Science, Matter, Energy, and Systems

Chapter 2

2-1 What Is Science?

- ***Concept 2-1*** *Scientists collect data and develop theories, models, and laws about how nature works.*

Science Is a Search for Order in Nature (1)

- Identify a problem
- Find out what is known about the problem
- Ask a question to be investigated
- Research = Gather information and data
- Hypothesize = Make testable predictions
- Experiment = Keep testing and making observations
- Accept or reject the hypothesis

Science Is a Search for Order in Nature (2)

- Important features of the scientific process
  - Curiosity
  - Skepticism
  - Peer review
  - Reproducibility
  - Openness to new ideas

The Scientific Process (aka Scientific Method)

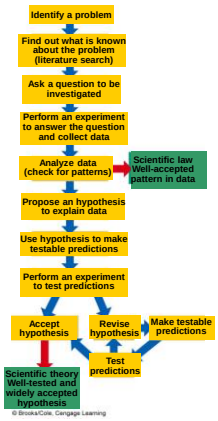


Fig. 2-2, p. 30

Scientists Use Reasoning, Imagination, and Creativity to Learn How Nature Works

- Important scientific tools
  - **Inductive reasoning**
  - **Deductive reasoning**
- Scientists also use
  - Intuition
  - Imagination
  - Creativity

Scientific Theories and Laws Are the Most Important Results of Science

- **Scientific theory**
  - Widely tested
  - Supported by extensive evidence
  - Accepted by most scientists in a particular area
- **Scientific law, law of nature**
- **Paradigm shift**

Science Focus: The Scientific Consensus over Global Warming

- How much has the earth's atmosphere warmed during the last 50 years?
- How much of this warming is due to human activity?
- How much is the atmosphere likely to warm in the future?
- Will this affect climate?
- 1988: Intergovernmental Panel on Climate Change (IPCC)

The Results of Science Can Be Tentative, Reliable, or Unreliable

- **Tentative science, frontier science**
- **Reliable science**
- **Unreliable science**

Environmental Science Has Some Limitations

- Particular hypotheses, theories, or laws have a high probability of being true while not being absolute
- Bias can be minimized
- Statistical methods may be used to estimate very large or very small numbers
- Environmental phenomena involve many interacting variables and complex interactions

Science Focus: Statistics and Probability

- **Statistics**
  - Collect, organize, and interpret numerical data
- **Probability**
  - The chance that something will happen or be valid (95% is a common standard)

2-2 What Is Matter?

- ***Concept 2-2*** *Matter consists of elements and compounds, which are in turn made up of atoms, ions, or molecules.*

Matter Consists of Elements and Compounds

- **Matter**
  - Has mass and takes up space
- **Elements**
  - Unique properties
  - Cannot be broken down chemically into other substances
- **Compounds**
  - Two or more different elements bonded together in fixed proportions

Elements Important to the Study of Environmental Science

Table 2-1

Elements Important to the Study of Environmental Science

Element	Symbol	Element	Symbol
Hydrogen	H	Bromine	Br
Carbon	C	Sodium	Na
Oxygen	O	Calcium	Ca
Nitrogen	N	Lead	Pb
Phosphorus	P	Mercury	Hg
Sulfur	S	Arsenic	As
Chlorine	Cl	Uranium	U
Fluorine	F		

Compounds Important to the Study of Environmental Science

Table 2-3

Compounds Important to the Study of Environmental Science

Compound	Formula	Compound	Formula
sodium chloride	NaCl	methane	CH_4
carbon monoxide	CO	glucose	$C_6H_{12}O_6$
carbon dioxide	CO_2	water	H_2O
nitric oxide	NO	hydrogen sulfide	H_2S
nitrogen dioxide	NO_2	sulfur dioxide	SO_2
nitrous oxide	N_2O	sulfuric acid	H_2SO_4
nitric acid	HNO_3	ammonia	NH_3

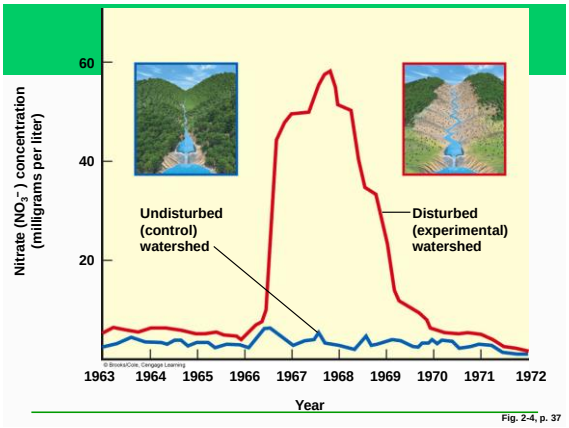
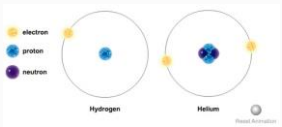


Fig. 2-4, p. 37

Atoms, Ions, and Molecules Are the Building Blocks of Matter (1)

- **Atomic theory = all elements are made up of atoms, most widely accepted theory in chemistry**
- **Subatomic particles**
  - Protons (p) with positive charge and neutrons (0) with no charge in nucleus
  - Negatively charged electrons (e) orbit the nucleus
- **Mass number**
  - Protons plus neutrons
- **Isotopes**
  - **An element with a different number of neutrons in the nucleus**

Animation: Subatomic particles



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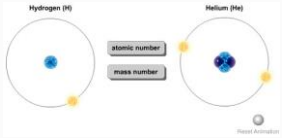
Animation: Atomic number, mass number



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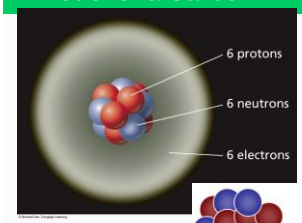
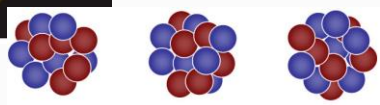
Model of a Carbon-12 Atom



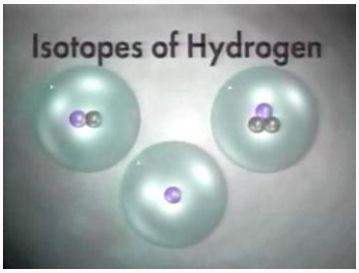


carbon-12
98.9%
6 protons
6 neutrons

carbon-13
1.1%
6 protons
7 neutrons

carbon-14
<0.1%
6 protons
8 neutrons

Animation: Isotopes



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Atoms, Ions, and Molecules Are the Building Blocks of Matter (2)

- **Ions** (see next animation)
  - Gain or lose electrons
  - Form ionic compounds
- **pH** (see pH scale animation)
  - Measure of acidity
  - H^+ and OH^-

Atoms, Ions, and Molecules Are the Building Blocks of Matter (3)

- **Molecule**
  - Two or more atoms of the same or different elements held together by chemical bonds
- **Chemical formula**
  - Shows number of each atom or ion (e.g., NaCl; CH_4)

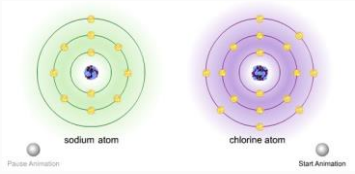
Ions Important to the Study of Environmental Science

Table 2-2

Ions Important to the Study of Environmental Science

Positive Ion	Symbol	Negative Ion	Symbol
hydrogen ion	H^+	chloride ion	Cl^-
sodium ion	Na^+	hydroxide ion	OH^-
calcium ion	Ca^{2+}	nitrate ion	NO_3^-
aluminum ion	Al^{3+}	sulfate ion	SO_4^{2-}
ammonium ion	NH_4^+	phosphate ion	PO_4^{3-}

Animation: Ionic bonds



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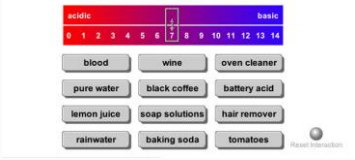
Animation: pH scale

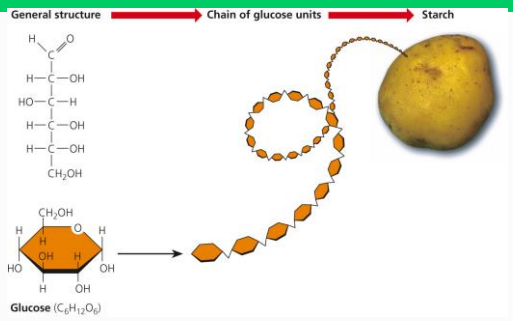


PLAY

Organic Compounds Are the Chemicals of Life

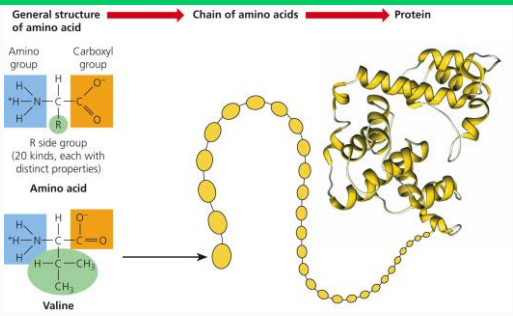
- **Inorganic compounds**
  - Also needed for life, e.g., NO_3^-
- **Organic compounds**
  - Hydrocarbons and chlorinated hydrocarbons
  - Simple carbohydrates
  - Macromolecules: complex organic molecules
    - Complex carbohydrates
    - Proteins
    - Nucleic acids
    - Lipids

Glucose Structure



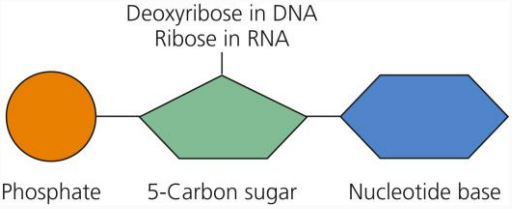
Supplement 4, Fig. 4

Amino Acids and Proteins



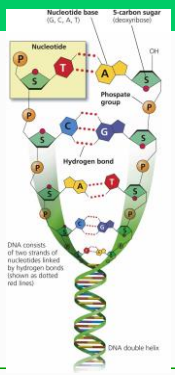
Supplement 4, Fig. 8

Nucleotide Structure in DNA and RNA



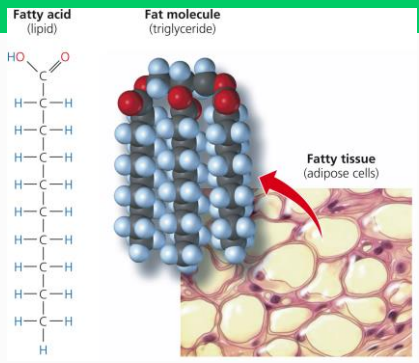
Supplement 4, Fig. 9

DNA Double Helix Structure and Bonding



Supplement 4, Fig. 10

Fatty Acid Structure and Trigyceride

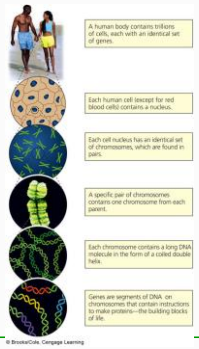


Supplement 4, Fig. 11

Matter Comes to Life through Genes, Chromosomes, and Cells

- **Cells:** fundamental units of life
- **Genes**: sequences of nucleotides within the DNA
- **Chromosomes**: composed of many genes

Cells, Nuclei, Chromosomes, DNA, and Genes



Examples of Differences in Matter Quality

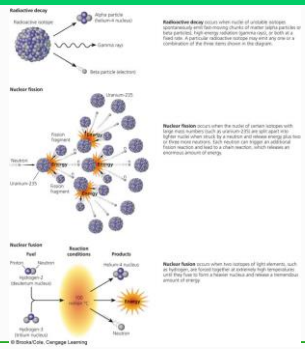
2-3 How Can Matter Change?

- ***Concept 2-3*** *When matter undergoes a physical or chemical change, no atoms are created or destroyed (the law of conservation of matter).*

Matter Undergoes Physical, Chemical, and Nuclear Changes

- **Physical change**
- **Chemical change, chemical reaction**
- **Nuclear change (Fig. 2-7)**
  - Natural radioactive decay
    - Radioisotopes: unstable
  - Nuclear fission
  - Nuclear fusion

Types of Nuclear Changes



Radioactive decay

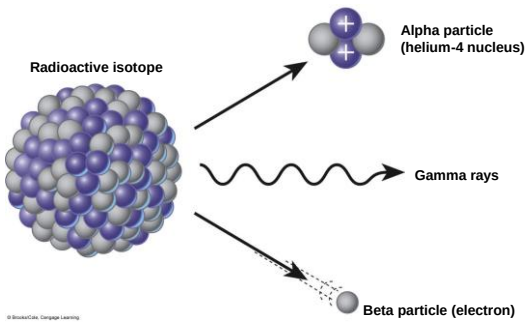
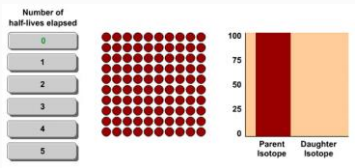


Fig. 2-7a, p. 41

Animation: Half-life



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Nuclear fission

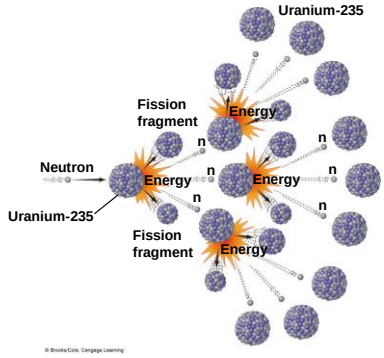


Fig. 2-7b, p. 41

Nuclear fusion

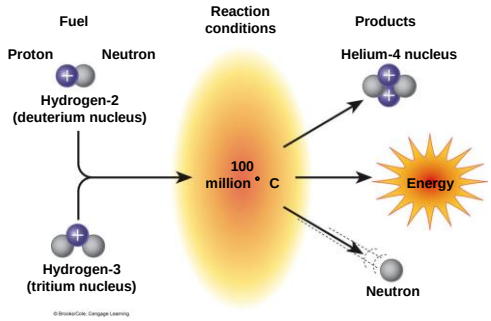


Fig. 2-7c, p. 41

We Cannot Create or Destroy Matter

- **Law of conservation of matter**
- Matter consumption
  - Matter is converted from one form to another (never "thrown away")

2-4 What is Energy and How Can It Be Changed?

- ***Concept 2-4A*** *When energy is converted from one form to another in a physical or chemical change, no energy is created or destroyed (first law of thermodynamics).*
- ***Concept 2-4B*** *Whenever energy is changed from one form to another, we end up with lower-quality or less usable energy than we started with (second law of thermodynamics).*

Animation: Total energy remains constant

PLAY

Energy Comes in Many Forms

- **Kinetic energy**
  - Heat
    - Transferred by radiation, conduction, or convection
  - Electromagnetic radiation (Fig. 2-8)
- **Potential energy**
  - Stored energy
    - Can be changed into kinetic energy

Energy Comes in Many Forms (1)

- **Kinetic energy**
  - Flowing water
  - Wind
  - **Heat**
    - Transferred by radiation, conduction, or convection
  - **Electromagnetic radiation**
- **Potential energy**
  - Stored energy
    - Can be changed into kinetic energy

Wind's Kinetic Energy Moves This Turbine

Fig. 2-10, p. 44

The Electromagnetic Spectrum

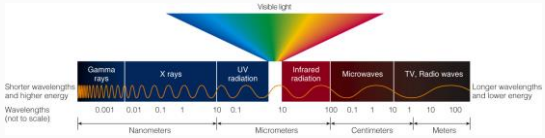
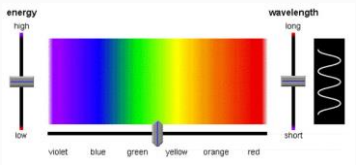


Fig. 2-11, p. 45

Visible light
Gamma rays
X rays
UV radiation
Infrared radiation
Microwaves
TV, Radio waves
Shorter wavelengths and higher energy
Longer wavelengths and lower energy
Wavelengths (not to scale)
0.001 0.01 0.1 1 10 0.1 10 100 0.1 1 10 1 10 100
Nanometers
Micrometers
Centimeters
Meters

Fig. 2-11, p. 45

Active Figure: Visible light



PLAY

Potential Energy

Fig. 2-12, p. 45

Energy Comes in Many Forms (2)

- Sun provides 99% of earth's energy
  - Warms earth to comfortable temperature
  - Plant photosynthesis
  - Winds
  - Hydropower
  - Biomass
  - **Fossil fuels**: oil, coal, natural gas

Nuclear Energy to Electromagnetic Radiation

Fig. 2-13, p. 46

Fossil fuels

Fig. 2-14a, p. 46

Some Types of Energy Are More Useful Than Others

- **High-quality energy**
  - High capacity to do work
  - Concentrated
  - High-temperature heat
  - Strong winds
  - Fossil fuels
- **Low-quality energy**
  - Low capacity to do work
  - Dispersed

Ocean Heat Is Low-Quality Energy

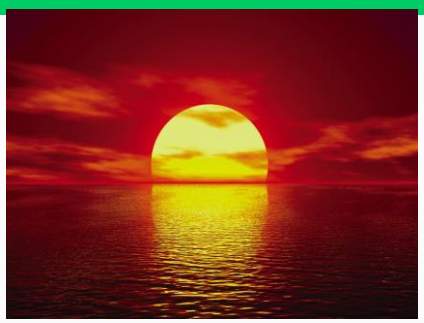


Fig. 2-15, p. 47

Energy Changes Are Governed by Two Scientific Laws

- First Law of Thermodynamics
  - Energy input **always** equals energy output
- Second Law of Thermodynamics
  - Energy always goes from a more useful to a less useful form when it changes from one form to another
- Energy efficiency or productivity – how much **useful** work is accomplished
  - Light bulbs and combustion engines are very inefficient: produce wasted heat

Energy-Wasting Technologies

Fig. 2-16a, p. 48

The Second Law of Thermodynamics in Living Systems

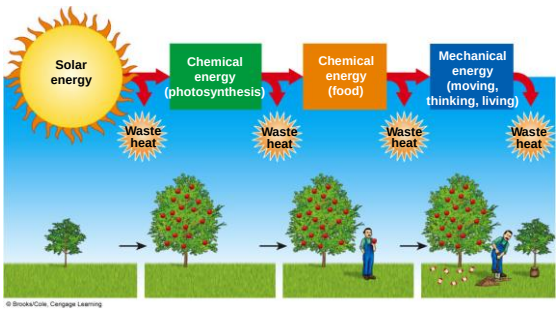


Fig. 2-9, p. 43

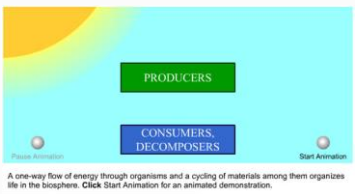
2-5 What Are Systems and How Do They Respond to Change?

- ***Concept 2-5*** *Systems have inputs, flows, and outputs of matter and energy, and feedback can affect their behavior.*

Systems Have Inputs, Flows, and Outputs

- **System**
  - Set of components that interact in a regular way
  - Human body, earth, the economy
- **Inputs** from the environment
- **Flows, throughputs** of matter and energy
- **Outputs** to the environment

Active Figure: Energy flow



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2-5 What Are Systems and How Do They Respond to Change?

- ***Concept 2-5A*** *Systems have inputs, flows, and outputs of matter and energy, and their behavior can be affected by* ***feedback****.*
- ***Concept 2-5B*** *Life, human systems, and the earth´s life support systems must conform to the law of conservation of matter and the two laws of thermodynamics.*

Systems Respond to Change through Feedback Loops

- **Positive feedback loop**
  - Causes system to change further in the same direction
  - Can cause major environmental problems
- **Negative,** or **corrective, feedback loop**
  - Causes system to change in opposite direction

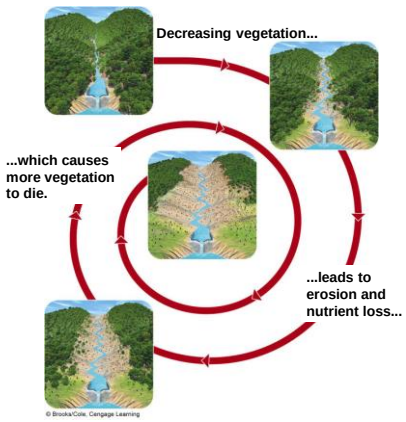
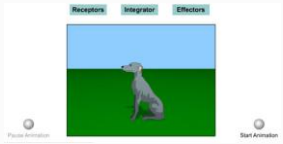


Fig. 2-11, p. 45

Animation: Feedback control of temperature



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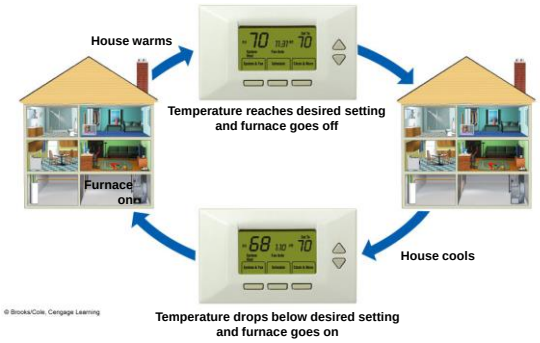

Fig. 2-12, p. 45

Time Delays Can Allow a System to Reach a Tipping Point

- Time delays vary
  - Between the input of a feedback stimulus and the response to it
- **Tipping point,** threshold level
  - Causes a shift in the behavior of a system
  - Melting of polar ice
  - Population growth

System Effects Can Be Amplified through Synergy

- **Synergistic interaction, synergy**
  - Two or more processes combine in such a way that combined effect is greater than the two separate effects
  - Helpful
    - Studying with a partner
  - Harmful
    - E.g., Smoking and inhaling asbestos particles

Human Activities Can Have Unintended Harmful Results aka "Unintended Consequences")

- Deforested areas turning to desert (agriculture…)
- Deplete fisheries
- Coral reefs dying
- Glaciers melting
- Sea levels rising
- Invasive Species

Three Big Ideas

1. There is no away.
2. You cannot get something for nothing.
3. You cannot break even.