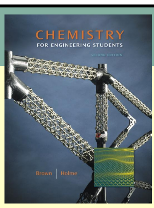

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Chapter 1
Introduction to Chemistry

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What is Engineering

- Engineers apply principles of math & science to solve technical problems.The laws and forces of nature are directed by engineers to meet human needs. Engineering is the application of science & math to solve technical problems and create new systems, products or devices to benefit civilization.

The Accrediting Board for *Engineering* and Technology (*ABET*)

ABET's Definition:

- Engineering is the profession in which a knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind

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Scientists & Engineers

- Scientists ask why?
- Scientists want to understand why our world behaves the way it does.
- Scientists emphasize the theoretical.

- Engineers ask "what can I make with it?"
- Engineers apply scientific principles to solve problems or meet human needs.
- Engineers apply established scientific theories and principles to create new products or solve technical problems

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Engineers

- Engineers are the link between scientific theory and the implementation of technology.
- The end result of science is new knowledge.
- The end result of engineering is design.

Design is a creative process that results in a new device, system, structure, or process that satisfies a specific human need.

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Chapter Objectives

- Describe how chemistry and engineering helped transform aluminum from a precious metal to an inexpensive structural material.
- Explain the usefulness of the macroscopic, microscopic, and symbolic perspectives in understanding chemical systems.
- Draw pictures to illustrate simple chemical phenomena (like the differences among solids, liquids, and gases) on the molecular scale.

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Chapter Objectives

- Explain the difference between inductive and deductive reasoning in your own words.
- Use appropriate ratios to convert measurements from one unit to another.
- Express the results of calculations using the correct number of significant figures.

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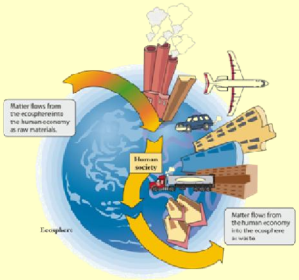
Aluminum



- In the 19th century aluminum was a rare and precious metal.
  - Pure aluminum never occurs in nature
  - Found in bauxite, an ore
- The now common use of aluminum is due to collaboration between chemistry and engineering.

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The Scientific Method

- Chemists use the scientific method to solve problems.
  - Make observations of nature.
  - Derive a hypothesis or build a model in response to observations.
  - Construct experiments to bolster or refute hypothesis or model.

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The Study of Chemistry

- The study of chemistry involves three levels of understanding, or three perspectives.
  - Macroscopic
  - Microscopic
  - Symbolic

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The Macroscopic Perspective

- Matter is anything that has mass and can be observed.
- Matter is observed through two types of changes.
  - Physical changes
  - Chemical changes

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The Macroscopic Perspective

- Physical properties are variables of matter that we can measure without changing the identity of the substance being observed.
  - Aluminum metal is a highly malleable metal; it can withstand large amounts of stress before it breaks or crumbles.
  - The density of an object is a ratio of its mass to its volume.
  - Other physical properties include: mass, color, viscosity, hardness, and temperature.

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The Macroscopic Perspective

- Chemical properties are determined only by observing how a substance changes its identity in chemical reactions.
  - Pure aluminum metal reacts with acid, such as in soft drinks, to form an aluminum salt and hydrogen gas
  - The ability of a compound to burn in oxygen, or combustion, is another chemical property.
  - The degradation of metals in the presence of air and moisture, or corrosion, is another common chemical property.

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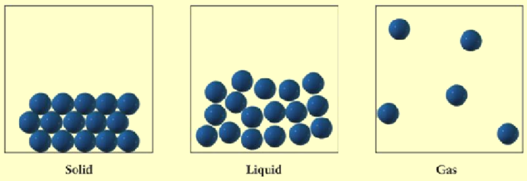
The Macroscopic Perspective

- There are three phases of matter.
  - Solids are hard and do not change their shapes easily at ordinary temperatures.
  - Liquids assume the shape of the portion of the container they fill.
  - Gases expand to occupy the entire volume of their containers.

The Microscopic, or Particulate, Perspective

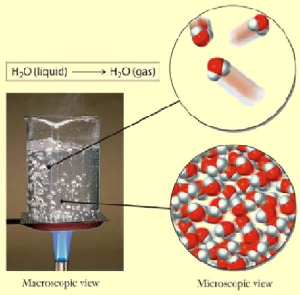
- Matter is composed of unimaginably small particles called atoms that retain the chemical identity of the element they represent.
- An element is composed of atoms with identical physical and chemical properties.
- Molecules are groups of atoms held together by attractive forces whose properties are distinguishable from those of the individual elements.

The Microscopic Perspective



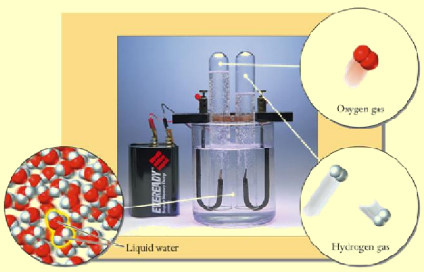
- Solid: particles maintain a regular ordered structure; maintains size and shape.
- Liquid: particles remain close but no longer ordered; takes shape of container.
- Gas: particles are widely separated and move independently of one another; fills available volume of container.

The Microscopic Perspective



- During a physical change, chemical composition does not change.
  - Heating liquid water to make gaseous water (steam)

The Microscopic Perspective

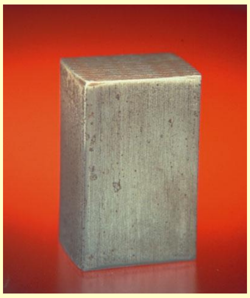


- During a chemical change, a chemical reaction occurs that changes the chemical composition of the matter involved.
  - Using electricity to convert water into oxygen and hydrogen molecules

Example Problem 1.1

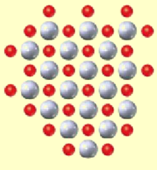
- A candle suspended above boiling water could be used to test a hypothesis about the chemical composition of the bubbles that rise from boiling water. What would be observed if the bubbles were composed of:
  - water
  - hydrogen
  - oxygen

The Symbolic Representation

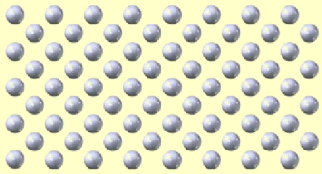


- Element abbreviations are used to represent:
  - pure aluminum, Al
  - aluminum oxide, Al_2O_3

The Symbolic Representation



Particulate level representation for aluminum oxide, Al_2O_3, in bauxite.



Particulate level representation for pure aluminum, Al.

The Science of Chemistry: Observations and Models

- Chemistry is an empirical science and is studied by:
  - Measuring physical properties and observing chemical reactions.
  - Models are created to explain observations and organize collected data.

Observations in Science

- Observations are recorded via measurements.
  - Accuracy - how close the observed value is to the "true" value.
  - Precision - the spread in values obtained from measurements; the reproducibility of values.

Observations in Science

(a) Poor precision and poor accuracy

- Measurements can have poor precision and poor accuracy.
  - Darts are scattered evenly across the board.

Observations in Science

(b) Good precision and poor accuracy

- Measurements can have good precision and poor accuracy.
  - Darts are clustered together.
  - But darts are clustered far from the bulls-eye.

Observations in Science

(c) Good precision and good accuracy

- Measurements can have good precision and good accuracy.
  - Darts are clustered together, and
  - darts are clustered close to or on the bulls-eye.

Observations in Science

- Measurements contain one of two types of errors:
  - Random Error - may make a measurement randomly too high or too low. (e.g., variation associated with equipment limitations)
  - Systematic Error - may make a measurement consistently too high or too low. (e.g., the presence of an impurity)

Interpreting Observations

- Inductive and deductive reasoning are used to interpret collected data and observations.
  - Inductive reasoning begins with a series of specific observations and attempts to generalize to a larger, more universal conclusion.
  - Deductive reasoning takes two or more statements or assertions and combines them so that a clear and irrefutable conclusion can be drawn.

Models in Science

- Models refer to a largely empirical description.
  - Gas pressure is proportional to temperature.
- Theories are explanations grounded in some more fundamental principle or assumption about the behavior of a system.
  - Relationship between gas pressure and temperature explained using kinetic energy.
- Laws are sufficiently refined, well tested, and widely accepted theories.

Numbers and Measurements in Chemistry

- Chemists quantify data, expressing collected data with units and significant figures.
  - Units - designate the type of quantity measured.
  - Prefixes - provide scale to a base unit.
  - Significant Figures - indicate the amount of information that is reliable when discussing a measurement.

Units

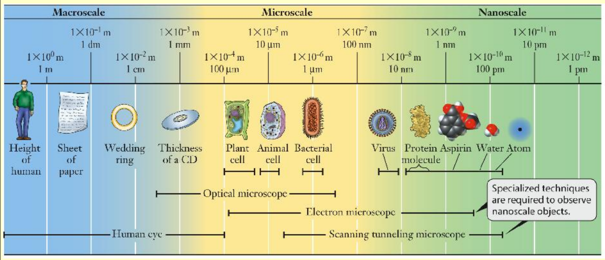
Table 1.1

Base quantities of the SI system of units

Property	Unit, with abbreviation
Mass	kilogram, kg
Time	second, s
Distance	meter, m
Electric current	ampere, A
Temperature	kelvin, K
Number of particles	mole, mol
Light intensity	candela, cd

- The base unit designates the type of quantity being measured.
- SI units (from French *Système International*) are the base units of science.
- Some units comprise combinations of these base units and are termed derived units
  - 1 J = 1 kg m^2 s^{-2}

Units



- Prefixes are used with base units to report and understand quantities of any size.

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SI Prefixes

Table 1.2

Prefixes used in the SI system

Factor	Name	Symbol	Factor	Name	Symbol
10^{24}	yotta	Y	10^{-1}	deci	d
10^{21}	zetta	Z	10^{-2}	centi	c
10^{18}	exa	E	10^{-3}	milli	m
10^{15}	peta	P	10^{-6}	micro	µ
10^{12}	tera	T	10^{-9}	nano	n
10^{9}	giga	G	10^{-12}	pico	p
10^{6}	mega	M	10^{-15}	femto	f
10^{3}	kilo	k	10^{-18}	atto	a
10^{2}	hecto	h	10^{-21}	zepto	z
10^{1}	deka	da	10^{-24}	yocto	y

- Prefixes are based on multiples of 10.

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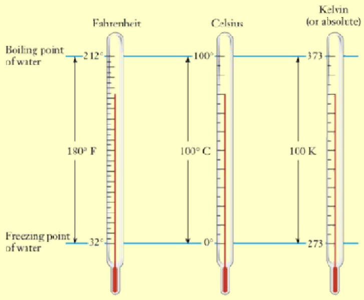
Temperature



- Temperature is measured using the Fahrenheit, Celsius, and Kelvin (absolute) temperature scales.

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Temperature Scale Conversions

$$^{o}\text{F} = (1.8 \times {}^{o}\text{C}) + 32$$

$$^{o}\text{C} = ({}^{o}\text{F} - 32)/1.8$$

$$\text{K} = {}^{o}\text{C} + 273.15$$

$$^{o}\text{C} = \text{K} - 273.15$$

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Numbers and Significant Figures

- Scientific notation is used to easily write very small and very large numbers.

  - Factor out powers of ten

$$54{,}000 = 5.4 \times 10^{4}$$

$$0.000042 = 4.2 \times 10^{-5}$$

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Numbers and Significant Figures

- All digits reported are considered significant except for certain types of zeros.
  - When a zero establishes the decimal place, it is not significant.
    - 51,300 m (3 significant figures)
    - 0.043 g (2 significant figures)
  - A zero is significant when it *follows* a decimal point or when it occurs between other significant figures.
    - 4.30 mL (3 significant figures)
    - 304.2 kg (4 significant figures)
  - All numbers are significant when written in correct scientific notation.

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Example Problem 1.2

- An alloy contains 2.05% of some impurity. How many significant figures are reported in this value?

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Numbers and Significant Figures

- For calculated values, the number of significant figures should be consistent with the data used in the calculation.
  - For multiplication and division, the number of significant figures in a result must be the same as the number of significant figures in the factor with the fewest significant figures.

$$0.24 \text{ kg} \times 4621 \text{ m} = 1100 \text{ kg m or } 1.1 \times 10^3 \text{ kg m}$$

  - For addition and subtraction, the number of significant figures are determined from the position of the first uncertain digit.

$$\begin{array}{r} 4.882 \text{ m} \\ +\ 0.3 \text{ m} \\ \hline 5.2 \text{ m} \end{array}$$

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Example Problem 1.3

- Report the result for the indicated arithmetic operations using the correct number of significant figures. Assume all values are measurements and not exact numbers.
  - 4.30×0.31
  - 4.033 + 88.1
  - 5.6/17.32

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Numbers and Significant Figures

- When counting discrete objects, the result has no ambiguity. Such measurements use exact numbers. They have infinite significant figures.
  - two pennies would be 2.000000…
- Exactly defined terms, such as metric prefixes, are also considered exact numbers.

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Problem Solving in Chemistry and Engineering

- There are several categories of problems:
  - Calculations involving ratios
  - Conceptual understanding of particulate level
  - Visualization of phenomena on different levels

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Using Ratios

- Ratios represent the relationship between two quantities and can be expressed two ways.

$$\text{Price} = \frac{\$4.45}{5.0 \text{ pounds}} = \$0.89 \text{ per pound}$$

$$\frac{5.0 \text{ pounds}}{\$4.45} = 1.1 \text{ pounds per dollar}$$

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Example Problem 1.4

- Suppose that your supermarket is offering 20-count shrimp for $5.99 per pound. How much should you expect to pay for one dozen shrimp?

Ratios in Chemistry Calculations

- Mass Density - ratio of an object's mass to its volume.
  - Temperature- and compound-specific
  - Allows conversion between mass and volume.

$$346\ \text{L} \times \frac{1000\ \text{mL}}{1\ \text{L}} \times \frac{0.975\ \text{g}}{1\ \text{mL}} = 3.37 \times 10^5\ \text{g}$$

  - Units of measurement can be used to determine how to write the appropriate ratio by "canceling" out; called dimensional analysis or the factor-label method.

Example Problem 1.5

- What is the wavelength, in meters, of orange light of wavelength 615 nm?

Example Problem 1.6

- The density of water at 25ºC is 0.997 g per mL. A child's swimming pool holds 346 L of water at this temperature. What mass of water is in the pool?

Conceptual Chemistry Problems

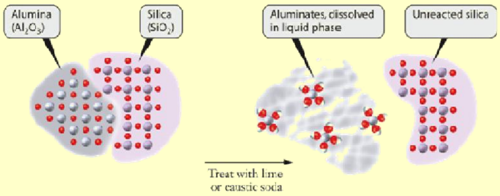
- Conceptual problems focus on the particulate perspective of chemistry.
- Depictions of atoms and molecules are used to visualize molecular phenomena.

Example Problem 1.7

- Draw a picture that shows what carbon dioxide molecules might look like as a solid and as a gas.

Visualization in Chemistry

- Depictions of atoms and molecules provide one important tool in the way chemistry is taught and learned.



- Digestion of bauxite ore with aqueous caustic soda, separating the alumina from silica in ore.

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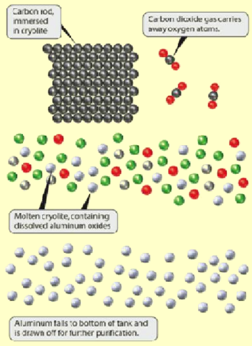
Visualization in Chemistry



- These particulate level illustrations provide a simplified view of the atomic scale process involved in smelting aluminum.

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Material Selection and Bicycle Frames

Table 1.3

Elastic modulus, yield strength, and density of some materials used in bicycle frames

Material	Elastic Modulus (psi)	Yield Strength Range (psi)	Density (g/cm^3)
Aluminum	10.0×10^6	$5.0 \times 10^3 - 6.0 \times 10^4$	2.699
Steel	30.0×10^6	$4.5 \times 10^4 - 1.6 \times 10^5$	7.87
Titanium	16.0×10^6	$4.0 \times 10^4 - 1.2 \times 10^5$	4.507

- Elastic modulus (a substance's tendency to be deformed in a nonpermanent manner), yield strength (point at which deformation becomes permanent), and density of some materials used in bicycle frames.

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