
   a. Every nonzero digit in a reported measurement is assumed to be significant.
   b. Zeros appearing between nonzero digits are never significant.
   c. Leftmost zeros acting as placeholders in front of nonzero digits in numbers less than one are not significant.
   d. All rightmost zeros to the right of the decimal point are always significant.
   e. Zeros to the left of the decimal point that act as placeholders for the first nonzero digit to the left of the decimal point are not significant.

19. Is the following sentence true or false? An answer is as precise as the most precise measurement from which it was calculated.__________________________

Round the following measurements as indicated.

20. Round 65.145 meters to 4 significant figures.__________________________
21. Round 100.1°C to 1 significant figure.______________________________
22. Round 155 cm to two significant figures.____________________________
23. Round 0.000718 kilograms to two significant figures.____________________
24. Round 65.145 meters to three significant figures._______________________
3.2 Units of Measurement

**Essential Understanding** Measurements are fundamental to the experimental sciences.

**Lesson Summary**

**Using SI Units** Scientists use an internationally recognized system of units to communicate their findings.
- The SI units are based on multiples of 10.
- There are seven SI base units: second, meter, kilogram, Kelvin, mole, ampere, and candela.
- Prefixes are added to the SI units because they extend the range of possible measurements.

**Temperature Scales** Temperature is a quantitative measure of the average kinetic energy of particles in an object.
- Scientists most commonly use the Celsius and Kelvin scales.
- The zero point on the Kelvin scale is called absolute zero.
- Kelvin-Celsius Conversion Equation is $K = ^{\circ}C + 273$.
- One degree on the Celsius scale is the same as one kelvin on the Kelvin scale.

**Density** Density is a ratio that compares the amount of mass per unit volume.
- The formula for density is $\text{density} = \frac{\text{mass}}{\text{volume}}$.
- Density depends on the kind of material but not on the size of the sample.
- The density of a substance changes with temperature.

**BUILD Math Skills**

**Converting Among Temperatures** The Fahrenheit scale is based on the melting point of ice (32 degrees above 0) and the boiling point of water (212 degrees above 0). However, since most of the rest of the world uses degrees Celsius, it is important to be able to convert from units of degrees Fahrenheit to degrees Celsius.

The SI base unit for temperature is Kelvin, or K. A temperature of 0 K refers to the lowest possible temperature that can be reached.
To convert degrees Celsius into kelvins:
▶ add 273 to the °C.

To convert kelvins into degrees Celsius:
▶ subtract 273 from the K.

**Sample Problem** Mercury melts at −39°C. What temperature is that in K?

\[-39°C + 273 = 234K\]

To convert Celsius temperatures into Fahrenheit:
▶ multiply the Celsius temperature by 9.
▶ divide the answer by 5.
▶ add 32.

**Sample Problem** Convert 40°C to °F.

\[
40 \times 9 = 360 \\
360 ÷ 5 = 72 \\
72 + 32 = 104°F
\]

To convert Fahrenheit temperatures into Celsius:
▶ subtract 32 from the Fahrenheit temperature.
▶ multiply the answer by 5.
▶ divide that answer by 9.
Sample Problem: Convert 77°F to °C.

Subtract 32 from the Fahrenheit temperature.

77 − 32 = 45

Multiply the answer by 5.

45 x 5 = 225

Divide that answer by 9.

225 ÷ 9 = 25°C

After reading Lesson 3.2, answer the following questions.

Using SI Units

2. Complete the table showing selected SI base units of measurement.

<table>
<thead>
<tr>
<th>Units of Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
</tr>
<tr>
<td>Length</td>
</tr>
<tr>
<td>Mass</td>
</tr>
<tr>
<td>Temperature</td>
</tr>
<tr>
<td>Time</td>
</tr>
</tbody>
</table>

3. All metric units of length are based on multiples of ________________.

4. The International System of Units (SI) is a revised version of the ________________.

5. Explain what is meant by a “derived unit.”

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
6. Give at least one example of a derived unit.

7. Complete the following table showing some metric units of length. Remember that the meter is the SI base unit for length.

<table>
<thead>
<tr>
<th>Metric Units of Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit</td>
</tr>
<tr>
<td>Meter</td>
</tr>
<tr>
<td>Kilometer</td>
</tr>
<tr>
<td>Centimeter</td>
</tr>
<tr>
<td>Millimeter</td>
</tr>
<tr>
<td>Nanometer</td>
</tr>
</tbody>
</table>

Match each metric unit with the best estimate of its length or distance.

8. Height of a stove top above the floor  

9. Thickness of about 10 sheets of paper  

10. Distance along a road spanning about 10 telephone poles  

11. Width of a key on a computer keyboard  

12. The space occupied by any sample of matter is called its ________________________.

13. Circle the letter of each sentence that is true about units of volume.

   a. The SI unit for volume is derived from the meter, the SI unit for length.
   b. The liter (L) is a unit of volume.
   c. The liter is an SI unit.
   d. There are 1000 cm³ in 1 L, and there are also 1000 mL in 1 L, so 1 cm³ is equal to 1 mL.
Match each of the three descriptions of a volume to the appropriate metric unit of volume.

**Example**

14. Interior of an oven → a. 1 L
15. A box of cookies → b. 1 m³
16. One-quarter teaspoon → c. 1 mL

17. A volume of 1 L is also equal to
   a. 1000 mL
   b. 1 dm³
   c. 1000 cm

18. The volume of any solid, liquid, or gas will change with ____________________.

19. A kilogram was originally defined as the mass of ____________________.

20. Circle the letter of the unit of mass commonly used in chemistry that equals 1/1000 kilogram.
    a. gram
    b. milligram
    c. milliliter

Match each unit of mass with the object whose mass would be closest to that unit.

**Mass**

21. A few grains of sand → a. 1 kg
22. A liter bottle of soda → b. 1 g
23. Five aspirin tablets → c. 1 mg

24. Is the following sentence true or false? The mass of an object changes with location.

25. When brought to the surface of the moon, will a mass have more or less weight than it did on the surface of Earth, or will it be the same weight? Explain.

__________________________________________________________________________
__________________________________________________________________________
Temperature Scales

26. Draw an arrow below the diagram, showing the direction of heat transfer between two objects.

| lower temperature | higher temperature |

27. What properties explain the behavior of liquid-filled thermometers?

28. What are the two reference temperatures on the Celsius scale?

29. What is the zero point, 0 K, on the Kelvin scale called?

30. A change of temperature equal to one kelvin is equal to a change of temperature of how many degrees Celsius?

31. Complete the diagram to show the reference temperatures in the Celsius and Kelvin scales.

![Celsius and Kelvin temperature scales diagram]

Density

32. Is the mass of one pound of lead greater than, less than, or equal to the mass of one pound of feathers?
33. Which material has a greater density, lead or feathers? ____________________

34. How is density defined? ________________________________________________

35. The mass of a sample is measured in grams, and its volume is measured in cubic centimeters. In what units would its density be reported?

36. Look at Table 3.6. Circle the letter of the material that will sink in liquid water at 4°C.
   a. aluminum
   b. corn oil
   c. ice
   d. gasoline

37. The density of a substance generally decreases as its temperature increases. Are there any exceptions to this statement? Explain.

   ________________________________________________________________
   ________________________________________________________________
   ________________________________________________________________

3.3 Solving Conversion Problems

**Essential Understanding** The numerical value of a measurement generally changes when you convert from one system to another, but the actual amount of the quantity measured does not change.

**Lesson Summary**

**Conversion Factors** Conversion factors are used to change a given measurement to some other unit of measure.

- A conversion factor is a ratio of equivalent measurements. It equals ± 1.
- Conversion factors have an unlimited number of significant figures. They are not considered when rounding the answer.

**Dimensional Analysis** Dimensional analysis is a way to solve problems using the units, or dimensions, of measurements.

- Dimensional analysis problems can be done in one step or they can require several steps.
- When using dimensional analysis, a measurement with one unit is changed to an equivalent measurement with another unit.
Conversion Factors

1. How are the two parts of a conversion factor related?

2. Look at Figure 3.12. In a conversion factor, the smaller number is part of the quantity that has the _______________ unit. The larger number is part of the quantity that has the _______________ unit.

3. Is the following sentence true or false? The actual size of a measurement multiplied by a conversion factor remains the same, because the measurement being converted is multiplied by unity.__________________________

4. Write two conversion factors based on the relationship between hours and minutes.

5. The average lead for a mechanical pencil is 6.0 cm long when it is new. Circle the letter of the conversion factor you would use to find its length in inches.
   a. \( \frac{2.54 \text{ cm}}{1 \text{ in.}} \)
   b. \( \frac{1 \text{ in.}}{2.54 \text{ cm}} \)
   c. \( \frac{1 \text{ in.}}{6.0 \text{ cm}} \)
   d. \( \frac{6.0 \text{ cm}}{1 \text{ in.}} \)

6. A student is asked to calculate the volume, in milliliters, of 2 cups of oil. There are 225 mL per cup. The student calculates the volume as follows:

\[
\text{Volume} = 2 \text{ cups} \times \frac{1 \text{ cup}}{25 \text{ mL}} = 0.08 \text{ cup}
\]
List three errors the student made.

Dimensional Analysis

7. What is dimensional analysis?

8. A container can hold 65 g of water. Circle the conversion factor needed to find the mass of water that 5 identical containers can hold.
   a. \( \frac{5 \text{ containers}}{65 \text{ g water}} \)
   b. \( \frac{1 \text{ container}}{65 \text{ g water}} \)
   c. \( \frac{65 \text{ g water}}{1 \text{ container}} \)
   d. \( \frac{65 \text{ g water}}{5 \text{ containers}} \)

9. Converting between units is easily done using ________________.

10. Circle the letter of the conversion factor that you would use to convert tablespoons to milliliters.
    a. \( \frac{4 \text{ fluid ounces}}{1 \text{ tablespoon}} \)
    b. \( \frac{1 \text{ tablespoon}}{4 \text{ fluid ounces}} \)
    c. \( \frac{1 \text{ tablespoon}}{15 \text{ mL}} \)
    d. \( \frac{15 \text{ mL}}{1 \text{ tablespoon}} \)

11. Show the calculation you would use to convert the following:
    a. 0.25 m to centimeters ________________
    b. 9.8 g to kilograms ________________
    c. 35 ms to seconds ________________
    d. 4.2 dL to liters ________________

12. Complex conversions between units may require using ________________ conversion factor.
13. How many conversion factors would you need to use to find the number of liters in a cubic decimeter? What are they?

14. How would you calculate the number of nanometers in 8.1 cm?

15. What is the equivalent of 0.35 lb in grams?

16. A scientist has 0.46 mL of a solution. How would she convert this volume to microliters?

17. Describe the steps you would use to solve this problem. In a scale drawing of a dining room floor plan, 10 mm equals 2 meters. If the homeowners wanted to purchase flooring that costs $10.89 per square yard, how much would they spend on flooring for the dining room? The dimensions of the dining room on the floor plan are 40 mm × 32 mm.

18. Name three common measurements that are expressed as a ratio of two units.

19. What technique can be used to convert complex units?

20. A normal concentration of glucose, or sugar, in the blood is 95 mg/dL. How many grams of sugar would be present per liter of blood? Show the conversion factors you use.

21. A man can run a mile in 4 minutes. Calculate his average speed in kilometers per hour. Show your work. (1 mile = 1.61 km)

22. A baseball player’s batting average is .254 (254 hits per 1000 at bats). If she is at bat an average of 3 times per game, how many hits will she make in 52 games? Show your work.
Guided Practice Problems

Answer the following questions about Practice Problem 6a.
Round 87.073 meters to three significant figures. Write your answer in scientific notation.

Analyze

a. To round to three significant figures, round to the nearest tenth.

Calculate

b. Write the number in scientific notation.
   Change to a coefficient between 1 and $10 \times 10$ with an integer exponent.

Answer the following questions about Practice Problem 21.
A student finds a shiny piece of metal that she thinks is aluminum. In the lab, she determines that the metal has a volume of 245 cm$^3$ and a mass of 612 g. Calculate the density. Is the metal aluminum?

Analyze

a. List the known values. Volume = 245 cm$^3$
   Mass = 612 g
   
   b. List the unknown.

Calculate

c. Use the following relationship to find the density. Remember to round your answer to three significant figures.

   \[
   \text{Density} = \frac{\text{mass}}{\text{volume}} = \frac{612 \text{ g}}{245 \text{ cm}^3} = \text{g/cm}^3
   \]

   d. To determine whether the piece of metal is aluminum, compare the density of the metal to the density of aluminum given in Table 3.6. Is the metal aluminum?

Evaluate

E. Underline the correct word(s) that complete(s) this statement. Because the mass of the metal is about two and one-half times the volume, a density of about 2.5 g/cm$^3$ is reasonable. Because a density of 2.50 g/cm$^3$ is nearly 10% less than 2.7 g/cm$^3$, the density of aluminum, the metal (is, is not) aluminum.
Answer the following questions about Practice Problem 45.
The radius of a potassium atom is 0.227 nm. Express this radius in centimeters.
Complete the following steps to solve the problem.

**Analyze**

a. Use the conversion factors for nanometers and centimeters.

\[
0.227 \text{ nm} \times \frac{\text{1 cm}}{1 \times 10^9 \text{ nm}} = \text{ cm}
\]

**Calculate**

b. Simplify.

\[
0.227 \times \frac{10^2}{10^9} = \text{ cm}
\]

c. Divide.

\[
\text{ cm}
\]

**Apply the Big idea**

A student places a cube of ironwood in water and it sinks. To find out why this wood sinks, he wants to find its density. He found that a large sample of ironwood has a mass of 1.8 kg and a volume of 1.5 L.

a. What is the density of ironwood in g/cm³? Show your work.

__________________________________________________________

__________________________________________________________

__________________________________________________________

b. Why did the ironwood sink in water?

__________________________________________________________

__________________________________________________________

__________________________________________________________
For Questions 1–9, complete each statement by writing the correct word or words. If you need help, you can go online.

3.1 Using and Expressing Measurements

1. In writing numbers in scientific notation, the ________________ is always a number greater than or equal to one and less than ten.

2. ________________ is a measure of how close a measurement comes to the actual or true value of whatever is measured.

3. ________________ is a measure of how close measurements in a series are to one another, irrespective of the actual value.

4. Measurements must always be reported to the correct number of ________________.

3.2 Units of Measurement

5. Metric units are easy to convert because they are based on ________________.

6. Scientists commonly use two equivalent units of temperature, the degree ________________ and the kelvin.

7. The ratio of the mass of an object to its volume is ________________.

3.3 Solving Conversion Problems

8. The two measurements used in a conversion factor are ________________, which means that they equal the same thing.

9. ________________ is a way to analyze and solve problems using the units of the measurements.
Review Key Equations

For each problem below, write the equation used to solve it.

1. Miguel found the density of a piece of iron. The accepted value of the density of iron is 7.87 g/cm³.
   a. The piece of iron that Miguel measured had a mass of 51.1 g and a volume of 6.63 cm³. What did Miguel calculate to be the density of iron?
   
   b. What was the error?
   
   c. What was the percent error?

2. Isabella measured the temperature of a gas as 24.3°C. To use this value in a calculation, she needed to convert the temperature to kelvins. What is this temperature in kelvins?

EXTENSION Solve each equation above.

1. a. 
   b. 
   c. 

2. 

Review Vocabulary

Place the letter of each of the terms in the vocabulary box by each location in the equation where it is used.

<table>
<thead>
<tr>
<th>a. conversion factor</th>
<th>d. gram</th>
<th>g. significant figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>b. density</td>
<td>e. kilogram</td>
<td></td>
</tr>
<tr>
<td>c. dimensional analysis</td>
<td>f. liter</td>
<td></td>
</tr>
</tbody>
</table>

A box had a mass of 4.5 kg and a volume of 6.4 L. Calculate the density of the box to two decimal places in g/cm³.

\[
\text{Density} = \frac{4.5 \text{ kg}}{6.4 \text{ L}} \times \frac{1000 \text{ g}}{1 \text{ kg}} \times \frac{1 \text{ L}}{1000 \text{ mL}} \times \frac{1 \text{ mL}}{1 \text{ cm}^3} = 0.70 \text{ g/cm}^3
\]