THE IMPORTANCE OF MEASUREMENT

In horse racing, the finish is sometimes so close that the winner can only be determined by a photograph taken at the instant the horses cross the finish line. In the 130th Belmont Stakes, for example, the horse named Real Quiet, the winner of both the Kentucky Derby and the Preakness, was beaten by only the length of a nose in the final race for the Triple Crown. Chemistry also requires making accurate and often very small measurements. **What types of measurements are made in chemistry?**

objectives

- Distinguish between quantitative and qualitative measurements
- Convert measurements to scientific notation

key terms

- qualitative measurements
- quantitative measurements
- scientific notation

Qualitative and Quantitative Measurements

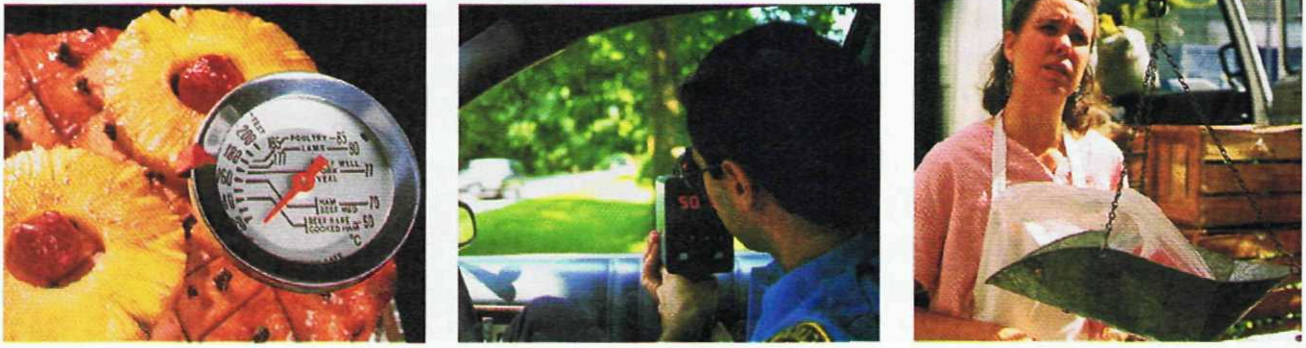
Everyone makes and uses measurements. For example, you decide how to dress in the morning based on the temperature outside. You measure the ingredients for your favorite cookie recipe. If you were building a cabinet for your stereo system, you would carefully measure the length of each piece of wood.

Measurements are fundamental to the experimental sciences as well. For that reason, it is important to be able to make measurements and to decide whether a measurement is correct. In chemistry, you will use the International System of Measurements (SI).

Not all measurements give the same amount of information. For example, how might you determine whether someone who is sick has a fever? You might simply touch the person's forehead and think, "Yes! This person feels feverish." This is an example of a qualitative measurement. **Qualitative measurements** give results in a descriptive, nonnumerical form. If several people touch the sick person's forehead, their qualitative measurements may not agree with yours. One reason for this is that a person's own temperature influences his or her perception of how warm another person feels. By using a thermometer, however, each person can eliminate this personal bias. The temperature takers will each report a numerical value, or quantitative measurement. **Quantitative measurements** give results in a definite form, usually as numbers and units. For example, the thermometer might reveal the person's temperature to be 39.2 °C (102.5 °F). This measurement has a definite value that can be compared with the person's temperature at a later time to check for changes. Yet this measurement, however definite, can be no more reliable than the instrument used to make the measurement and the care with which it is used and read.

Figure 3.1

Instruments are needed to make quantitative measurements. A meat thermometer, a radar gun, and a grocery scale are common instruments used to measure temperature, speed, and weight, respectively.



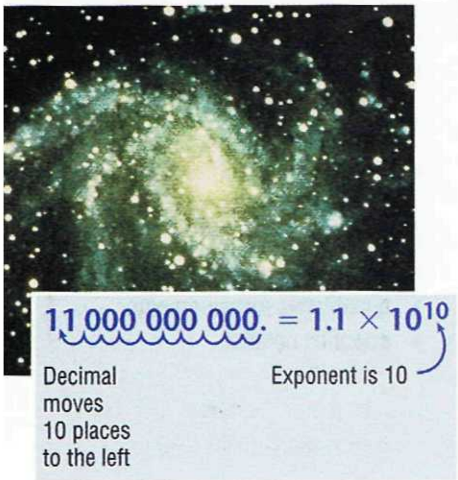


Figure 3.2
Expressing very large numbers, such as the estimated number of stars in a galaxy, is easier if scientific notation is used. The number of decimal places moved is equal to the exponent.

Scientific Notation

In chemistry, you will often encounter very small and very large numbers. The mass of an atom of gold, for example, is 0.000 000 000 000 000 000 000 327 gram. A gram of hydrogen contains 602 000 000 000 000 000 000 000 hydrogen atoms. Writing and using such small or large numbers is very cumbersome. You can work more easily with these numbers by writing them in scientific, or exponential, notation.

In **scientific notation,** a number is written as the product of two numbers: a coefficient and 10 raised to a power. For example, the number 36 000 is written in scientific notation as 3.6×10^4. The coefficient in this number is 3.6. In scientific notation, the coefficient is always a number greater than or equal to one and less than ten. The power of 10, or exponent, in this example is 4. The exponent indicates how many times the coefficient 3.6 must be multiplied by 10 to equal the number 36 000.

$$3.6 \times 10^4 = 3.6 \times 10 \times 10 \times 10 \times 10 = 36\,000$$

For numbers greater than ten, the exponent is positive and equals the number of places the original decimal point has been moved to the left to write the number in scientific notation. Numbers less than ten have a negative exponent. For example, the number 0.0081 written in scientific notation is 8.1×10^{-3}. The exponent -3 indicates that the coefficient 8.1 must be divided by 10 three times to equal 0.0081, as shown in **Figure 3.3.**

$$8.1 \times 10^{-3} = \frac{8.1}{10 \times 10 \times 10} = 0.0081$$

For numbers less than ten, the value of the exponent equals the number of places the original decimal point has been moved to the right to write the number in scientific notation. Can you express the mass of a single atom of gold, which is 0.000 000 000 000 000 000 000 327 gram, in scientific notation? Try it!

Multiplication and Division Using scientific notation makes calculating more straightforward. To multiply numbers written in scientific notation, multiply the coefficients and add the exponents. For example,

$$(3.0 \times 10^4) \times (2.0 \times 10^2) = (3.0 \times 2.0) \times 10^{4+2} = 6.0 \times 10^6$$

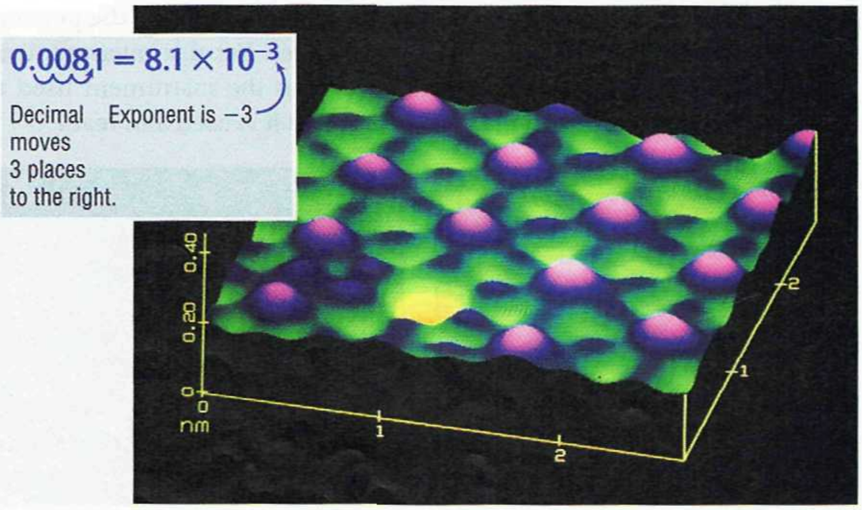


Figure 3.3
A tiny distance, such as that between the atoms in this electron micrograph, can be expressed conveniently in scientific notation. The direction in which the decimal point is moved determines the sign of the exponent. What is the sign of the exponent in this case?

To divide numbers written in scientific notation, first divide the coefficients. Then subtract the exponent in the denominator (bottom) from the exponent in the numerator (top). For example,

$$\frac{3.0 \times 10^4}{2.0 \times 10^2} = \frac{3.0}{2.0} \times 10^{4-2} = 1.5 \times 10^2$$

Addition and Subtraction Before you add or subtract numbers written in scientific notation, you must make the exponents the same because the exponents determine the locations of the decimal points in the original numbers. The decimal points must be aligned before you add two numbers. For numbers in scientific notation, making the exponents the same aligns the decimal points. For example, when adding 5.40×10^3 to 6.0×10^2, you must adjust the exponents to make them the same. You can choose to adjust 6.0×10^2 to 0.60×10^3.

$$\begin{array}{r} 5.40 \times 10^3 \\ +\ 0.60 \times 10^3 \\ \hline 6.00 \times 10^3 \end{array}$$

section review 3.1

1. a. What is the difference between a qualitative measurement and a quantitative measurement?
   b. How is a number converted to scientific notation?
2. Classify each statement as either qualitative or quantitative.
   a. The basketball is brown.
   b. The diameter of the basketball is 31 centimeters.
   c. The air pressure in the basketball is 12 pounds per square inch.
   d. The surface of the basketball has indented seams.
3. Write each measurement in scientific notation.
   a. the length of a football field, 91.4 meters
   b. the diameter of a carbon atom, 0.000 000 000 154 meter
   c. the radius of Earth, 6 378 000 meters
   d. the diameter of a human hair, 0.000 008 meter
   e. the average distance between the center of the sun and the center of Earth, 149 600 000 000 meters
4. Solve each problem, and express each answer in correct scientific notation.
   a. $(4 \times 10^7) \times (2 \times 10^{-3})$
   b. $\dfrac{(6.3 \times 10^{-2})}{(2.1 \times 10^4)}$
   c. $(4.6 \times 10^3) - (1.8 \times 10^3)$
   d. $(7.1 \times 10^{-2}) + (5 \times 10^{-3})$

Chem ASAP! **Assessment 3.1** Check your understanding of the important ideas and concepts in Section 3.1.

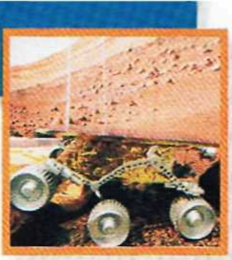
LINK TO ART

Measurement and Art

Although some people believe that art and science are very different, artists and scientists share many of the same methods in their work. For example, artists and scientists are both concerned with measurements. A sculptor designing a realistic statue of a human figure must be certain that the head and its features, as well as the arms, legs, and body, are in proportion to each other. An artist may use a pantograph in making scale drawings. A pantograph is a device in which a pencil traced over an original drawing creates a new drawing that is larger or smaller in scale than the original drawing.

section 3.2

UNCERTAINTY IN MEASUREMENTS



objectives

- Distinguish among the accuracy, precision, and error of a measurement
- Identify the number of significant figures in a measurement and in the result of a calculation

key terms

- accuracy
- precision
- accepted value
- experimental value
- error
- percent error
- significant figures

On July 4, 1997, the Mars Pathfinder spacecraft landed on Mars. Shortly after landing, the spacecraft released a small robotic rover called Sojourner to explore the Martian surface around the landing site in Ares Vallis. NASA scientists had to make thousands of precise calculations to ensure that Pathfinder reached its destination safely. All measurements have some uncertainty. **How do scientists ensure the accuracy and precision of their measurements?**

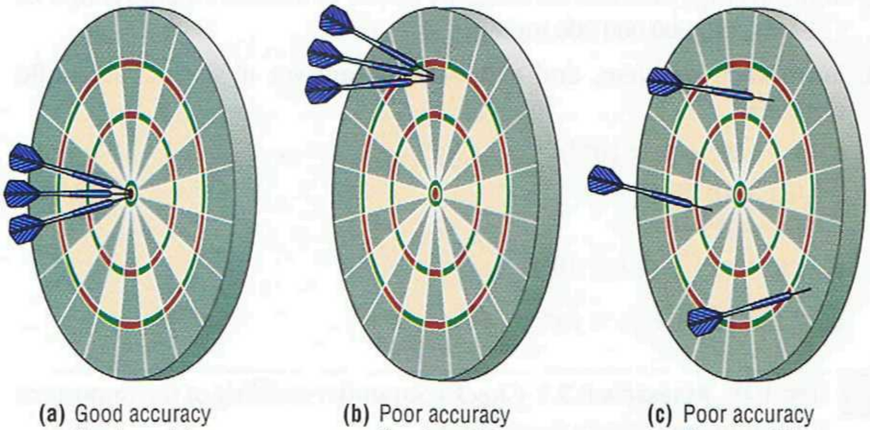
Accuracy, Precision, and Error

Your success in the chemistry lab and in many of your daily activities depends on your ability to make reliable measurements. Ideally, measurements are both correct and reproducible.

Correctness and reproducibility relate to the concepts of accuracy and precision, two words that mean the same thing to many people. In chemistry, however, their meanings are quite different. **Accuracy** is a measure of how close a measurement comes to the actual or true value of whatever is measured. **Precision** is a measure of how close a series of measurements are to one another. Note that the precision of a measurement depends on more than one measurement.

By contrast, an individual measurement may be accurate or inaccurate. Darts on a dartboard illustrate accuracy and precision in measurement. Let *the bull's-eye of the dartboard represent the true, or correct, value of what* you are measuring. The closeness of a dart to the bull's-eye corresponds to the degree of accuracy. The closer it comes to the bull's-eye, the more accurately the dart was thrown. The closeness of several darts to one another corresponds to the degree of precision. The closer together the darts are, the greater the precision and the reproducibility. Look at **Figure 3.4** as you consider the following outcomes.

(a) All of the darts land close to the bull's-eye and to one another. Closeness to the bull's-eye means that the degree of accuracy is great. Each dart in the bull's-eye corresponds to an accurate measurement of a value. Closeness of the darts to one another indicates high precision.



(a) Good accuracy
Good precision

(b) Poor accuracy
Good precision

(c) Poor accuracy
Poor precision

Figure 3.4

The distribution of darts illustrates the difference between accuracy and precision. ***(a)*** *Good accuracy and good precision: The darts are close to the bull's-eye and to one another.* ***(b)*** *Poor accuracy and good precision: The darts are far from the bull's-eye but close to one another.* ***(c)*** *Poor accuracy and poor precision: The darts are far from the bull's-eye and from one another.*

Figure 3.5

This scale has not been properly zeroed. So the reading obtained for the person's weight is inaccurate. There is a difference between the person's correct weight and the measured value.

(b) All of the darts land close to one another but far from the bull's-eye. The precision is high because of the closeness of grouping and thus the high level of reproducibility. The results are inaccurate, however, because of the distance of the darts from the bull's-eye.

(c) The darts land far from one another and from the bull's-eye. The results are both inaccurate and imprecise.

To evaluate the accuracy of a measurement, it must be compared with the correct value. Suppose you use a thermometer to measure the boiling point of pure water at standard atmospheric pressure. The thermometer reads 99.1 °C. You probably know that the true or accepted value of the boiling point of pure water under these conditions is actually 100.0 °C. There is a difference between the **accepted value,** which is the correct value based on reliable references, and the **experimental value,** the value measured in the lab. The difference between the accepted value and the experimental value is called the **error.**

$$\text{Error} = \text{experimental value} - \text{accepted value}$$

Error can be positive or negative depending on whether the experimental value is greater than or less than the accepted value.

For the boiling-point measurement, the error is 99.1 °C − 100.0 °C, or −0.9 °C. The magnitude of the error shows the amount by which the experimental value is too high or too low, compared with the accepted value. Often, it is useful to calculate the relative error, or percent error. The **percent error** is the absolute value of the error divided by the accepted value, multiplied by 100%.

$$\text{Percent error} = \frac{|\text{error}|}{\text{accepted value}} \times 100\%$$

Using the absolute value of the error means that the percent error will always be a positive value. For the boiling-point measurement, the percent error is calculated as follows.

$$\begin{aligned}\text{Percent error} &= \frac{|99.1\ {}^\circ\text{C} - 100.0\ {}^\circ\text{C}|}{100.0\ {}^\circ\text{C}} \times 100\% \\ &= \frac{0.9\ \cancel{{}^\circ\text{C}}}{100.0\ \cancel{{}^\circ\text{C}}} \times 100\% \\ &= 0.009 \times 100\% \\ &= 0.9\%\end{aligned}$$

Significant Figures in Measurements

If you use a liquid-filled thermometer that is calibrated in 1 °C intervals, you can easily read the temperature to the nearest degree. With such a thermometer, however, you can also estimate the temperature to about the nearest tenth of a degree by noting the closeness of the liquid inside to the calibrations. Suppose you estimate a temperature that lies between 23 °C and 24 °C to be 24.3 °C. This estimated number has three digits. The first two digits (2 and 4) are known with certainty. But the rightmost digit has been estimated and involves some uncertainty. These reported digits all convey useful information, however, and are called significant figures. The **significant figures** in a measurement include all of the digits that are known, plus a last digit that is estimated. Measurements must always be reported to the correct number of significant figures because, as you will soon learn, calculated answers depend upon the number of significant figures in the values used in the calculation.

Suppose you take someone's temperature with a thermometer that is calibrated in 0.1 °C intervals. You can read the temperature with virtual certainty to the nearest 0.1 °C, and you can estimate it to the nearest 0.01 °C. You might report the temperature as 35.82 °C. This measurement has four significant figures, the rightmost of which is uncertain. Instruments differ in the number of significant figures that can be obtained from them and thus in the precision of measurements. The three meter sticks in **Figure 3.6** can be used to make successively more precise measurements of the board.

To determine whether a digit in a measured value is significant, you need to apply the following rules.

1. Every nonzero digit in a reported measurement is assumed to be significant. The measurements 24.7 meters, 0.743 meter, and 714 meters each express a measure of length to three significant figures.

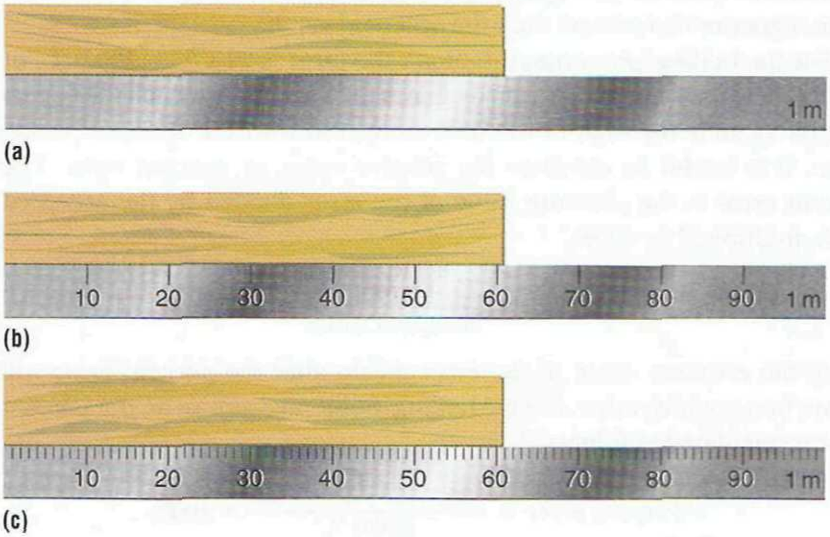


Figure 3.6

Three differently calibrated meter sticks can be used to measure the length of a board. What measurement is obtained in each case? Are there differences in the number of significant figures in the three measurements? Explain.

LINK TO ENGINEERING

Computer-Aided Design

Measurement is important, but making or specifying a large number of measurements can be very time consuming. An engineer designing a complex machine must specify hundreds of dimensions. Today, computer-aided design (CAD) programs have replaced many tedious aspects of technical design. A CAD program usually permits a designer to begin with a few important elements and measurements of the object being designed. As the design progresses, the program computes the dimensions of added elements and produces drawings of the object from any perspective the designer desires. When one dimension in a design is changed, CAD programs automatically adjust all of the other dimensions in proportion. The introduction of CAD programs has reduced the time needed to design complex items as well as the number of errors that plague big projects.

Chem ASAP!

Animation 2

See how the accuracy of a calculated result depends on the sensitivity of the measuring instruments.

2. Zeros appearing between nonzero digits are significant. The measurements 7003 meters, 40.79 meters, and 1.503 meters each have four significant figures.

3. Leftmost zeros appearing in front of nonzero digits are not significant. They act as placeholders. The measurements 0.0071 meter, 0.42 meter, and 0.000 099 meter each have only two significant figures. The zeros to the left are not significant. By writing the measurements in scientific notation, you can get rid of such placeholding zeros: in this case, 7.1×10^{-3} meter, 4.2×10^{-1} meter, and 9.9×10^{-5} meter.

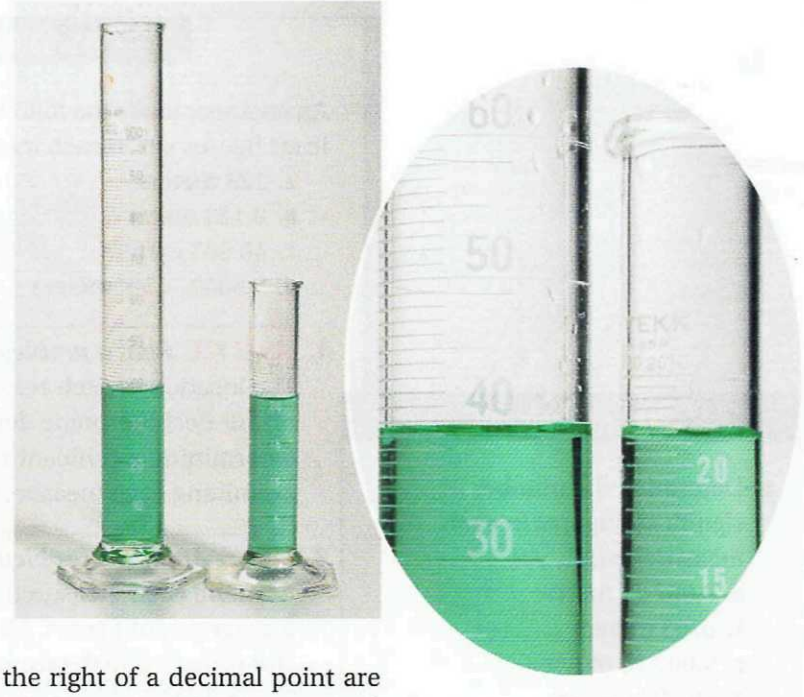


Figure 3.7
Two differently calibrated graduated cylinders are used to measure the volume of a liquid. Which cylinder would give more precise measurements?

4. Zeros at the end of a number and to the right of a decimal point are always significant. The measurements 43.00 meters, 1.010 meters, and 9.000 meters each have four significant figures.

5. Zeros at the rightmost end of a measurement that lie to the left of an understood decimal point are not significant if they serve as placeholders to show the magnitude of the number. The zeros in the measurements 300 meters, 7000 meters, and 27 210 meters are not significant. The numbers of significant figures in these values are one, one, and four, respectively. If such zeros were known measured values, however, then they would be significant. For example, if the value of 300 meters resulted from a careful measurement rather than a rough, rounded measurement, the zeros would be significant. Ambiguity is avoided if measurements are written in scientific notation. For example, if all of the zeros in the measurement 300 meters were significant, writing the value as 3.00×10^{2} meters makes it clear that these zeros are significant.

6. There are two situations in which measurements have an unlimited number of significant figures. The first involves counting. If you carefully count that there are 23 people in your classroom, then there are exactly 23 people, not 22.9 or 23.1. This measurement can only be a whole number and has an unlimited number of significant figures, in the form of zeros understood to be to the right of the decimal point; thus, 23.000 000 … is understood. The second situation of unlimited significant figures involves exactly defined quantities, such as those usually used within a system of measurement. When, for example, you write 60 minutes = 1 hour, these quantities have an unlimited number of significant figures; there are exactly 60 minutes in an hour, by definition. It is important to recognize when quantities are exact and to round calculated answers correctly in problems involving such values.

Sample Problem 3-1

An engineer made the following measurements. How many significant figures are in each measurement?

a. 123 meters
b. 0.123 meter
c. 40 506 meters
d. 9.8000×10^4 meters
e. 30.0 meters
f. 22 meter sticks
g. 0.070 80 meter
h. 98 000 meters

1. ***ANALYZE*** *Plan a problem-solving strategy.*
The location of each zero in the measurement and the location of the decimal point determine which of the rules apply for determining significant figures. These locations are known by examining each measurement value.

2. ***SOLVE*** *Apply the problem-solving strategy.*
Examine each measurement and apply the rules for determining significant figures. All nonzero digits are significant (rule 1). Use rules 2–5 to determine if the zeros are significant.
a. 3 (rule 1)
b. 3 (rule 3)
c. 5 (rule 2)
d. 5 (rule 4)
e. 3 (rule 4)
f. unlimited (rule 6)
g. 4 (rules 2, 3, 4)
h. 2 (rule 5)

3. ***EVALUATE*** *Do the results make sense?*
The rules for determining significant digits have been correctly applied in each case.

Practice Problems

5. Determine the number of significant figures in each measurement.
  a. 0.057 30 meter
  b. 8765 meters
  c. 0.000 73 meter
  d. 40.007 meters

6. How many significant figures are in each measurement?
  a. 143 grams
  b. 0.074 meter
  c. 8.750×10^{-2} gram
  d. 1.072 meters

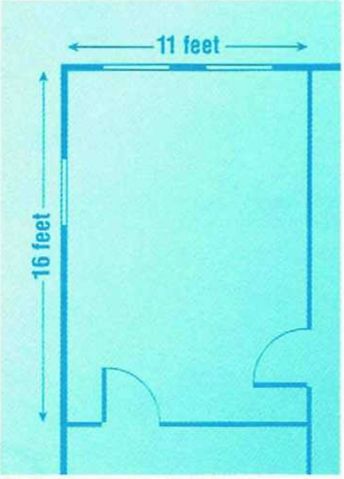


Figure 3.8
The room shown in the blueprint measures 11 feet by 16 feet. What is the calculated area of the room to the correct number of significant figures?

Significant Figures in Calculations

Rounding Suppose you use a calculator to find the area of a floor that measures 7.7 meters by 5.4 meters. The calculator would give an answer of 41.58 square meters. The calculated area is expressed to four significant figures. However, each of the measurements used in the calculation is expressed to only two significant figures. It is important to know that the calculated area cannot be more precise than the measured values used to obtain it.

The calculated area must be rounded to make it consistent with the measurements from which it was calculated. In general, an answer cannot be more precise than the least precise measurement from which it was calculated.

To round a number, you must first decide how many significant figures the answer should have. This decision depends on the given measurements and on the mathematical process used to arrive at the answer. Once you know the number of significant figures your answer should have, round to that many digits, counting from the left. If the digit immediately to the right of the last significant digit is less than 5, it is simply dropped and the value of the last significant digit stays the same. If the digit in question is 5 or greater, the value of the digit in the last significant place is increased by 1. For example, rounding 56.312 meters to four significant figures produces the result 56.31 meters because 2, the digit to the right of the last significant digit, is less than 5. Rounding 56.316 meters gives the result 56.32 meters because 6, the digit to the right of the last significant figure, is greater than 5.

Sample Problem 3-2

Round each measurement to the number of significant figures shown in parentheses. Write the answers in scientific notation.

a. 314.721 meters (4)
b. 0.001 775 meter (2)
c. 64.32×10^{-1} meters (1)
d. 8792 meters (2)

1. ***ANALYZE*** *Plan a problem-solving strategy.*
Using the rules for determining significant figures, round each number. Then, apply the rules for expressing numbers in scientific notation.

2. ***SOLVE*** *Apply the problem-solving strategy.*
Count from the left and apply the rule to the digit immediately to the right of the digit to which you are rounding. The arrows point to the digit immediately following the last significant digit. (The number of significant figures for each is shown in parentheses.)

a. $314.7\underset{\uparrow}{2}1$ meters

2 is less than 5, so do not round up.
314.7 meters (4) = 3.147×10^{2} meters

b. $0.001\,7\underset{\uparrow}{7}5$ meter

7 is greater than 5, so round up.
0.0018 meter (2) = 1.8×10^{-3} meter

c. $6\underset{\uparrow}{4}.32 \times 10^{-1}$ meters

4 is less than 5, so do not round up.
60×10^{-1} meters (1) = 6 meters

(Note that 6 meters can be expressed in scientific notation as 6×10^{0} meters.)

d. $87\underset{\uparrow}{9}2$ meters

9 is greater than 5, so round up.
8800 meters (2) = 8.8×10^{3} meters

3. ***EVALUATE*** *Do the results make sense?*
The rules for rounding and for writing numbers in scientific notation have been correctly applied.

Practice Problems

7. Round each measurement to three significant figures. Write your answers in scientific notation.
a. 87.073 meters
b. 4.3621×10^{8} meters
c. 0.015 52 meter
d. 9009 meters
e. 1.7777×10^{-3} meter
f. 629.55 meters

8. Round each measurement in Practice Problem 7 to one significant figure. Write your answers in scientific notation.

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Problem-Solving 7
Solve Problem 7 with the help of an interactive guided tutorial.

Addition and Subtraction The answer to an addition or subtraction calculation should be rounded to the same number of decimal places (not digits) as the measurement with the least number of decimal places. Work through Sample Problem 3-3 below which provides examples of rounding in addition and subtraction calculations.

Sample Problem 3-3

Perform the following addition and subtraction operations. Give each answer to the correct number of significant figures.

a. 12.52 meters + 349.0 meters + 8.24 meters

b. 74.626 meters − 28.34 meters

1. ***ANALYZE*** ***Plan a problem-solving strategy.***

Perform the required math operation and then analyze each measurement to determine the number of decimal places required in the answer.

2. ***SOLVE*** ***Apply the problem-solving strategy.***

Round the answers to match the measurement with the least number of decimal places.

a. Align the decimal points and add the numbers.

$$\begin{array}{rl} 12.52 & \text{meters} \\ 349.0 & \text{meters} \\ +\ \ 8.24 & \text{meters} \\ \hline 369.\underset{\uparrow}{7}6 & \text{meters} \end{array}$$

The second measurement (349.0 meters) has the least number of digits (one) to the right of the decimal point. Thus the answer must be rounded to one digit after the decimal point. The answer is rounded to 369.8 meters, or 3.698×10^2 meters.

b. Align the decimal points and subtract the numbers.

$$\begin{array}{rl} 74.626 & \text{meters} \\ -\ 28.34 & \text{meters} \\ \hline 46.286 & \text{meters} \end{array}$$

The answer must be rounded to two digits after the decimal point to match the second measurement. The answer is 46.29 meters, or 4.629×10^1 meters.

3. ***EVALUATE*** ***Do the results make sense?***

The mathematical operations have been correctly carried out and the resulting answers are reported to the correct number of decimal places.

Practice Problems

9. Perform each operation. Give your answers to the correct number of significant figures.
  - **a.** 61.2 meters + 9.35 meters + 8.6 meters
  - **b.** 9.44 meters − 2.11 meters
  - **c.** 1.36 meters + 10.17 meters
  - **d.** 34.61 meters − 17.3 meters

10. Find the total mass of three diamonds that have masses of 14.2 grams, 8.73 grams, and 0.912 gram.

Chem ASAP!

Problem-Solving 10

Solve Problem 10 with the help of an interactive guided tutorial.

Multiplication and Division In calculations involving multiplication and division, you need to round the answer to the same number of significant figures as the measurement with the least number of significant figures.

You can see in **Figure 3.9** that the calculator answer (5.7672) must be rounded to three significant figures because each measurement used in the calculation has only three significant figures.

The position of the decimal point has nothing to do with the rounding process when multiplying and dividing measurements. The position of the decimal point is important only in rounding the answers of addition or subtraction problems.

Figure 3.9

This calculator was used to multiply the length and width measurements of a bolt of fabric, 3.24 meters by 1.78 meters, each of which has three significant figures. The area of the fabric is really not known with the precision suggested by the calculator. What is the product when correctly rounded?

Sample Problem 3-4

Perform the following operations. Give the answers to the correct number of significant figures.

- **a.** 7.55 meters × 0.34 meter
- **b.** 2.10 meters × 0.70 meter
- **c.** 2.4526 meters ÷ 8.4
- **d.** 0.365 meter ÷ 0.0200

1. ***ANALYZE*** *Plan a problem-solving strategy.*
   Perform the required math operation and then analyze each of the original numbers to determine the correct number of significant figures required in the answer.

2. ***SOLVE*** *Apply the problem-solving strategy.*

   Round the answers to match the measurement with the least number of significant figures.

   - **a.** 7.55 meters × 0.34 meter = 2.567 square meters = 2.6 square meters
     (0.34 meter has two significant figures.)
   - **b.** 2.10 meters × 0.70 meter = 1.47 square meters = 1.5 square meters
     (0.70 meter has two significant figures.)
   - **c.** 2.4526 meters ÷ 8.4 = 0.291 976 meter = 0.29 meter
     (8.4 has two significant figures.)
   - **d.** 0.365 meter ÷ 0.0200 = 18.25 meters = 18.3 meters
     (Both numbers have three significant figures.)

3. ***EVALUATE*** *Do the results make sense?*
   The mathematical operations have been performed correctly, and the resulting answers are reported to the correct number of places.

Practice Problems

11. Solve each problem. Give your answers to the correct number of significant figures and in scientific notation.

- **a.** 8.3 meters × 2.22 meters
- **b.** 8432 meters ÷ 12.5
- **c.** 35.2 seconds × 1 minute/60 seconds

12. Calculate the volume of a warehouse that has inside dimensions of 22.4 meters by 11.3 meters by 5.2 meters. (Volume = $l \times w \times h$)

Chem ASAP!

Problem-Solving 12

Solve Problem 12 with the help of an interactive guided tutorial.

MINI LAB

Accuracy and Precision

PURPOSE

To measure the dimensions of an object as accurately and precisely as possible and to apply rules for rounding answers calculated from the measurements.

MATERIALS

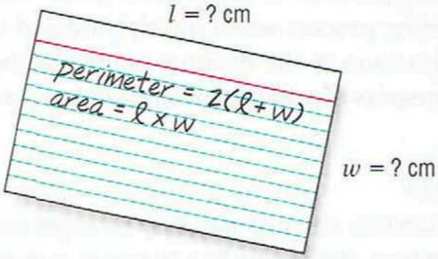
- index card (3″ × 5″)
- metric ruler

PROCEDURE

1. Use a metric ruler to measure in centimeters the length and width of an index card as accurately and precisely as you can. The hundredths place in your measurement should be estimated.
2. Calculate the perimeter [2 × (length + width)] and the area (length × width) of the index card. Write both your unrounded answers and your correctly rounded answers on the chalkboard.

ANALYSIS AND CONCLUSIONS

1. How many significant figures are in your measurements of length and of width?



2. How do your measurements compare with those of your classmates?
3. How many significant figures are in your calculated value for the area? In your calculated value for the perimeter? Do your rounded answers have as many significant figures as your classmates' measurements?
4. Assume that the correct (accurate) length and width of the card are 12.70 cm and 7.62 cm, respectively. Calculate the percent error for each of your two measurements.

section review 3.2

13. Explain the differences between accuracy, precision, and error of a measurement.
14. Determine the number of significant figures in each of the following measurements and calculation results.
    - **a.** 12 basketball players
    - **b.** 0.010 square meter
    - **c.** 507 thumbtacks
    - **d.** 0.070 020 meter
    - **e.** 10 800 meters
    - **f.** 5.00 cubic meters
15. Solve the following and express each answer in scientific notation.
    - **a.** $(5.3 \times 10^4) + (1.3 \times 10^4)$
    - **b.** $(7.2 \times 10^{-4}) \div (1.8 \times 10^3)$
    - **c.** $10^4 \times 10^{-3} \times 10^6$
    - **d.** $(9.12 \times 10^{-1}) - (4.7 \times 10^{-2})$
    - **e.** $(5.4 \times 10^4) \times (3.5 \times 10^9)$
    - **f.** $(1.2 \times 10^2) \times (8.9 \times 10^2)$
16. A technician experimentally determined the boiling point of octane to be 124.1 °C. The actual boiling point of octane is 125.7 °C. Calculate the error and the percent error.

Chem ASAP! Assessment 3.2 Check your understanding of the important ideas and concepts in Section 3.2.

portfolio project

Interview workers who construct buildings or highways about the importance of accurate measurements.

INTERNATIONAL SYSTEM OF UNITS

Weights and measures were among the earliest human inventions. Length units were used for construction; units of weight were needed for trading goods. Body parts made convenient units of length. An inch was measured with a thumb, a foot was the length of a foot, and a yard was the distance from one's nose to the tip of an extended arm. Archeologists think that polished stones found in the ruins of ancient Babylonian cities were standards of weight. The carat measures the mass of gold, silver, and gems. Arabs based the carat on the seed of the carob plant. **What system do modern scientists use for measurement?**

objectives

- List SI units of measurement and common SI prefixes
- Distinguish between the mass and weight of an object

key terms

- International System of Units (SI)
- meter (m)
- volume
- liter (L)
- weight
- kilogram (kg)
- gram (g)

Units of Length

When you make a measurement, you must assign the correct units to the numerical value. Without the units, it is impossible to communicate the measurement clearly to others. Imagine the confusion that would follow if someone told you to "walk five in that direction." Your immediate response would be "Five what? Feet, meters, yards, miles?"

All measurements depend on units that serve as reference standards. The standards of measurement used in science are those of the metric system. The metric system is important because of its simplicity and ease of use. All metric units are based on 10 or multiples of 10. As a result, you can convert between units easily. The metric system was originally established in France in 1790. The **International System of Units** (abbreviated **SI,** after the French name, *Le Systéme International d'Unités*) is a revised version of the metric system. The SI was adopted by international agreement in 1960. There are seven SI base units, which are listed in **Table 3.1.** From these base units, all other SI units of measurement can be derived. Derived units are used for measurements such as volume, density, and pressure.

Table 3.1

Units of Measurement

Quantity	SI base unit or SI derived unit	Symbol	Non-SI unit	Symbol
Length	meter*	m		
Volume	cubic meter	m^3	liter	L
Mass	kilogram*	kg		
Density	grams per cubic centimeter grams per milliliter	g/cm^3 g/mL		
Temperature	kelvin*	K	degree Celsius	°C
Time	second*	s		
Pressure	pascal	Pa	atmosphere millimeter of mercury	atm mm Hg
Energy	joule	J	calorie	cal
Amount of substance	mole*	mol		
Luminous intensity	candela*	cd		
Electric current	ampere*	A		

*denotes SI base unit

Table 3.2

Commonly Used Prefixes in the Metric System

Prefix	Symbol	Meaning	Factor	Scientific notation
mega	M	1 million times larger than the unit it precedes	1 000 000	10^{6}
kilo	k	1000 times larger than the unit it precedes	1000	10^{3}
deci	d	10 times smaller than the unit it precedes	1/10	10^{-1}
centi	c	100 times smaller than the unit it precedes	1/100	10^{-2}
milli	m	1000 times smaller than the unit it precedes	1/1000	10^{-3}
micro	μ	1 million times smaller than the unit it precedes	1/1 000 000	10^{-6}
nano	n	1000 million times smaller than the unit it precedes	1/1 000 000 000	10^{-9}
pico	p	1 trillion times smaller than the unit it precedes	1/1 000 000 000 000	10^{-12}

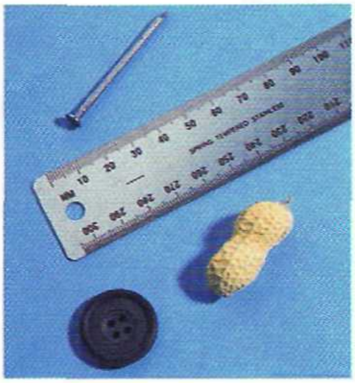


Figure 3.10

A meter stick is divided into 100 centimeters (cm). Each centimeter is further divided into 10 millimeters (mm). How many millimeters are there in a meter?

All measured quantities can be reported in SI units. Sometimes, however, non-SI units are preferred for convenience or for practical reasons. **Table 3.1** also lists some derived SI units and non-SI units of measurement that are used in this textbook.

Size is an important property of matter. In SI, the basic unit of length, or linear measure, is the **meter** (**m**). All measurements of length can be expressed in meters. (The length of a page in this book is about one-fourth of a meter.) For very large and very small lengths, however, it may be more convenient to use a unit of length that has a prefix. **Table 3.2** lists the prefixes in common use. For example, the prefix *milli-* means 1/1000, so a millimeter (mm) is 1/1000 of a meter, or 0.001 m. A hyphen (-) measures about 1 mm.

For large distances, it is usually most appropriate to express measurements in kilometers (km). The prefix *kilo-* means 1000, so 1 km equals 1000 m. A standard marathon distance race of about 42 000 m is more conveniently expressed as 42 km (42 × 1000 m). **Table 3.3** summarizes the relationships among units of length.

Table 3.3

Metric Units of Length

Unit	Symbol	Relationship	Example
Kilometer	km	1 km $=$ 10^{3} m	length of about five city blocks $\approx$ 1 km
Meter	m	base unit	height of doorknob from the floor $\approx$ 1 m
Decimeter	dm	10^{1} dm $=$ 1 m	diameter of large orange $\approx$ 1 dm
Centimeter	cm	10^{2} cm $=$ 1 m	width of shirt button $\approx$ 1 cm
Millimeter	mm	10^{3} mm $=$ 1 m	thickness of dime $\approx$ 1 mm
Micrometer	μm	10^{6} μm $=$ 1 m	diameter of bacterial cell $\approx$ 1 μm
Nanometer	nm	10^{9} nm $=$ 1 m	thickness of RNA molecule $\approx$ 1 nm

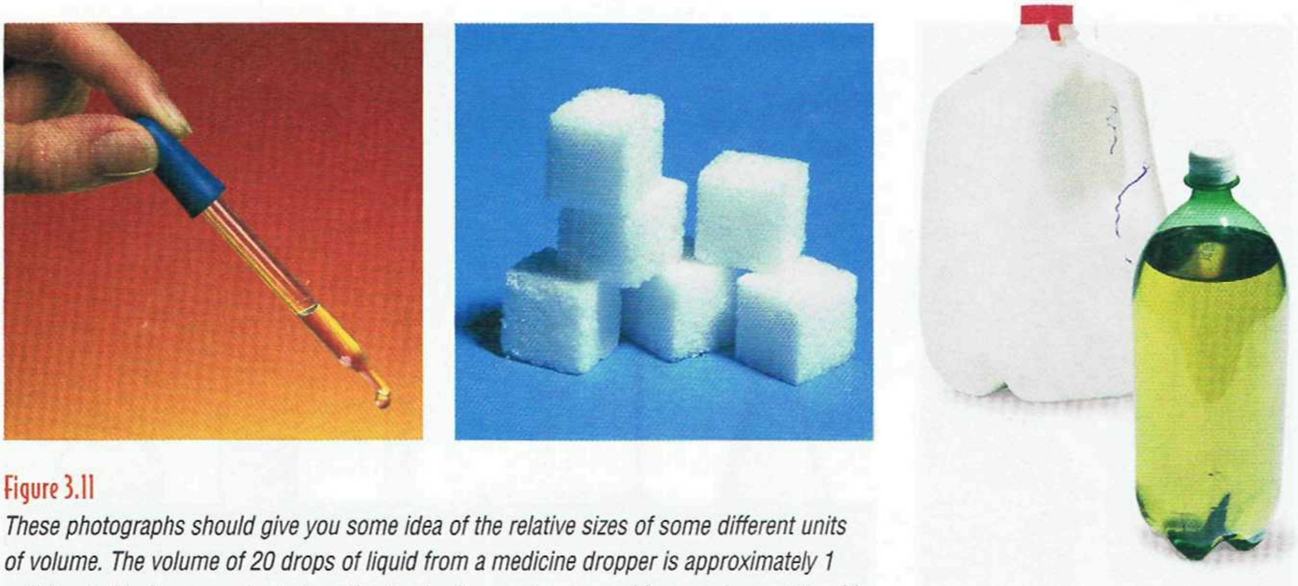


Figure 3.11

These photographs should give you some idea of the relative sizes of some different units of volume. The volume of 20 drops of liquid from a medicine dropper is approximately 1 milliliter (mL). A sugar cube is 1 centimeter (cm) on each edge and has a volume of 1 cubic centimeter (cm^3). These two volumes are equivalent; that is, a volume of 1 mL is the same as a volume of 1 cm^3. A gallon of milk has about twice the volume of a two-liter bottle of soda. Note that a gallon is a non-SI unit and it is used here only for comparison purposes.

Units of Volume

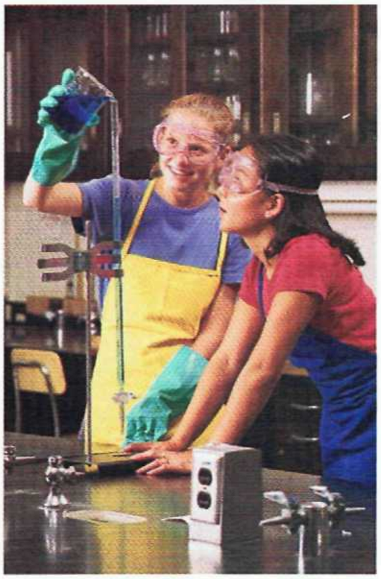
The space occupied by any sample of matter is called its **volume.** You calculate the volume of any cubic or rectangular solid by multiplying its length by its width by its height. The unit for volume is thus derived from units of length. The SI unit of volume is the amount of space occupied by a cube that is 1 m along each edge. This volume is a cubic meter (m^3). An automatic dishwasher has a volume of about 1 m^3.

A more convenient unit of volume for everyday use is the liter, a non-SI unit. A **liter** (L) is the volume of a cube that is 10 centimeters (cm) along each edge ($10 \text{ cm} \times 10 \text{ cm} \times 10 \text{ cm} = 1000 \text{ cm}^3 = 1 \text{ L}$). A decimeter (dm) is equal to 10 cm, so 1 L is also equal to 1 cubic decimeter (dm^3). A smaller non-SI unit of volume is the milliliter (mL); 1 mL is 1/1000 of a liter. Thus there are 1000 mL in 1 L. Because 1 L is defined as 1000 cm^3, 1 mL and 1 cm^3 are the same volume. The units milliliter and cubic centimeter are thus used interchangeably. **Table 3.4** summarizes the most commonly used relationships among units of volume.

Table 3.4

Metric Units of Volume

Unit	Symbol	Relationship	Example
Liter	L	base unit	quart of milk ≈ 1 L
Milliliter	mL	10^3 mL = 1 L	20 drops of water ≈ 1 mL
Cubic centimeter	cm^3	1 cm^3 = 1 mL	cube of sugar ≈ 1 cm^3
Microliter	μL	10^6 μL = 1 L	crystal of table salt ≈ 1 μL



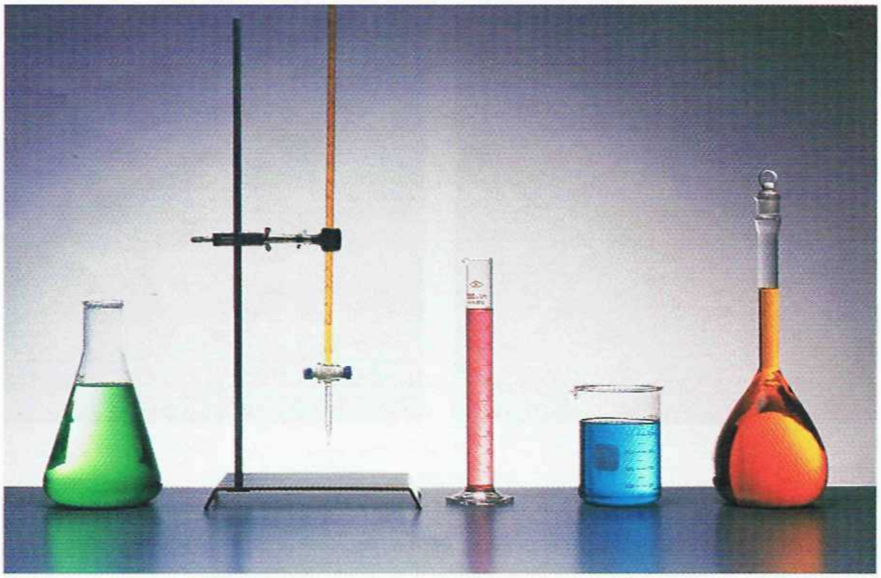


Figure 3.12

Shown left to right are five types of glassware used to measure volume: Erlenmeyer flask, buret, graduated cylinder, beaker, and volumetric flask. Beakers, Erlenmeyer flasks, and graduated cylinders are used to measure approximate volumes. Volumetric flasks and burets allow more precise measurements. What would you use to measure a large volume, such as 1 L, accurately?

Figure 3.13

An astronaut's weight on the moon is one-sixth as much as it is on Earth. Earth exerts six times the force of gravity as the moon. The astronaut's lowered weight accounts for his ability to jump high on the moon. How does his mass on the moon compare with his mass on Earth?

There are many devices for measuring the volume of a liquid. Examples of volumetric glassware are shown in **Figure 3.12.** A graduated cylinder is useful for dispensing approximate volumes. A pipet or buret must be used, however, when accuracy is important. A volumetric flask contains a specified volume of liquid when it is filled to the calibration mark. Volumetric flasks are available in many sizes. A syringe is used to measure small volumes of liquids for injection.

The volume of any solid, liquid, or gas will change with temperature (although the change is much more dramatic for gases). Accurate volume-measuring devices are calibrated at a given temperature—usually 20 degrees Celsius (20 °C), which is about normal room temperature.

Units of Mass

The astronaut shown saluting on the surface of the moon in **Figure 3.13** weighs one-sixth of what he weighs on Earth. The reason for this difference is that the force of gravity on Earth is about six times what it is on the moon. **Weight** is a force that measures the pull on a given mass by gravity. Weight is different from mass, which is a measure of the quantity of matter. Although the weight of an object can change with its location, its mass remains constant regardless of its location—whether it is on Earth or on the moon. Objects can thus become weightless, but they can never become massless.

The mass of an object is measured in comparison to a standard mass of 1 **kilogram (kg)**, which is the basic SI unit of mass. A kilogram was originally defined as the mass of 1 L of liquid water at 4 °C. A cube of water

Table 3.5

Metric Units of Mass			
Unit	**Symbol**	**Relationship**	**Example**
Kilogram (base unit)	kg	$1\ \text{kg} = 10^3\ \text{g}$	small textbook ≈ 1 kg
Gram	g	$1\ \text{g} = 10^{-3}\ \text{kg}$	dollar bill ≈ 1 g
Milligram	mg	$10^3\ \text{mg} = 1\ \text{g}$	ten grains of salt ≈ 1 mg
Microgram	μg	$10^6\ \mu\text{L} = 1\ \text{g}$	particle of baking powder ≈ 1 μg

at 4 °C measuring 10 cm on each edge would have a volume of 1 L and a mass of 1000 grams (g), or 1 kg. A **gram (g)** is 1/1000 of a kilogram and is a more commonly used unit of mass in chemistry. The mass of 1 cm^3 of water at 4 °C is 1 g. The relationships among units of mass are shown in **Table 3.5.**

You can use a platform balance to measure the mass of an object. The object is placed on one side of the balance, and standard masses are added to the other side until the balance beam is level, as shown in **Figure 3.14.** The unknown mass is equal to the sum of the standard masses. Laboratory balances range from very sensitive instruments with a maximum capacity of only a few milligrams to devices for measuring quantities in kilograms. An analytical balance is used to measure objects of less than 100 g and can determine mass to the nearest 0.0001 g (0.1 mg).

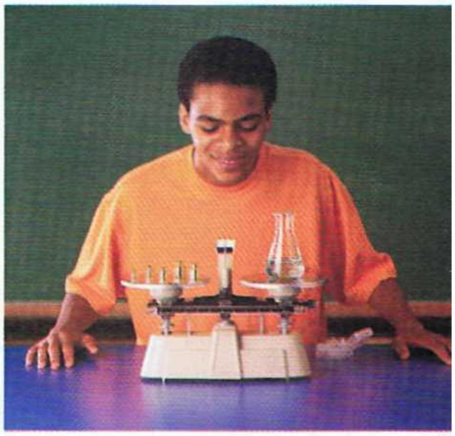


Figure 3.14

A platform balance compares an unknown mass with a known mass. The mass of the water and the flask is the same as the sum of the standard masses.

section review 3.3

17. Name the quantity measured by each of the following SI units and give the SI symbol of the unit.

a. mole

b. kilogram/cubic meter

c. second

d. pascal

e. meter

f. kilogram

18. State the difference between mass and weight.

19. What is the symbol and meaning of each prefix?

a. *milli-*

b. *nano-*

c. *deci-*

d. *centi-*

20. As you climbed a mountain and the force of gravity decreased, would your weight increase, decrease, or remain constant? How would your mass change?

21. What is the volume of a paperback book 21 cm tall, 12 cm wide, and 3.5 cm thick?

22. List these units in order, from largest to smallest.

a. 1 dm^3

b. 1 μL

c. 1 mL

d. 1 L

e. 1 cL

f. 1 dL

Chem ASAP! Assessment 3.3 Check your understanding of the important ideas and concepts in Section 3.3.