Science, Matter, Energy, and Systems

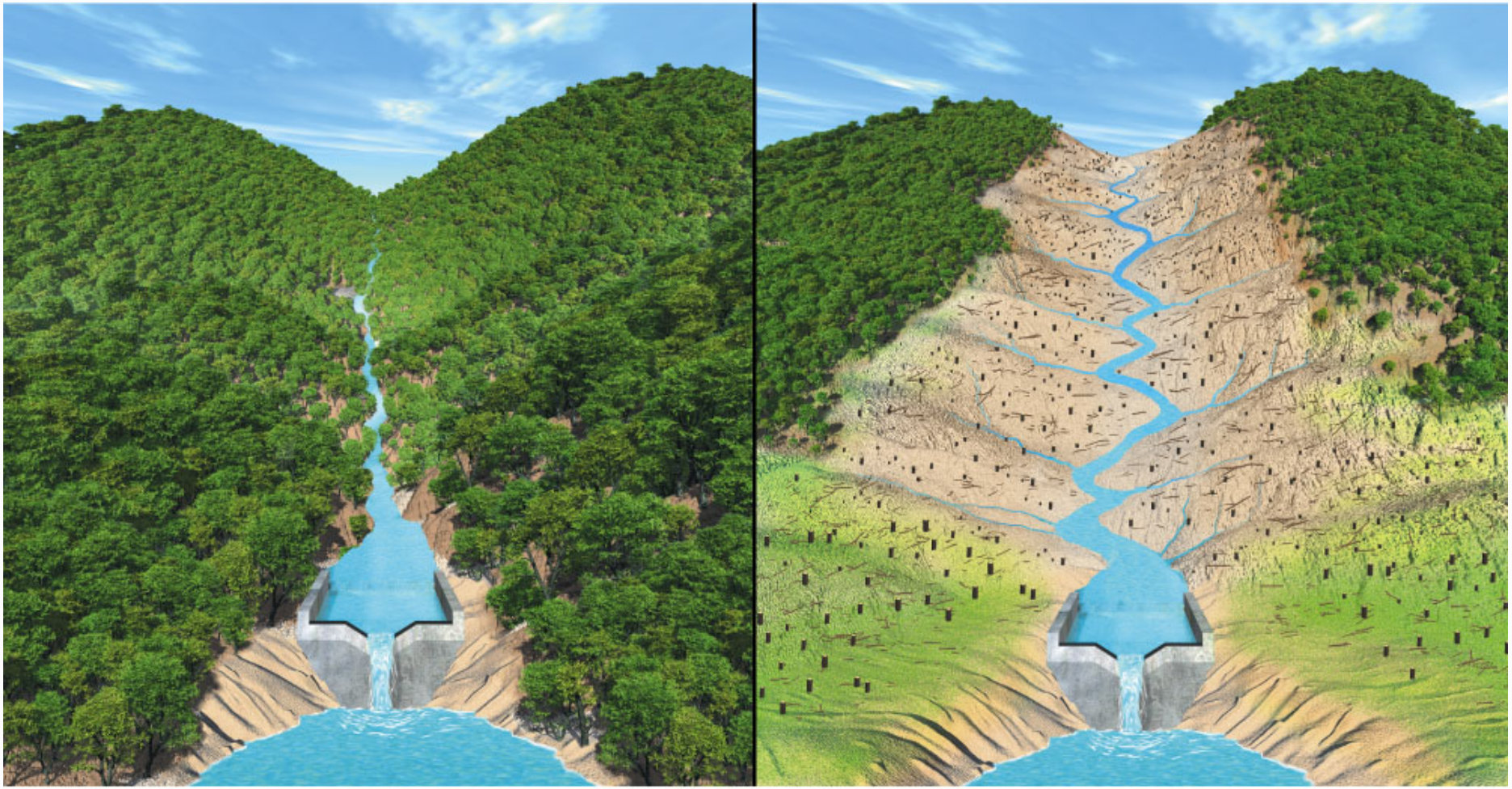
Chapter 2

Core Case Study: Carrying Out a Controlled Scientific Experiment

- F. Herbert Bormann, Gene Likens, *et al.:* Hubbard Brook Experimental Forest in NH (U.S.)

- Compared the loss of water and nutrients from an uncut forest (control site) with one that had been stripped (experimental site)

The Effects of Deforestation on the Loss of Water and Soil Nutrients



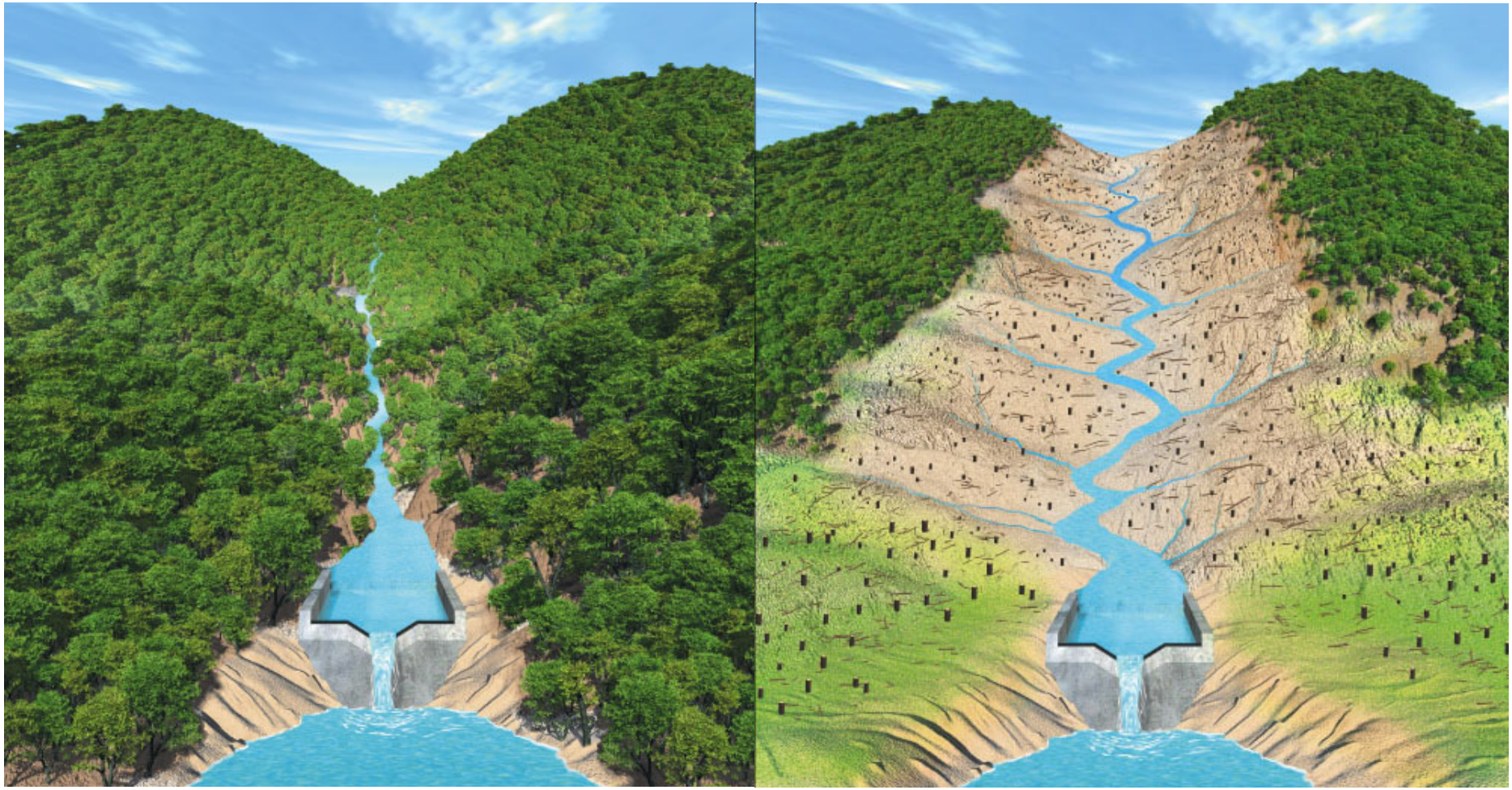


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Fig. 2-1, p. 28

2-1 What Is Science?

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

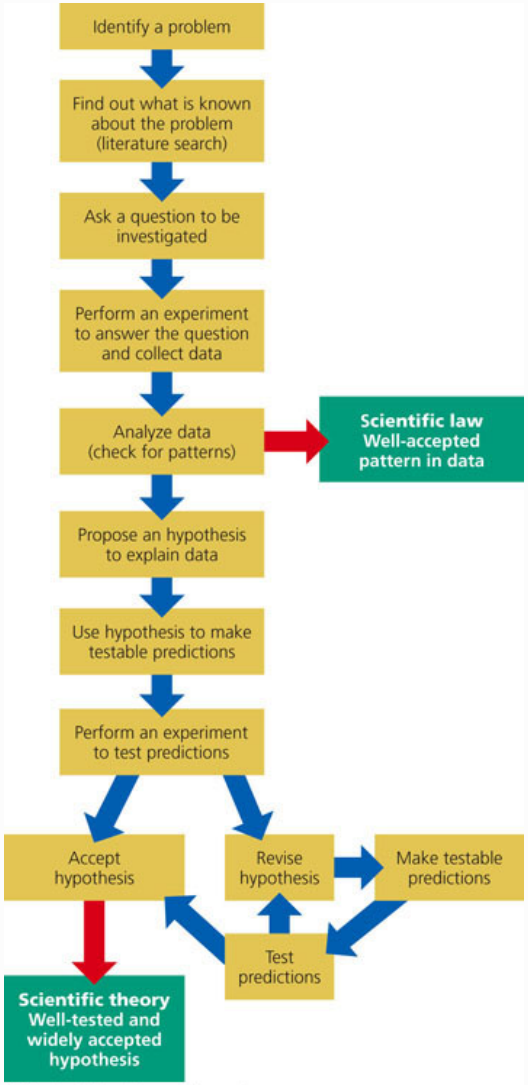
Science Is a Search for Order in Nature (1)

- Identify a problem
- Find out what is known about the problem
- Ask a question to be investigated
- Gather data
- Hypothesize
- Make testable predictions
- 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



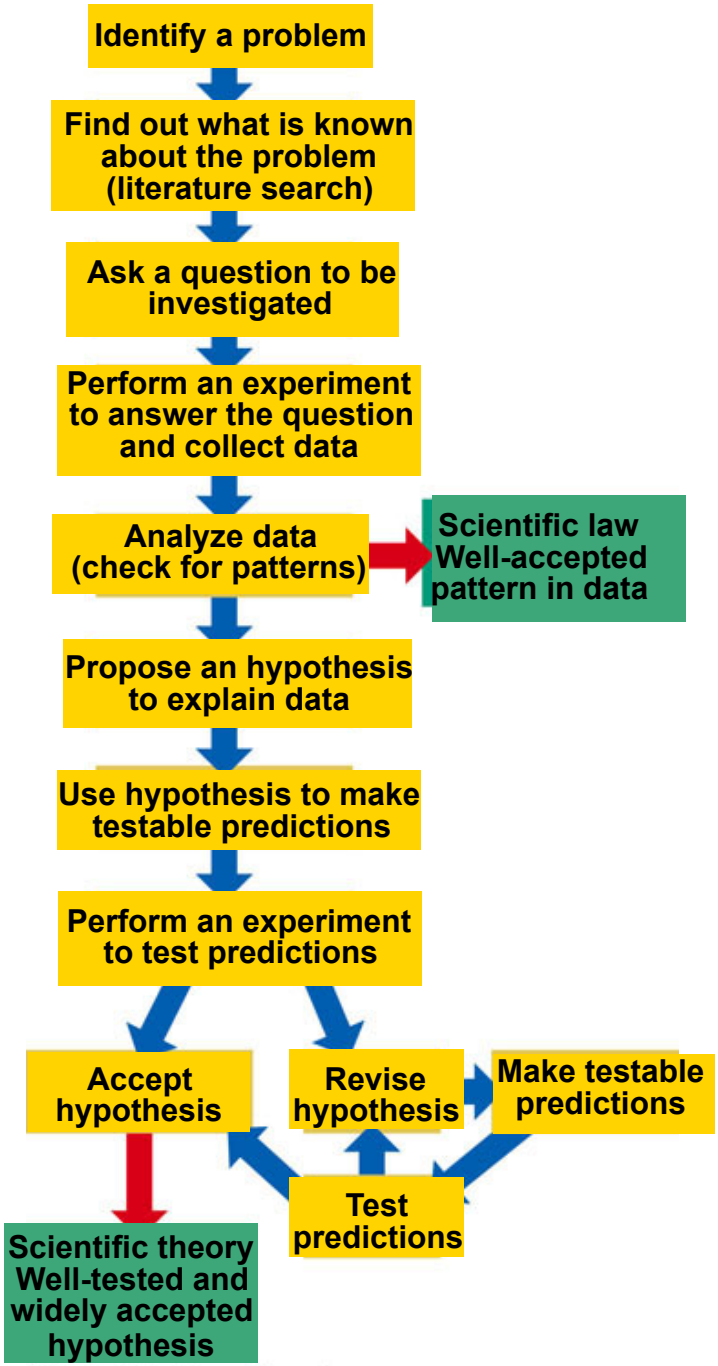


Fig. 2-2, p. 30

Science Focus: Easter Island: Revisions to a Popular Environmental Story

- Some revisions in a popular environmental story
  - Polynesians arrived about 800 years ago
  - Population may have reached 3000
  - Used trees in an unsustainable manner, **but** rats may have multiplied and eaten the seeds of the trees

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

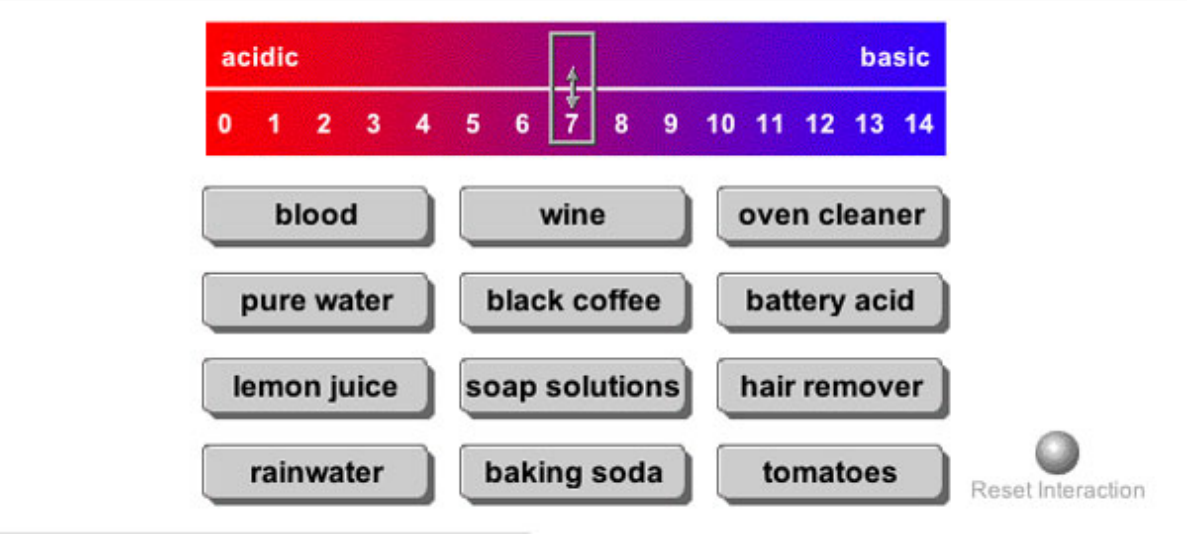
Environmental Science Has Some Limitations

- Particular hypotheses, theories, or laws have a high probability of being true while not being absolute
- Bias can be minimized by scientists
- Statistical methods may be used to estimate very large or very small numbers
- Environmental phenomena involve interacting variables and complex interactions
- Scientific process is limited to the natural world

Science Focus: Statistics and Probability

- **Statistics**
  - Collect, organize, and interpret numerical data
- **Probability**
  - The chance that something will happen or be valid

Animation: pH scale



PLAY

Video: ABC News: Easter Island

PLAY

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		

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

- **Atomic theory**

- **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**

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

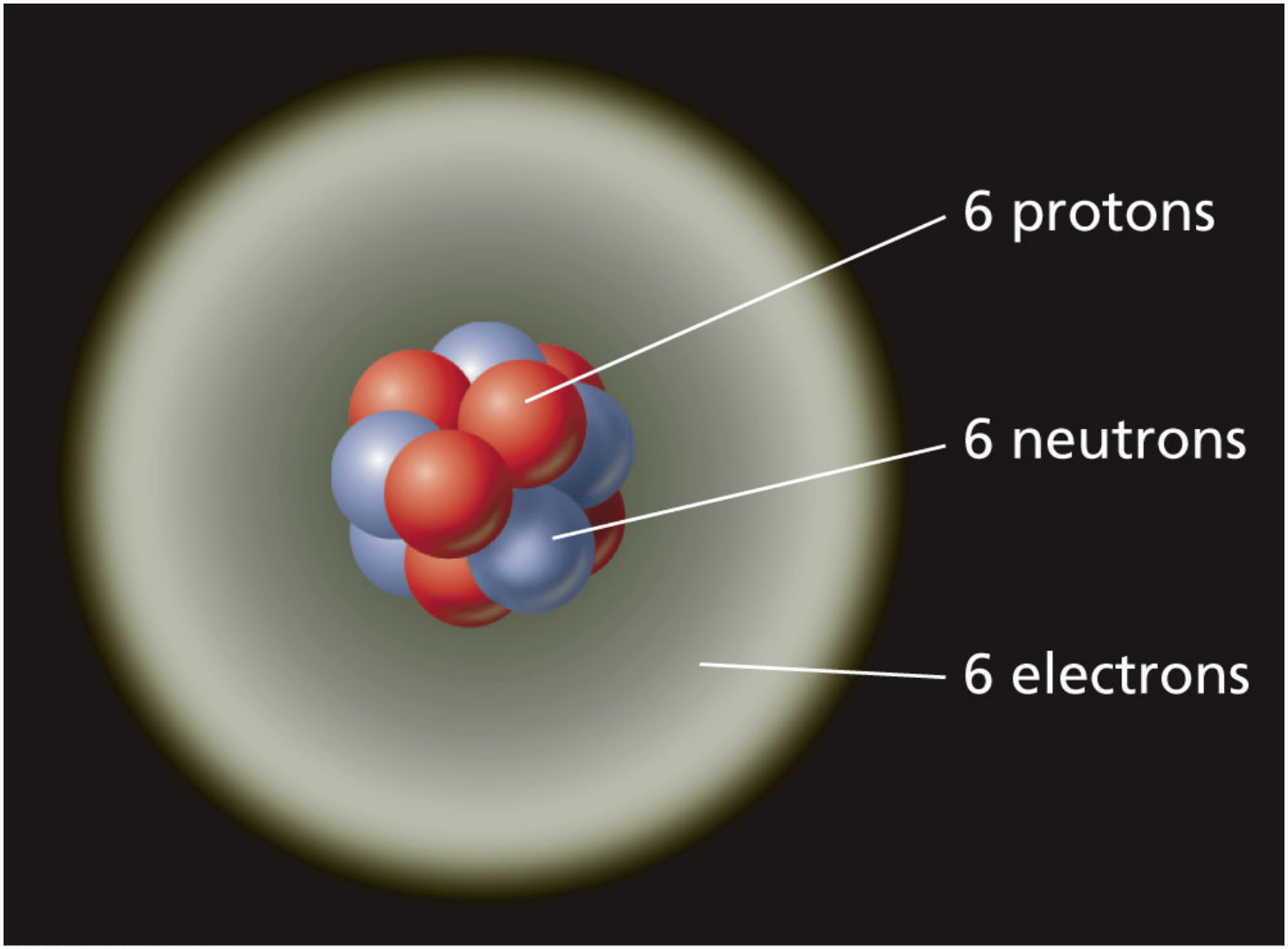
- **Ions**
  - Gain or lose electrons
  - Form ionic compounds

- **pH**
  - 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**

Model of a Carbon-12 Atom



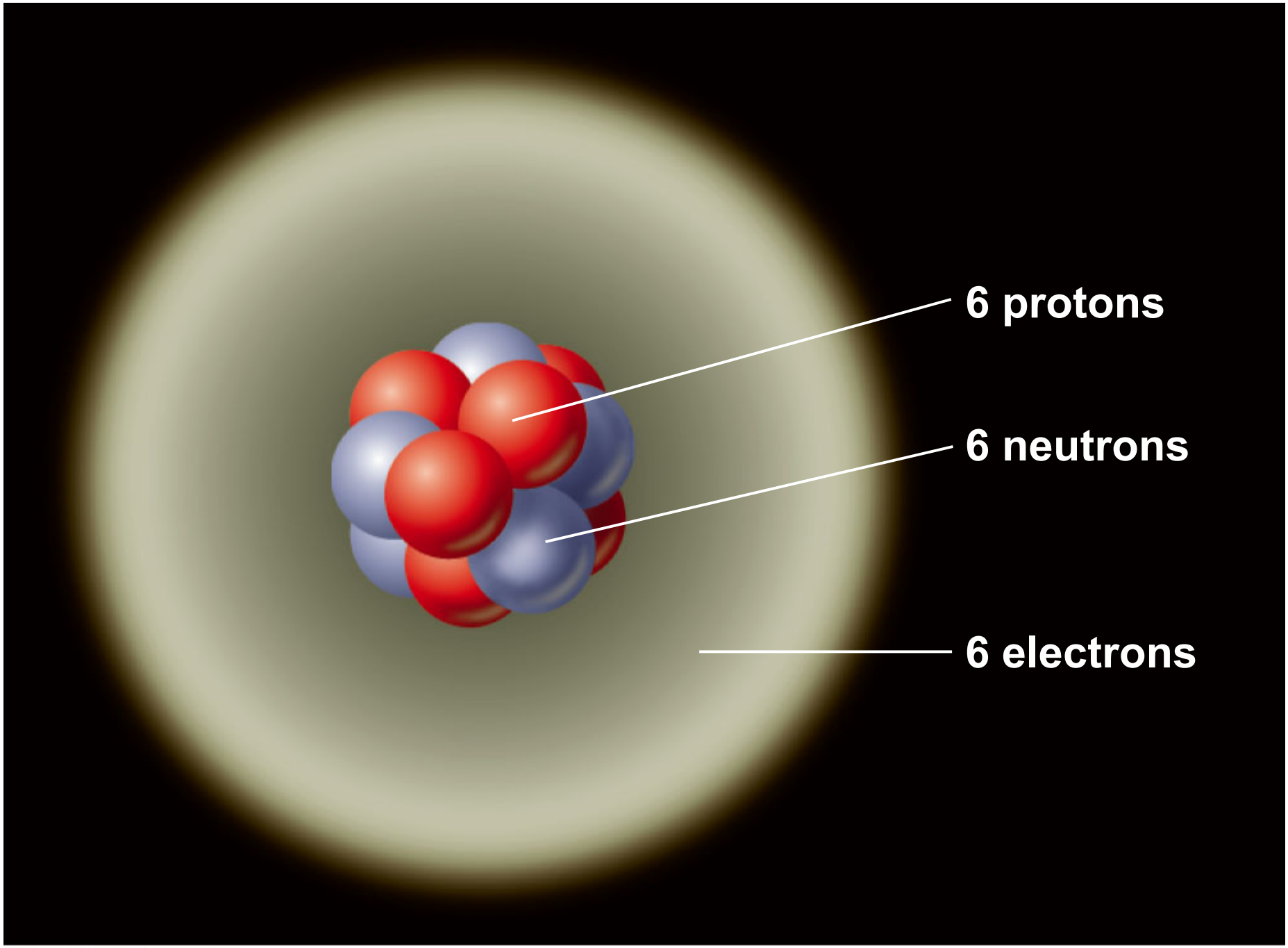


Fig. 2-3, p. 36

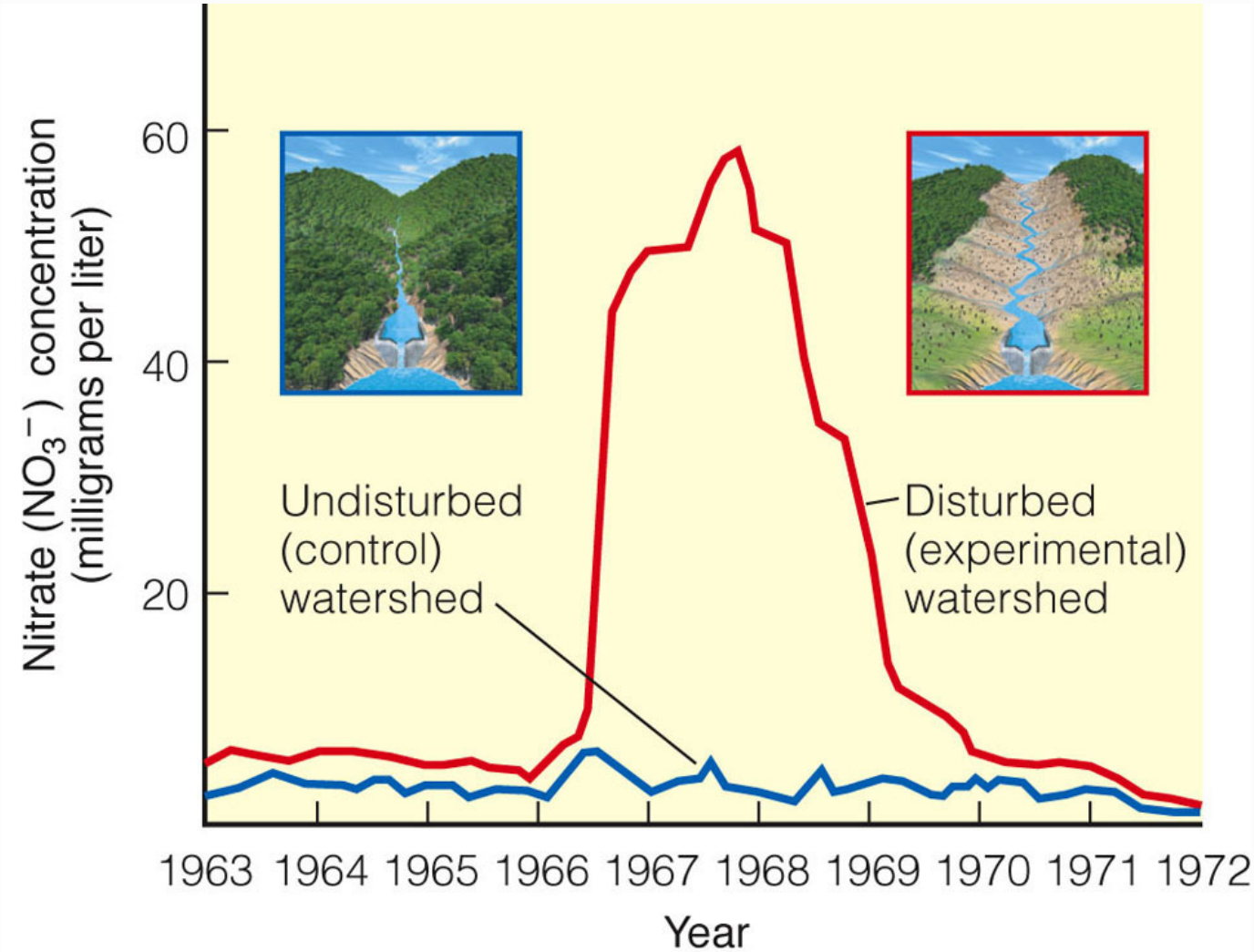
Ions Important to the Study of Environmental Science

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-}

Loss of NO_3^- from a Deforested Watershed



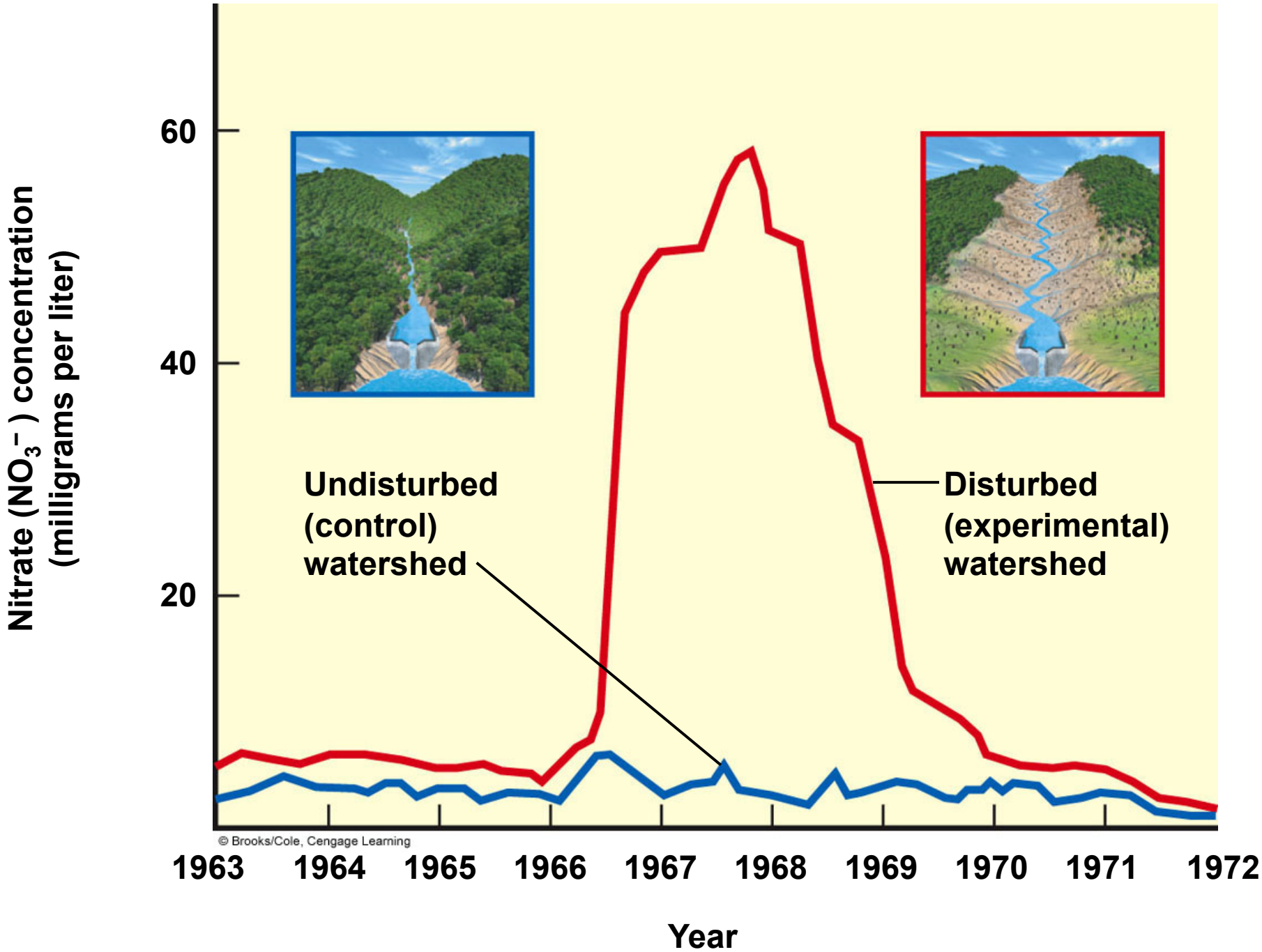

Nitrate (NO_3^-) concentration (milligrams per liter)
60
40
20
Undisturbed (control) watershed
Disturbed (experimental) watershed
© Brooks/Cole, Cengage Learning
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
Year

Fig. 2-4, p. 37

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

Organic Compounds Are the Chemicals of Life

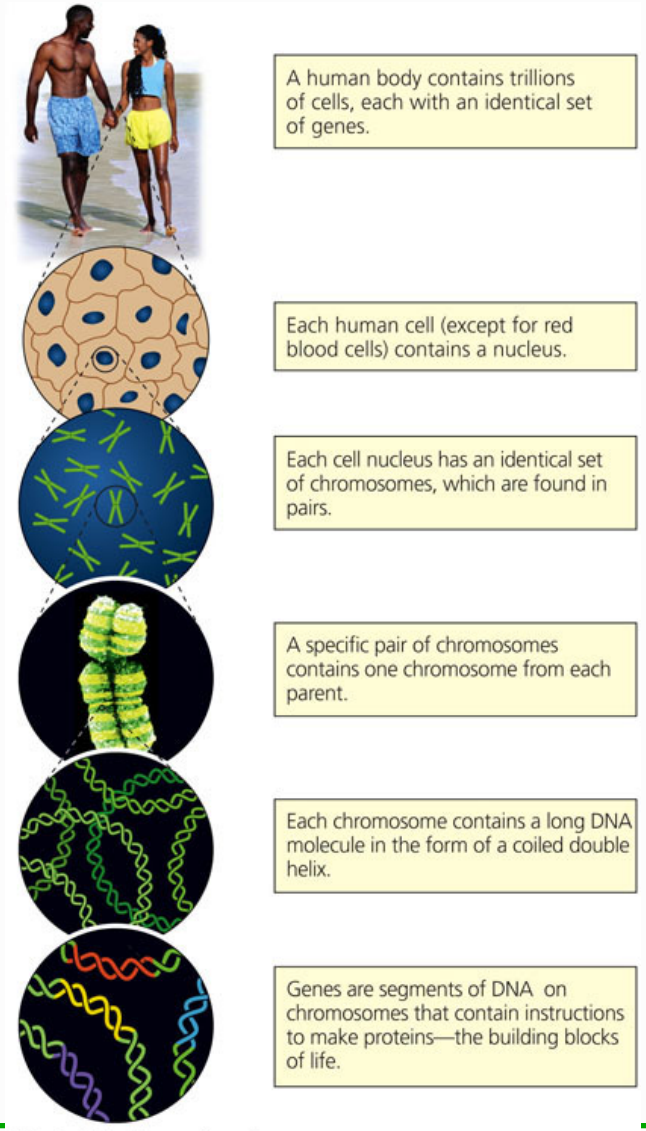
- **Inorganic compounds**

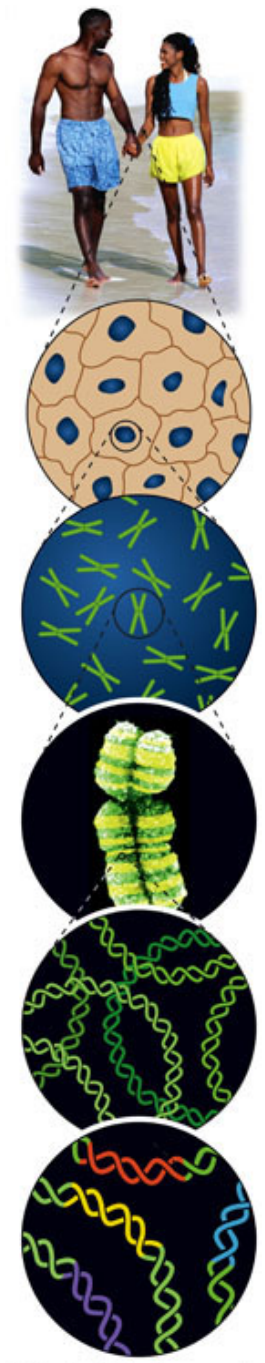
- **Organic compounds**
  - Hydrocarbons and chlorinated hydrocarbons
  - Simple carbohydrates
  - Macromolecules: complex organic molecules
    - Complex carbohydrates
    - Proteins
    - Nucleic acids
    - Lipids

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





A human body contains trillions of cells, each with an identical set of genes.

Each human cell (except for red blood cells) contains a nucleus.

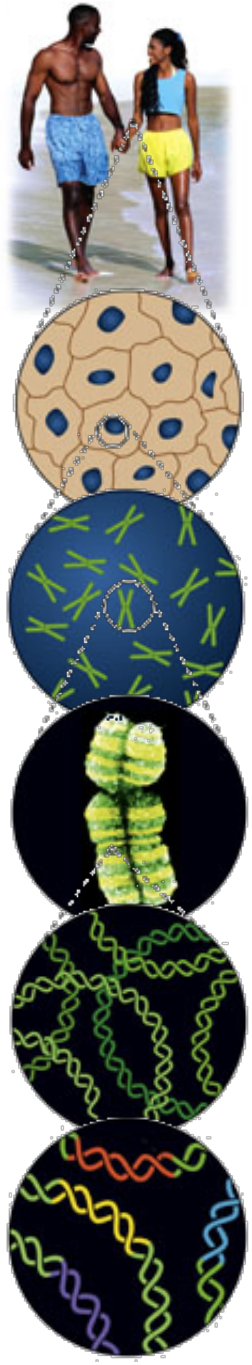
Each cell nucleus has an identical set of chromosomes, which are found in pairs.

A specific pair of chromosomes contains one chromosome from each parent.

Each chromosome contains a long DNA molecule in the form of a coiled double helix.

Genes are segments of DNA on chromosomes that contain instructions to make proteins—the building blocks of life.

Fig. 2-5, p. 38



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Stepped Art

Fig. 2-5, p. 38

Matter Occurs in Various Physical Forms

- Solid
- Liquid
- Gas

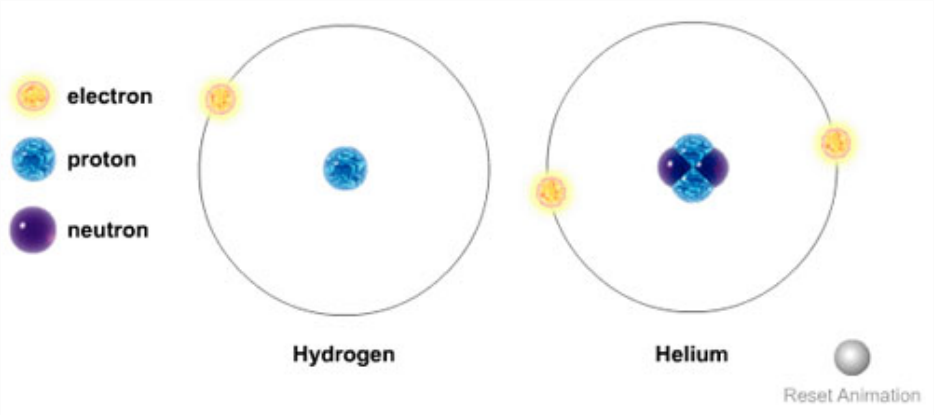
Some Forms of Matter Are More Useful than Others

- High-quality matter
- Low-quality matter

Examples of Differences in Matter Quality

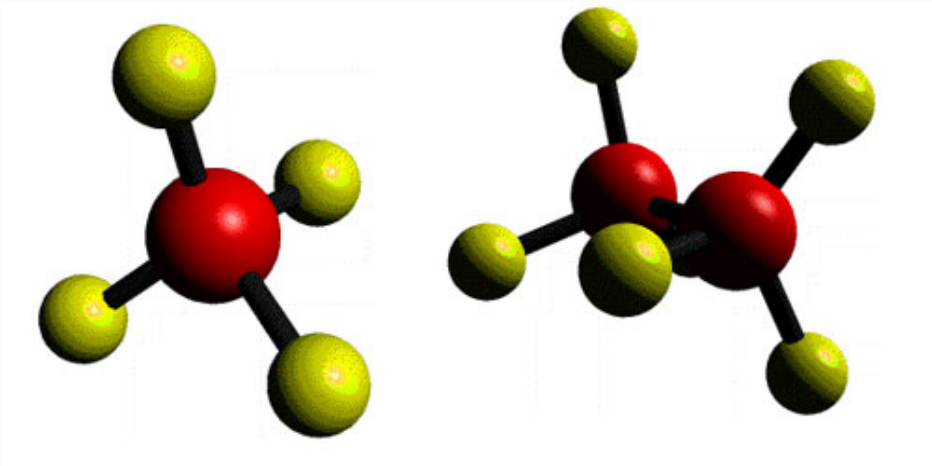
Fig. 2-6, p. 39

Animation: Subatomic particles



PLAY

Animation: Carbon bonds



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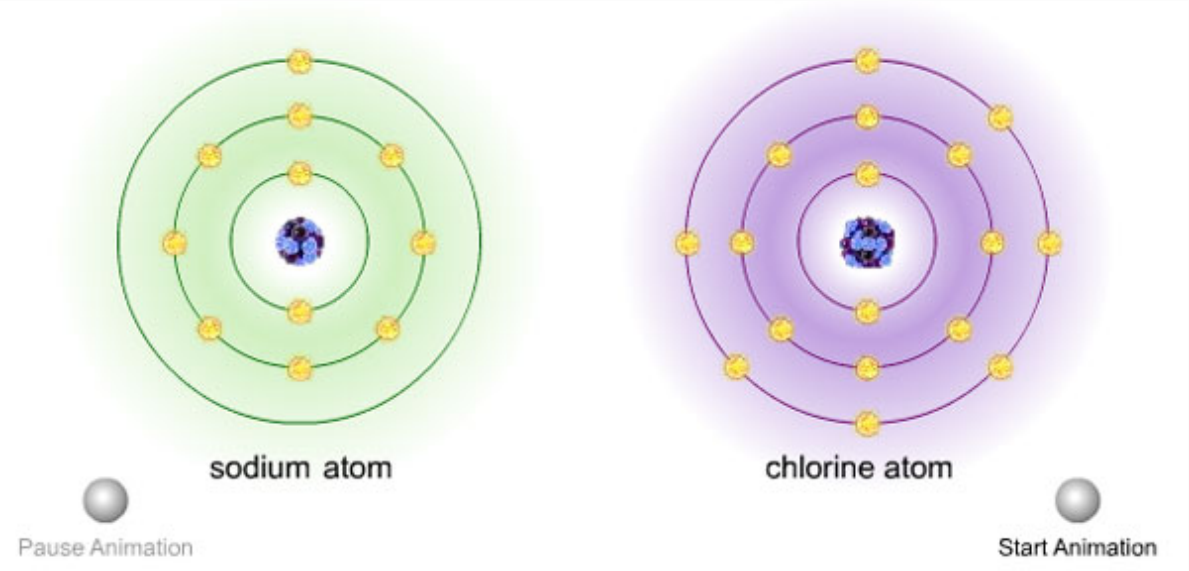
Animation: Ionic bonds



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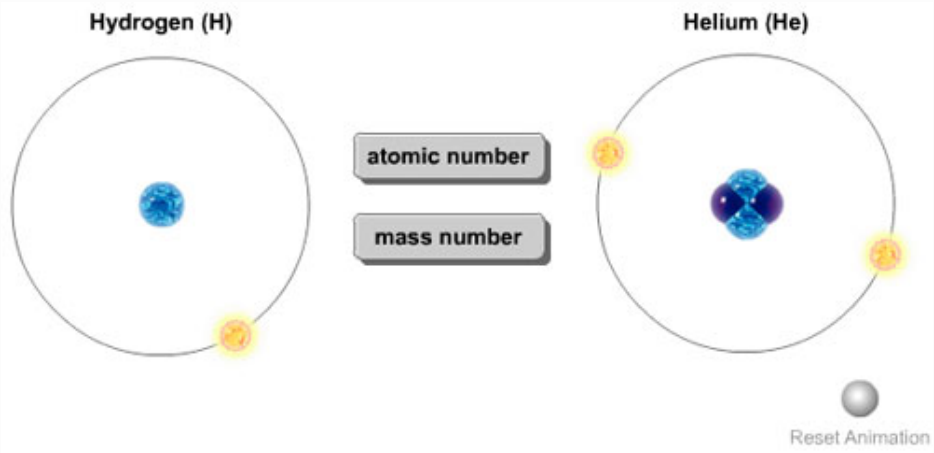
Animation: Atomic number, mass number



PLAY

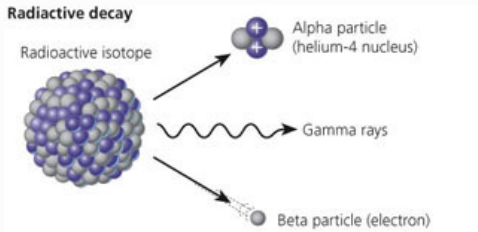
2-3 How Can Matter Change?

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

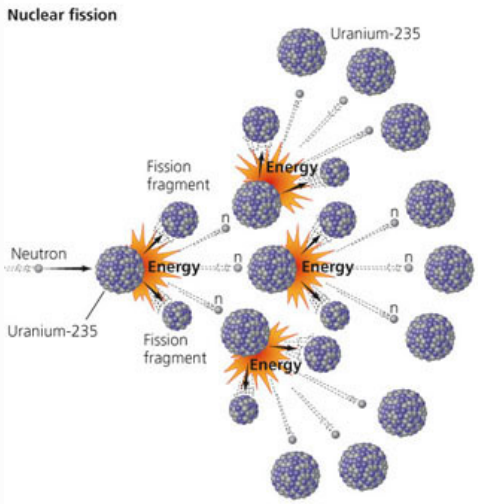
Matter Undergoes Physical, Chemical, and Nuclear Changes

- **Physical change**
- **Chemical change, chemical reaction**
- **Nuclear change**
  - Natural radioactive decay
    - Radioisotopes: unstable
  - Nuclear fission
  - Nuclear fusion

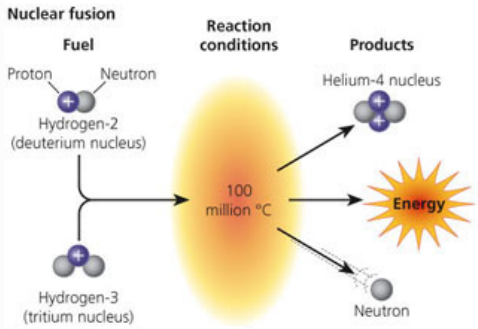
Types of Nuclear Changes



Radioactive decay occurs when nuclei of unstable isotopes spontaneously emit fast-moving chunks of matter (alpha particles or beta particles), high-energy radiation (gamma rays), or both at a fixed rate. A particular radioactive isotope may emit any one or a combination of the three items shown in the diagram.

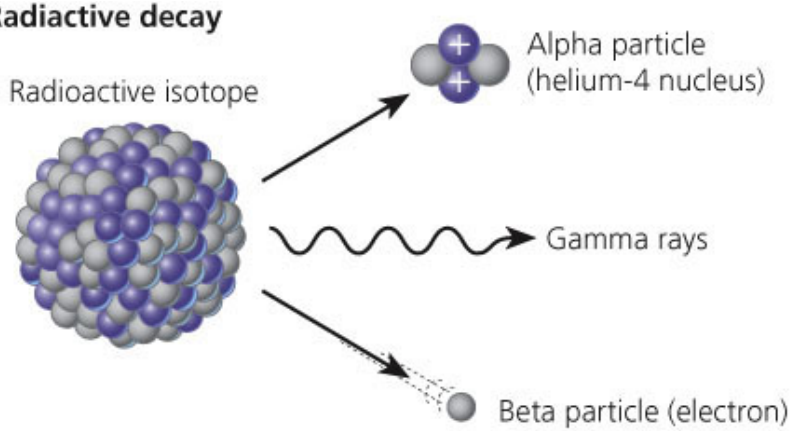


Nuclear fission occurs when the nuclei of certain isotopes with large mass numbers (such as uranium-235) are split apart into lighter nuclei when struck by a neutron and release energy plus two or three more neutrons. Each neutron can trigger an additional fission reaction and lead to a *chain reaction*, which releases an enormous amount of energy.



Nuclear fusion occurs when two isotopes of light elements, such as hydrogen, are forced together at extremely high temperatures until they fuse to form a heavier nucleus and release a tremendous amount of energy.

Radiactive decay



Nuclear fission

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Radioactive decay

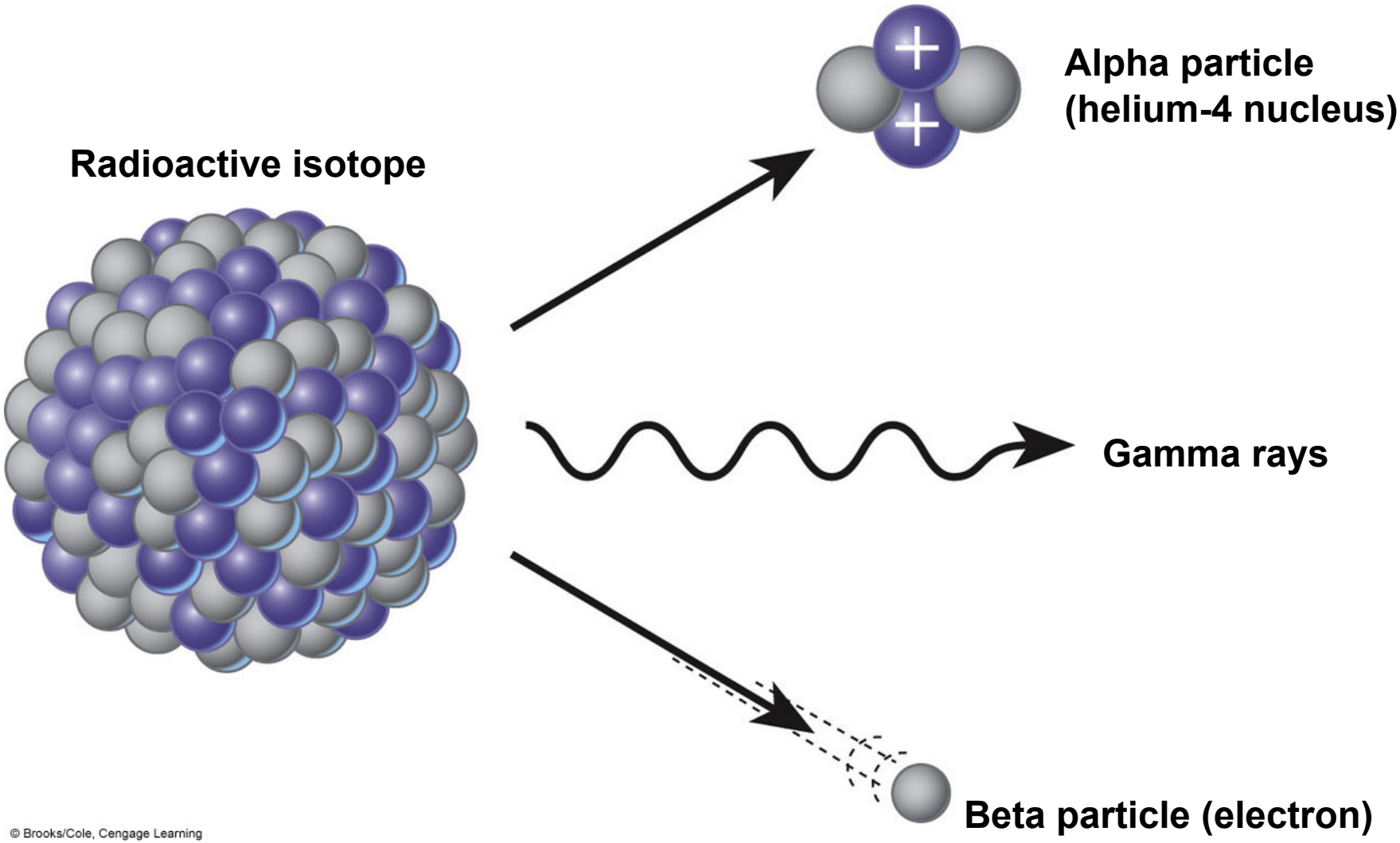
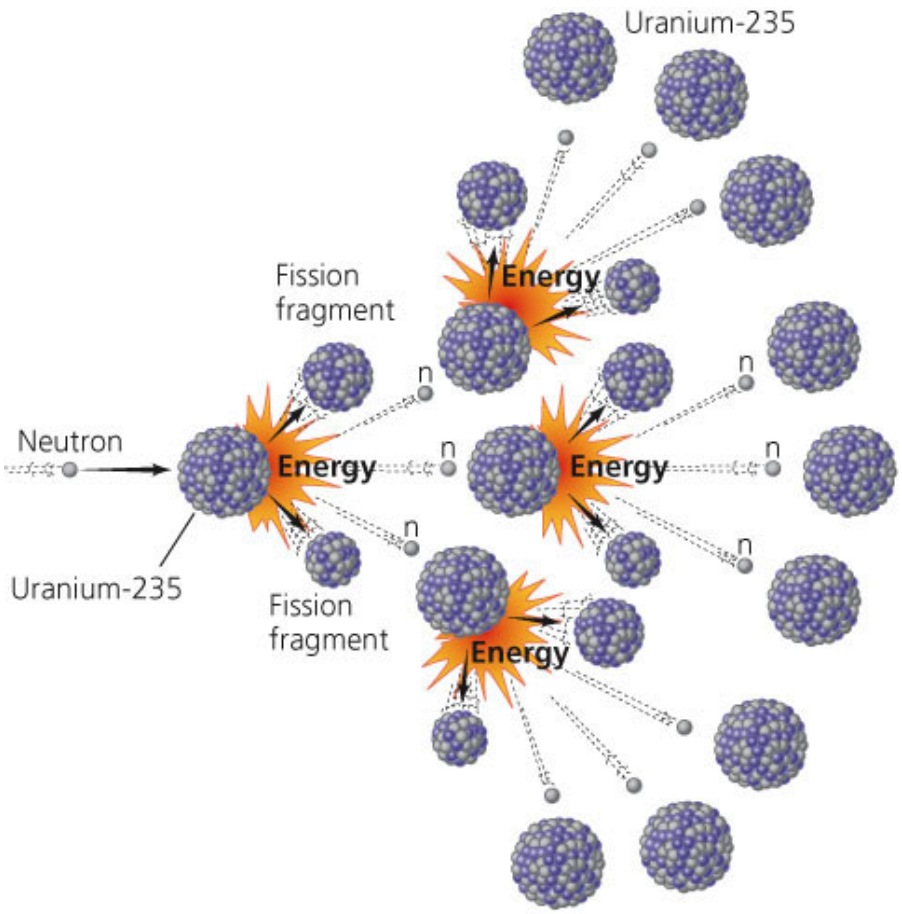


Fig. 2-7a, p. 41



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Nuclear fission

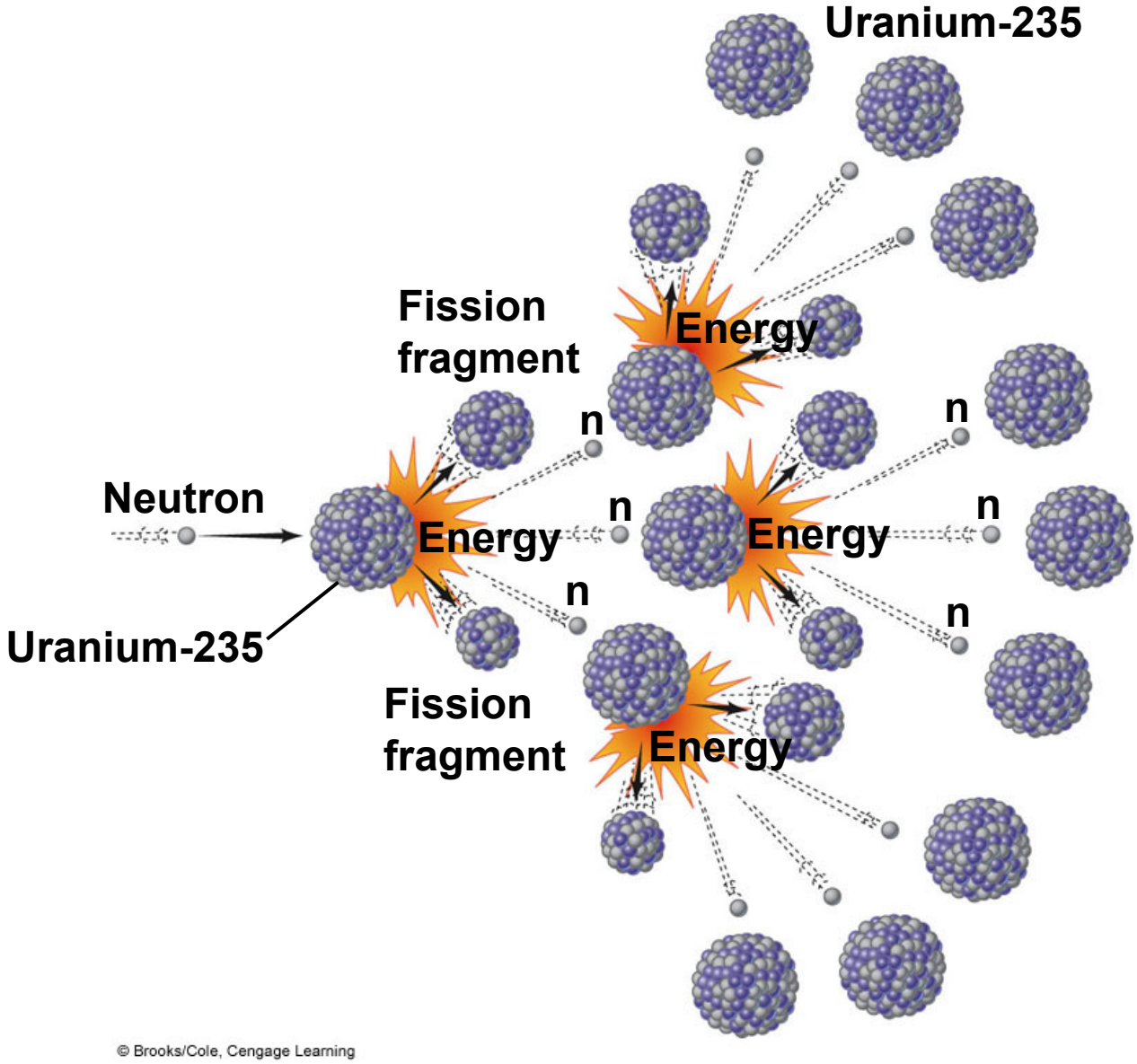

Fig. 2-7b, p. 41

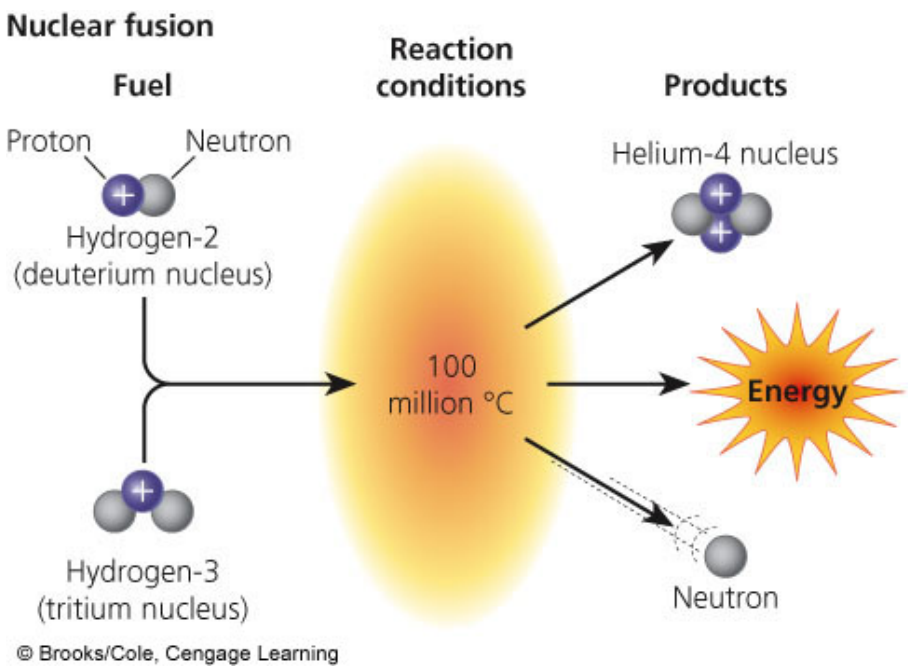

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Fig. 2-7c, p. 41

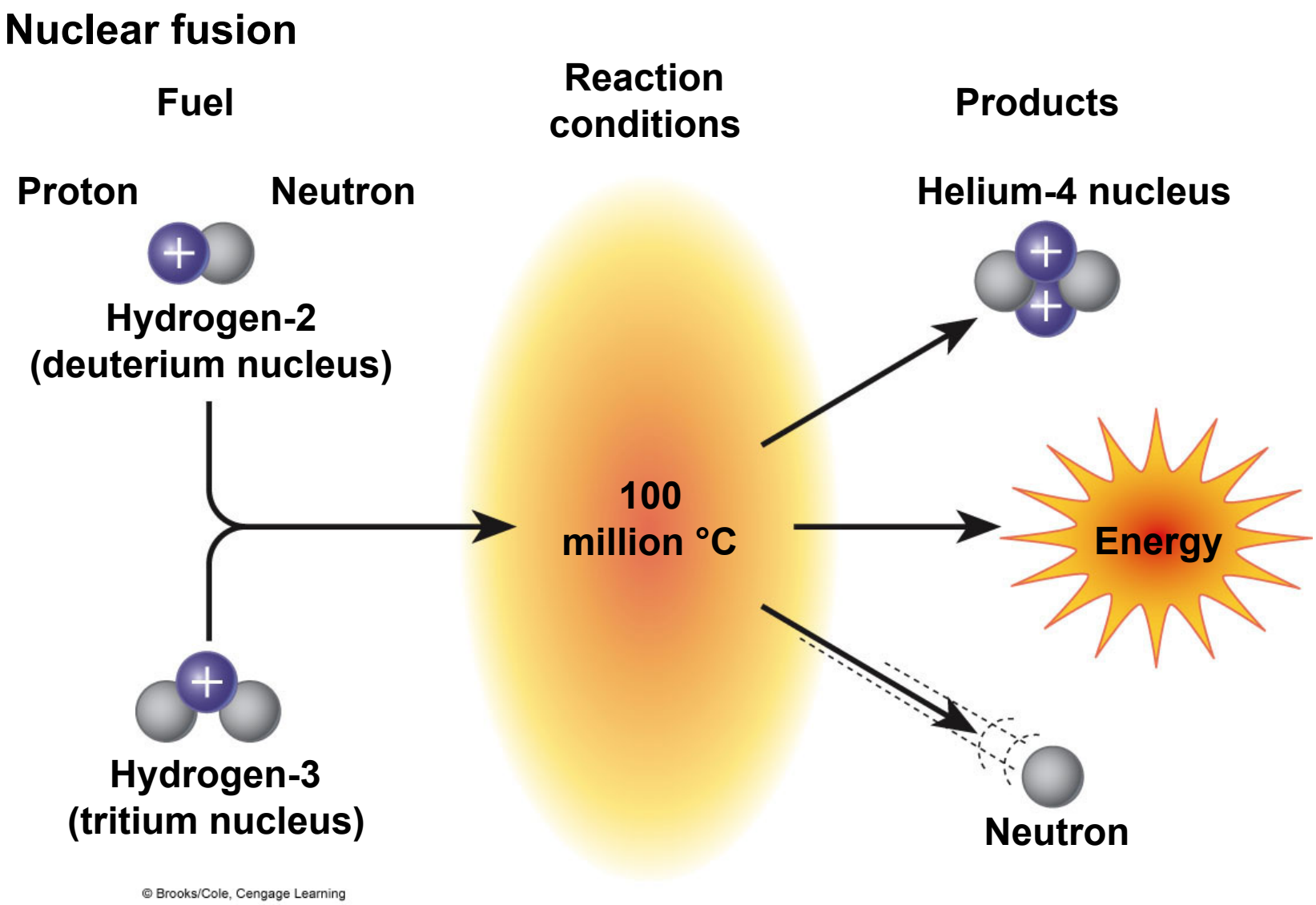
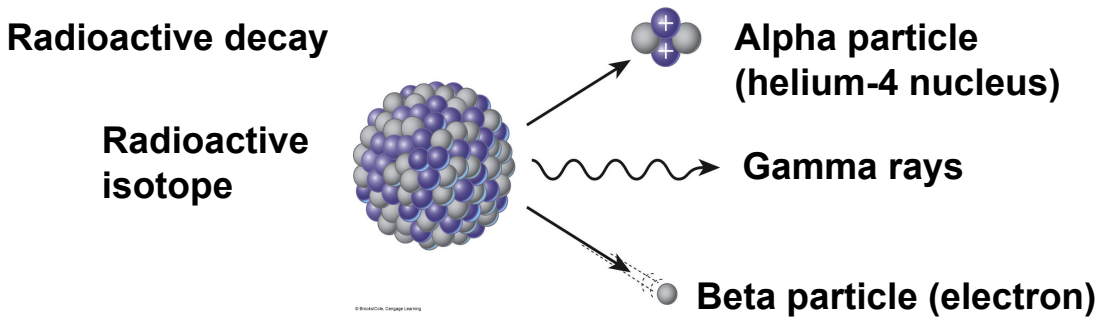
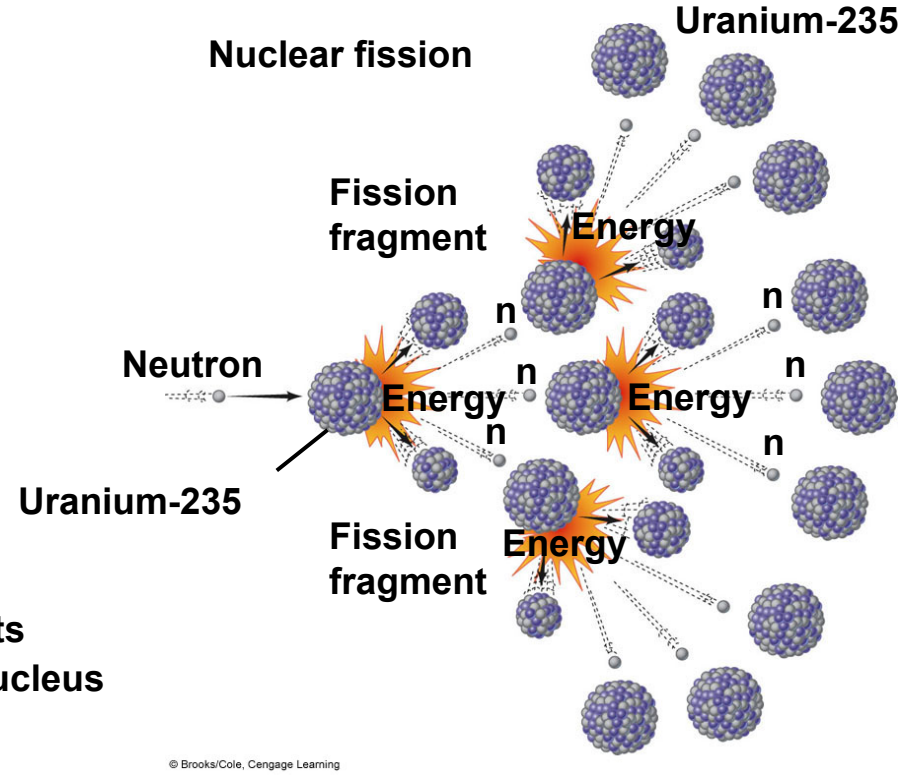
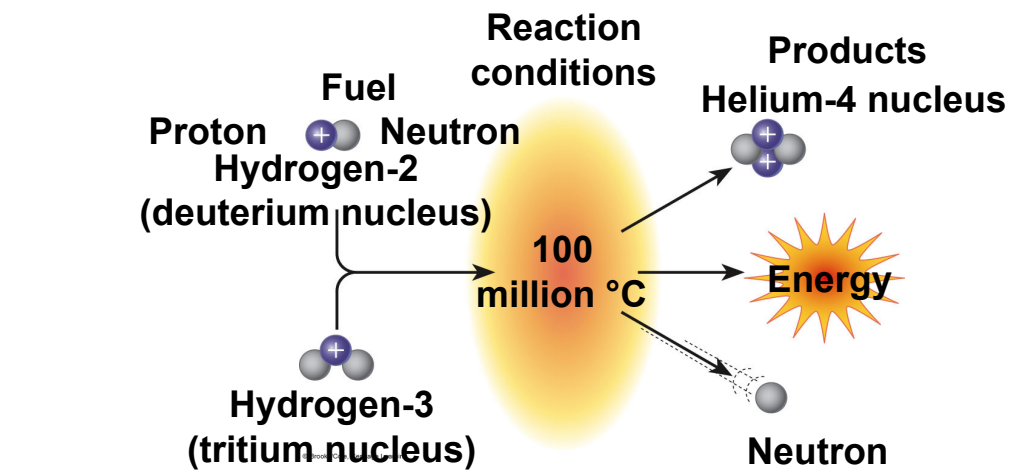

Nuclear fusion
Fuel
Reaction conditions
Products
Proton
Neutron
Helium-4 nucleus
Hydrogen-2 (deuterium nucleus)
100 million °C
Energy
Hydrogen-3 (tritium nucleus)
Neutron
© Brooks/Cole, Cengage Learning

Fig. 2-7c, p. 41







Stepped Art

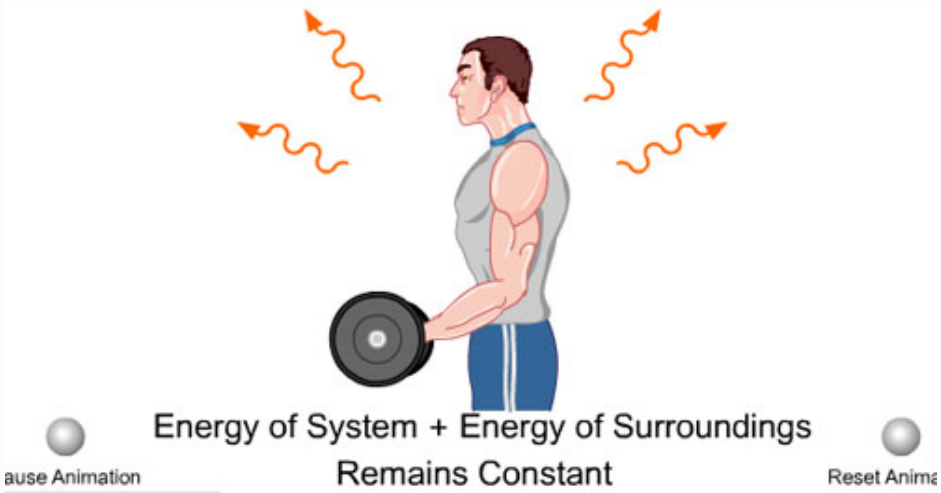
Fig. 2-7, p. 41

We Cannot Create or Destroy Matter

- **Law of conservation of matter**

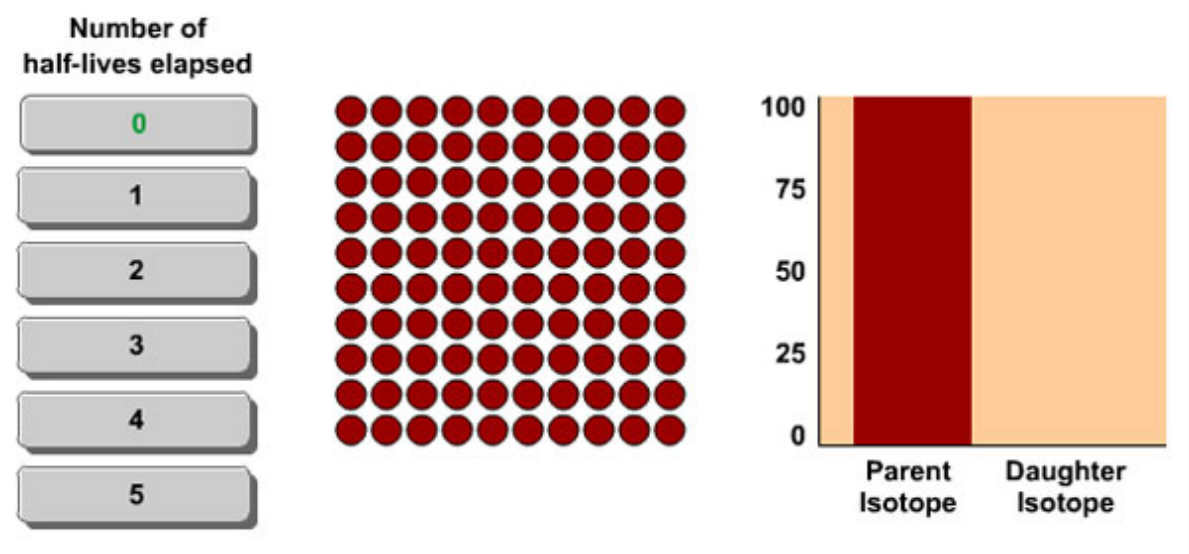
- Matter consumption
  - Matter is converted from one form to another

Animation: Total energy remains constant



PLAY

Animation: Half-life



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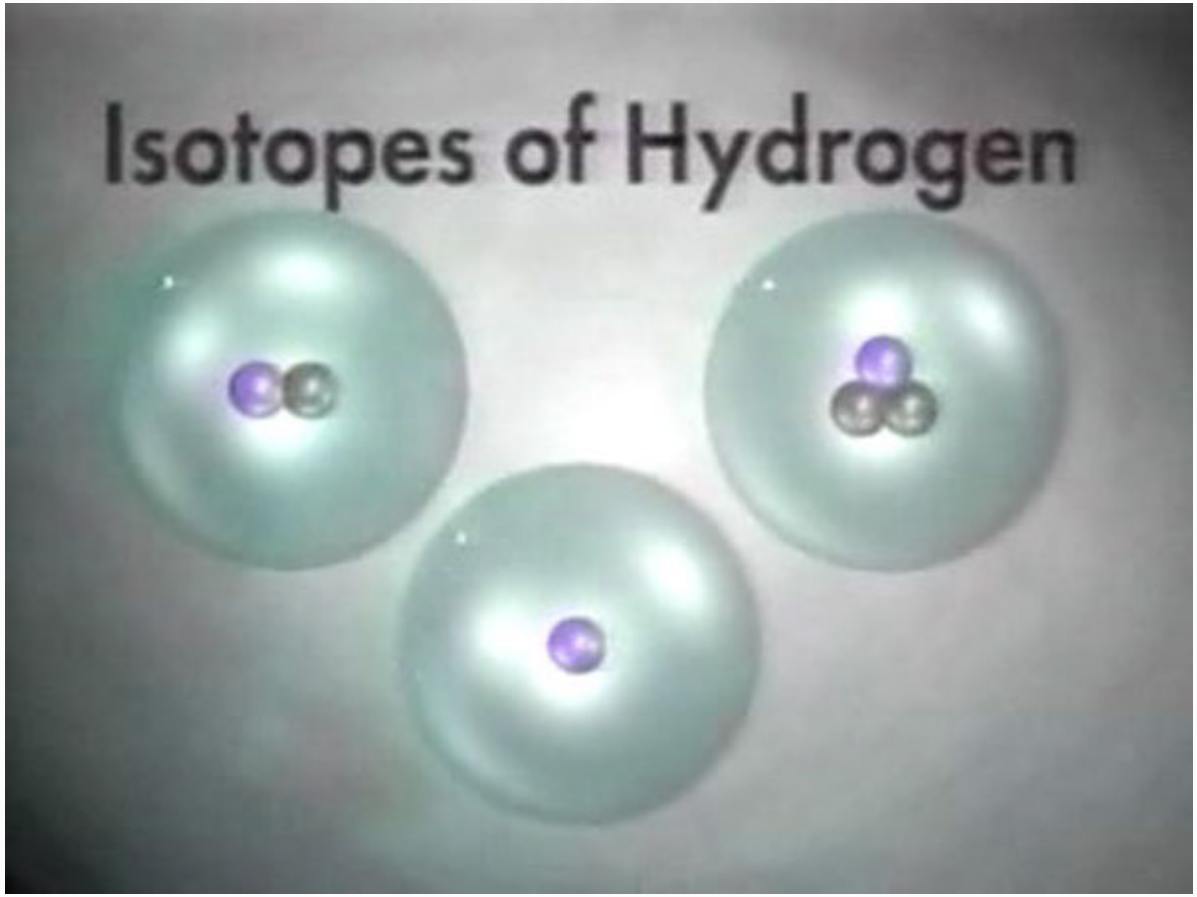
Animation: Isotopes



PLAY

Animation: Positron-emission tomography (PET)

PLAY

Video: Nuclear energy

PLAY

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).*

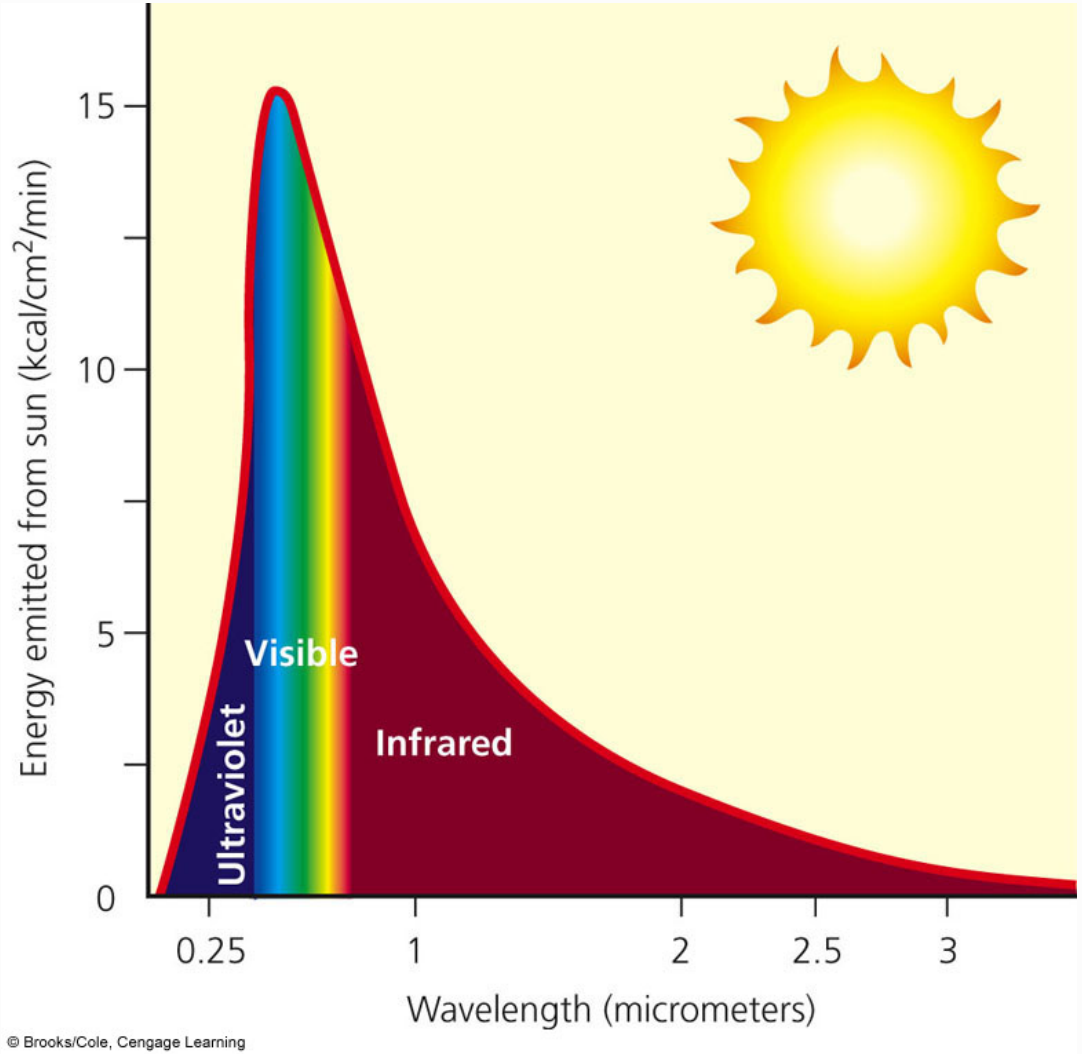
- ***Concept 2-4B*** *Whenever energy is changed from one form to another, we end up with lower-quality or less usable energy than we started with (second law of thermodynamics).*

Energy Comes in Many Forms

- **Kinetic energy**
  - Heat
    - Transferred by radiation, conduction, or convection
  - Electromagnetic radiation

- **Potential energy**
  - Stored energy
    - Can be changed into kinetic energy

The Spectrum of Electromagnetic Radiation



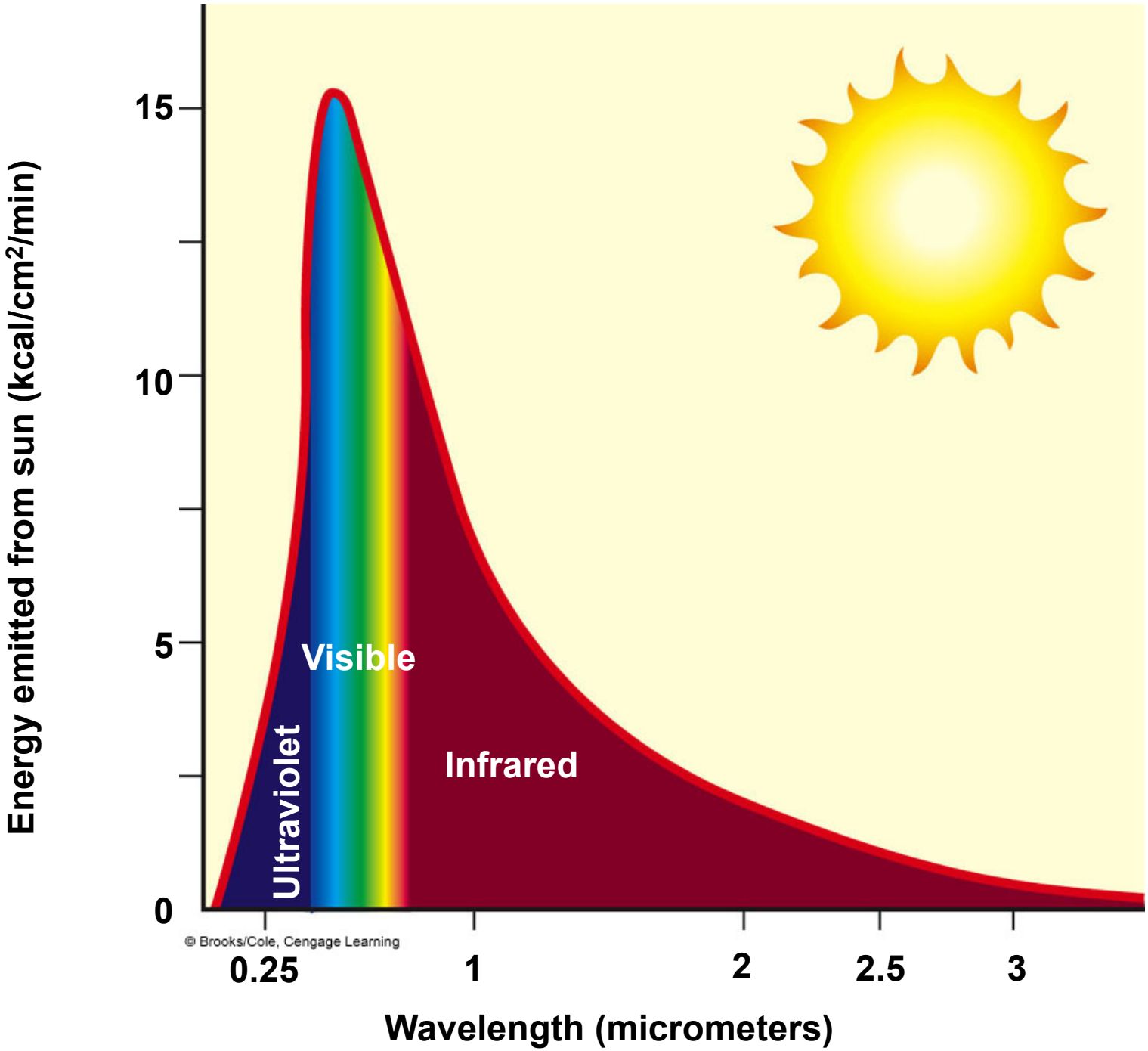
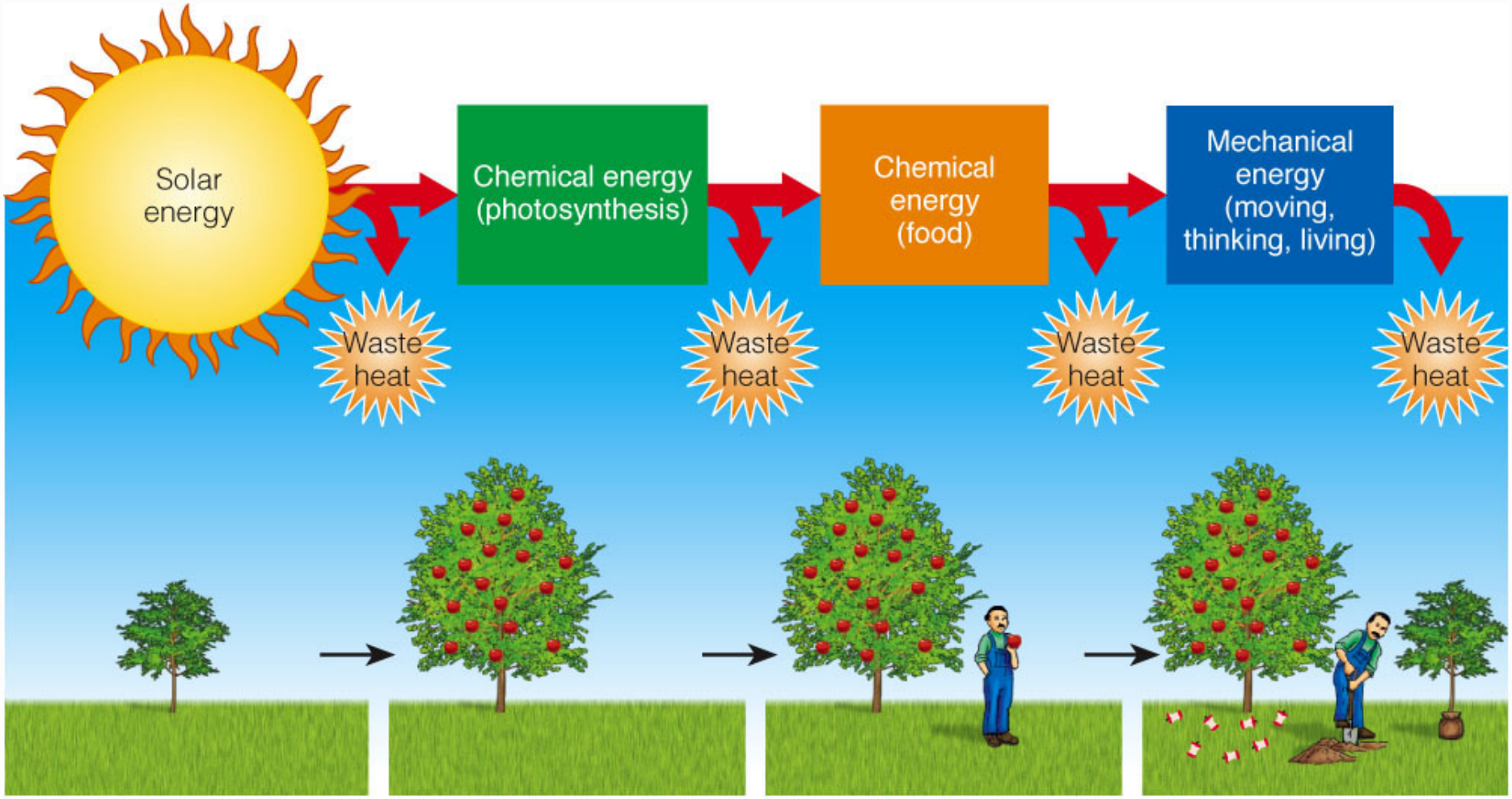

Energy emitted from sun (kcal/cm²/min)
15
10
5
0
Visible
Ultraviolet
Infrared
© Brooks/Cole, Cengage Learning
0.25
1
2
2.5
3
Wavelength (micrometers)

Fig. 2-8, p. 42

The Second Law of Thermodynamics in Living Systems



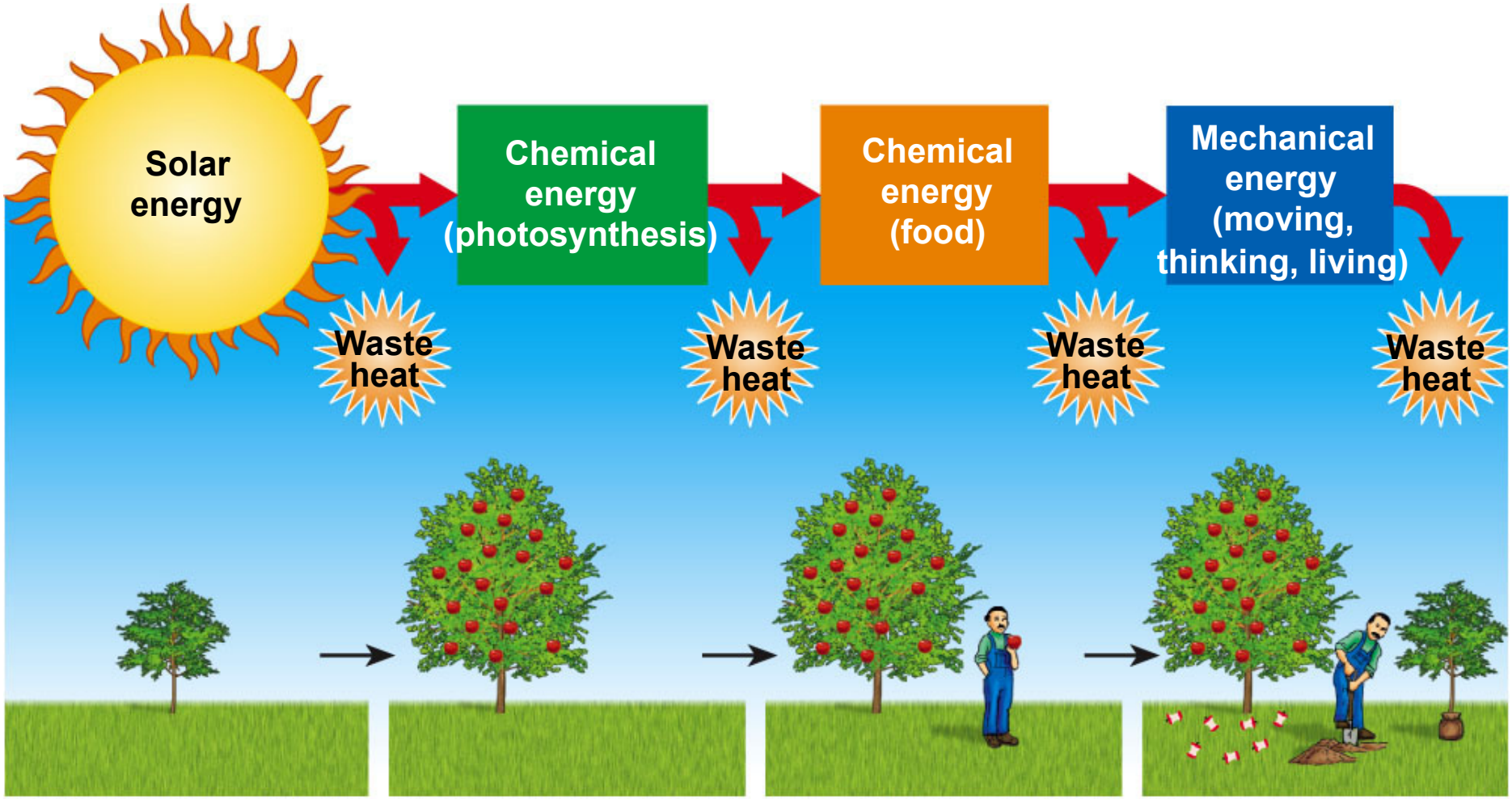


Fig. 2-9, p. 43

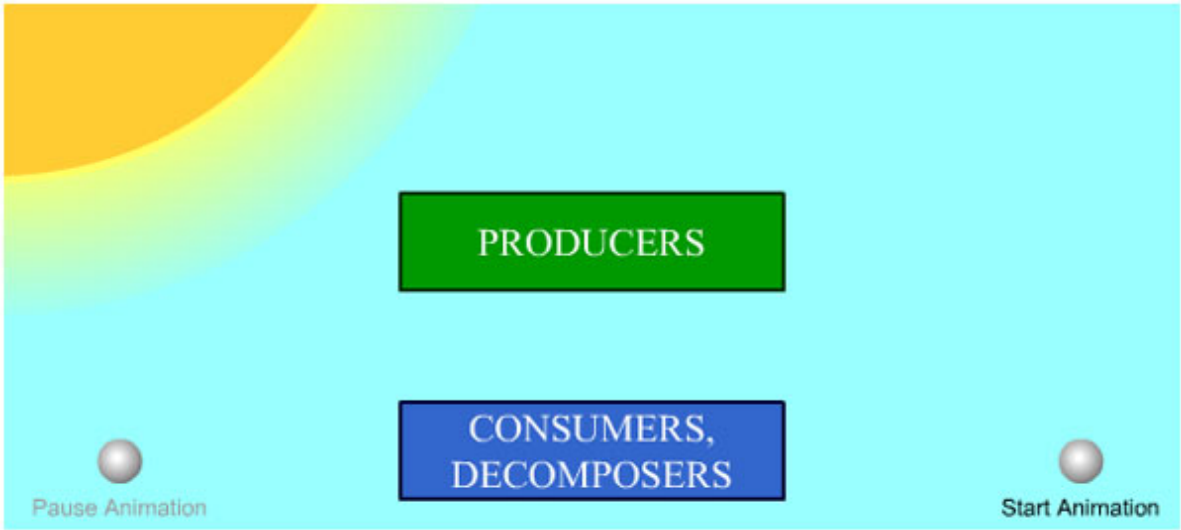
Some Types of Energy Are More Useful Than Others

- High-quality energy
- Low-quality energy

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

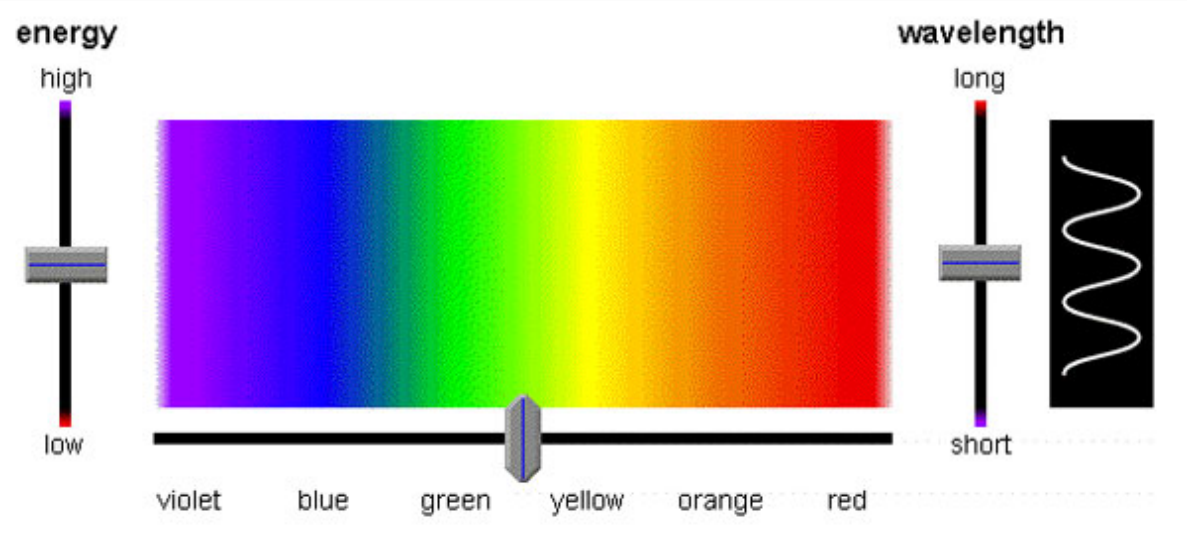
Active Figure: Energy flow



A one-way flow of energy through organisms and a cycling of materials among them organizes life in the biosphere. **Click** Start Animation for an animated demonstration.

PLAY

Active Figure: Visible light



PLAY

Animation: Martian doing mechanical work

PLAY

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

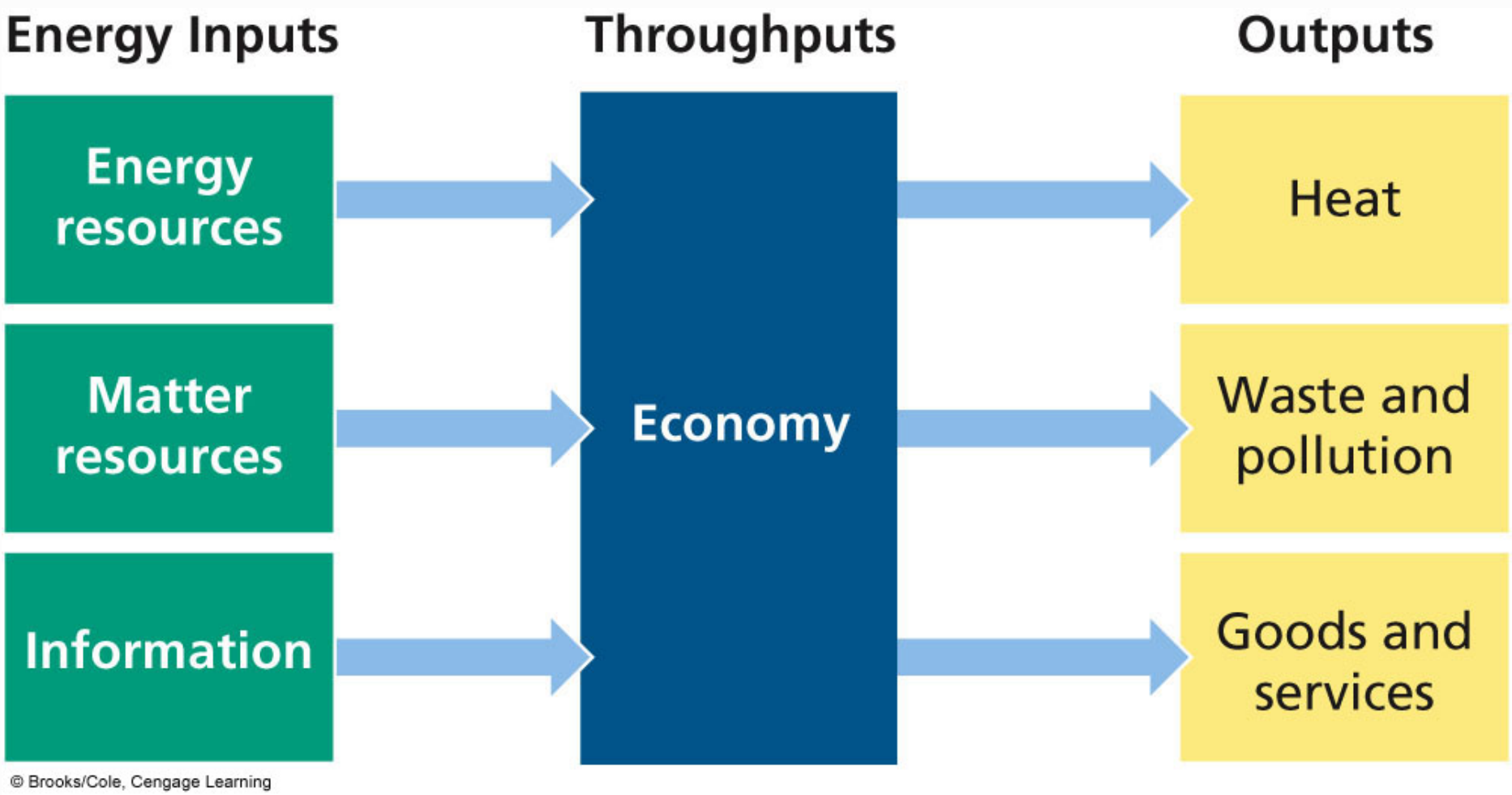
- ***Concept 2-5A*** *Systems have inputs, flows, and outputs of matter and energy, and their behavior can be affected by feedback.*

- ***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 Have Inputs, Flows, and Outputs

- **System**
  - **Inputs** from the environment
  - **Flows, throughputs**
  - **Outputs**

Inputs, Throughput, and Outputs of an Economic System



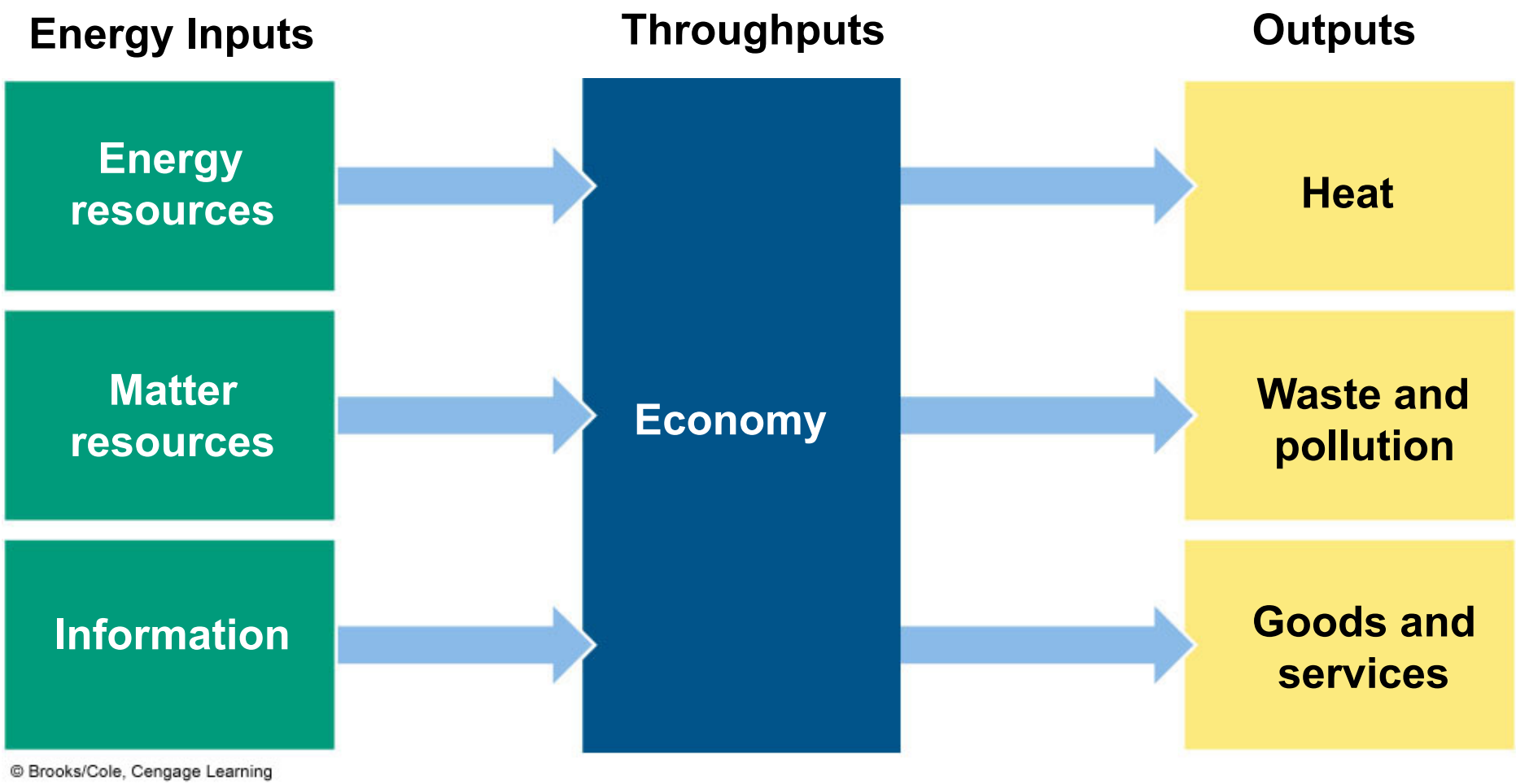

Energy Inputs
Throughputs
Outputs
Energy resources
Matter resources
Information
Economy
Heat
Waste and pollution
Goods and services
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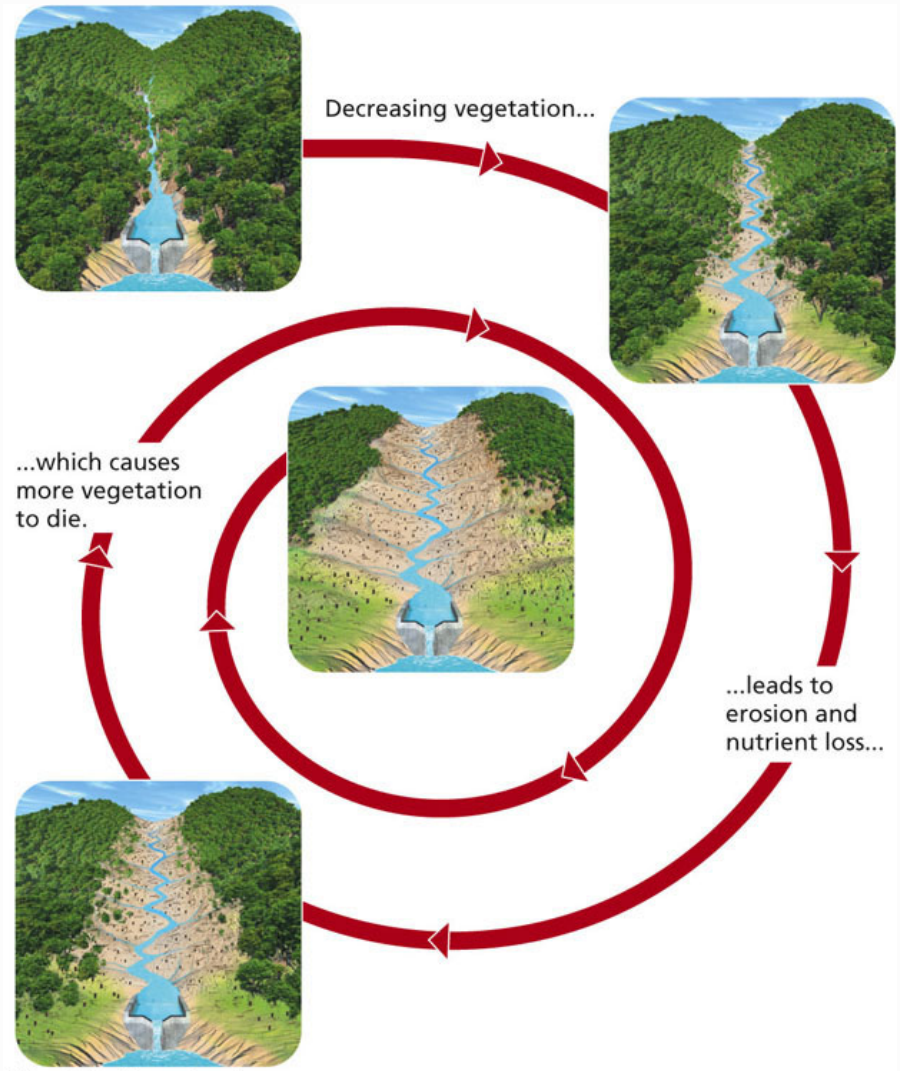
Fig. 2-10, p. 44

Systems Respond to Change through Feedback Loops

- **Positive feedback loop**
- **Negative,** or **corrective, feedback loop**

Positive Feedback Loop



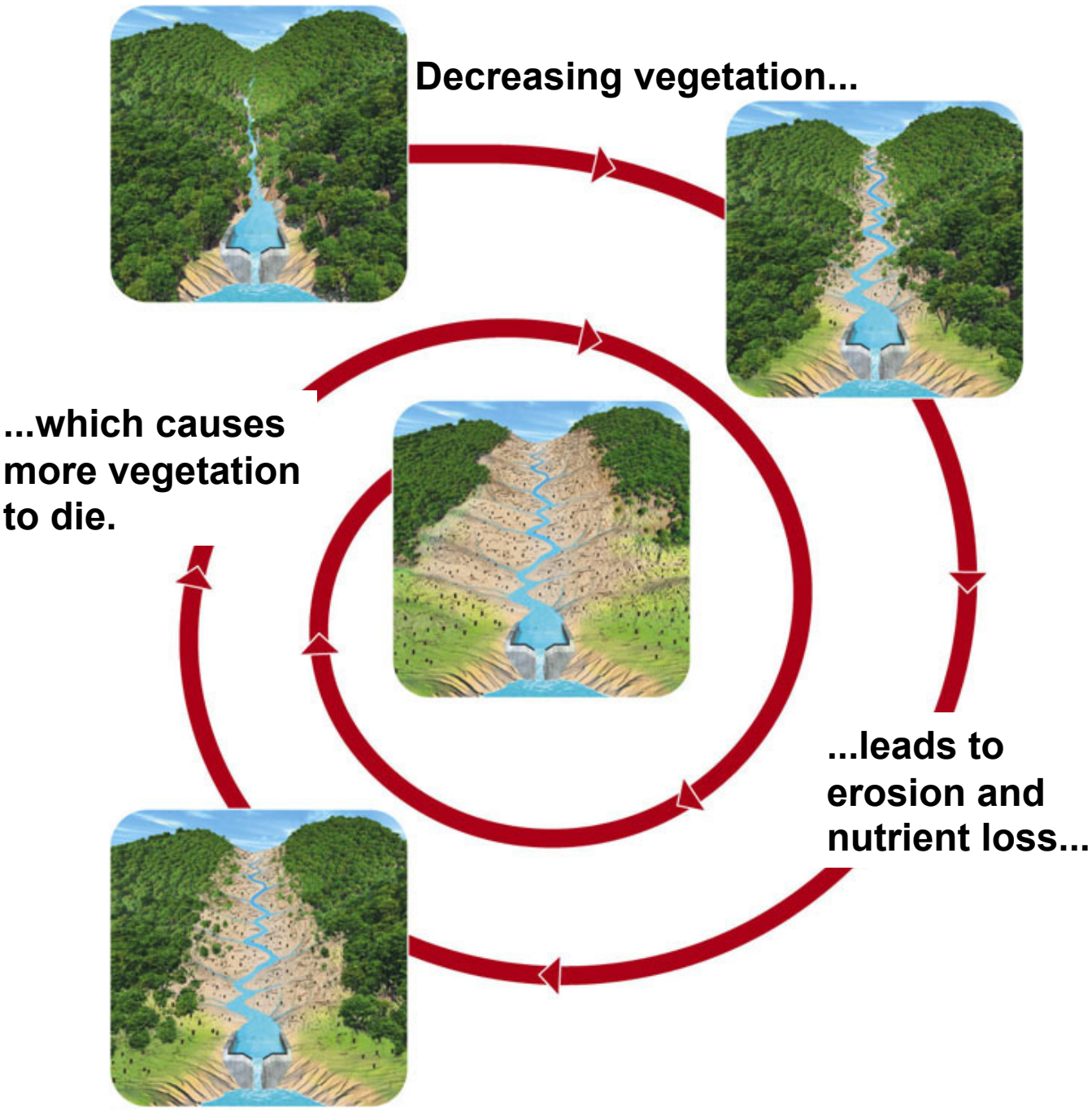
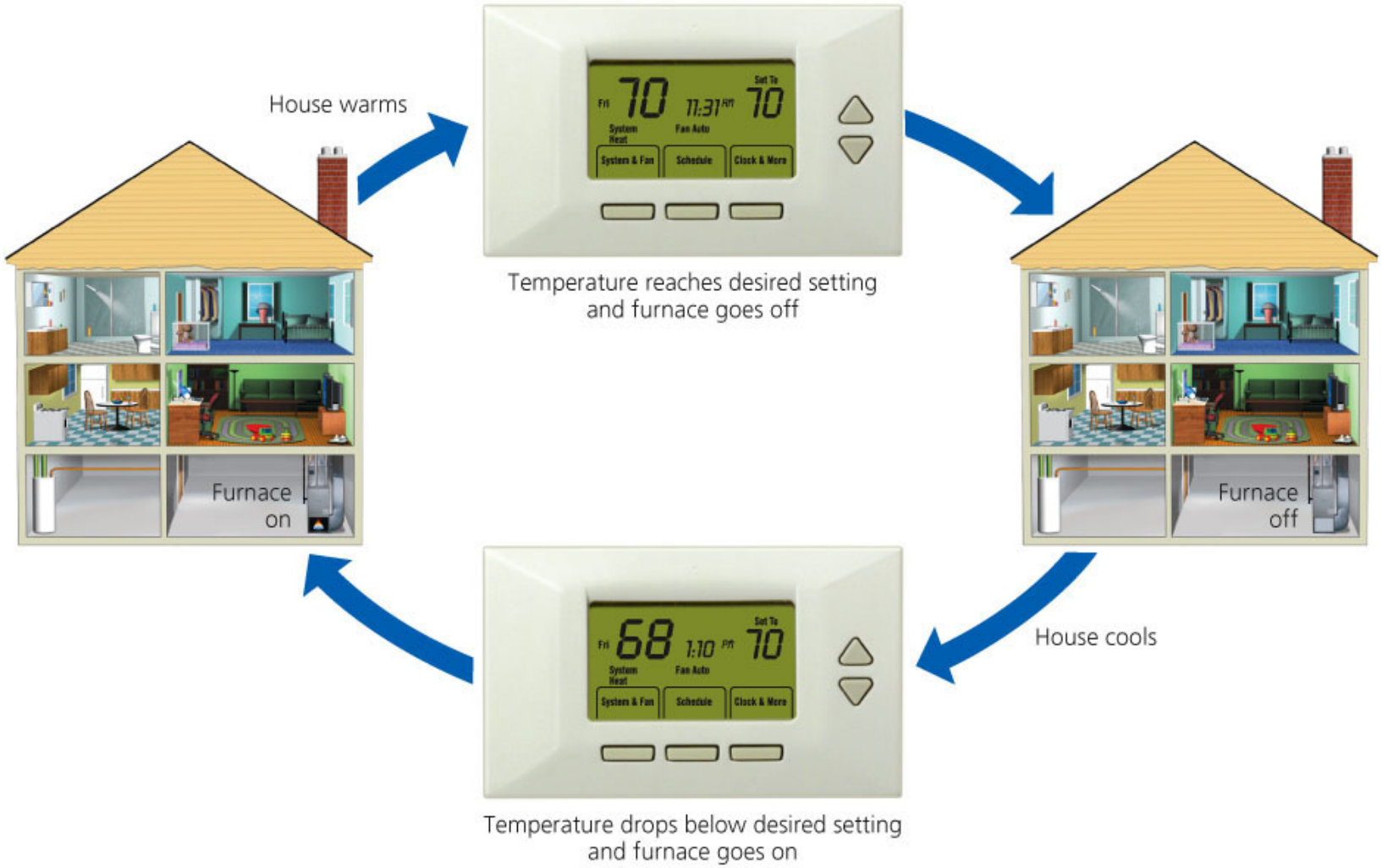


Fig. 2-11, p. 45

Negative Feedback Loop



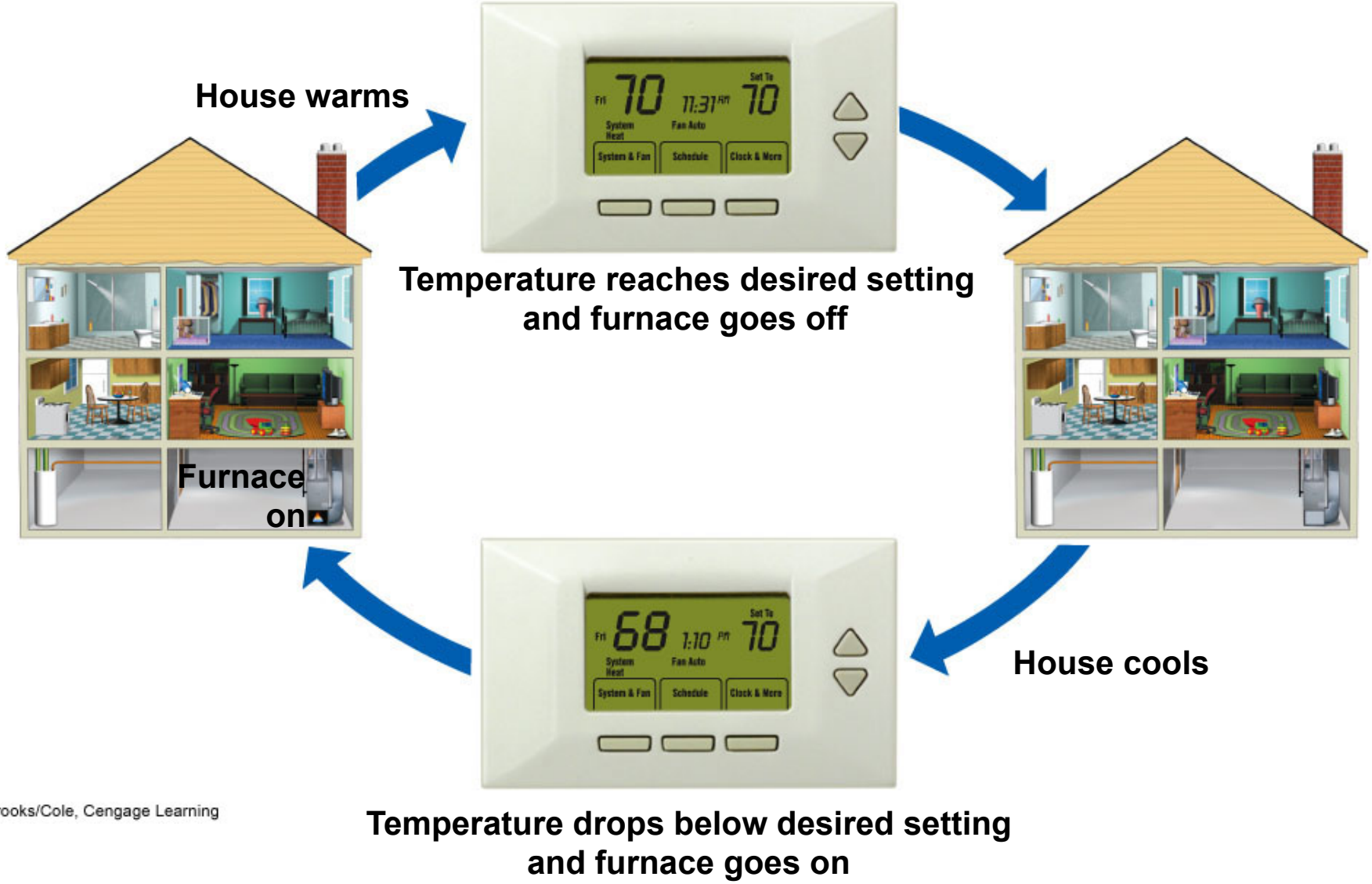


Fig. 2-12, p. 45

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

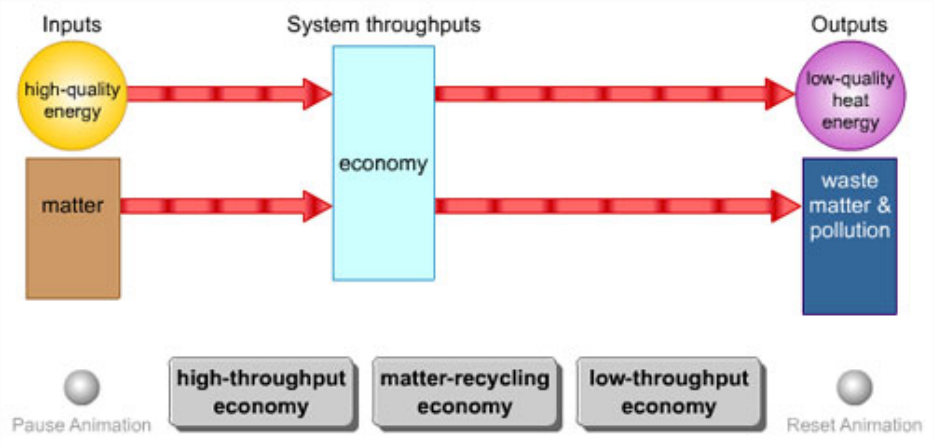
System Effects Can Be Amplified through Synergy

- **Synergistic interaction, synergy**
  - Helpful
  - Harmful
    - E.g., Smoking and inhaling asbestos particles

Human Activities Can Have Unintended Harmful Results

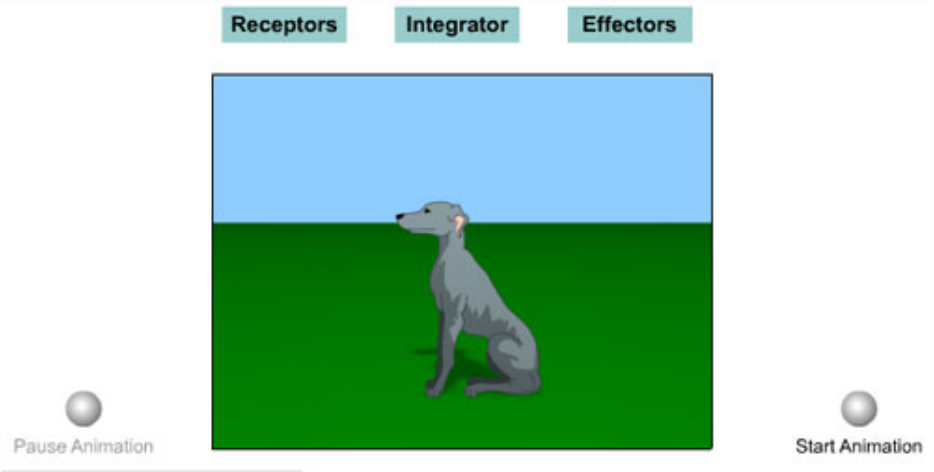
- Deforested areas turning to desert
- Coral reefs dying
- Glaciers melting
- Sea levels rising

Animation: Economic types



PLAY

Animation: Feedback control of temperature



PLAY