Chapter 3

3.1 Measurements and Their Uncertainty

Using and Expressing Measurements

- A **measurement** is a quantity that has both a number and a unit.
  - Measurements are fundamental to the experimental sciences. For that reason, it is important to be able to make measurements and to decide whether a measurement is correct.

Using and Expressing Measurements

- In **scientific notation**, a given number is written as the product of two numbers: a coefficient and 10 raised to a power.
  - The number of stars in a galaxy is an example of an estimate that should be expressed in scientific notation.

Accuracy, Precision, and Error

- **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.

Accuracy, Precision, and Error

- To evaluate the accuracy of a measurement, the measured value must be compared to the correct value.
- To evaluate the precision of a measurement, you must compare the values of two or more repeated measurements.

Accuracy, Precision, and Error

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

- Determining Error
  - The **accepted value** is the correct value.
  - The **experimental value** is the value measured in the lab.
  - The difference between the experimental value and the accepted value is called the **error**.

Accuracy, Precision, and Error

- The **percent error** is the absolute value of the error divided by the accepted value, multiplied by 100%.

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

Practice Problem

- A technician experimentally determined the boiling point of octane to be 124.1ºC. The actual boiling point of octane is 125.7ºC. Calculate the error and percent error.

Significant Figures in Measurements

- Suppose you estimate a weight that is between 2.4 lb and 2.5 lb to be 2.46 lb. The first two digits (2 and 4) are known. The last digit (6) is an estimate and involves some uncertainty. All three digits 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.

Significant Figures in Measurements

- Measurements must always be reported to the correct number of significant figures because calculated answers often depend on the number of significant figures in the values used in the calculation.

Rules

- 1) Nonzero integers are always significant
  - Ex: 1457 has 4
- 2) Leading zeros (before nonzero numbers) are not significant
  - Ex: 0.0025 has 2

Rules

- 3) Captive zeros (between nonzero digits) are always significant
  - Ex: 1.008 has 4

Rules

- 4) Trailing zeros (at right after nonzero integers) are significant <u>only</u> if there is a decimal point
  - Ex: <u>1</u>00 has 1, but <u>100</u>. has 3
  - Ex: 0.00<u>250</u> has 3

Rules

- 5) Exact numbers (counting numbers) have unlimited (infinite) significant figures
  - Ex: 3 apples, 8 molecules
  - Definitions: 1 inch = exactly 2.54 cm

CONCEPTUAL PROBLEM 3.1

Counting Significant Figures in Measurements

How many significant figures are in each measurement?

a. 123 m

b. 40,506 mm

c. 9.8000×10^4 m

d. 22 meter sticks

e. 0.070 80 m

f. 98,000 m

for Conceptual Problem 3.1

2. How many significant figures are in each measurement?

a. 143 grams

b. 0.074 meter

c. 8.750×10^{-2} gram

d. 1.072 meter

Give number of Sig Fig's

- 1) 123
- 2) 0.123
- 3) 40506
- 4) 9.800
- 5) 4.5600
- 6) 0.07080
- 7) 98000
- 8) 0.05730
- 9) 0.00073
- 10) 0.010

Significant Figures in Calculations

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

Sample Problem 3.1

Rounding Measurements

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

a. 314.721 meters (four)

b. 0.001 775 meter (two)

c. 8792 meters (two)

3. Round each measurement to three significant figures. Write your answers in scientific notation.

a. 87.073 meters

b. 4.3621×10^{8} meters

c. 0.01552 meter

d. 9009 meters

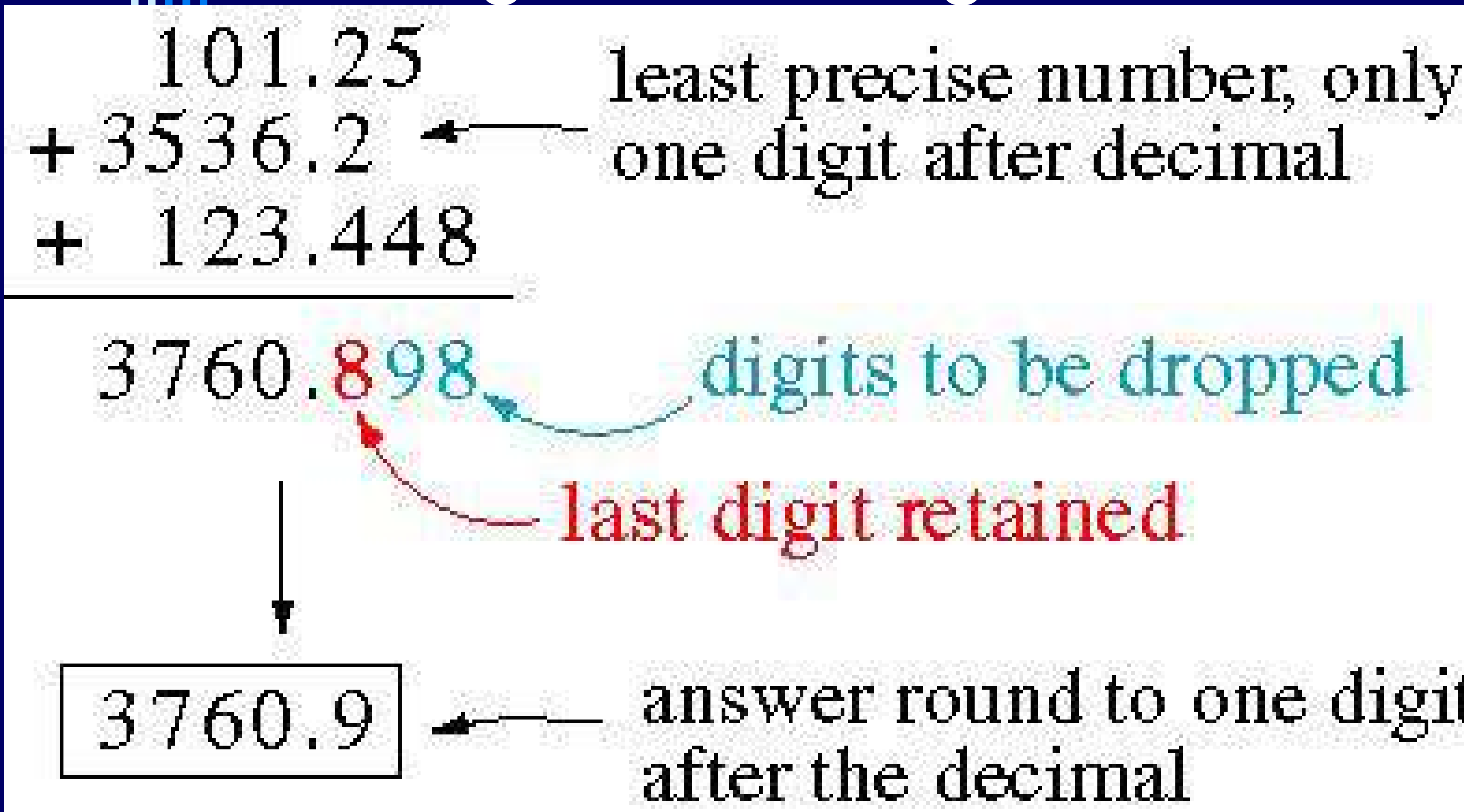
e. 1.7777×10^{-3} meter

f. 629.55 meters

Significant Figures in Calculations

- 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.

Adding/Subtracting



Sample Problem 3.2

Significant Figures in Addition

Calculate the sum of the three measurements. Give the answer to the correct number of significant figures.

12.52 meters + 349.0 meters + 8.24 meters

for Sample Problem 3.2

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

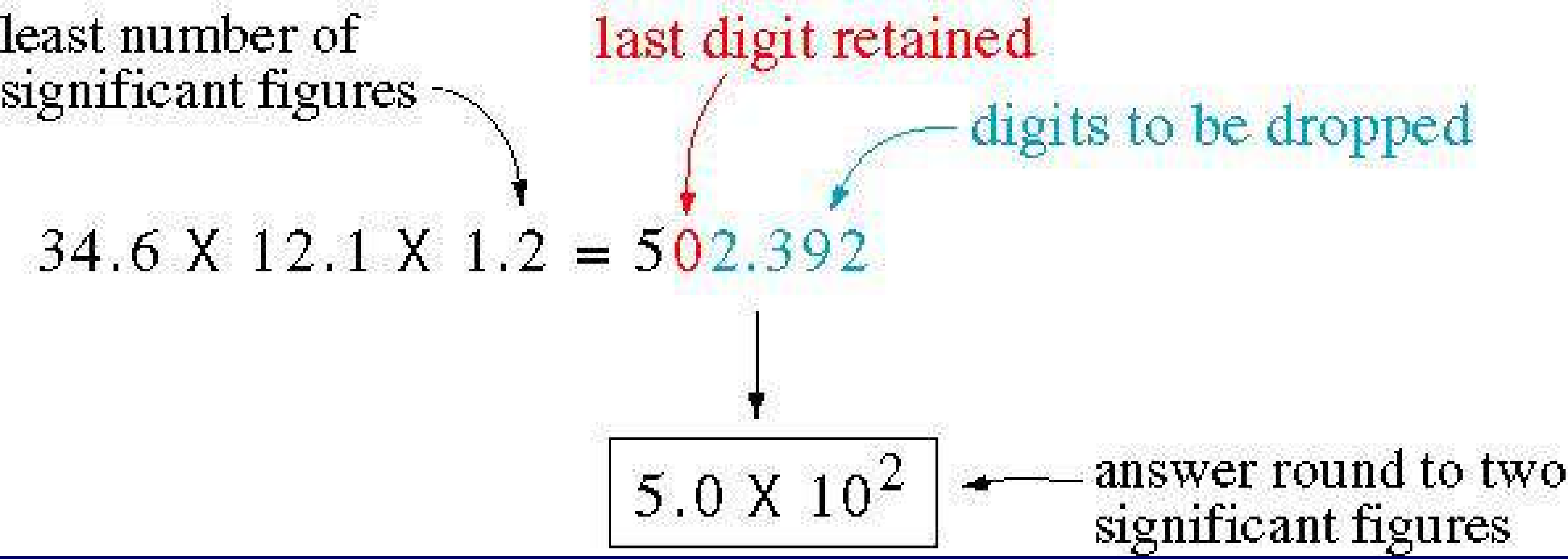
Practice

- 1) 61.2 + 9.35 + 8.6
- 2) 9.44 – 2.11
- 3) 1.36 + 10.17
- 4) 34.61 – 17.3
- 5) 12.52 + 349.0 + 8.24

Significant Figures in Calculations

- 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.

Multiplying/Dividing



Sample Problem 3.3

Significant Figures in Multiplication and Division

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

for Sample Problem 3.3

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

Practice

- 1) 8.3×2.22
- 2) $8432 \div 12.5$
- 3) 7.55×0.34
- 4) $0.365 \div 0.0200$
- 5) 2.10×0.70

3.1 Section Quiz

- 1. Which set of measurements of a 2.00-g standard is the most precise?
  - a) 2.00 g, 2.01 g, 1.98 g
  - b) 2.10 g, 2.00 g, 2.20 g
  - c) 2.02 g, 2.03 g, 2.04 g
  - d) 1.50 g, 2.00 g, 2.50 g

3.1 Section Quiz

- 2. A student reports the volume of a liquid as 0.0130 L. How many significant figures are in this measurement?
  - a) 2
  - b) 3
  - c) 4
  - d) 5

3.2 The International System of Units

Measuring with SI Units

Table 3.1

SI Base Units		
Quantity	**SI base unit**	**Symbol**
Length	meter	m
Mass	kilogram	kg
Temperature	kelvin	K
Time	second	s
Amount of substance	mole	mol
Luminous intensity	candela	cd
Electric current	ampere	A

Units and Quantities

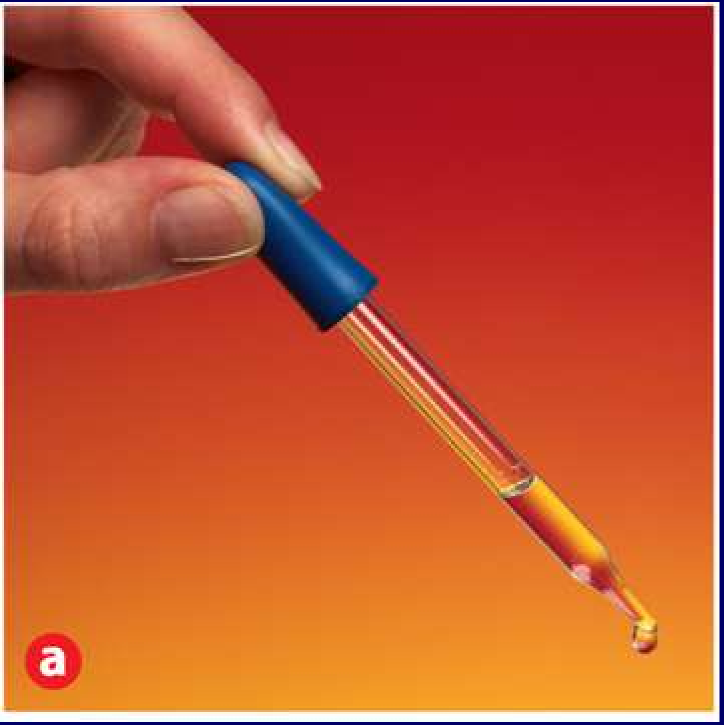
Table 3.3

Metric Units of Length		
Unit	**Relationship**	**Example**
Kilometer (km)	1 km = 10^3 m	length of about five city blocks ≈ 1 km
Meter (m)	base unit	height of doorknob from the floor ≈ 1 m
Decimeter (dm)	10^1 dm = 1 m	diameter of large orange ≈ 1 dm
Centimeter (cm)	10^2 cm = 1 m	width of shirt button ≈ 1 cm
Millimeter (mm)	10^3 mm = 1 m	thickness of dime ≈ 1 mm
Micrometer (μm)	10^6 μm = 1 m	diameter of bacterial cell ≈ 1 μm
Nanometer (nm)	10^9 nm = 1 m	thickness of RNA molecule ≈ 1 nm

Units and Quantities

- Units of Volume
  - The SI unit of volume is the amount of space occupied by a cube that is 1 m along each edge – a cubic meter $(m)^3$. A more convenient unit of volume is the liter (volume of a cube that is 10 cm on each edge), a non-SI unit.

Units and Quantities

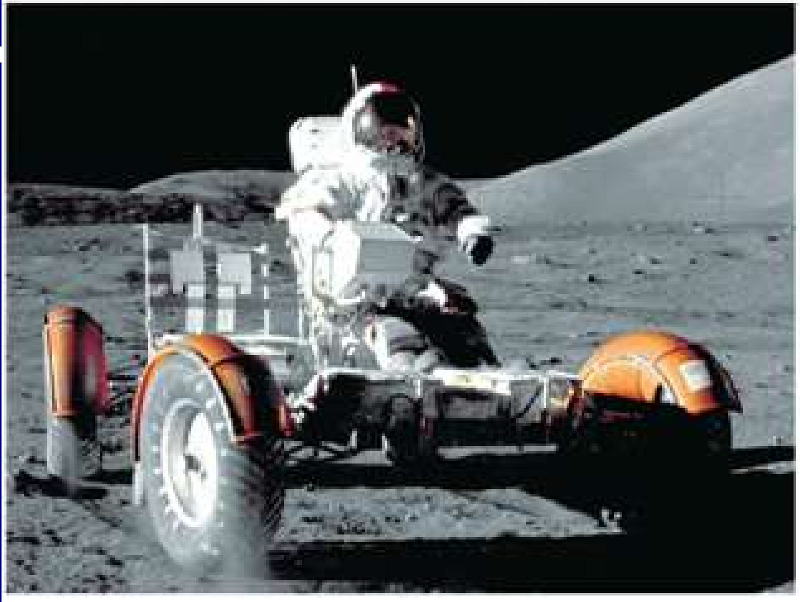


- The volume of 20 drops of liquid from a medicine dropper is approximately 1 mL.

Units and Quantities

- A sugar cube has a volume of 1 cm^3. 1 mL is the same as 1 cm^3.

Units and Quantities



- **Weight** is a force that measures the pull on a given mass by gravity.
  - The astronaut shown on the surface of the moon weighs one sixth of what he weighs on Earth.

Units of Temperature

- Temperature is a measure of how hot or cold an object is.
- Thermometers are used to measure temperature.

- On the **Celsius scale**, the freezing point of water is 0°C and the boiling point is 100°C.
- On the **Kelvin scale**, the freezing point of water is 273.15 kelvins (K), and the boiling point is 373.15 K.
- The zero point on the Kelvin scale, 0 K, or **absolute zero**, is equal to –273.15 °C.

Units and Quantities

- Because one degree on the Celsius scale is equivalent to one kelvin on the Kelvin scale, converting from one temperature to another is easy. You simply add or subtract 273, as shown in the following equations.

$$K = {}^\circ C + 273$$

$${}^\circ C = K - 273$$

Sample Problem 3.4

Converting Between Temperature Scales

Normal human body temperature is 37°C. What is that temperature in kelvins?

for Sample Problem 3.4

17. The element silver melts at 960.8°C and boils at 2212°C. Express these temperatures in kelvins.

Units and Quantities

- Units of Energy
  - **Energy** is the capacity to do work or to produce heat.
    - The joule and the calorie are common units of energy.

Units and Quantities

- The **joule (J)** is the SI unit of energy.
- One **calorie (cal)** is the quantity of heat that raises the temperature of 1 g of pure water by 1°C.

$$1\ \mathrm{J} = 0.2390\ \mathrm{cal} \qquad 1\ \mathrm{cal} = 4.184\ \mathrm{J}$$

3.2 Section Quiz.

- 1. Which of the following is not a base SI unit?
  - a) meter
  - b) gram
  - c) second
  - d) mole

3.2 Section Quiz.

- 2. If you measured both the mass and weight of an object on Earth and on the moon, you would find that

  a) both the mass and the weight do not change.

  b) both the mass and the weight change.

  c) the mass remains the same, but the weight changes.

  d) the mass changes, but the weight remains the same.

3.2 Section Quiz.

- 3. A temperature of 30 degrees Celsius is equivalent to

  a) 303 K.

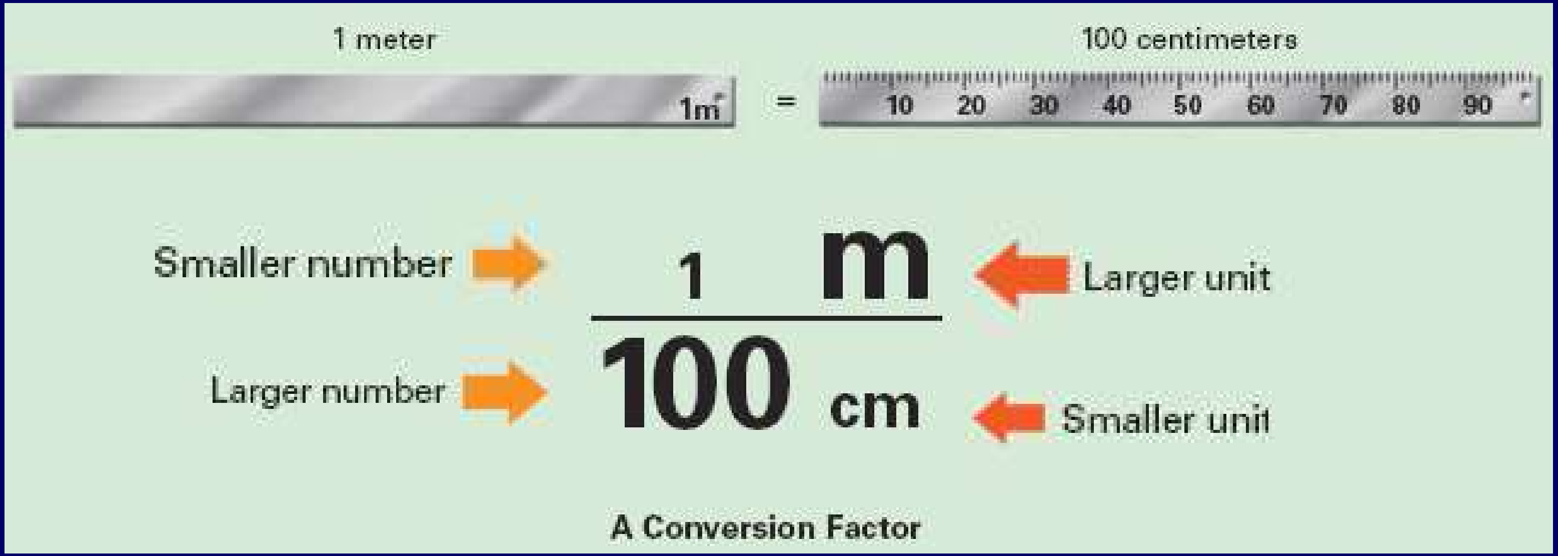
  b) 300 K.

  c) 243 K.

  d) 247 K.

3.3 Conversion Problems

- A **conversion factor** is a ratio of equivalent measurements.
- The ratios 100 cm/1 m and 1 m/100 cm are examples of conversion factors.



Conversion Factors

- When a measurement is multiplied by a conversion factor, the numerical value is generally changed, but the actual size of the quantity measured remains the same.

Dimensional Analysis

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

Sample Problem 3.5

Using Dimensional Analysis

How many seconds are in a workday that lasts exactly eight hours?

for Sample Problem 3.5

29. How many seconds are in exactly a 40-hour work week?

Sample Problem 3.6

Using Dimensional Analysis

The directions for an experiment ask each student to measure 1.84 g of copper (Cu) wire. The only copper wire available is a spool with a mass of 50.0 g. How many students can do the experiment before the copper runs out?

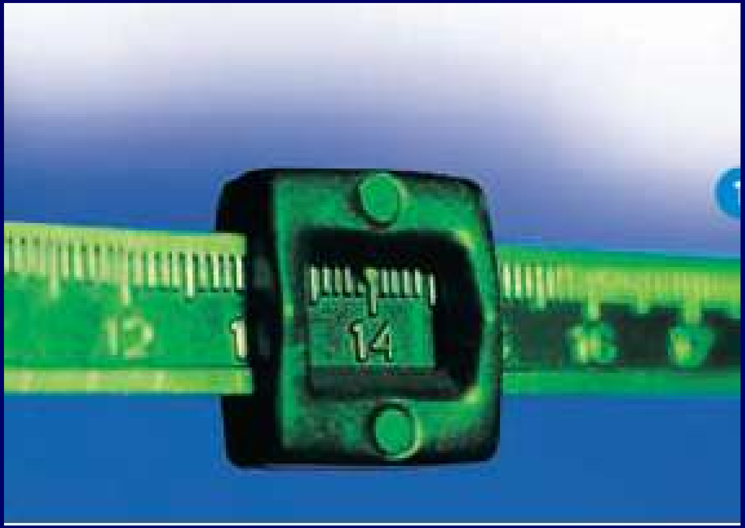
for Sample Problem 3.6

30. An experiment requires that each student use an 8.5-cm length of magnesium ribbon. How many students can do the experiment if there is a 570-cm length of magnesium ribbon available?

Sample Problem 3.7

Converting Between Metric Units

Express 750 dg in grams.



3.7

Analyze ***List the knowns and the unknown.***

Knowns
- mass = 750 dg
- 1 g = 10 dg

Unknown
- mass = ? g

The desired conversion is decigrams $\longrightarrow$ grams. Using the expression relating the units, 10 dg = 1 g, multiply the given mass by the proper conversion factor.

Practice Problem 32

- Convert the following:
  - A) 0.044 km to meters
  - B) 4.6 mg to grams
  - C) 0.107 g to centigrams

for Sample Problem 3.7

33. Convert the following.

a. 15 cm^3 to liters

b. 7.38 g to kilograms

c. 6.7 s to milliseconds

d. 94.5 g to micrograms

Sample Problem 3.8

Converting Between Metric Units

What is 0.073 cm in micrometers?

3.8

Analyze ***List the knowns and the unknown.***

Knowns

- length = 0.073 cm = 7.3×10^{-2} cm
- 10^2 cm = 1 m
- 1 m = 10^6 μm

Unknown

- length = ? μm

The desired conversion is from centimeters to micrometers. The problem can be solved in a two-step conversion.

for Sample Problem 3.8

35. The diameter of Earth is 1.3×10^4 km. What is the diameter expressed in decimeters?

More Practice

- 500 mL = _____ L
- 400 mg = _____ kg
- 15 m = _____ mm
- 150 mg = _____ g
- 4.2 L = _____ cm^3

More Practice

- 3 hrs = _____ sec
- 0.035 mg = _____ cg
- 5.5 kg = _____ lbs (1 kg = 2.2 lbs)
- 2.5 yds = _____ in (1 yd = 36 in)
- 1.3 yrs = _____ hr (1 yr = 365 days)

Sample Problem 3.9

Converting Ratios of Units

The mass per unit volume of a substance is a property called density. The density of manganese, a metallic element, is 7.21 g/cm^3. What is the density of manganese expressed in units kg/m^3?

for Sample Problem 3.9

37. There are 7.0×10^6 red blood cells (RBC) in 1.0 mm^3 of blood. How many red blood cells are in 1.0 L of blood?

3.3 Assessment 45

- Light travels at a speed of 3.00×10^{10} cm/s. What is the speed of light in kilometers/hour.

3.3 Section Quiz

- 1. 1 Mg = 1000 kg. Which of the following would be a correct conversion factor for this relationship?

  a) $\times$ 1000.

  b) $\times$ 1/1000.

  c) $\div$ 1000.

  d) 1000 kg/1Mg.

3.3 Section Quiz

- 2. The conversion factor used to convert joules to calories changes

  a) the quantity of energy measured but not the numerical value of the measurement.

  b) neither the numerical value of the measurement nor the quantity of energy measured.

  c) the numerical value of the measurement but not the quantity of energy measured.

  d) both the numerical value of the measurement and the quantity of energy measured.

3.3 Section Quiz

- 3. How many μ g are in 0.0134 g?

  a) 1.34×10^{-4}

  b) 1.34×10^{-6}

  c) 1.34×10^{6}

  d) 1.34×10^{4}

3.3 Section Quiz

- 4. Express the density 5.6 g/cm^3 in kg/m^3.

  a) $5.6 \times 10^6 kg/m^3$

  b) $5.6 \times 10^3 kg/m^3$

  c) $0.56\ kg/m^3$

  d) $0.0056\ kg/m^3$

3.4 Density

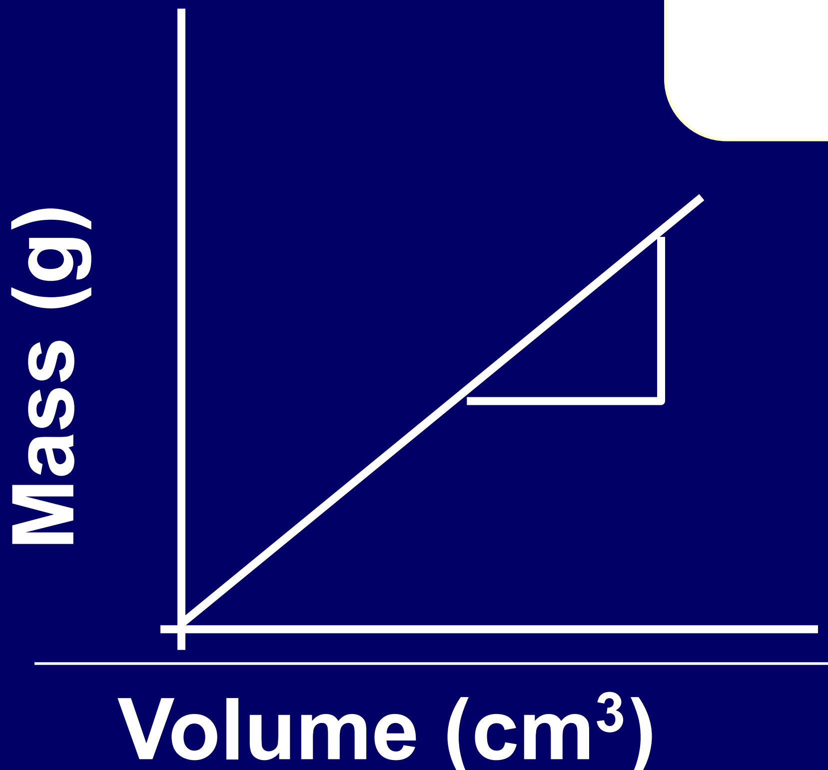
Determining Density

- **Density** is the ratio of the mass of an object to its volume.

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

Density

$$\text{slope} = \frac{\text{Äy}}{\text{Äx}} = \frac{M}{V} = D$$



Density and Temperature

- Experiments show that the volume of most substances increases as the temperature increases. Meanwhile, the mass remains the same. Thus, the density must change.
  - **The density of a substance generally decreases as its temperature increases.**

Sample Problem 3.10

Calculating Density

A copper penny has a mass of 3.1 g and a volume of 0.35 cm^3. What is the density of copper?

for Sample Problem 3.10

47. A bar of silver has a mass of 68.0 g and a volume 6.48 cm^3. What is the density of silver?

Sample Problem 3.11

Using Density to Calculate Volume

What is the volume of a pure silver coin that has a mass of 14 g? The density of silver (Ag) is 10.5 g/cm^3.

48. Use dimensional analysis and the given densities to make the following conversions.

a. 14.8 g of boron to cm^3 of boron. The density of boron is 2.34 g/cm^3.

b. 4.62 g of mercury to cm^3 of mercury. The density of mercury is 13.5 g/cm^3.

Density Problem

- A 147 g piece of metal has a density of 7.00 g/mL. A 50-mL graduated cylinder contains 20.0 mL of water. What is the final volume after the metal is added to the graduated cylinder?

Density problem

- Vinegar is 5% acetic acid by mass and has a density of 1.02 g/mL. What mass of acetic acid in grams is present in 185 mL of vinegar?

3.4 Section Quiz

- 1. If 50.0 mL of corn syrup has a mass of 68.7 g, the density of the corn syrup is

  a) 0.737 g/mL.

  b) 0.727 g/mL.

  c) 1.36 g/mL.

  d) 1.37 g/mL.

3.4 Section Quiz

- 2. What is the volume of a pure gold coin that has a mass of 38.6 g? The density of gold is 19.3 g/cm^3.

  a) 0.500 cm^3

  b) 2.00 cm^3

  c) 38.6 cm^3

  d) 745 cm^3

3.4 Section Quiz

- 3. As the temperature increases, the density of most substances

  a) increases.

  b) decreases.

  c) remains the same.

  d) increases at first and then decreases.