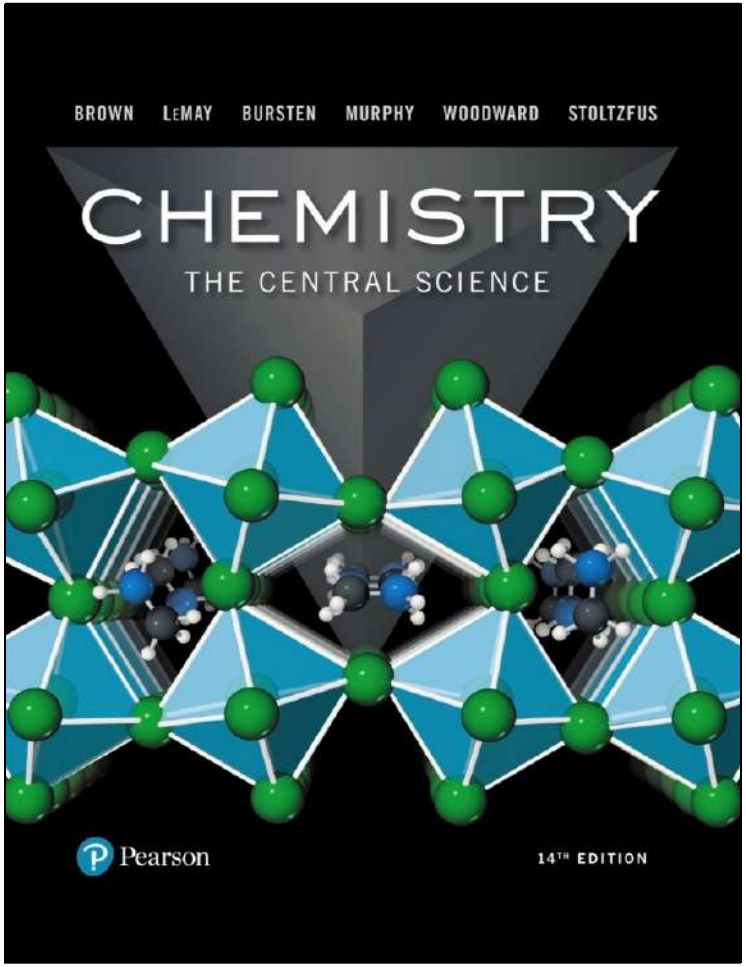
Chemistry: The Central Science

Fourteenth Edition

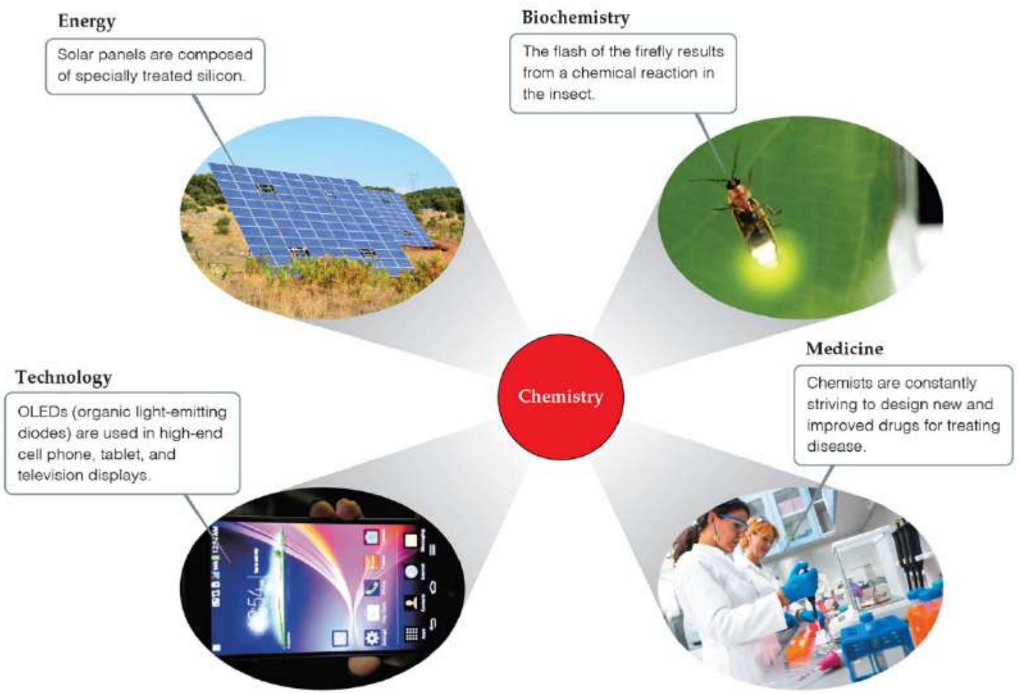


Chapter 1

Introduction: Matter, Energy, and Measurement

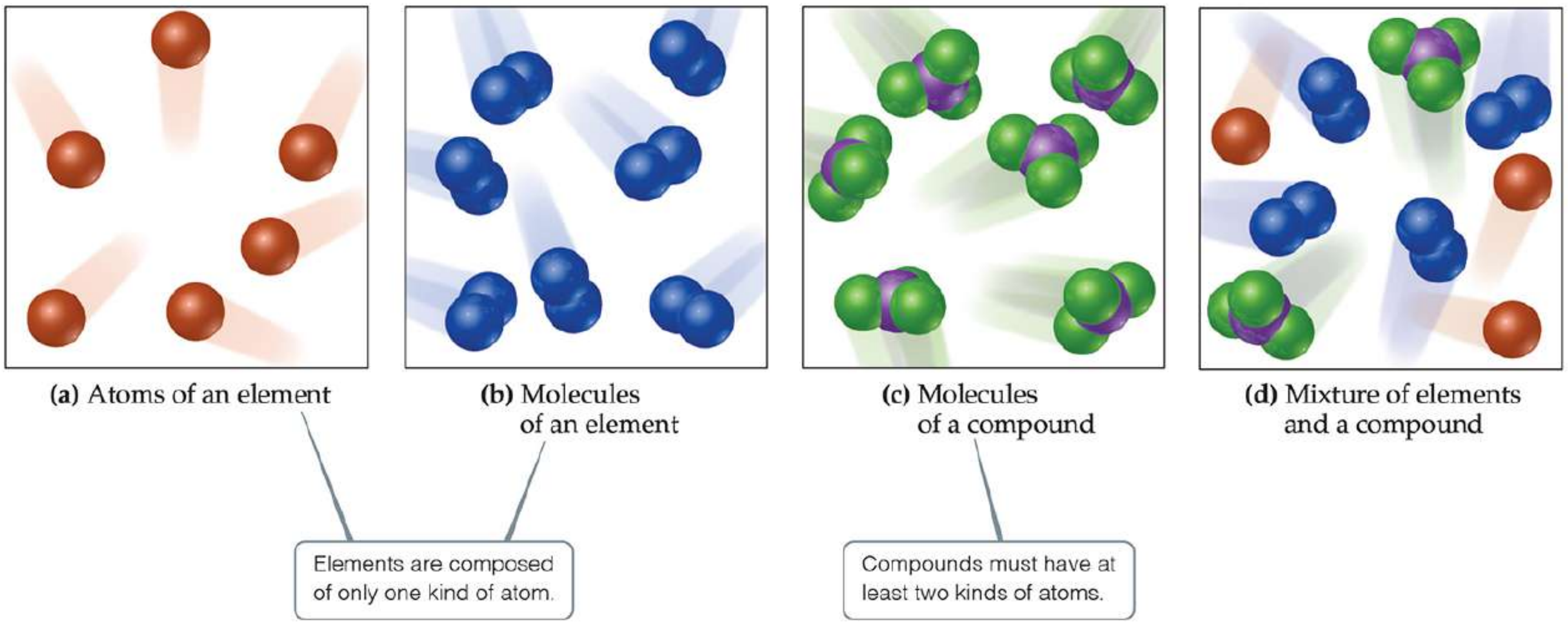
Chemistry

- Chemistry is the study of **matter**, its properties, and the changes it undergoes.
- It is central to our fundamental understanding of many science-related fields.



Matter

Matter is anything that has mass and takes up space.

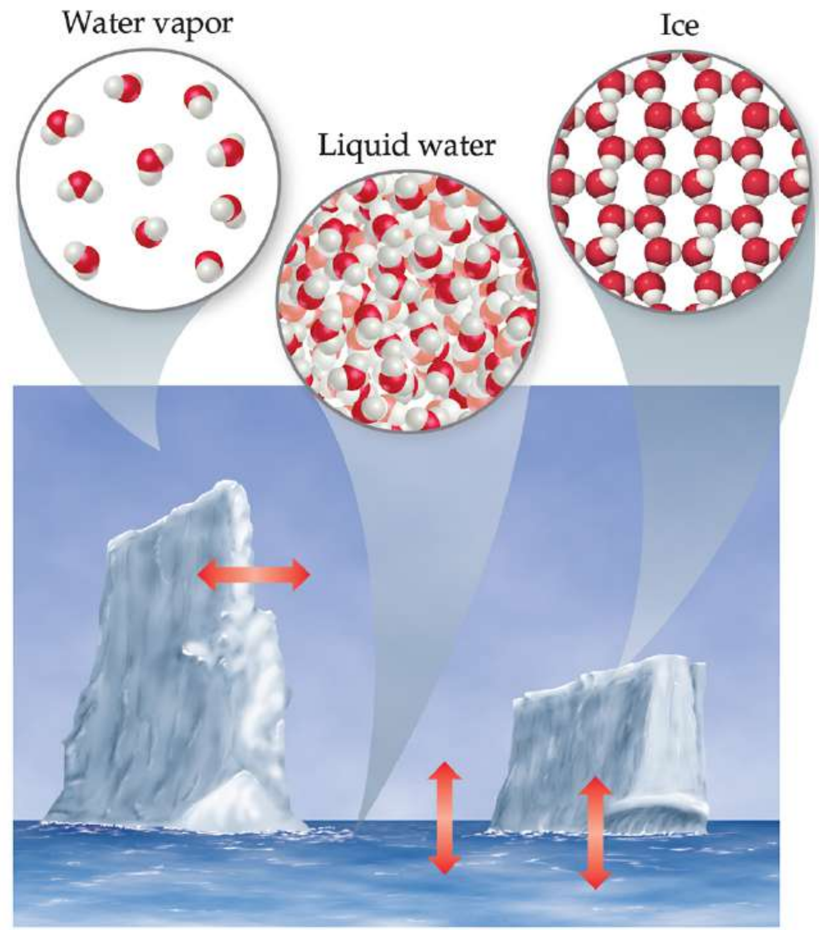


Methods of Classification

- State of Matter
- Composition of Matter

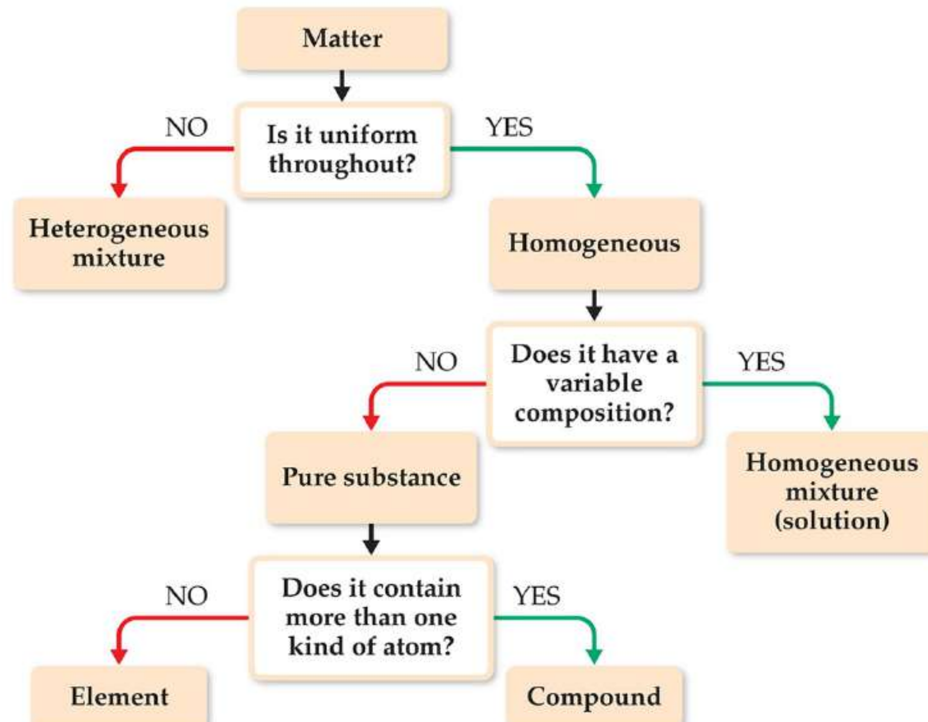
States of Matter

- The three states of matter are
  1) **solid.**
  2) **liquid.**
  3) **gas.**
- In this figure, those states are **ice**, **liquid water**, and **water vapor**.



Classification of Matter Based on Composition (1 of 2)

- If you follow this scheme, you can determine how to classify any type of matter.
  - Homogeneous mixture
  - Heterogeneous mixture
  - Element
  - Compound

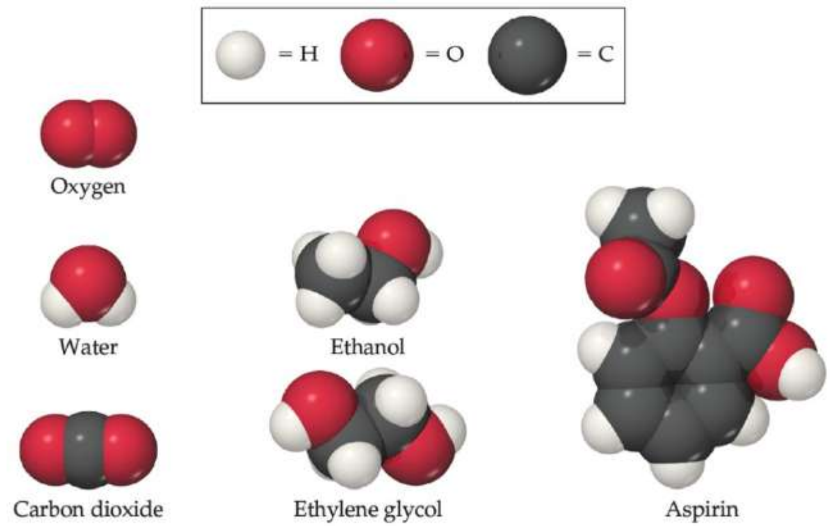


Classification of Matter—Substances

- A **substance** has distinct properties and a composition that does not vary from sample to sample.
- The two types of substances are **elements** and **compounds**.
  - An **element** is a substance which can **not** be decomposed to simpler substances.
  - A **compound** is a substance which **can** be decomposed to simpler substances because it is made up of more than one element.

Classification of Matter Based on Composition (2 of 2)

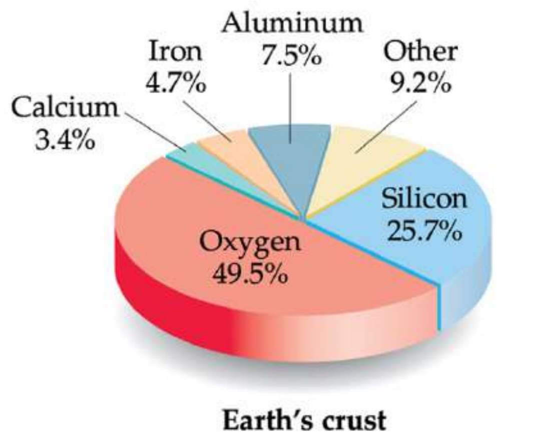
- **Atoms** are the building blocks of matter.
- Each **element** is made of a unique kind of atom, but can be made of more than one atom of that kind.
- A **compound** is made of atoms from two or more different elements.

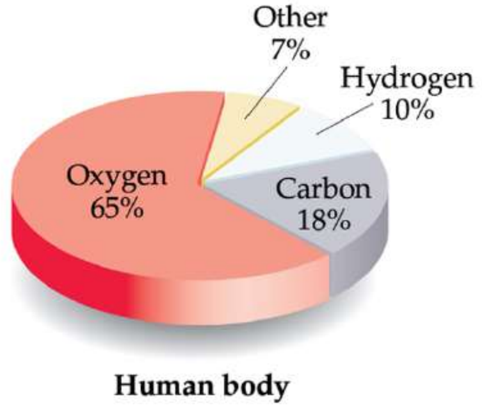


Note: Balls of different colors are used to represent atoms of different elements. Attached balls represent connections between atoms that are seen in nature. These groups of atoms are called **molecules**.

Elements and Composition

- There are currently 118 named elements.
- Only five elements make up 90% of the Earth's crust by mass.
- Only three elements make up 90% of the human body by mass!
- Note the importance of oxygen!





Representing Elements

Table 1.1 Some Common Elements and Their Symbols

Carbon	C	Aluminum	Al	Copper	Cu (from **cuprum**)
Fluorine	F	Bromine	Br	Iron	Fe (from **ferrum**)
Hydrogen	H	Calcium	Ca	Lead	Pb (from **plumbum**)
Iodine	I	Chlorine	Cl	Mercury	Hg (from **hydrargyrum**)
Nitrogen	N	Helium	He	Potassium	K (from **kalium**)
Oxygen	O	Lithium	Li	Silver	Ag (from **argentum**)
Phosphorus	P	Magnesium	Mg	Sodium	Na (from **natrium**)
Sulfur	S	Silicon	Si	Tin	Sn (from **stannum**)

- Chemists usually represent elements as **symbols**.
- **Symbols** are one or two letters; the first is always capitalized.
- Some elements are based on Latin, Greek, or other foreign language names.

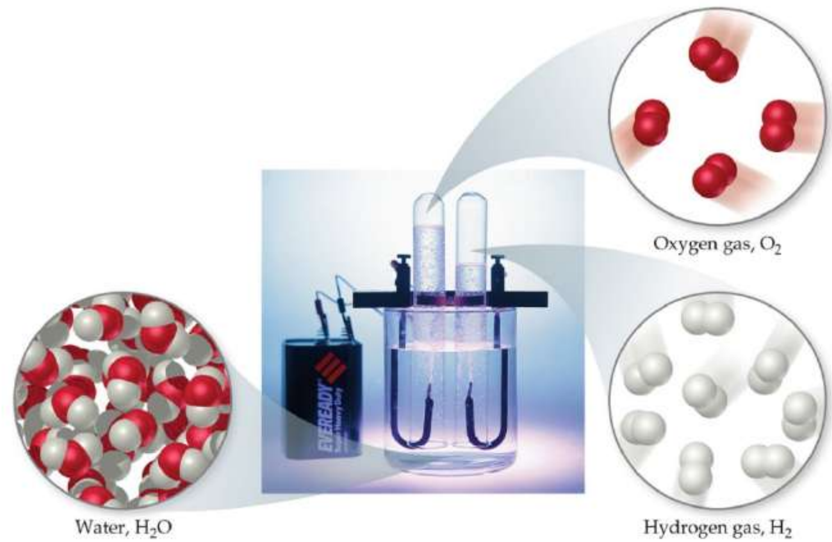
Compounds and Composition


Hydrogen atom
(written H)


Oxygen atom
(written O)


Water molecule
(written H_2O)

- Compounds have a definite composition. That means that the relative number of atoms of each element in the compound is the same in any sample.
- This is **The Law of Constant Composition** (or **The Law of Definite Proportions**).



Classification of Matter—Mixtures

- **Mixtures** exhibit the properties of the substances that make them.
- Mixtures can vary in composition throughout a sample (**heterogeneous**) or can have the same composition throughout the sample (**homogeneous**).
- A homogeneous mixture is also called a **solution**.

(a) (b)

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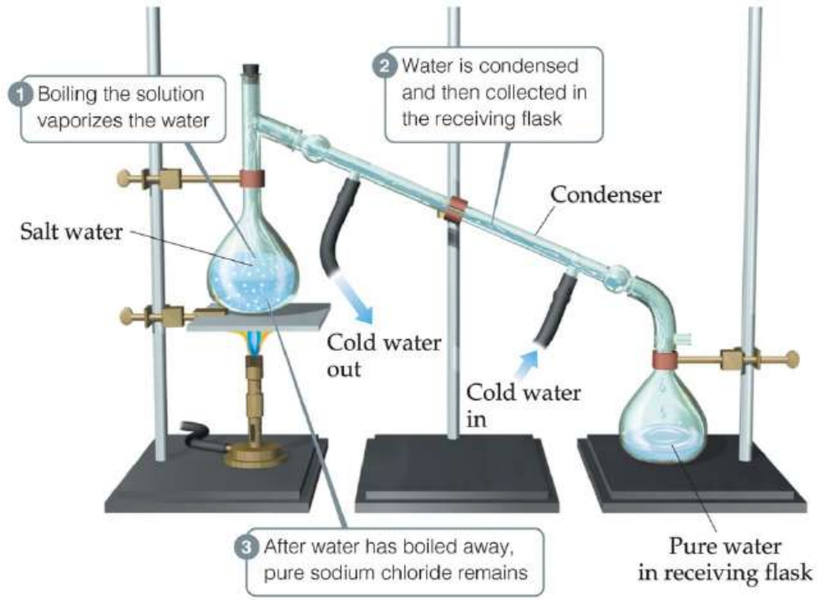
Two Types of Properties

- Physical properties
- Chemical properties

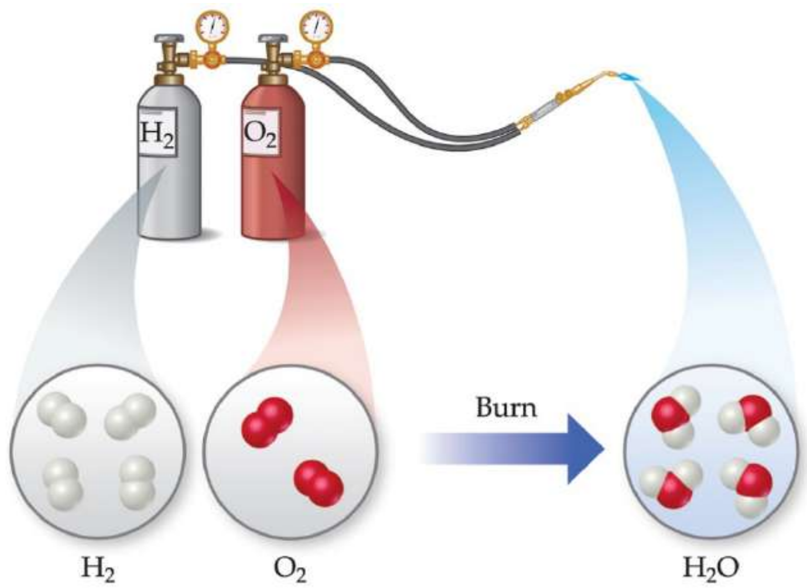
Physical Properties

- **Physical properties** can be observed without changing a substance into another substance.
  - Some examples include color, odor, density, melting point, boiling point, and hardness.



Chemical Properties

- **Chemical properties** can **only** be observed when a substance is changed into another substance.
  - One common chemical property is flammability, or the ability to burn in oxygen.



Types of Properties

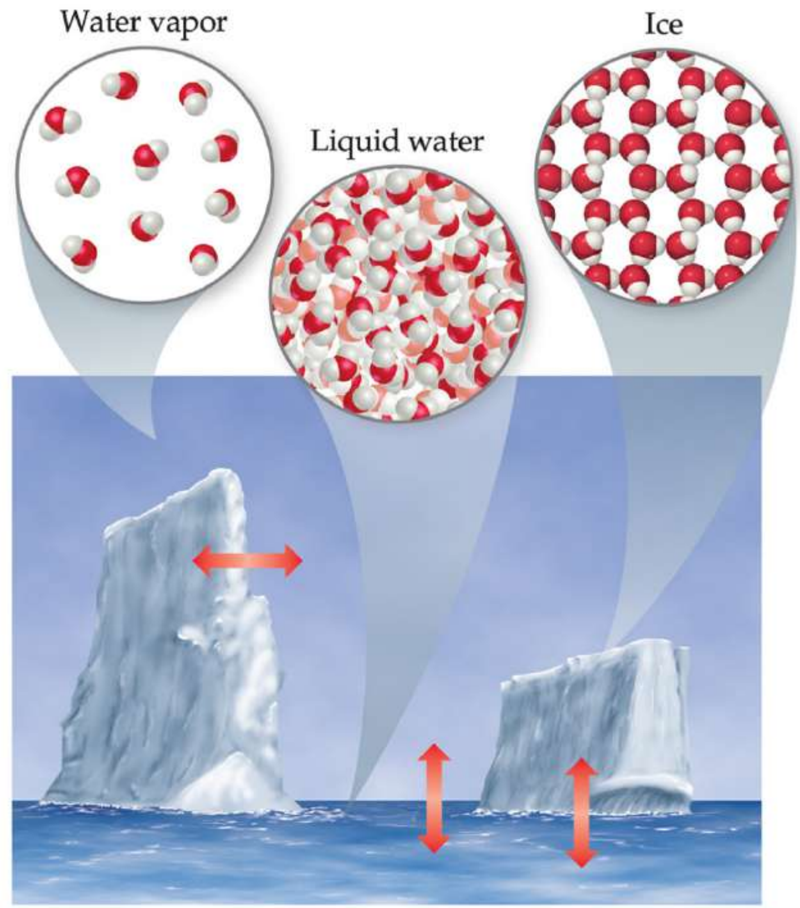
- **Intensive properties** are independent of the amount of the substance that is present.
  - Examples include density, boiling point, or color.
  - These are important for **identifying** a substance.
- **Extensive properties** depend upon the amount of the substance present.
  - Examples include mass, volume, or energy.

Types of Changes

- **Physical changes** are changes in matter that do **not** change the composition of a substance.
  - Examples include changes of state, temperature, and volume.
- **Chemical changes** result in new substances.
  - Examples include combustion, oxidation, and decomposition.

Changes in State of Matter

- Converting between the three states of matter is a **physical change**.
- When ice melts or water evaporates, there are still 2 H atoms and 1 O atom in each molecule.



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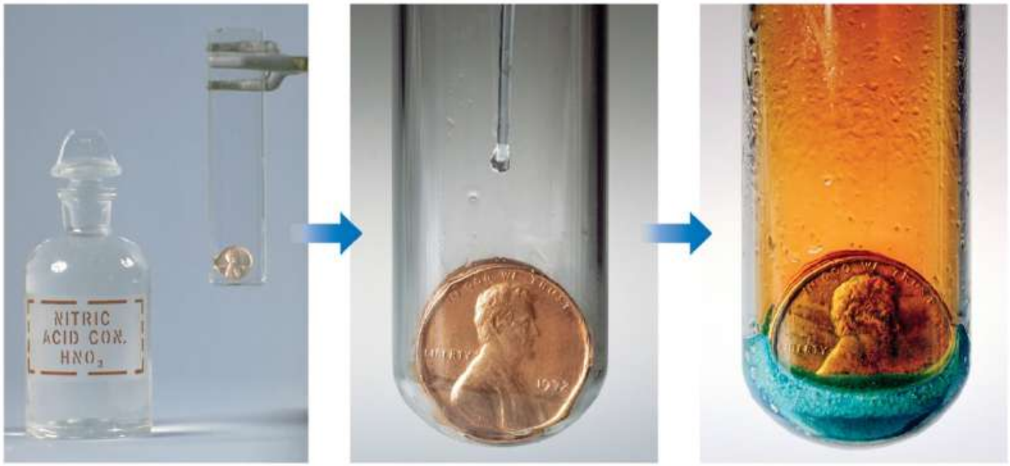
Chemical Reactions (Chemical Change)



In the course of a chemical reaction, the reacting substances are converted to new substances. Here, the copper penny reacts with nitric acid; it gives a blue solution of copper(II) nitrate and a brown gas called nitrogen dioxide.

Note: Physical properties, like color, often helps us
See that chemical change has occurred.

Separating Mixtures

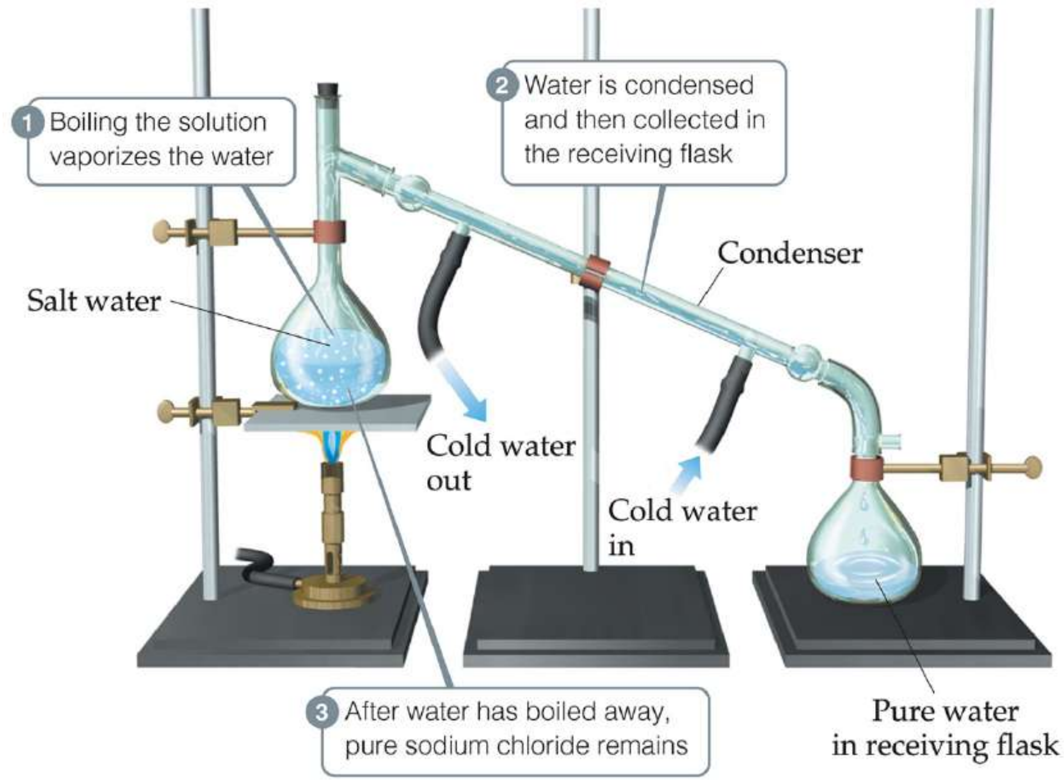
- Mixtures can be separated based on physical properties of the components of the mixture. Some methods used are
  - filtration
  - distillation
  - chromatography

Filtration

- In filtration, solid substances are separated from liquids and solutions.

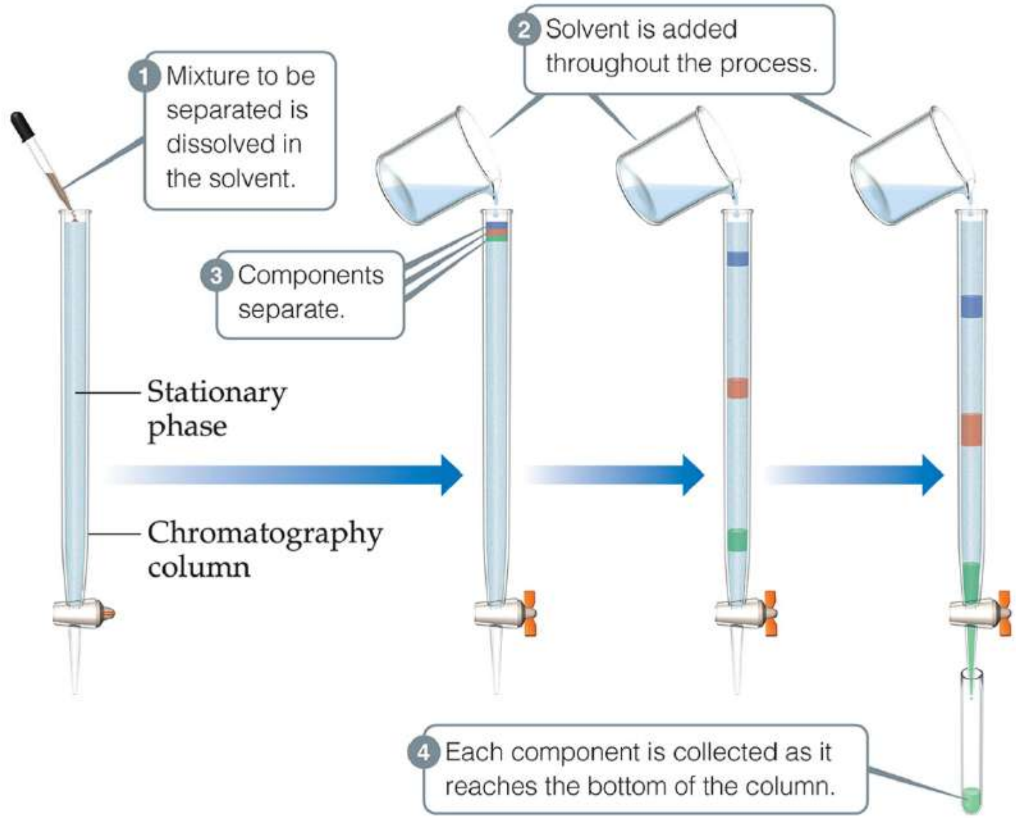
Distillation

- Distillation uses differences in the boiling points of substances to separate a homogeneous mixture into its components.



Chromatography

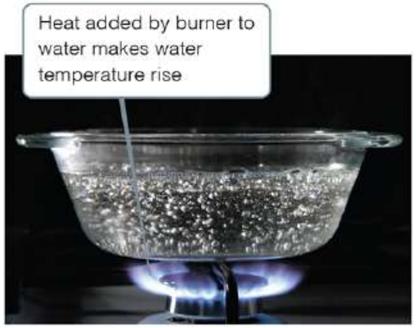
- This technique separates substances on the basis of differences in the ability of substances to adhere to the solid surface, in this case, dyes to paper.



Energy (1 of 2)

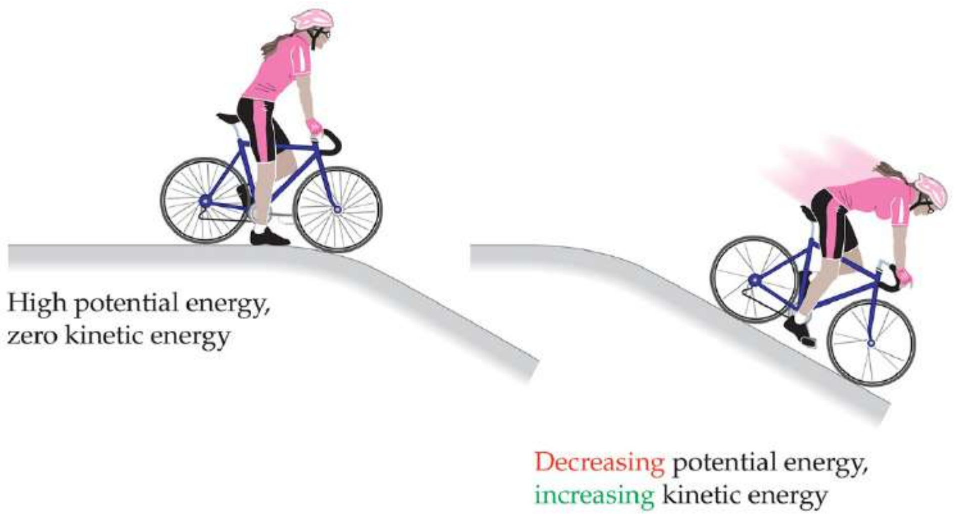
- **Energy** is the capacity to do work or transfer heat.
- **Work** is the energy transferred when a force exerted on an object causes a displacement of that object.
- **Heat** is the energy used to cause the temperature of an object to increase.
- **Force** is any push or pull on an object.

(a)



(b)

Two Fundamental Forms of Energy



- **Kinetic energy** is the energy of motion.
  - Its magnitude depends on the object's mass and its velocity:

$$KE = \frac{1}{2} mv^2$$

- **Potential energy** of an object depends on its relative position compared to other objects.

Numbers and Chemistry

- Numbers play a major role in chemistry. Many topics are **quantitative** (have a numerical value).
- Concepts of numbers in science
  - Units of measurement
  - Quantities that are measured and calculated
  - Uncertainty in measurement
  - Significant figures
  - Dimensional analysis

Units of Measurements—SI Units

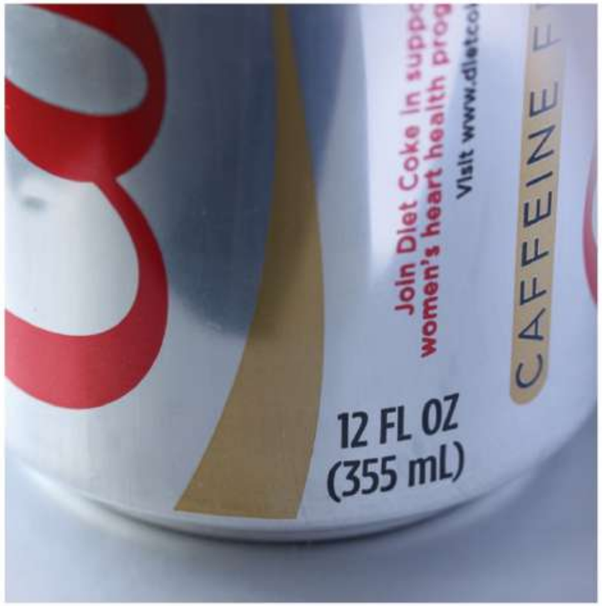
- **Système International d'Unités** ("The International System of Units")
- A different base unit is used for each quantity.

Table 1.3 SI Base Units

Physical Quantity	Name of Unit	Abbreviation
Length	Meter	m
Mass	Kilogram	kg
Temperature	Kelvin	K
Time	Second	s or sec
Amount of substance	Mole	mol
Electric current	Ampere	A or amp
Luminous intensity	Candela	cd

Units of Measurement—Metric System

- The base units used in the metric system
  - Mass: gram (g)
  - Length: meter (m)
  - Time: second (s or sec)
  - Temperature: degrees Celsius (°C) **or** Kelvins (K)
  - Amount of a substance: mole (mol)
  - Volume: cubic (centimeter) (cc or cm^3) **or** liter (l)



Units of Measurement—Metric System Prefixes (1 of 3)

Prefixes convert the base units into units that are appropriate for common usage or appropriate measure (as seen with mL on the can in the last slide).

Units of Measurement—Metric System Prefixes (2 of 3)

Table 1.4 Prefixes Used in the Metric System and with SI Units

Prefix	Abbreviation	Meaning	Example
Peta	P	10^{15}	1 petawatt (PW) $=1\times 10^{15}$ watts[a]
Tera	T	10^{12}	1 terawatt (TW) $=1\times 10^{12}$ watts
Giga	G	10^{9}	1 gigawatt (GW) $=1\times 10^{9}$ watts
Mega	M	10^{6}	1 megawatt (MW) $=1\times 10^{6}$ watts
Kilo	k	10^{3}	1 kilowatt (kW) $=1\times 10^{3}$ watts
Deci	d	10^{-1}	1 deciwatt (dW) $=1\times 10^{-1}$ watt
Centi	c	10^{-2}	1 centiwatt (cW) $=1\times 10^{-1}$ watt
Milli	m	10^{-3}	1 milliwatt (mW) $=1\times 10^{-3}$ watt
Micro	μ[b]	10^{-6}	1 microwatt (μW) $=1\times 10^{-6}$ watt

Units of Measurement—Metric System Prefixes (3 of 3)

[Table 1.4 continued]

Prefix	Abbreviation	Meaning	Example
Nano	n	10^{-9}	1 nanowatt (nW) $= 1 \times 10^{-9}$ watt
Pico	p	10^{-12}	1 picowatt (pW) $= 1 \times 10^{-12}$ watt
Femto	f	10^{-15}	1 femtowatt (fW) $= 1 \times 10^{-15}$ watt
Atto	a	10^{-18}	1 attowatt (aW) $= 1 \times 10^{-18}$ watt
Zepto	z	10^{-21}	1 zeptowatt (zW) $= 1 \times 10^{-21}$ watt

[a]The watt (W) is the SI unit of power, which is the rate at which energy is either generated or consumed. The SI unit of energy is the joule (J); $1\ J = 1\ kg \cdot m^2/s^2$ and $1\ W = 1\ J/s$.

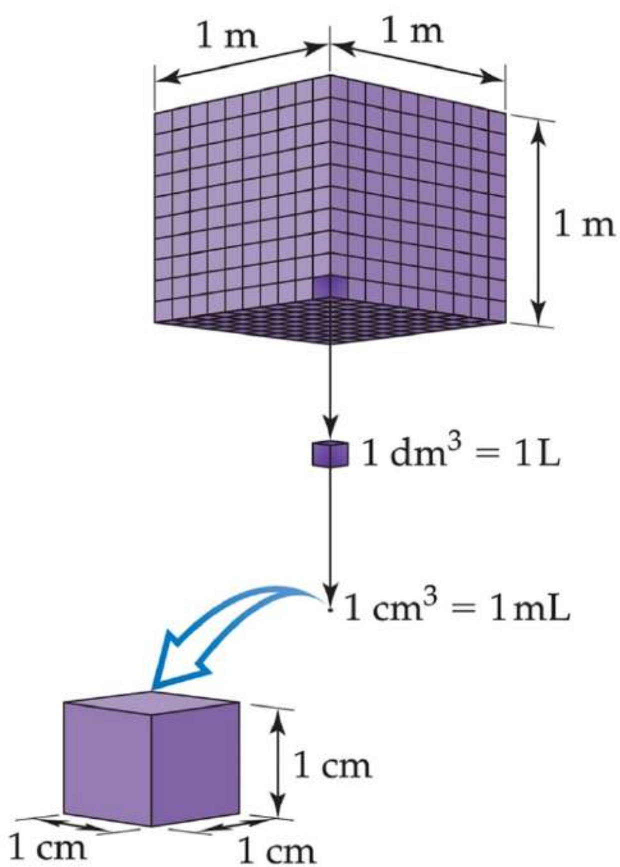
[b]Greek letter mu, pronounced “mew.”

Mass and Length

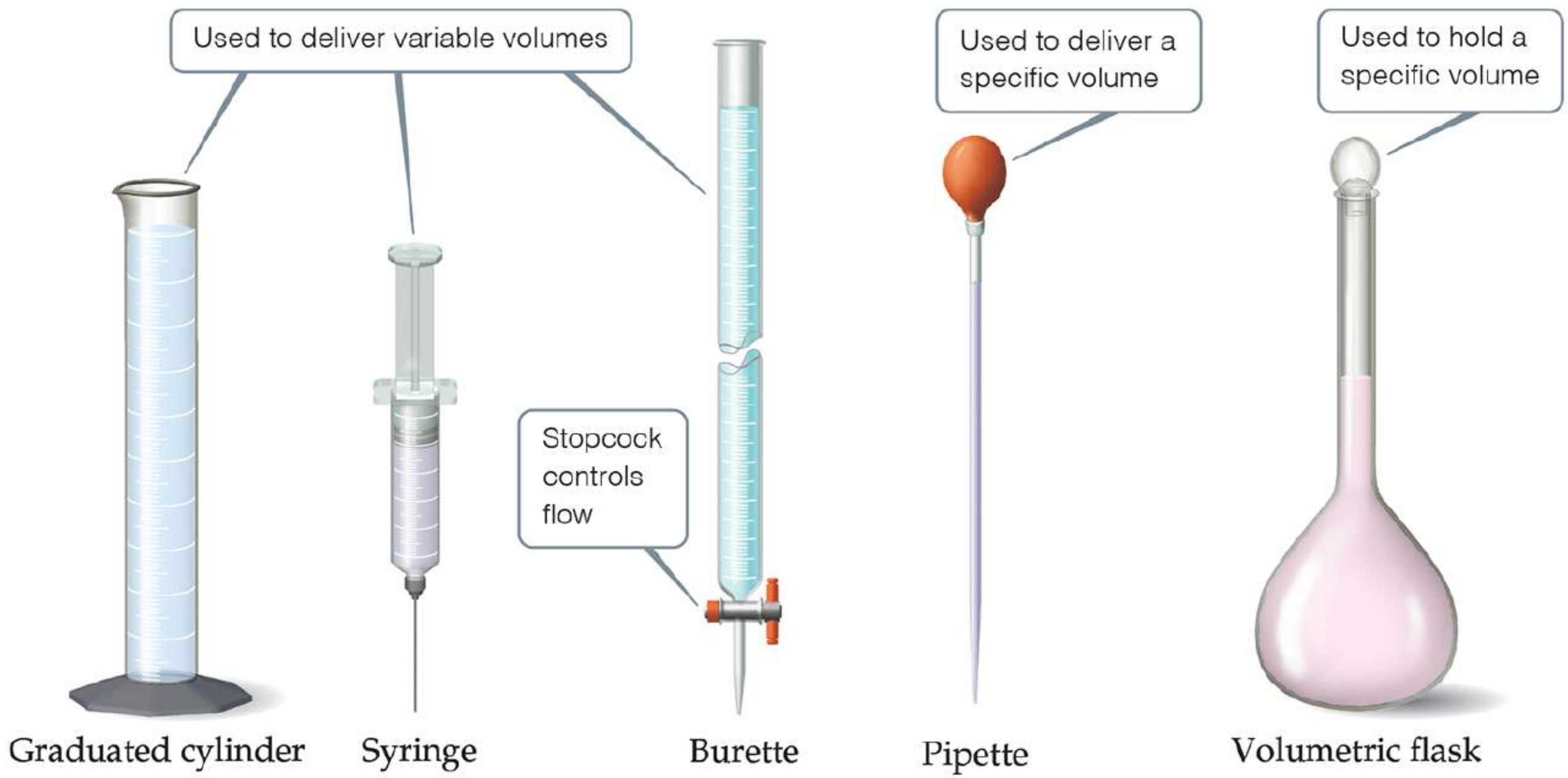
- These are basic units we measure in science.
- **Mass** is a measure of the amount of material in an object. SI uses the kilogram as the base unit. The metric system uses the gram as the base unit.
- **Length** is a measure of distance. The meter is the base unit.

Volume

- Note that volume is not a base unit for SI; it is a **derived unit** from length $(m \times m \times m = m^3)$.
- The most commonly used metric units for volume are the liter (L) and the milliliter (mL).
  - A liter is a cube 1 decimeter (dm) long on each side.
  - A milliliter is a cube 1 centimeter (cm) long on each side, also called 1 cubic centimeter $(cm \times cm \times cm = cm^3)$.

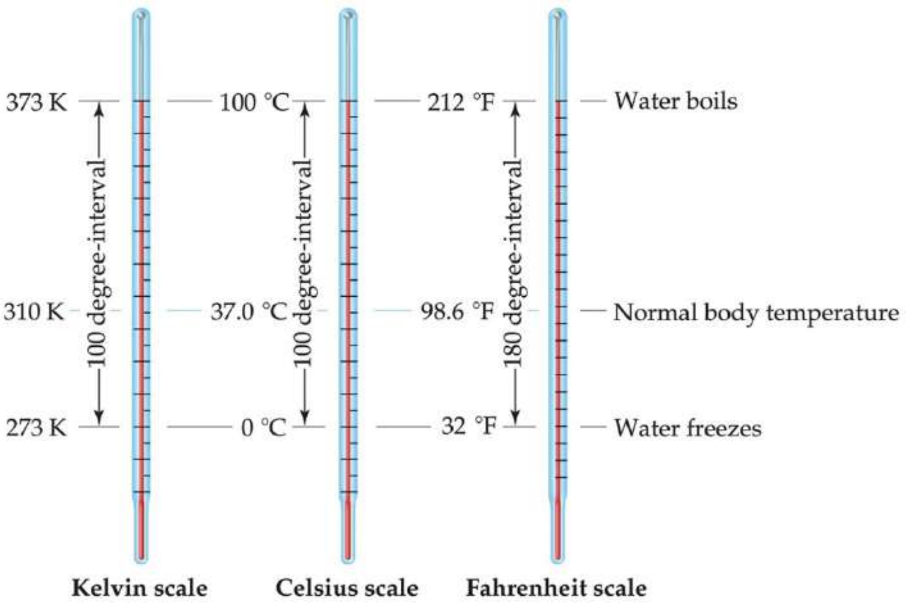


Glassware for Measuring Volume



Temperature (1 of 3)

- In general usage, **temperature** is considered the "hotness and coldness" of an object that determines the direction of heat flow.
- Heat flows spontaneously from an object with a higher temperature to an object with a lower temperature.



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Temperature (2 of 3)

- In scientific measurements, the Celsius and Kelvin scales are most often used.
- The Celsius scale is based on the properties of water.
  - 0 degree Celsius is the freezing point of water.
  - 100 degree Celsius is the boiling point of water.
- The Kelvin is the SI unit of temperature.
  - It is based on the properties of gases.
  - There are no negative Kelvin temperatures.
  - The lowest possible temperature is called absolute zero (0 K).
- K = degree Celsius + 273.15

Temperature (3 of 3)

- The Fahrenheit scale is not used in scientific measurements, but you hear about it in weather reports!
- The equations below allow for conversion between the Fahrenheit and Celsius scales:
  - $°F = \frac{9}{5}(°C) + 32$
  - $°C = \frac{5}{9}(°F - 32)$

Energy (2 of 2)

- The unit of energy: Joule (J). It is a derived unit:
  - $KE = \frac{1}{2}mv^2$
  - If the object is 2 kg, and it moves at 1 m/s, it will posses 1 J of kinetic energy:
  - $1J = \frac{1}{2}(2\text{ kg})(1\text{ m/s})^2$ OR : $1\text{ J} \equiv 1\text{ kg} \cdot \text{m}^2/\text{s}^2$
- The kJ is commonly used for chemical change.
- Historically, the calorie was used: 1 cal = 4.184 J
- This calorie is **Not** the nutritional Calorie. That one is a kcal.

1 nutritional Calorie = 1 Cal = 1000 cal

Density

- Density is a physical property of a substance.
- It has units that are derived from the units for mass and volume.
- The most common units are g/mL or g/cm^3.
- $D = \frac{m}{V}$

Table 1.5 Densities of selected Substances at 25 degree Celsius

Substance	Density (g/cm^3)
Air	0.001
Balsa wood	0.16
Ethanol	0.79
Water	1.00
Ethylene glycol	1.09
Table sugar	1.59
Table salt	2.16
Iron	7.9
Gold	19.32

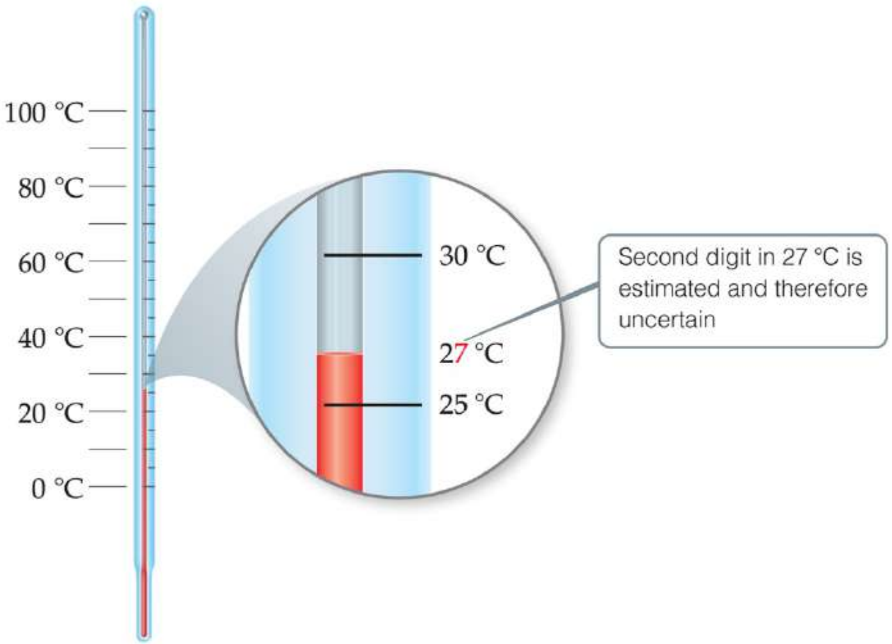
This is the end of the lecture

Numbers Encountered in Science

- **Exact** numbers are counted or given by definition. For example, there are 12 eggs in 1 dozen.
- **Inexact** (or **measured**) numbers depend on how they were determined. Scientific instruments have limitations (**equipment errors**) and individuals can read some instrumentation differently (**human errors**).

Uncertainty in Measurements

- Different measuring devices have different uses and different degrees of accuracy.
- All measured numbers have some degree of inaccuracy.
- The last digit measured is considered **reliable**, but **Not exact**.



Accuracy versus Precision

- **Precision** is a measure of how closely individual measurements agree with one another.
- **Accuracy** refers to how closely individual measurements agree with the correct, or “true,” value.
- Experimentally, we often take several measurements and determine a standard deviation.

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Significant Figures (1 of 2)

- All digits of a measured quantity, including the uncertain ones, are called **significant figures**.
- When rounding calculated numbers, we pay attention to significant figures so we do not overstate the accuracy of our answers.

Significant Figures (2 of 2)

1. All nonzero digits are significant.
2. Zeroes between nonzero digits are significant.
3. Zeroes at the beginning of a number are never significant.
4. Zeroes at the end of a number are significant if it contains a decimal point.

Problem: whole numbers ending in zeroes.

1.03×10^4 g	(three significant figures)
1.030×10^4 g	(four significant figures)
1.0300×10^4 g	(five significant figures)

Significant Figures in Calculations

- The least certain measurement limits the number of significant figures in the answer.
- When addition or subtraction is performed, answers are rounded to the least significant **decimal place**.
- When multiplication or division is performed, answers are rounded to the same number of digits as the measurement with the **fewest number of significant figures**.
- Know the number of appropriate digits throughout, but round off at the end only!

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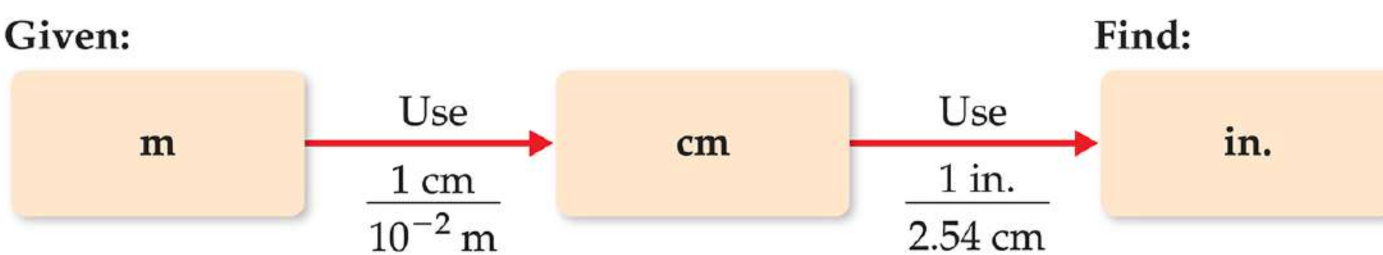
Dimensional Analysis

- **Dimensional analysis** is used to change units.
- We apply **conversion factors** (e.g., 1 in = 2.54 cm), which are equalities.
- We can set up a ratio of comparison for the equality:

1 in./2.54 cm **or** 2.54 cm/1 in.

- We use the ratio which allows us to change units (puts the units we have in the denominator to cancel).
- We can use multiple conversions, as long as each one is an equality.



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