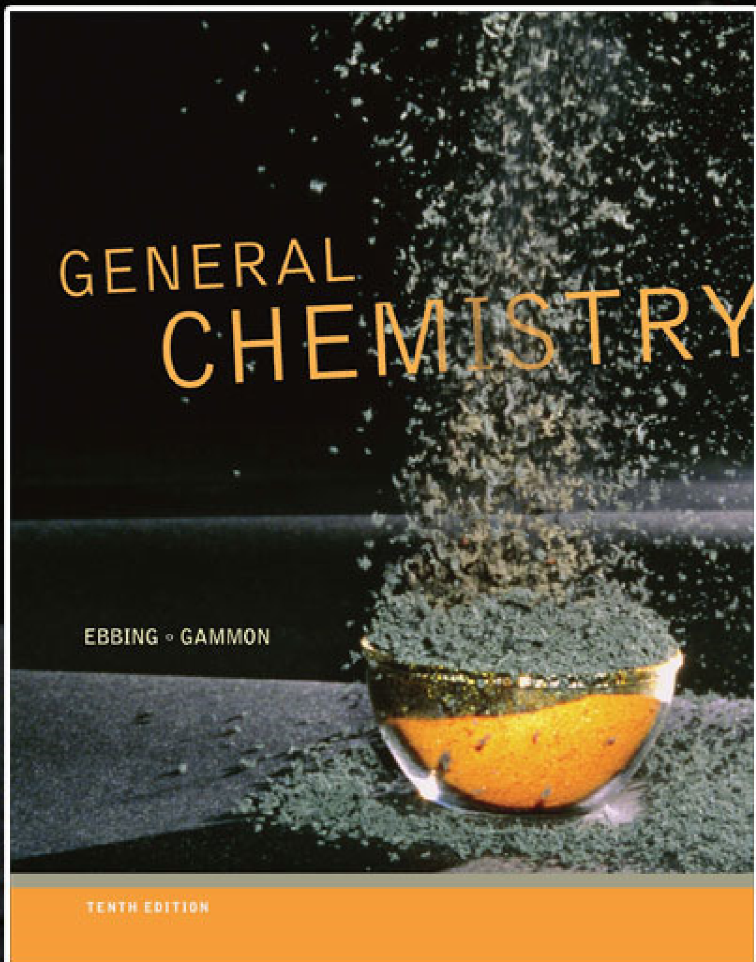


Chapter 1
Chemistry and Measurement

Contents and Concepts

An Introduction to Chemistry

We start by defining the science called chemistry and introducing some fundamental concepts.

1. Modern Chemistry: A Brief Glimpse
2. Experiment and Explanation
3. Law of Conservation of Mass
4. Matter: Physical State and Chemical Constitution

Physical Measurements

Making and recording measurements of the properties and chemical behavior of matter is the foundation of chemistry.

5. Measurements and Significant Figures
6. SI Units
7. Derived Units
8. Units and Dimensional Analysis (Factor-Label Method)

Learning Objectives

An Introduction to Chemistry

1. Modern Chemistry: A Brief Glimpse
   a. Provide examples of the contributions of chemistry to humanity.

2. Experiment and Explanation
   a. Describe how chemistry is an experimental science.
   b. Understand how the scientific method is an approach to performing science.

3. Law of Conservation of Mass
    a. Explain the law of conservation of mass.
    b. Apply the law of conservation of mass.

4. Matter: Physical State and Chemical Constitution
    a. Compare and contrast the three common states of matter: solid, liquid, and gas.
    b. Describe the classifications of matter: elements, compounds, and mixtures (heterogeneous and homogeneous).

c. Understand the difference between chemical changes (chemical reactions) and physical changes.
d. Distinguish between chemical properties and physical properties.

Physical Measurements

5. Measurement and Significant Figures
    a. Define and use the terms *precision* and *accuracy* when describing measured quantities.
    b. Learn the rules for determining significant figures in reported measurements.

c. Know how to represent numbers using scientific notation.
d. Apply the rules of significant figures to reporting calculated values.
e. Be able to recognize exact numbers.
f. Know when and how to apply the rules for rounding.
g. Use significant figures in calculations.

6. SI Units
    a. Become familiar with the SI (metric) system of units.
    b. Convert from one temperature scale to another.

7. Derived Units
    a. Define and provide examples of derived units.
    b. Calculate the density of a substance.
    c. Use density to relate mass and volume.

8. Units and Dimensional Analysis (Factor-Label Method)
    a. Apply dimensional analysis to solving numerical problems.
    b. Convert from one metric unit to another metric unit.
    c. Convert from one metric volume to another metric volume.
    d. Convert from any unit to another unit.

Chemistry

The study of the composition and structure of materials and of the changes that materials undergo.

Experiment

An observation of natural phenomena carried out in a controlled manner so that the results can be duplicated and rational conclusions obtained.

Law

A concise statement or mathematical equation about a fundamental relationship or regularity of nature.

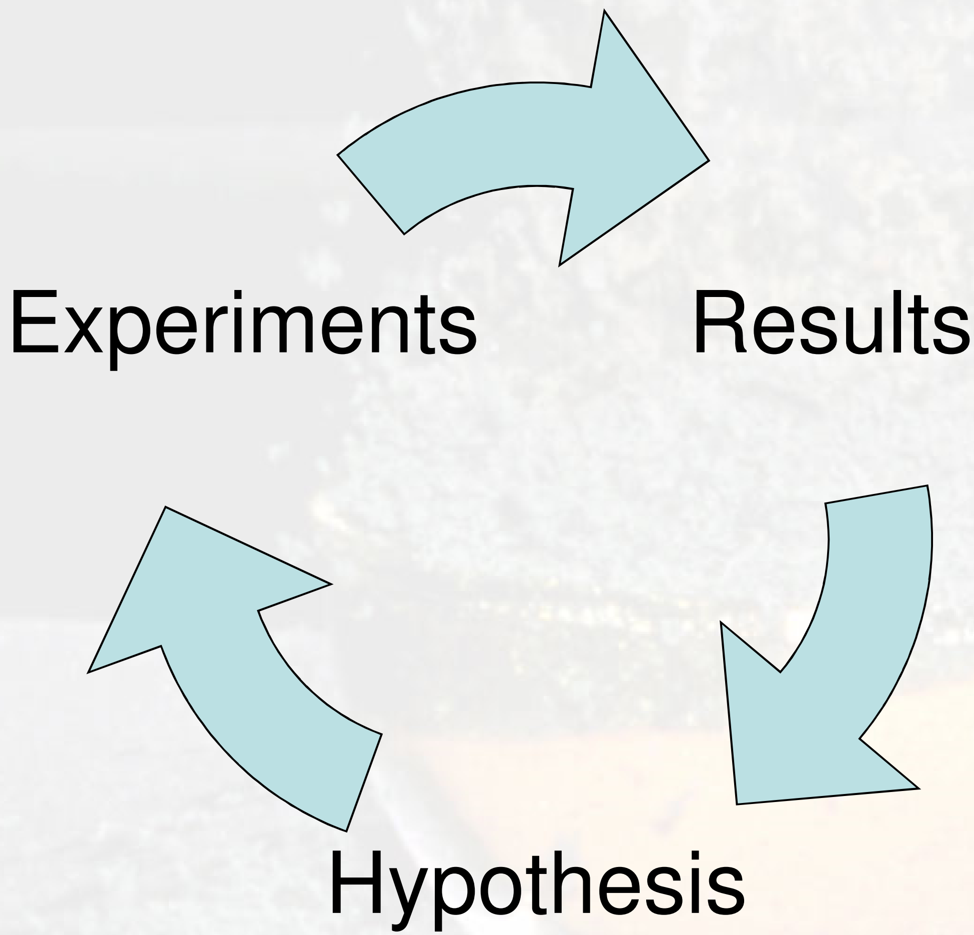
Hypothesis

A tentative explanation of some regularity of nature.

Theory

A tested explanation of a basic natural phenomenon.

Scientific Method



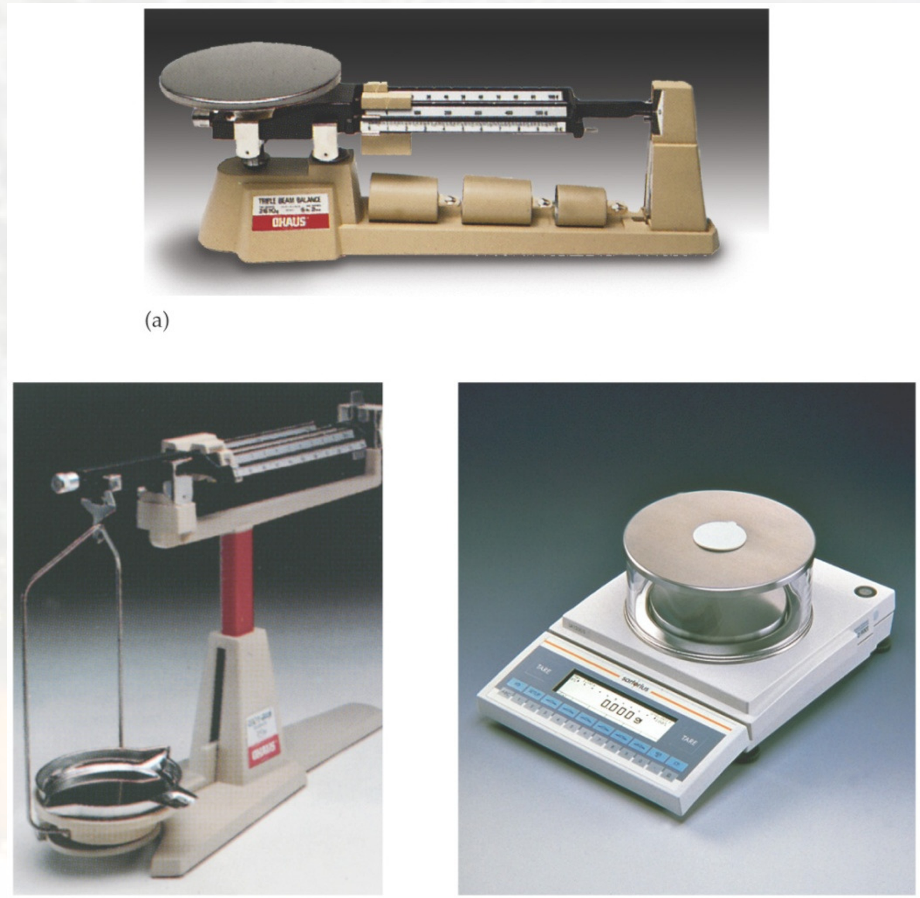
Matter

Whatever occupies space and can be perceived by our senses.

Mass

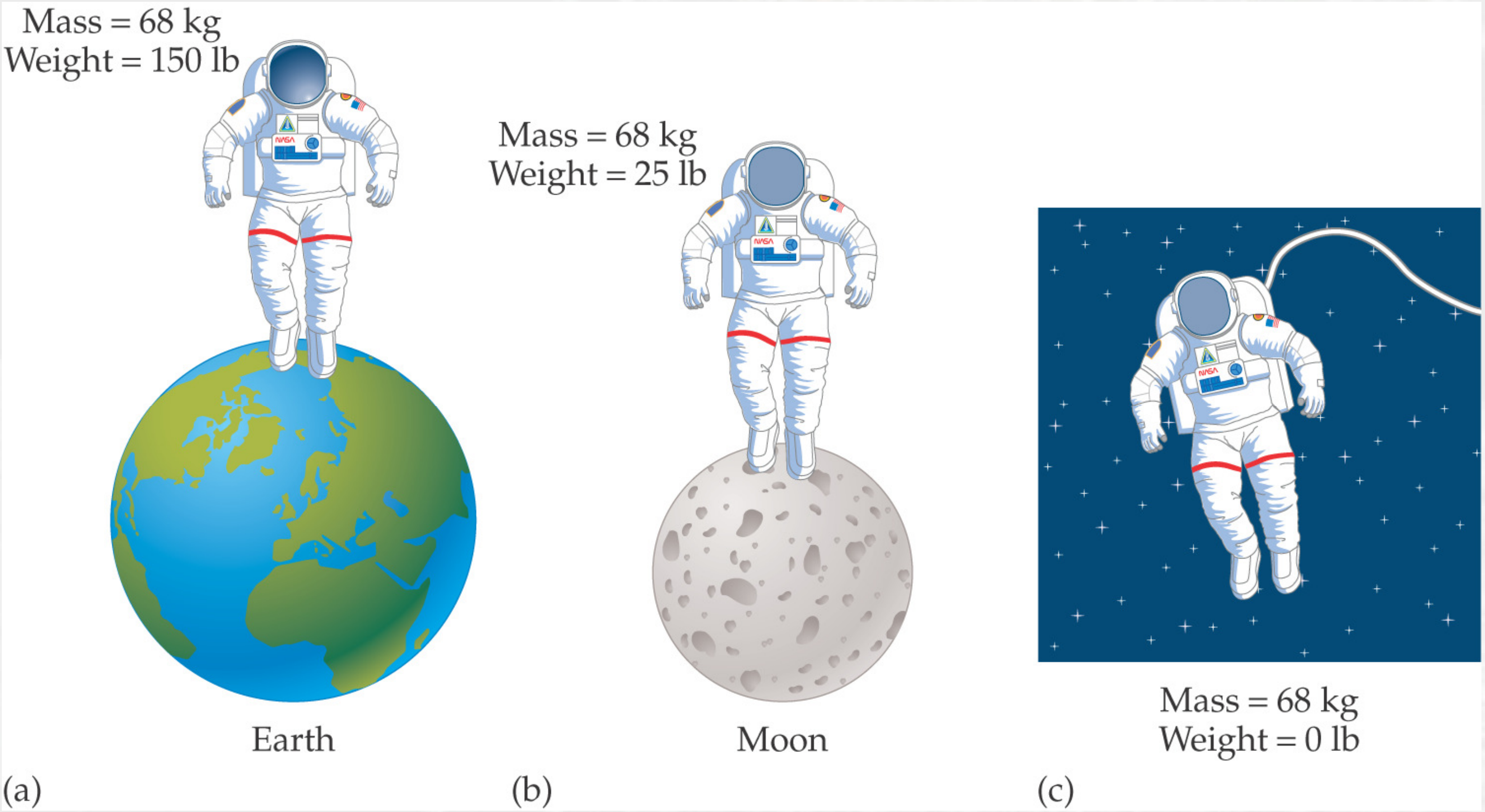
The quantity of matter in a material.

- The *mass* of an object is a measure of the amount of matter it possesses.
- Mass is measured with a balance and is not affected by gravity.
- Mass and weight are *not* interchangeable.



(a) (b) (c)

- Mass and weight are not the same.
  - Weight is the force exerted by gravity on an object.



Law of Conservation of Mass

The total mass remains constant during a chemical change (chemical reaction).

?

Aluminum powder burns in oxygen to produce a substance called aluminum oxide. A sample of 2.00 grams of aluminum is burned in oxygen and produces 3.78 grams of aluminum oxide. How many grams of oxygen were used in this reaction?

aluminum + oxygen = aluminum oxide

2.00 g + oxygen = 3.78 g

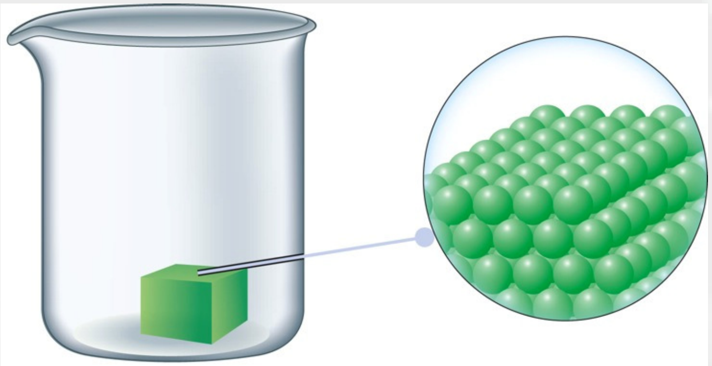
oxygen = $\boxed{1.78 \text{ g}}$

States of Matter

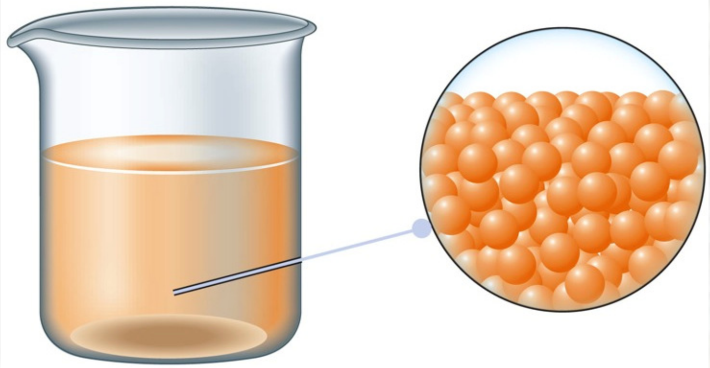
Solid: characterized by rigidity; fixed volume and fixed shape.

Liquid: relatively incompressible fluid; fixed volume, no fixed shape.

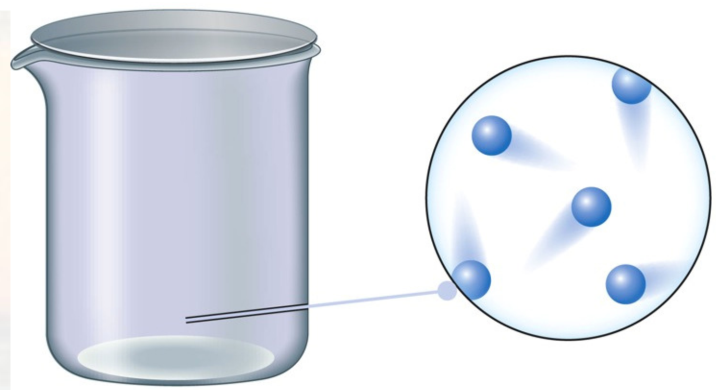
Gas: compressible fluid; no fixed volume, no fixed shape.



Solid



Liquid



Gas

Physical Change

A change in the form of matter but not in its chemical identity.

For example:

- Melting
- Dissolving

Chemical Change = Chemical Reaction

A change in which one or more kinds of matter are transformed into a new kind of matter or several new kinds of matter.

For example:

- Rusting
- Burning

Physical Property

A characteristic that can be observed for a material without changing its chemical identity.

For example:

- Physical state
- Boiling point
- Color

Chemical Property

A characteristic of a material involving its chemical change.

For example:

- Ability to react with oxygen
- Ability to react with fluorine

Substance

A kind of matter that cannot be separated into other kinds of matter by any physical process such as distillation or sublimation.

?

Potassium is a soft, silvery-colored metal that melts at 64°C. It reacts vigorously with water, with oxygen, and with chlorine. Identify all of the physical properties and chemical properties given in this description.

Physical Property	Chemical Property
Soft	Reacts with water
Silvery-colored	Reacts with oxygen
Melting point (64°C)	Reacts with chlorine

Element

- Consists of only one kind of atom.
- Cannot be decomposed into simpler substances by any chemical/physical means.
- Can exist as either atoms or molecules.

For example:

Argon

Nitrogen

Compound

A substance composed of two or more elements chemically combined.

For example:

Water (H_2O)

Carbon dioxide (CO_2)

Mixture

A material that can be separated by physical means into two or more substances

For example:

- Italian salad dressing
- Saltwater

Heterogeneous Mixture

A mixture that consists of physically distinct parts, each with different properties.

For example:

Salt and iron filings

Oil and vinegar

Phase

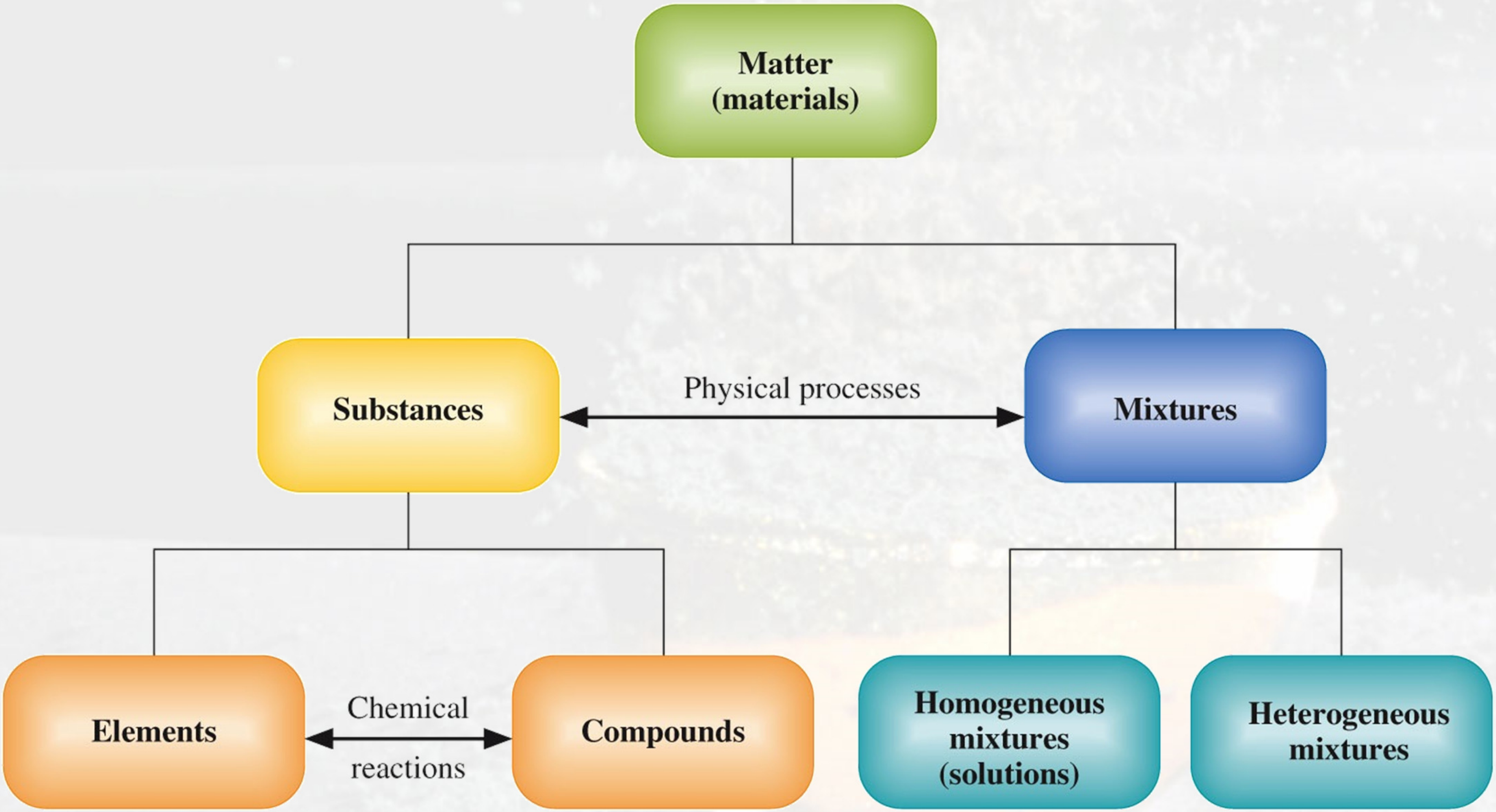
One of several different homogeneous materials present in the portion of matter under study.

Homogenous Mixture

A mixture that is uniform in its properties; also called a solution.

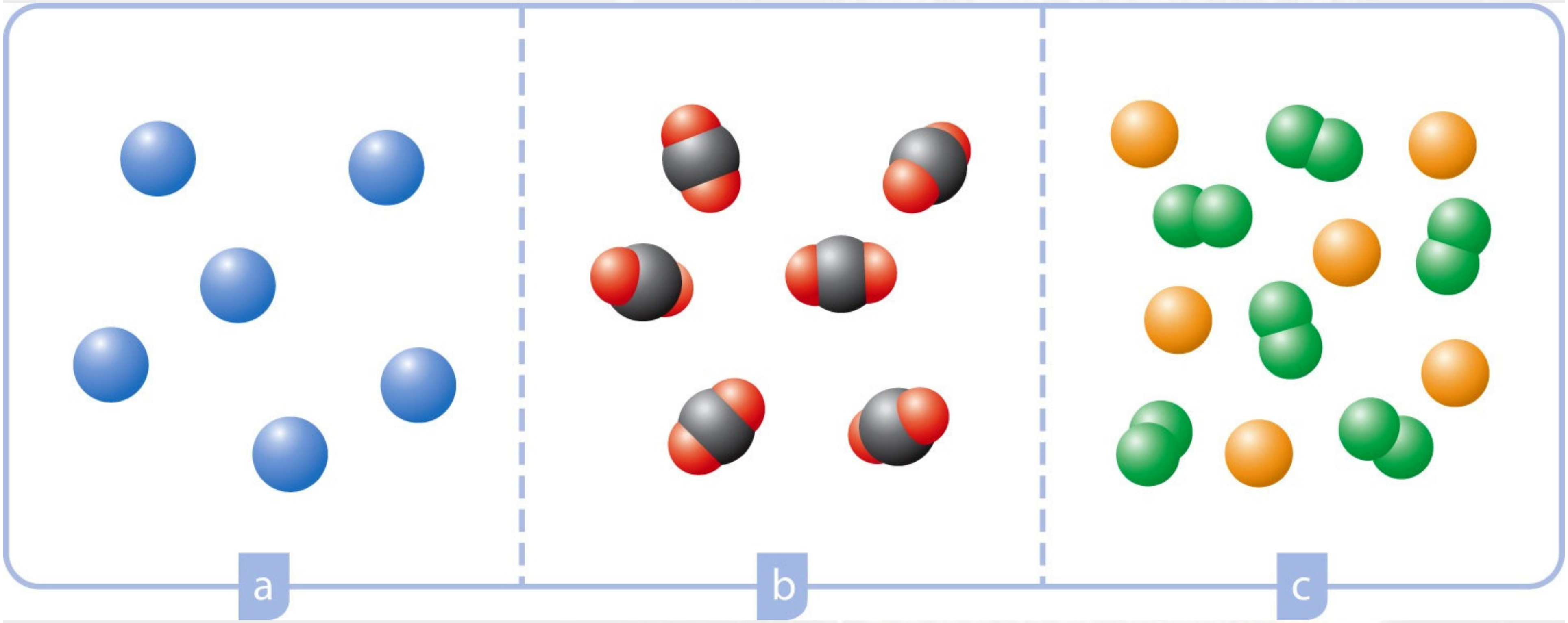
For example:

- Saltwater
- Air


Matter
(materials)
Substances
Physical processes
Mixtures
Elements
Chemical
reactions
Compounds
Homogeneous
mixtures
(solutions)
Heterogeneous
mixtures

?

Matter can be represented as being composed of individual units. For example, the smallest individual unit of matter can be represented as a single circle, and chemical combinations of these units of matter as connected circles, with each element represented by a different color. Using this model, label each figure on the next slide as an element, a compound, or a mixture.



A. Element

B. Compound (made of two elements)

C. Mixture of two elements

Measurement

The comparison of a physical quantity with a fixed standard of measurement—a **unit.**

For example:

Centimeter

Kilogram

Precision

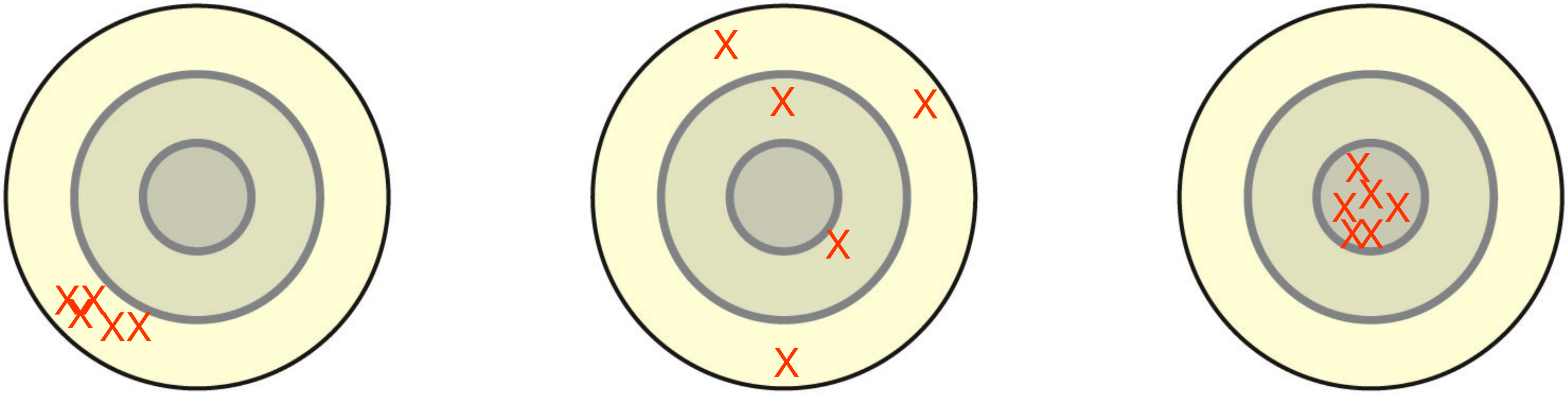
The closeness of the set of values obtained from repeated measurement of the same quantity.

Accuracy

The closeness of a single measurement to its true value.

?

Imagine that you shot five arrows at each of the targets depicted on the next slide. Each "x" represents one arrow. Choose the best description for each target.



A B C

1. Poor accuracy and good precision
2. Poor accuracy and poor precision
3. Good accuracy and good precision
4. Good accuracy and poor precision

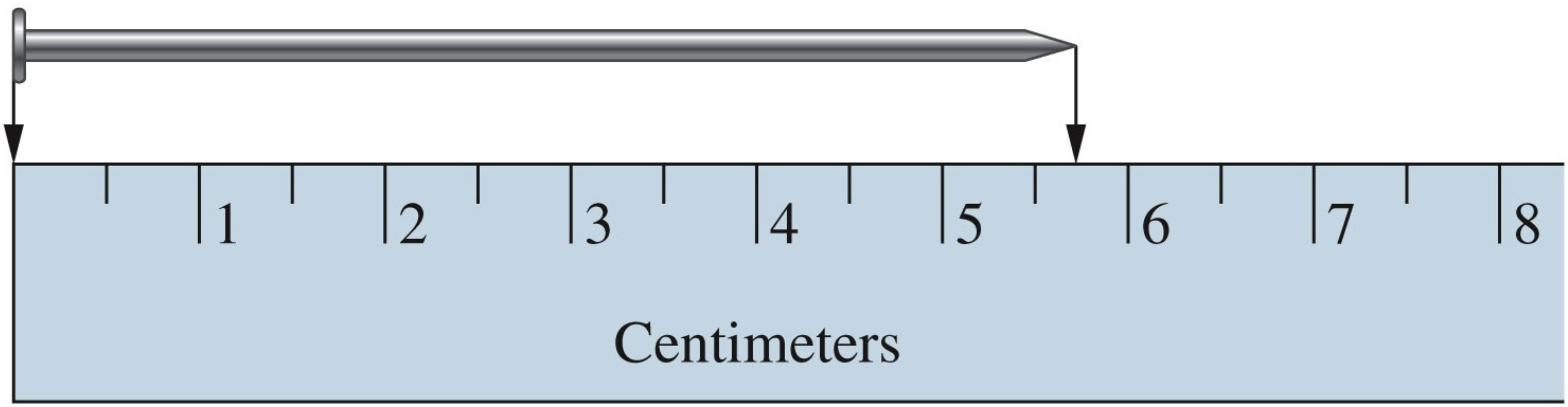
A: --- B: --- C: ---

Significant Figures

Those digits in a measured number (or in the result of a calculation with measured numbers) that include all certain digits plus a final digit having some uncertainty.

?

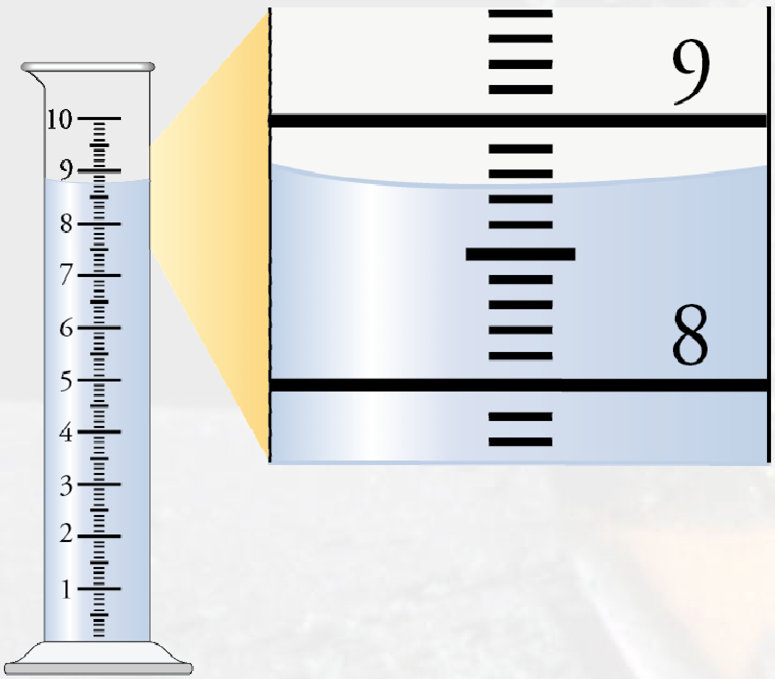
What is the length of the nail to the correct number of significant figures?



5.7 cm

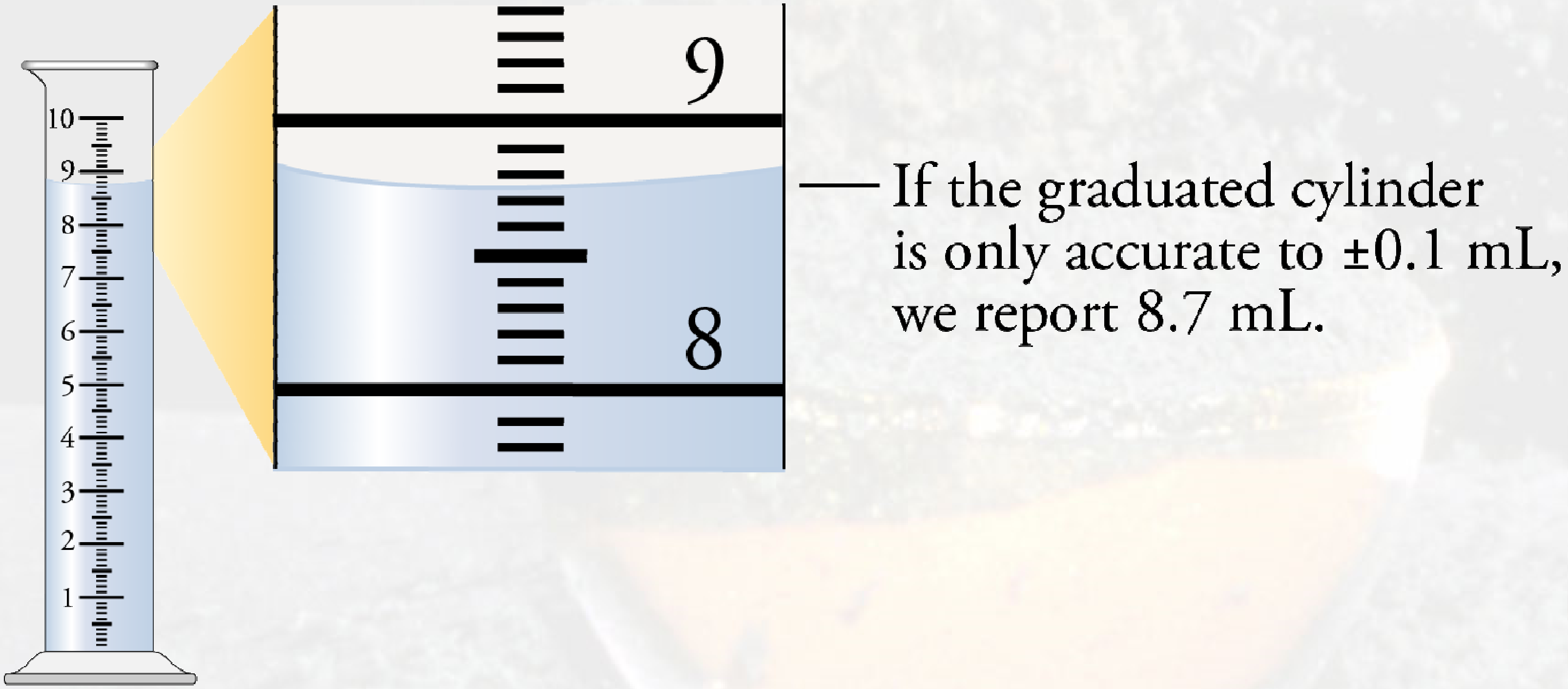
(The tenths place is estimated)

Graduated cylinder

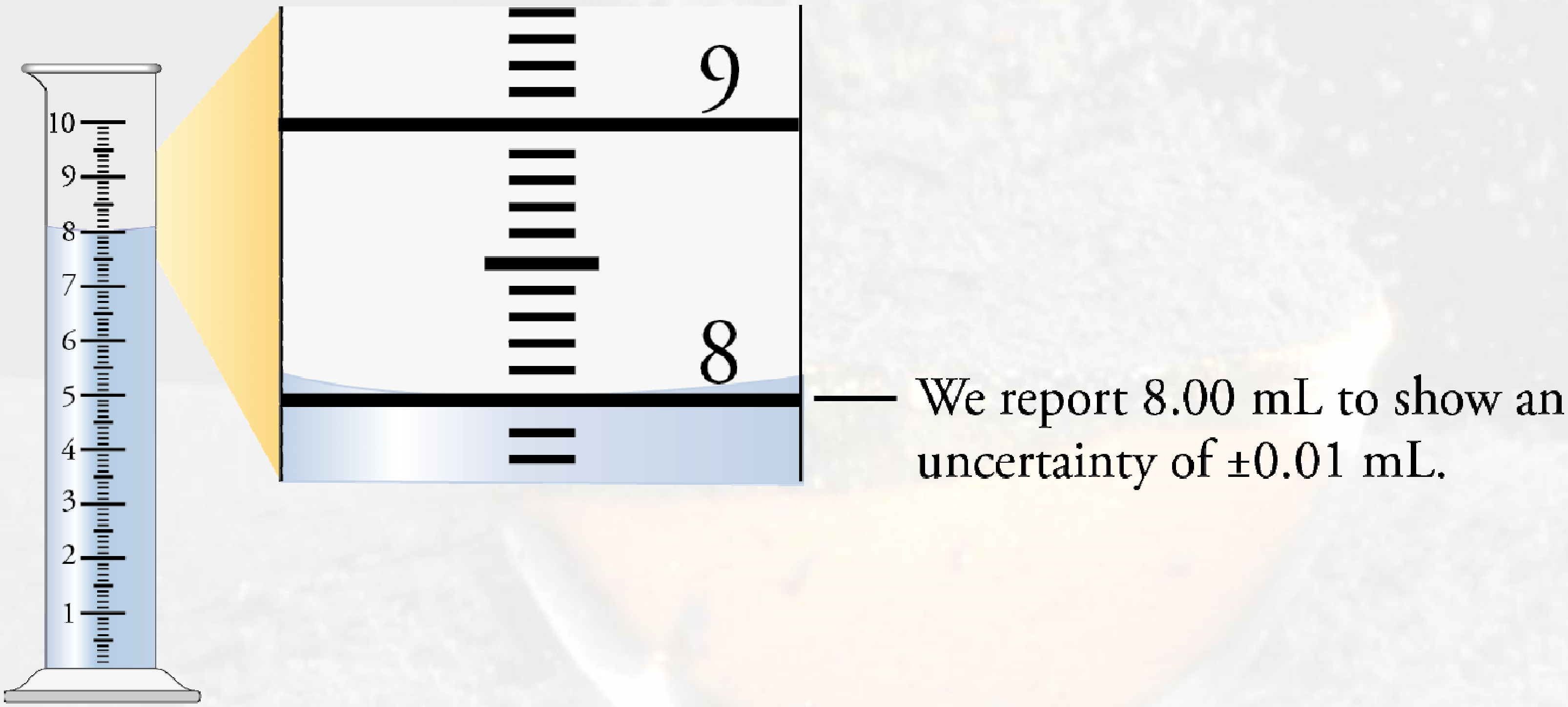


Comparing the position of the bottom of the meniscus and the milliliter scale yields a measurement of 8.74 mL.

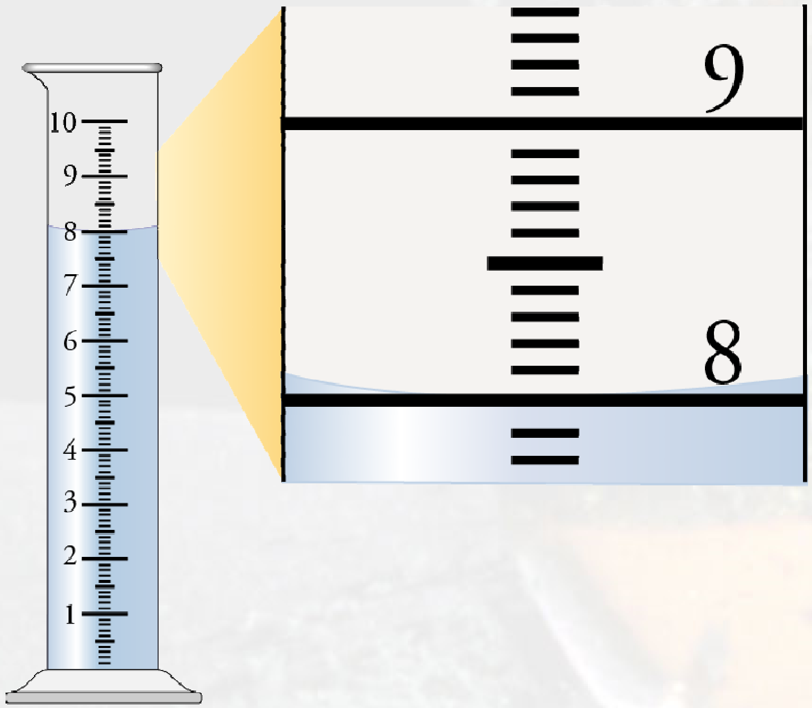
Graduated cylinder
Accurate ±0.1



Graduated cylinder
Trailing Zeros



Graduated cylinder
Trailing Zeros



If the graduated cylinder is only accurate to ±0.1 mL, we report 8.0 mL.

Digital Readout

Report all digits unless otherwise instructed.

Number of Significant Figures

The number of digits reported for the value of a measured or calculated quantity, indicating the precision of the value.

Number of Significant Figures

1. All nonzero digits are significant.
2. Zeros between nonzero digits are significant.
3. Leading zeros are not significant.
4. Terminal zeros are significant if they are to the right of the decimal point.
5. Terminal zeros in a number without a specific decimal point may or may not be significant.

- Any digit that is not zero is significant
  - 1.234 kg 4 significant figures
- Zeros between nonzero digits are significant
  - 606 m 3 significant figures
- Zeros to the left of the first nonzero digit are **not** significant
  - 0.08 L 1 significant figure
- If a number is greater than 1, then all zeros to the right of the decimal point are significant
  - 2.0 mg 2 significant figures
- If a number is less than 1, then only the zeros that are at the end and in the middle of the number are significant
  - 0.00420 g 3 significant figures

Significant Figures in Calculations

Multiplication and Division

Your answer should have the same number of

significant figures

as are in the measurement with the least number of significant figures.

Addition and Subtraction

Your answer should have the same number of

decimal places

as are in the measurement with the least number of decimal places.

Exact Number

A counted number or defined number.

For example:

The number of students in the front row

1 inch is defined as 2.54 centimeters

Rounding

The procedure of dropping nonsignificant digits and adjusting the last digit reported in the final result of a calculation.

Rounding Procedure

1. Look at the leftmost digit to be dropped.

2. If this digit is 5 or greater:

   Add 1 to the last digit to be retained

   Drop all digits farther to the right

3. If this digit is less than 5:

   Drop all digits farther to the right

For example:

1.2151 rounded to three significant figures is

1.22

1.2143 rounded to three significant figures is

1.21

?

Perform the following calculation and round your answer to the correct number of significant figures:

$$\frac{6.8914}{1.289 \times 7.28}$$

Calculator answer:

0.734383925

The answer should be rounded to three significant figures:

0.734

?

Perform the following calculation and round your answer to the correct number of significant figures:

$$0.453 - 1.59$$

Calculator answer:

-1.137

The answer should be rounded to two decimal places:

-1.14

?

Perform the following calculation and round your answer to the correct number of significant figures:

$$0.456 - 0.421$$

Calculator answer:

0.035

The answer should be rounded to three decimal places:

0.035

?

Perform the following calculation and round your answer to the correct number of significant figures:

$$92.35(0.456 - 0.421)$$

Calculator answer:

3.23225

The answer should be rounded to two significant figures because 0.456 – 0.421 = 0.035

3.2

Scientific Notation

The number of atoms in 12 g of carbon:

602,200,000,000,000,000,000,000

6.022×10^{23}

The mass of a single carbon atom in grams:

0.0000000000000000000000199

1.99×10^{-23}

$$\boxed{N \times 10^{n}}$$

N is a number between 1 and 10

n is a positive or negative integer

Scientific Notation

- A mass reported as 25.0 mg: 3 sig. numbers
- If the mass is written in microgram:

i) 25,000 μg ===> ambiguous

ii) 2.50×10^4 μg ===> 3 sig. figures

Scientific Notation

The representation of a number in the form

$$A \times 10^n$$

$$1 \leq A < 10$$

where *n* is an integer

Every digit included in A is significant.

?

Write the following numbers in scientific notation:

0.000653

350,000

0.02700

6.53×10^{-4}

3.5×10^{5}

2.700×10^{-2}

Scientific Notation and Metric Prefixes

Because each of the metric prefixes has an equivalent power of 10, the prefix may be substituted for the power of 10.

For example:

$$7.9 \times 10^{-6}\ \text{s}$$

$$10^{-6} = \text{micro, } \mu$$

$$7.9 \times 10^{-6}\ \text{s} = 7.9\ \mu\text{s}$$

?

Write the following measurements without scientific notation using the appropriate SI prefix:

4.851×10^{-9} g

3.16×10^{-2} m

8.93×10^{-12} s

4.851 ng

3.16 cm

8.93 ps

?

Using scientific notation, make the following conversions:

6.20 km to m

2.54 cm to m

1.98 ns to s

5.23 μg to g

6.20×10^{3} m

2.54×10^{-2} m

1.98×10^{-9} s

5.23×10^{-6} g

SI Units

An international system of units made up of a particular choice of metric units.

Base Units

The seven metric units from which all other units can be derived.

Table 1.1 SI Base Units

Quantity	Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Temperature	kelvin	K
Amount of substance	mole	mol
Electric current	ampere	A
Luminous intensity	candela	cd

Table 1.2 Selected SI Prefixes

Prefix	Multiple	Symbol
mega	10^{6}	M
kilo	10^{3}	k
deci	10^{-1}	d
centi	10^{-2}	c
milli	10^{-3}	m
micro	10^{-6}	μ*
nano	10^{-9}	n
pico	10^{-12}	p

*Greek letter mu, pronounced "mew."

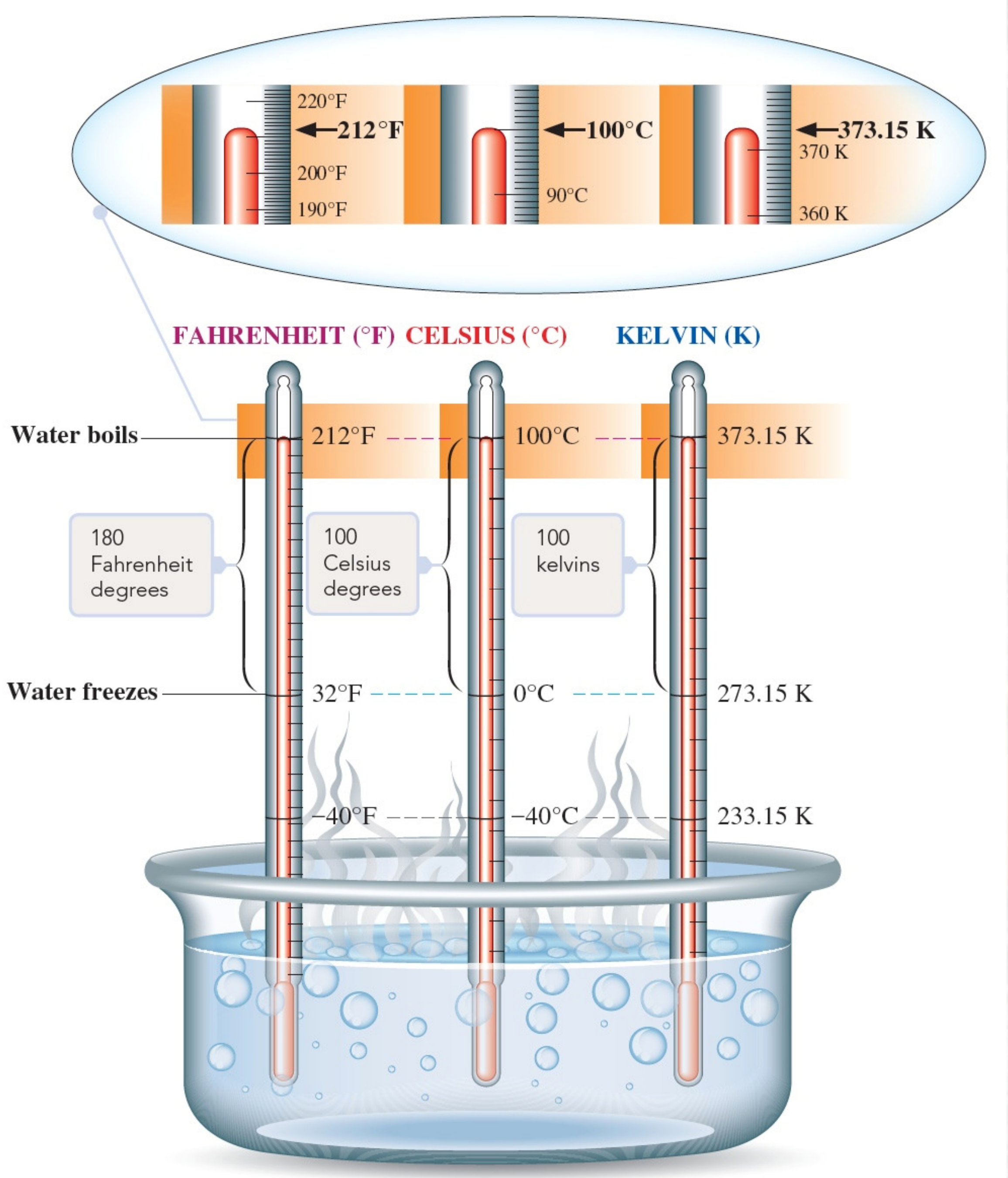
Temperature

A measure of “hotness”

Heat flows from an area of higher temperature to an area of lower temperature.

Temperature Units

- Celsius, °C
- Fahrenheit, °F
- Kelvin, K


220°F
212°F
200°F
190°F
100°C
90°C
373.15 K
370 K
360 K
FAHRENHEIT (°F)
CELSIUS (°C)
KELVIN (K)
Water boils
212°F
100°C
373.15 K
180 Fahrenheit degrees
100 Celsius degrees
100 kelvins
Water freezes
32°F
0°C
273.15 K
−40°F
−40°C
233.15 K

Converting Between Temperature Units

Finding Kelvin temperature from Celsius temperature.

$$t_K = \left(t_C \times \frac{1\,K}{1°C}\right) + 273.15\,K$$

Finding Fahrenheit temperature from Celsius temperature.

$$t_F = \left(t_C \times \frac{9°F}{5°C}\right) + 32°\,F$$

Converting Between Temperature Units

Finding Celsius temperature from Fahrenheit temperature.

$$t_C = (t_F - 32°F)\,\frac{5°C}{9°F}$$

Finding Celsius temperature from Kelvin temperature.

$$t_C = (t_K - 273.15\,K)\,\frac{1°C}{1\,K}$$

?

In winter, the average low temperature in interior Alaska is -30.° F (two significant figures). What is this temperature in degrees Celsius and in kelvins?

$$t_C = (t_F - 32°F)\,\frac{5°C}{9°F}$$

$$t_C = (-30.°F - 32°F)\,\frac{5°C}{9°F}$$

$$t_C = (-62°F)\,\frac{5°C}{9°F}$$

$$t_C = -34.4444444°C$$

$$\boxed{t_C = -34°C}$$

$$t_K = \left(t_C \times \frac{1\,K}{1°C} \right) + 273.15\,K$$

$$t_K = \left(-34°C \times \frac{1\,K}{1°C} \right) + 273.15\,K$$

$$t_K = -34\,K + 273.15\,K$$

$$t_K = 239.15\,K$$

$$\boxed{t_K = 239\,K}$$

Derived Units

Combinations of fundamental units.

For example:

$$\text{Speed} = \frac{\text{distance}}{\text{time}} = \frac{\text{m}}{\text{s}}$$

$$\text{Volume} = \text{length} \times \text{width} \times \text{height} = \text{m}^3$$

Quantity	Definition of Quantity	SI Unit
Area	length × length	m^2
Volume	length × length × length	m^3
Density	mass per unit volume	kg/m^3
Speed	distance per unit time	m/s
Acceleration	change in speed per unit time	m/s^2

Quantity	Definition of Quantity	SI Unit
Force	mass × acceleration	kg ▪ m/s^2 = N (newton)
Pressure	force per unit area	kg/m ▪ s^2 = Pa (pascal)
Energy	force × distance	kg ▪ m^2/s^2 = J (joule)

Density

Mass per unit volume $$d = \frac{m}{V}$$

Common units

solids	g/cm^3
liquids	g/mL
gases	g/L

?

Oil of wintergreen is a colorless liquid used as a flavoring. A 28.1-g sample of oil of wintergreen has a volume of 23.7 mL. What is the density of oil of wintergreen?

$$m = 28.1 \text{ g}$$

$$V = 23.7 \text{ mL}$$

$$d = \frac{m}{V}$$

$$d = \frac{28.1 \text{ g}}{23.7 \text{ mL}}$$

$$d = 1.18565491 \frac{\text{g}}{\text{mL}}$$

$$\boxed{d = 1.19 \frac{\text{g}}{\text{mL}}}$$

?

A sample of gasoline has a density of 0.718 g/mL. What is the volume of 454 g of gasoline?

$$m = 454\ \text{g}$$

$$d = 0.718\ \frac{\text{g}}{\text{mL}}$$

$$d = \frac{m}{V}$$

$$V = \frac{m}{d}$$

$$V = \frac{454\ \text{g}}{0.718\ \frac{\text{g}}{\text{mL}}}$$

$$V = 632.311978\ \text{mL}$$

$$\boxed{V = 632\ \text{mL}}$$

Units and Dimensional Analysis

(Factor-Label Method)

A method of calculations in which one carries along the units for quantities.

Conversion Factor

A factor equal to 1 that converts a quantity expressed in one unit to a quantity expressed in another unit.

?

A sample of sodium metal is burned in chlorine gas, producing 573 mg of sodium chloride. How many grams and kilograms is this?

$$1\ \text{mg} = 10^{-3}\ \text{g} \qquad \text{and} \qquad 1\ \text{kg} = 10^{3}\ \text{g}$$

$$573\ \text{mg} \times \frac{10^{-3}\ \text{g}}{1\ \text{mg}} \qquad 0.573\ \text{g} \times \frac{1\ \text{kg}}{10^{3}\ \text{g}}$$

$$573 \times 10^{-3}\ \text{g} \qquad 0.573 \times 10^{-3}\ \text{kg}$$

$$\boxed{0.573\ \text{g}} \qquad \boxed{5.73 \times 10^{-4}\ \text{kg}}$$

?

An experiment calls for 54.3 mL of ethanol. What is this volume in cubic meters?

$$1\ \text{mL} = 1\ \text{cm}^3$$

$$(1\ \text{cm})^3 = \left(10^{-2}\ \text{m}\right)^3$$

$$1\ \text{mL} = 1\ \text{cm}^3 = 10^{-6}\ \text{m}^3$$

$$54.3\ \text{mL} \times \frac{10^{-6}\ \text{m}^3}{1\ \text{mL}}$$

$$54.3 \times 10^{-6}\ \text{m}^3$$

$$\boxed{5.43 \times 10^{-5}\ \text{m}^3}$$

?

The Star of Asia sapphire in the Smithsonian Institute weighs 330 carats (three significant figures). What is this weight in grams? One carat equals 200 mg (exact).

$$1\ \text{carat} = 200\ \text{mg (exact)}$$

$$1\ \text{mg} = 10^{-3}\ \text{g}$$

$$330.\ \text{carats} \times \frac{200\ \text{mg}}{1\ \text{carat}} \times \frac{10^{-3}\ \text{g}}{1\ \text{mg}}$$

$$66000 \times 10^{-3}$$

$$\boxed{6.60 \times 10^{1}\ \text{g} = 66.0\ \text{g}}$$

?

The dimensions of Noah's ark were reported as 3.0×10^2 cubits by 5.0×10^1 cubits. Express this size in units of feet and meters. (1 cubit = 1.5 ft)

$$1 \text{ cubit} = 1.5 \text{ ft}$$

$$3 \text{ ft} = 1 \text{ yd}$$

$$1 \text{ yd} = 0.9144 \text{ m (exact)}$$

$$3.0 \times 10^2 \text{ cubits} \times \frac{1.5 \text{ ft}}{1 \text{ cubit}} \qquad 5.0 \times 10^1 \text{ cubits} \times \frac{1.5 \text{ ft}}{1 \text{ cubit}}$$

$$4.5000000 \times 10^2 \text{ ft} \qquad 7.5000000 \times 10^1 \text{ ft}$$

$$\boxed{4.5 \times 10^2 \text{ ft} \quad \text{by} \quad 7.5 \times 10^1 \text{ ft} = 75 \text{ ft}}$$

$$1\ \text{cubit} = 1.5\ \text{ft}$$

$$3\ \text{ft} = 1\ \text{yd}$$

$$1\ \text{yd} = 0.9144\ \text{m (exact)}$$

$4.5 \times 10^2\ \text{ft}$ by $7.5 \times 10^1\ \text{ft} = 75\ \text{ft}$

$$4.5 \times 10^2\ \text{ft} \times \frac{1\ \text{yd}}{3\ \text{ft}} \times \frac{0.9144\ \text{m}}{1\ \text{yd}} \qquad 75\ \text{ft} \times \frac{1\ \text{yd}}{3\ \text{ft}} \times \frac{0.9144\ \text{m}}{1\ \text{yd}}$$

$$1.37160000 \times 10^2\ \text{m} \qquad 22.8600000\ \text{m}$$

$$\boxed{1.4 \times 10^2\ \text{m} \quad \text{by} \quad 23\ \text{m}}$$

?

How many significant figures are in each of the following measurements?

a. 310.0 kg
b. 0.224800 m
c. 0.05930 kg
d. 4.380×10^{-8} m
e. 3.100 s
f. 91,000

a. 4 significant figures
b. 6 significant figures
c. 4 significant figures
d. 4 significant figures
e. 4 significant figures
f. 2 significant figures