ENVIRONMENTAL SCIENCE 13e

CHAPTER 2:

Science, Matter, and Energy

Core Case Study: A Story about a Forest (1)

- Hubbard Brook Experimental Forest
- Question: What is the environmental impact of forest clear-cutting?
- Controlled experiment – isolate variables
  - **Control group**
  - **Experimental group**

Core Case Study: A Story about a Forest (2)

- Measure loss of water and nutrients
- Compare results
  - 30–40% increase in runoff
  - 6–8 times more nutrient loss
- Draw conclusions
  - Cause-and-effect relationships

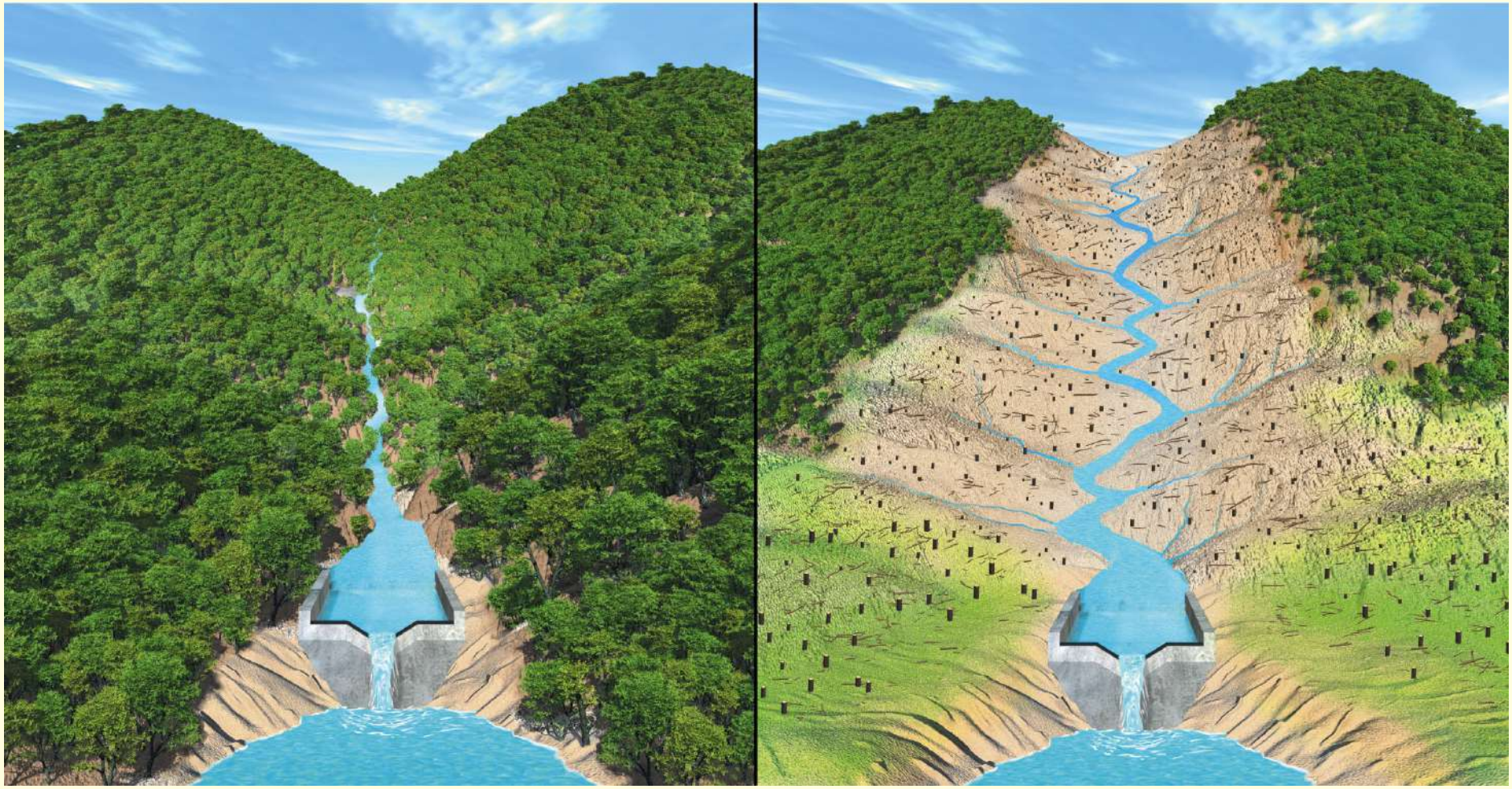


Fig. 2-1, p. 23

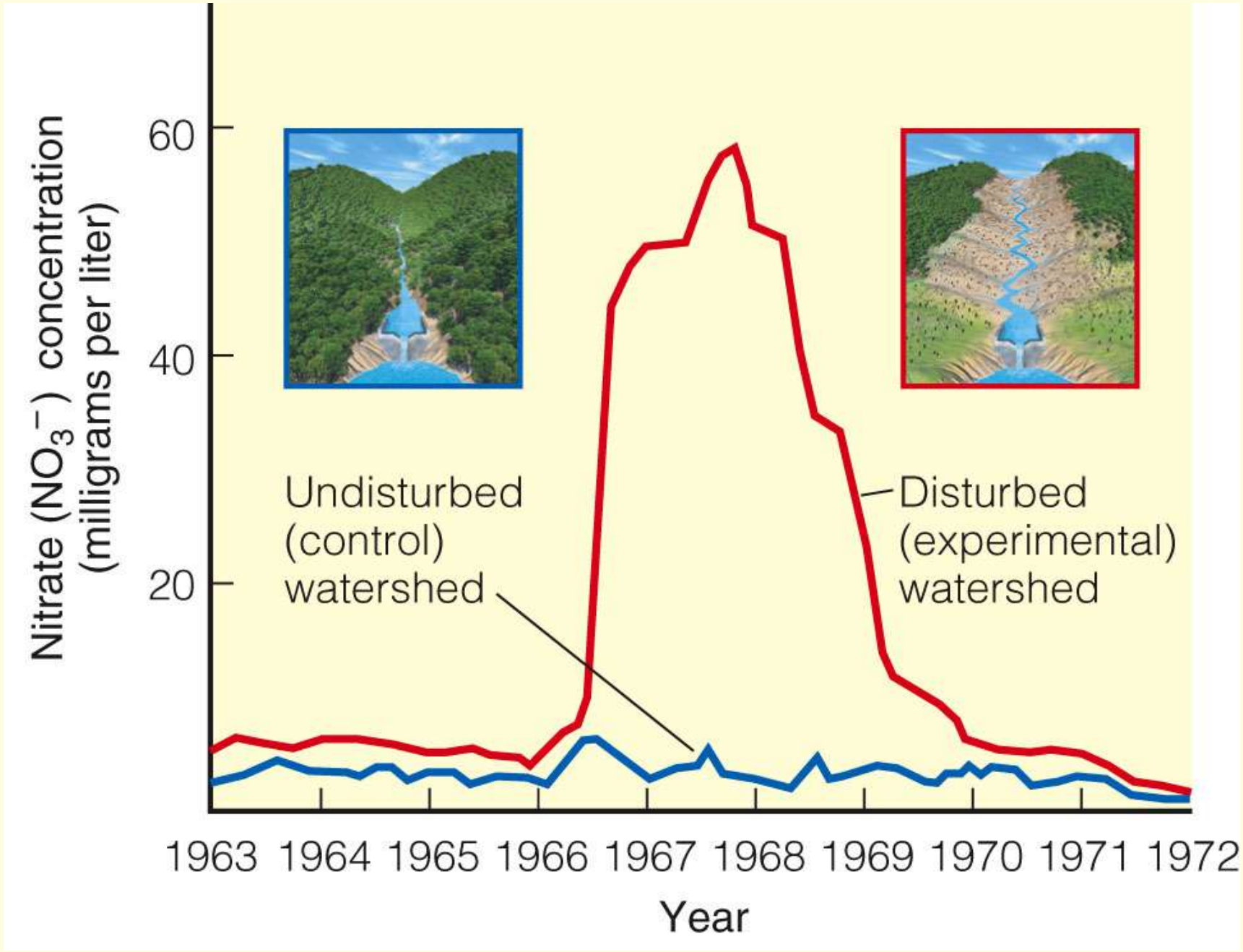
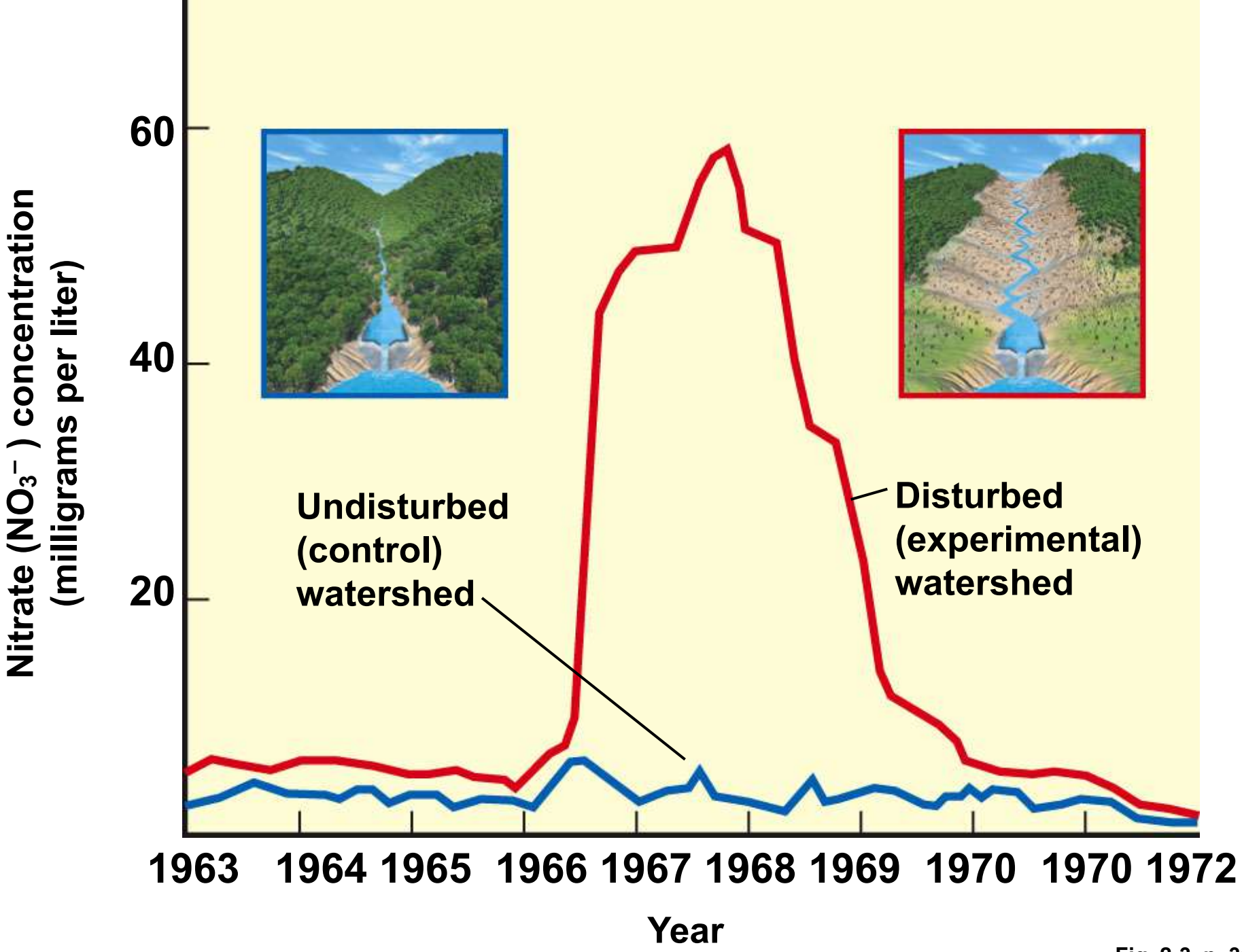

Nitrate (NO_3^-) concentration (milligrams per liter)
60
40
20
Undisturbed (control) watershed
Disturbed (experimental) watershed
1963 1964 1965 1966 1967 1968 1969 1970 1971 1972
Year

Fig. 2-3, p. 30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1963
1964
1965
1966
1967
1968
1969
1970
1970
1972
Year

Fig. 2-3, p. 30

2-1 What Do Scientists Do?

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

Science

- Search for order in nature
  - Observe behavior
  - Attempt to identify cause and effect
  - Make predictions
  - Test predictions
  - Draw conclusions

The Scientific Process (1)

- Identify **problem/question**
- Learn what is known about problem/question
- Ask question to be investigated
- Collect **data**
- Formulate a testable **scientific hypothesis**

The Scientific Process (2)

- Make **testable projections**
- Test projections with **experiments**
- Develop **models**
- Propose **scientific theories**
- Derive **natural laws**

The Scientific Process (3)

- Four features of the scientific process:
  - **Curiosity**
  - **Skepticism**
  - **Peer review**
  - **Reproducibility**

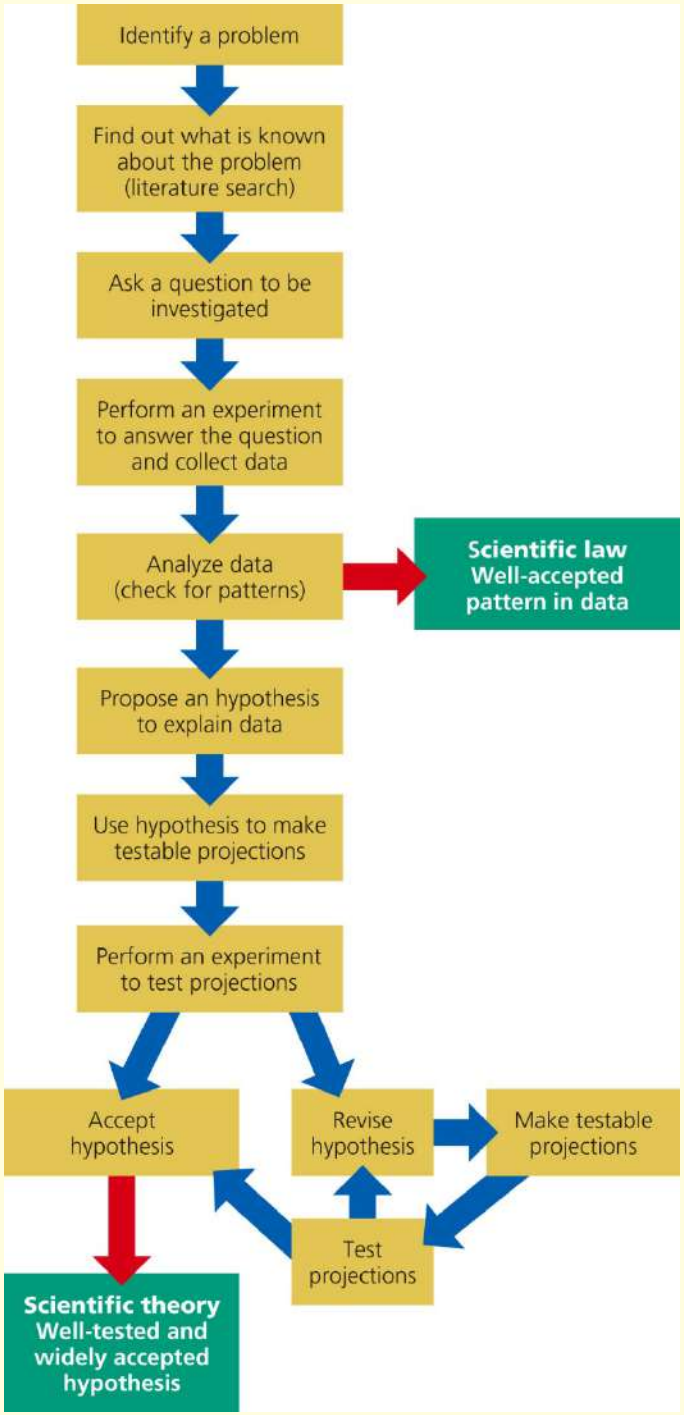
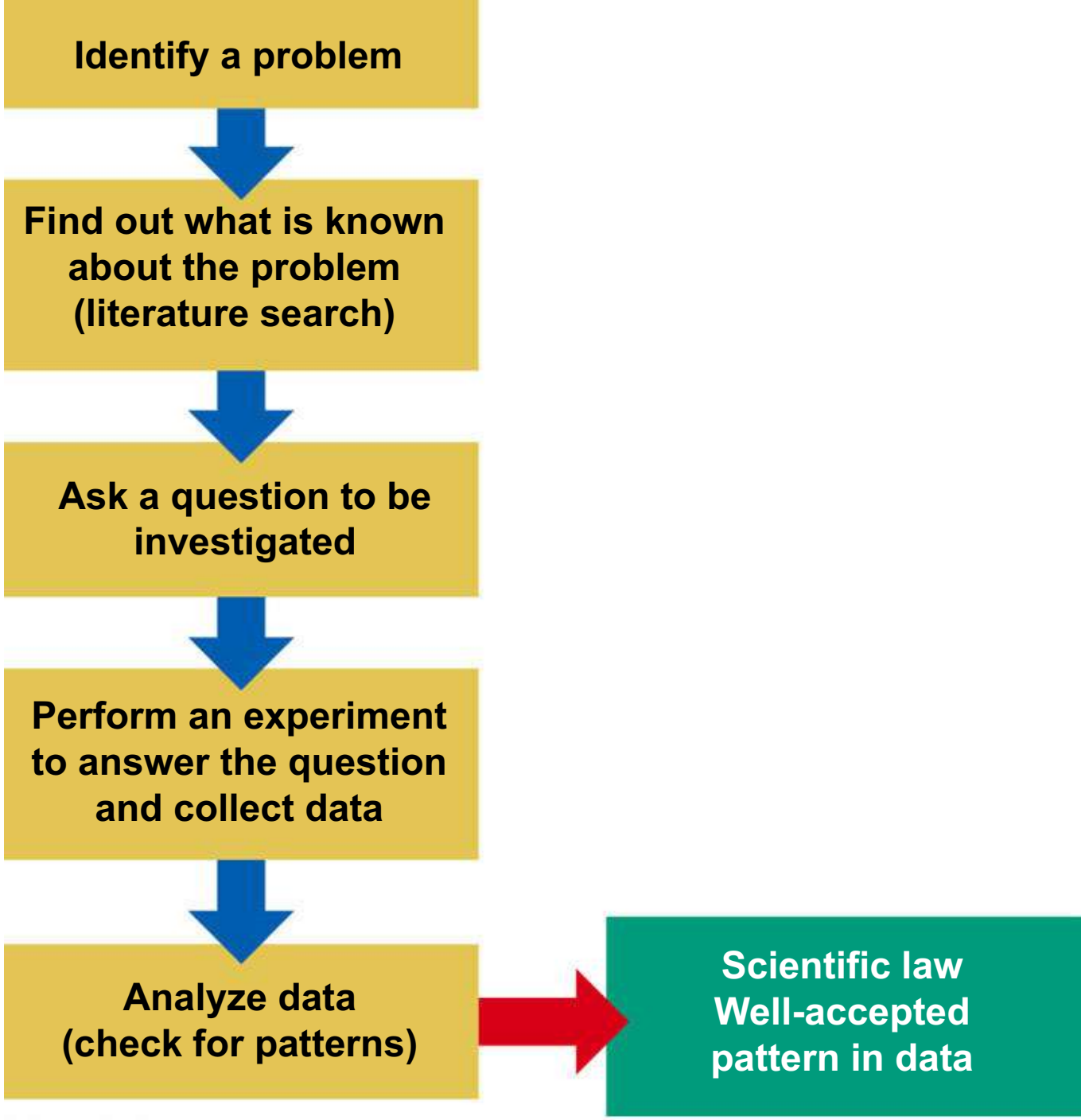

Identify a problem
Find out what is known about the problem (literature search)
Ask a question to be investigated
Perform an experiment to answer the question and collect data
Analyze data (check for patterns)
Scientific law Well-accepted pattern in data
Propose an hypothesis to explain data
Use hypothesis to make testable projections
Perform an experiment to test projections
Accept hypothesis
Revise hypothesis
Make testable projections
Test projections
Scientific theory Well-tested and widely accepted hypothesis

Fig. 2-2, p. 25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Scientific law
Well-accepted pattern in data

Fig. 2-2, p. 25

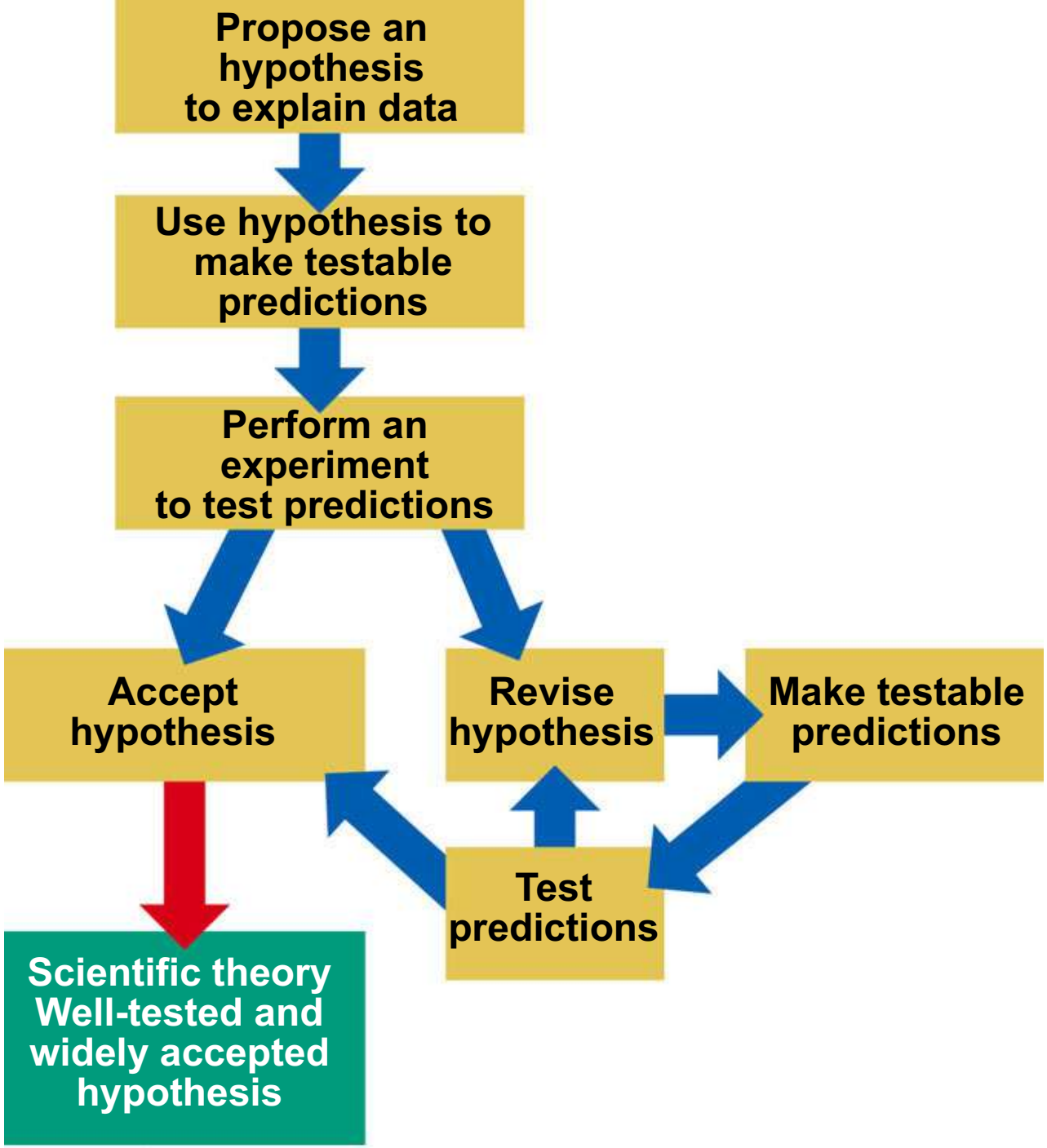
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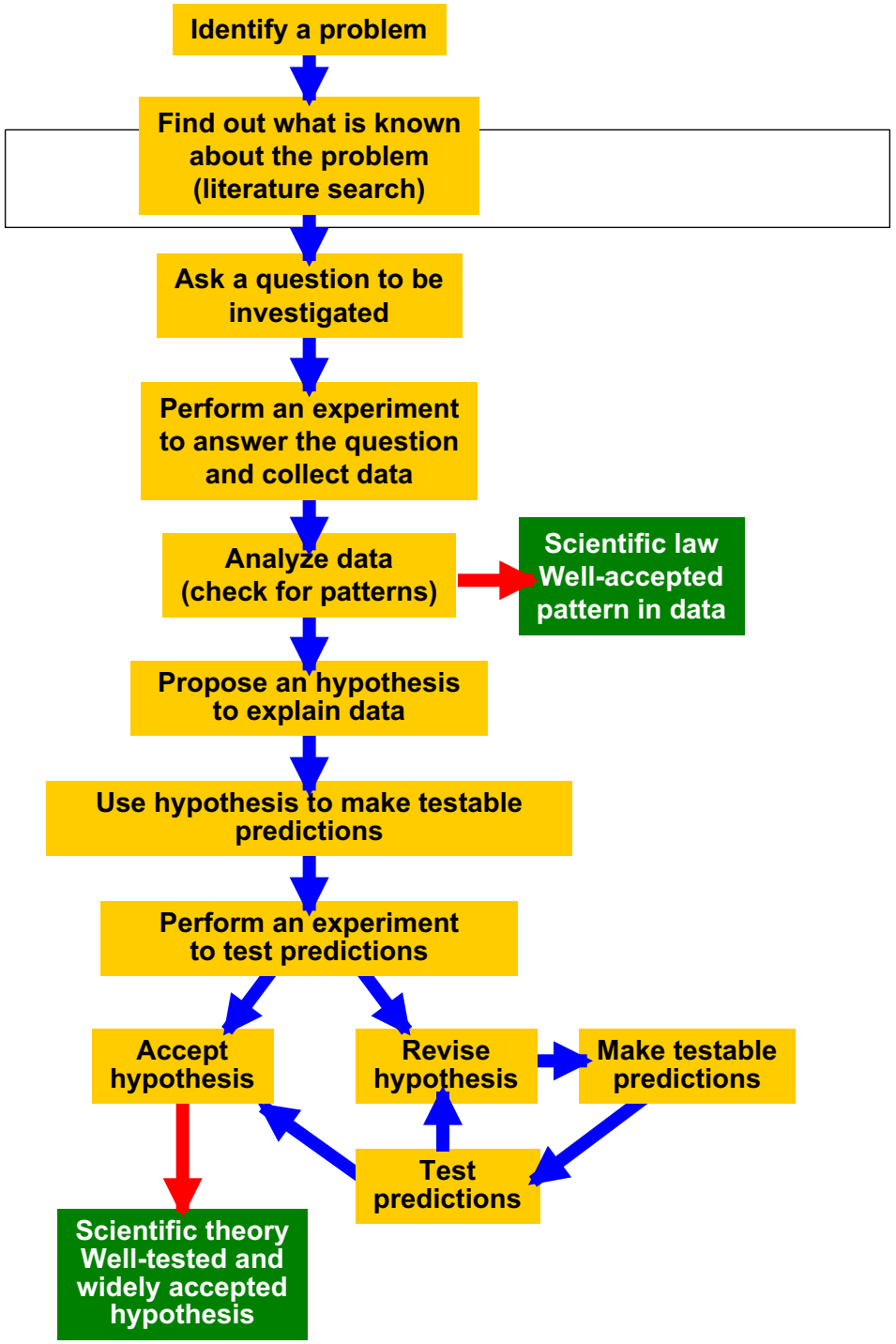
Fig. 2-2, p. 25



Stepped Art

Fig. 2-2, p. 25

Results of Science

- Goals
  - **Scientific theories**
  - **Scientific laws**
- Degree of certainty and general acceptance
  - **Frontier/tentative science**
  - **Reliable science**
  - **Unreliable science**

Scientific Limitations

- Limitations – 100% certain?
  - Absolute proof versus probability
  - Observational bias
  - Complex interactions, many variables
  - Estimates and extrapolating numbers
  - Mathematical models

Science Focus: Climate Change (1)

- **Natural greenhouse effect**
  - Keeps atmosphere temperatures moderate

Three questions

1. How much warming over the last 50 years?
2. How much of the warming is caused by humans adding carbon dioxide to atmosphere?
3. How much will the atmosphere warm in the future, and what effects will it have?

Science Focus: Climate Change (2)

- International Panel on Climate Change
- 2007 IPCC report:
  - Very likely: 0.74 C° increase 1906-2005
  - Very likely: human activities main cause of global warming
  - Likely: earth mean surface temperature to increase by ~3 C ° between 2005 and 2100.
- Climate change critics: most are not climate experts

2-2 What Is Matter and How Do Physical and Chemical Changes Affect It?

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

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

What Is Matter?

- **Matter** – has mass and occupies space
- **Elements** and **Compounds**
  - Atoms
  - Ions
  - Molecules

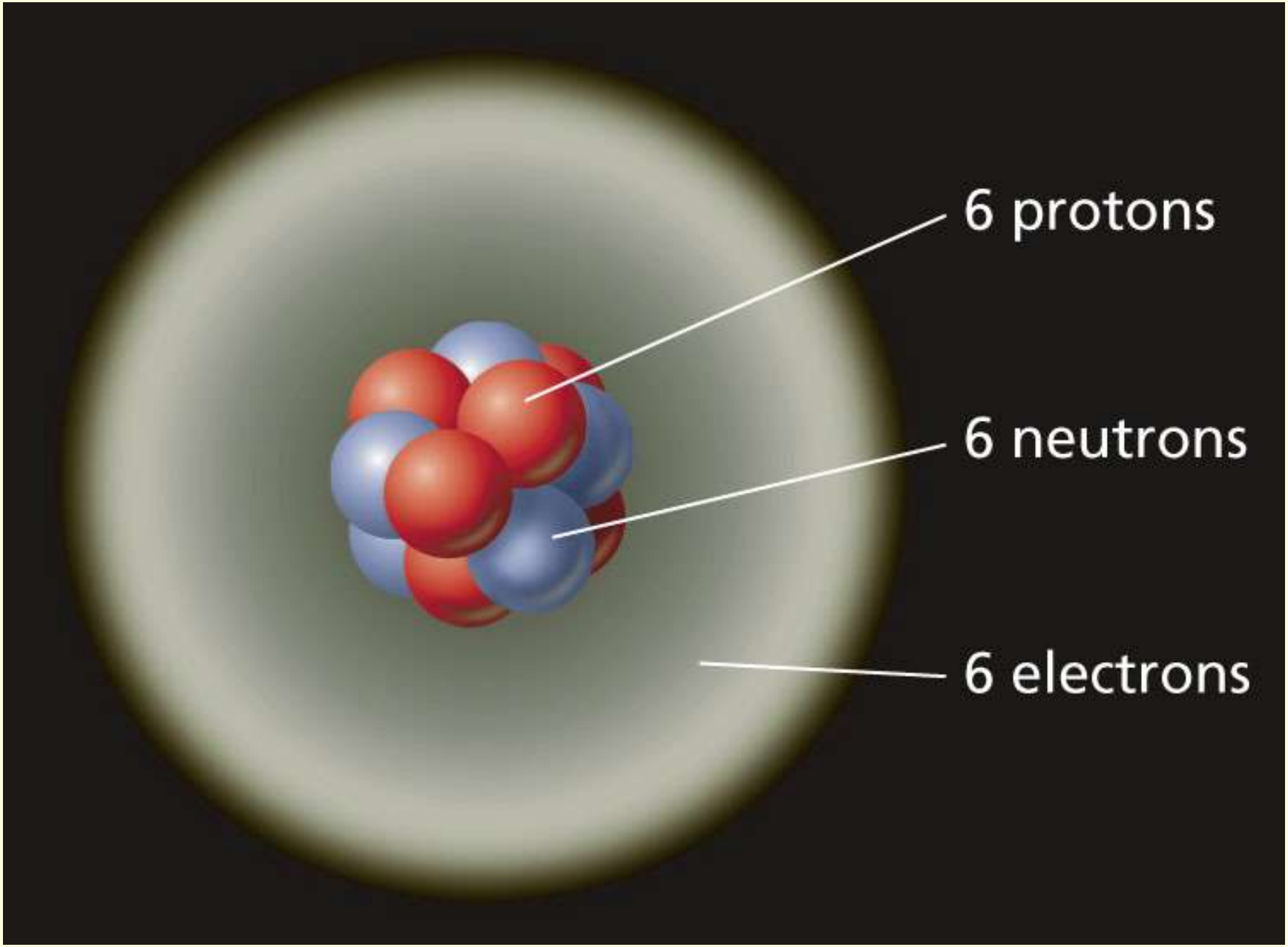
Table 2-1

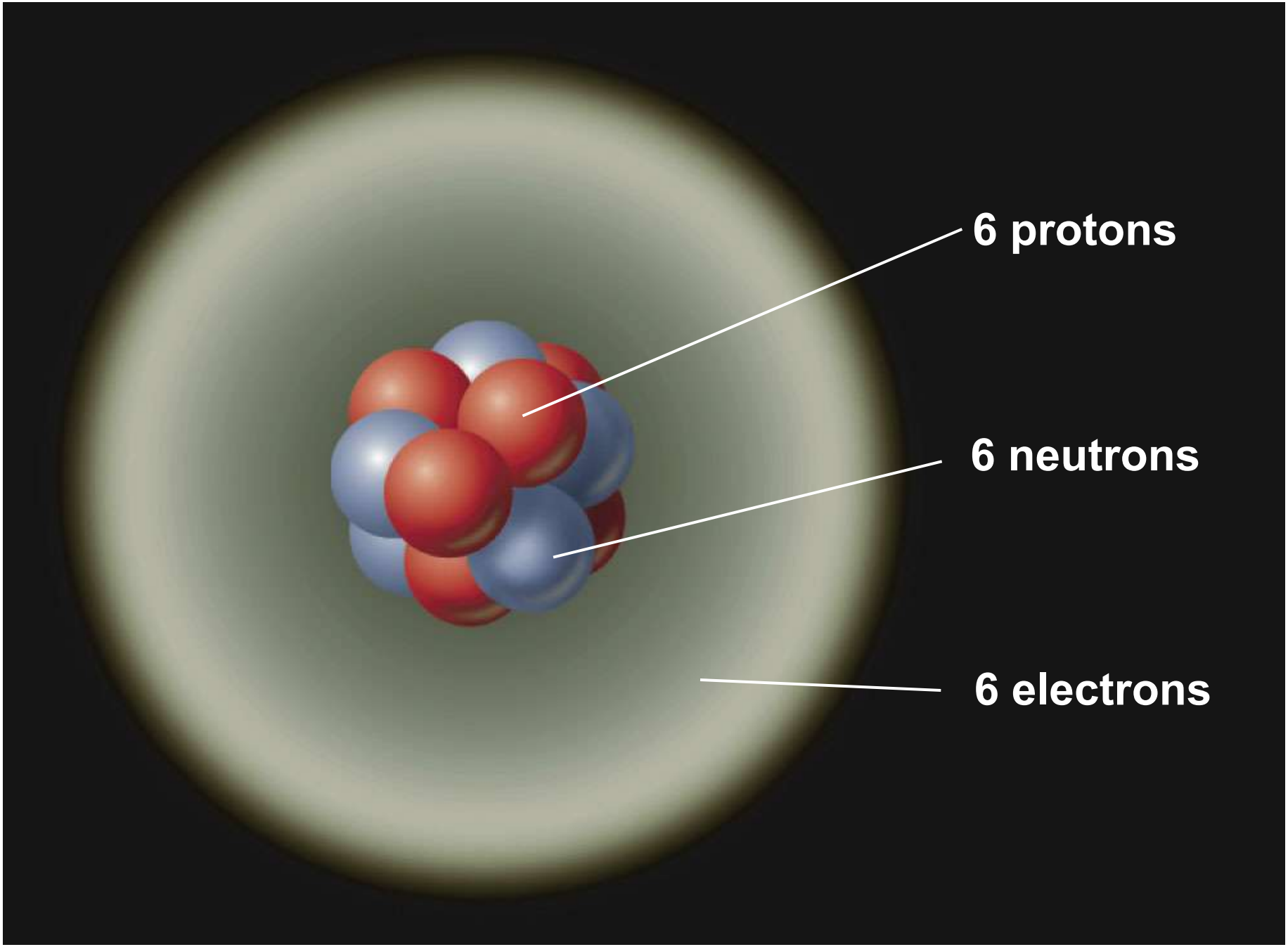
Chemical Elements Important to the Study of Environmental Science

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

Building Blocks of Matter (1)

- **Atomic Theory** – elements made from atoms
- **Atoms**
  - **Protons** – positive charge
  - **Neutrons** – uncharged
  - **Electrons** – negative charge
- **Nucleus**
  - One or more protons
  - Usually one or more neutrons


6 protons
6 neutrons
6 electrons



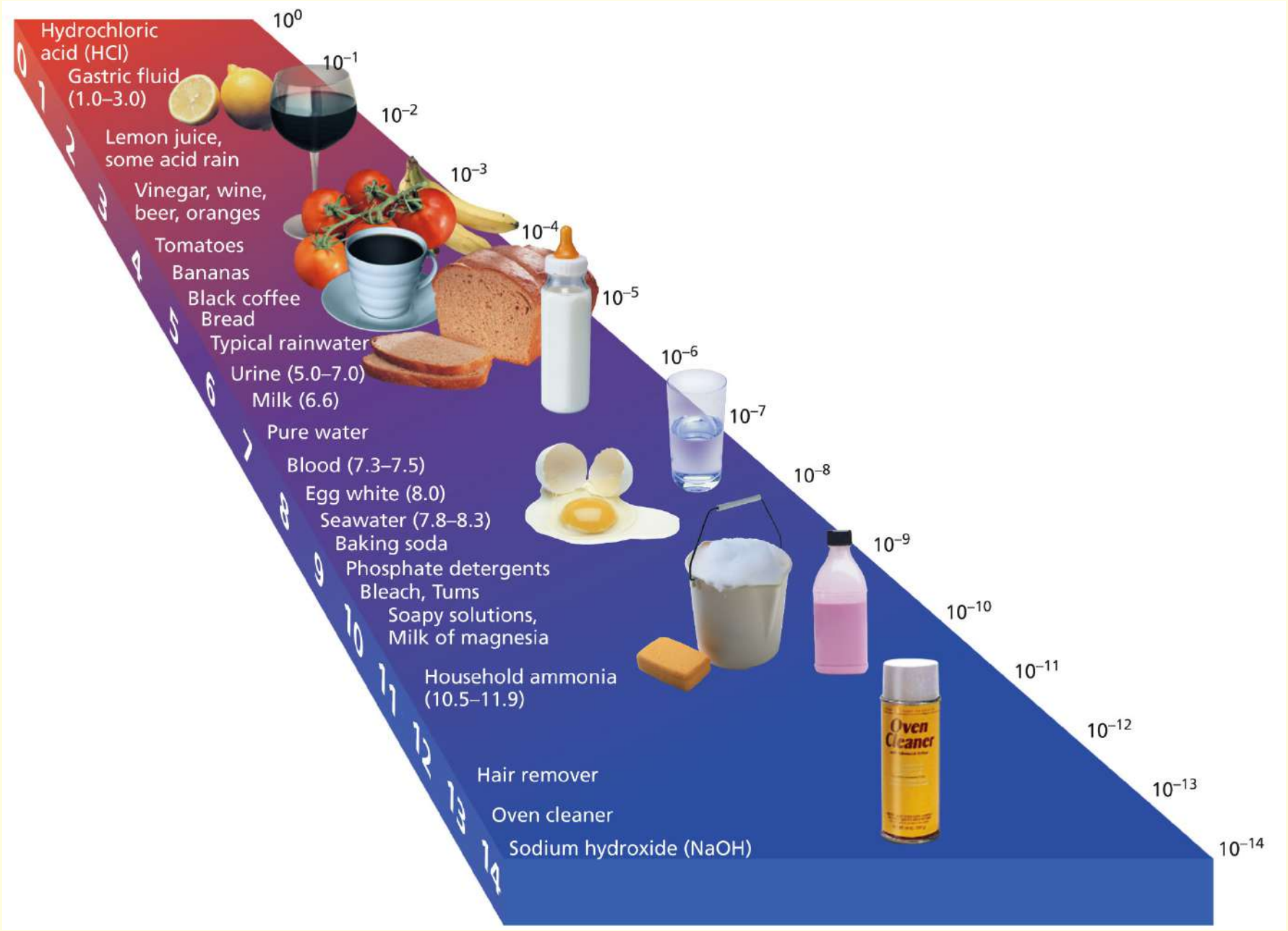
Supplement 6, Fig. 1, p. S26

Building Blocks of Matter (2)

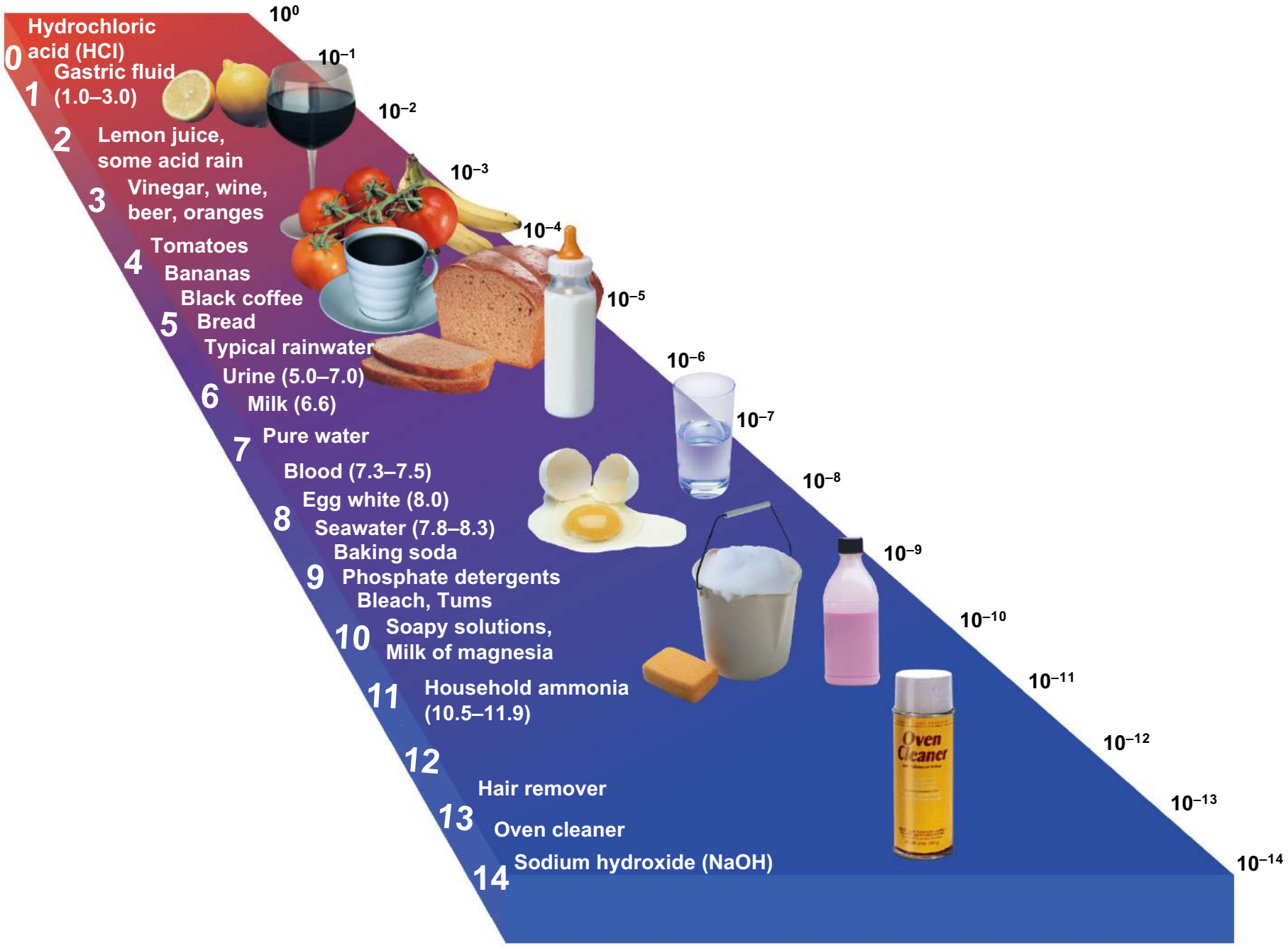
- **Atomic number**
  - Number of protons
- **Mass number**
  - Neutrons + protons
- **Isotopes**
  - Same atomic number, different mass
  - Same number of protons, different number of neutrons

Building Blocks of Matter (3)

- **Ion**
  - One or more net positive or negative electrical charges
- **Molecule**
  - Combination of two or more atoms
- **Chemical formula**
  - Number and type of each atom or ion
- **Compounds**
  - Organic
  - Inorganic



Supplement 6, Fig. 6, p. S28



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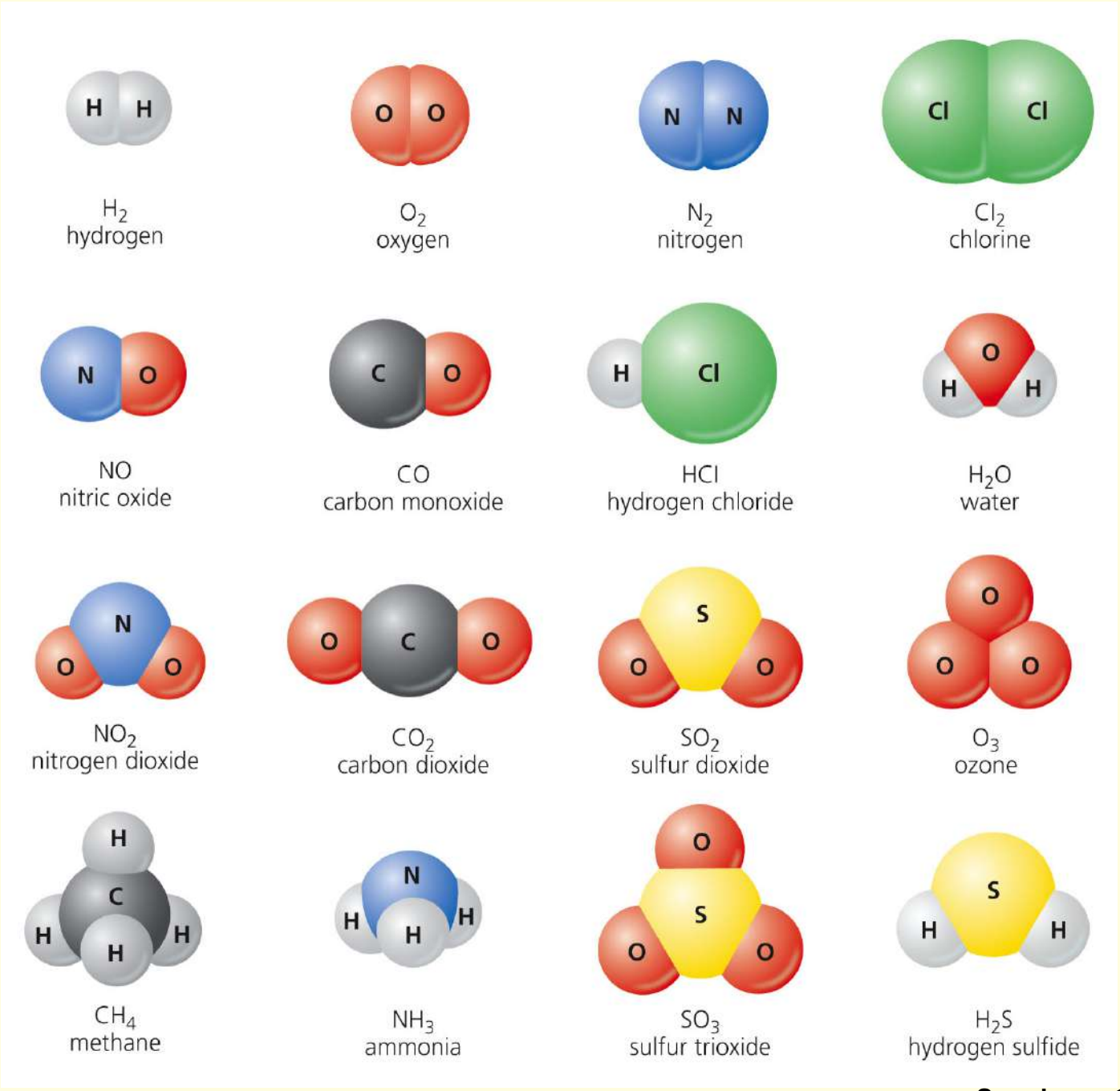
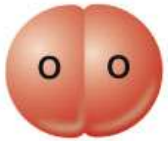


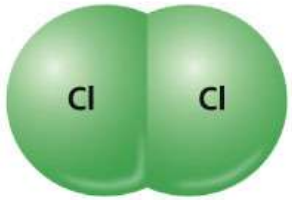
Supplement 6, Fig. 5, p. S27

H_2
hydrogen



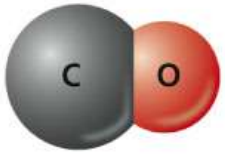
O_2
oxygen

N_2
nitrogen

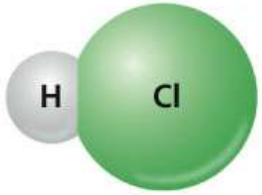


Cl_2
chlorine

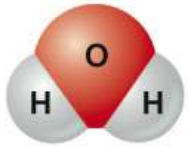
NO
nitric oxide



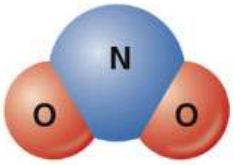
CO
carbon monoxide



HCl
hydrogen chloride

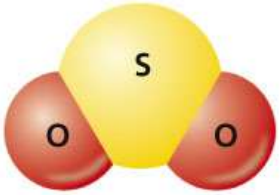


H_2O
water

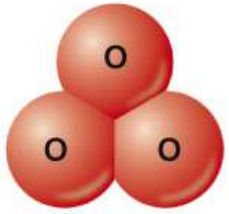


NO_2
nitrogen dioxide

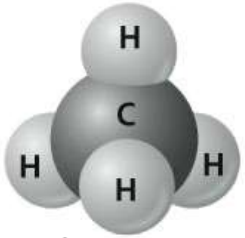
CO_2
carbon dioxide



SO_2
sulfur dioxide

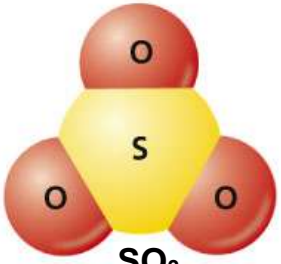


O_3
ozone

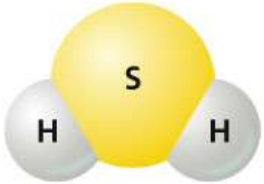


CH_4
methane

NH_3
ammonia



SO_3
sulfur trioxide



H_2S
hydrogen sulfide

Supplement 6, Fig. 5, p. S27

Table 2-2

Ions Important to the Study of Environmental Science

Positive Ion	Symbol
hydrogen ion	H^+
sodium ion	Na^+
calcium ion	Ca^{2+}
aluminum ion	Al^{3+}
ammonium ion	NH_4^+
Negative Ion	**Symbol**
chloride ion	Cl^-
hydroxide ion	OH^-
nitrate ion	NO_3^-
carbonate ion	CO_3^{2-}
sulfate ion	SO_4^{2-}
phosphate ion	PO_4^{3-}

Table 2-3

Compounds Important to the Study of Environmental Science

Compound	Formula
sodium chloride	$NaCl$
Sodium hydroxide	$NaOH$
carbon monoxide	CO
carbon dioxide	CO_2
nitric oxide	NO
nitrogen dioxide	NO_2
nitrous oxide	N_2O
nitric acid	HNO_3
methane	CH_4
water	H_2O
hydrogen sulfide	H_2S
Sulfur dioxide	SO_2
sulfuric acid	H_2SO_4
calcium carbonate	$CaCO_3$
glucose	$C_6H_{12}O_6$
ammonia	NH_3

Organic Compounds

- Carbon-based compounds
  - Hydrocarbons
  - Chlorinated hydrocarbons
  - Simple carbohydrates
  - Complex carbohydrates
  - Proteins
  - Nucleic acids (DNA and RNA)
  - Lipids

Matter Becomes Life

- **Cells**
- **Genes**
  - DNA
  - Traits
- **Chromosomes**
  - DNA
  - Proteins

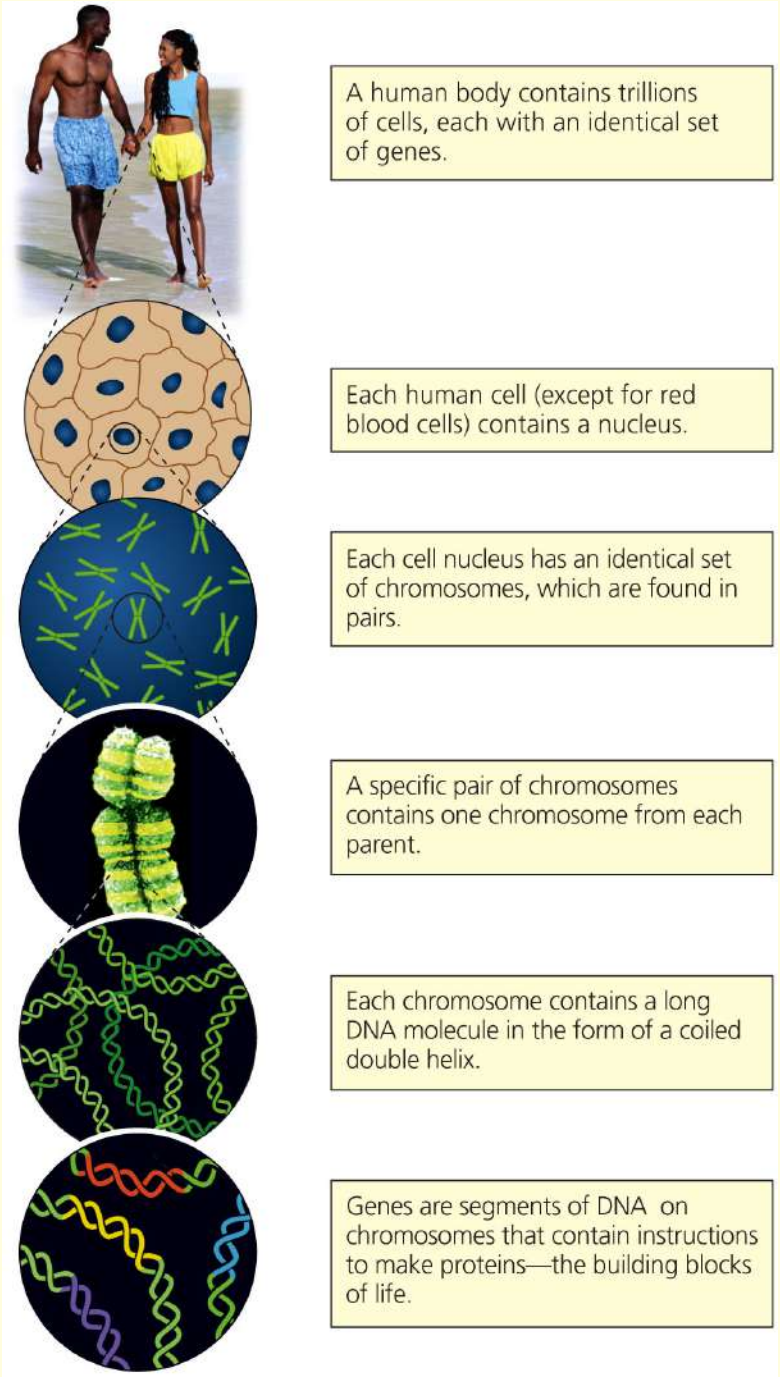
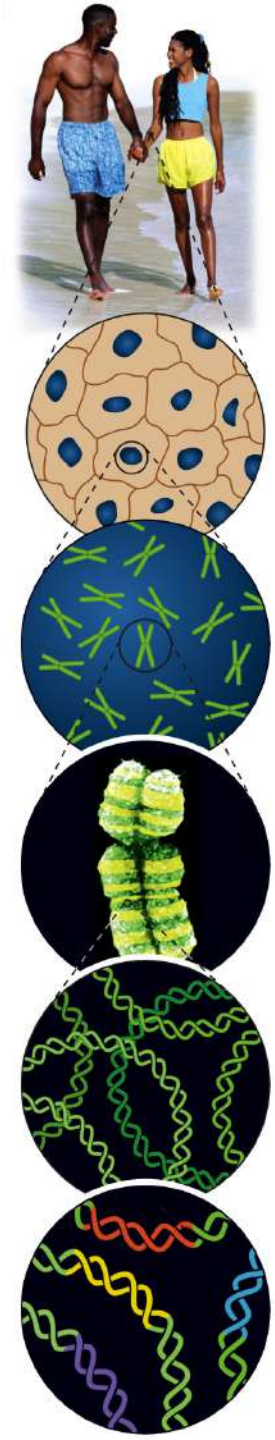

A human body contains trillions of cells, each with an identical set of genes.
Each human cell (except for red blood cells) contains a nucleus.
Each cell nucleus has an identical set of chromosomes, which are found in pairs.
A specific pair of chromosomes contains one chromosome from each parent.
Each 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. 2-4, p. 31



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Stepped Art

Fig. 2-4, p. 31

Matter Quality

- Usefulness as a resource
  - Availability
  - Concentration
- **High quality**
- **Low quality**


High Quality
Low Quality
Solid
Gas
Salt
Solution of salt in water
Coal
Coal-fired power plant emissions
GASOLINE
Gasoline
Automobile emissions
SODA
Aluminum can
Aluminum ore

Fig. 2-5, p. 32

High Quality

Low Quality

Solid

Gas

Salt

Solution of salt in water

Coal

Coal-fired power plant emissions

Gasoline

Automobile emissions

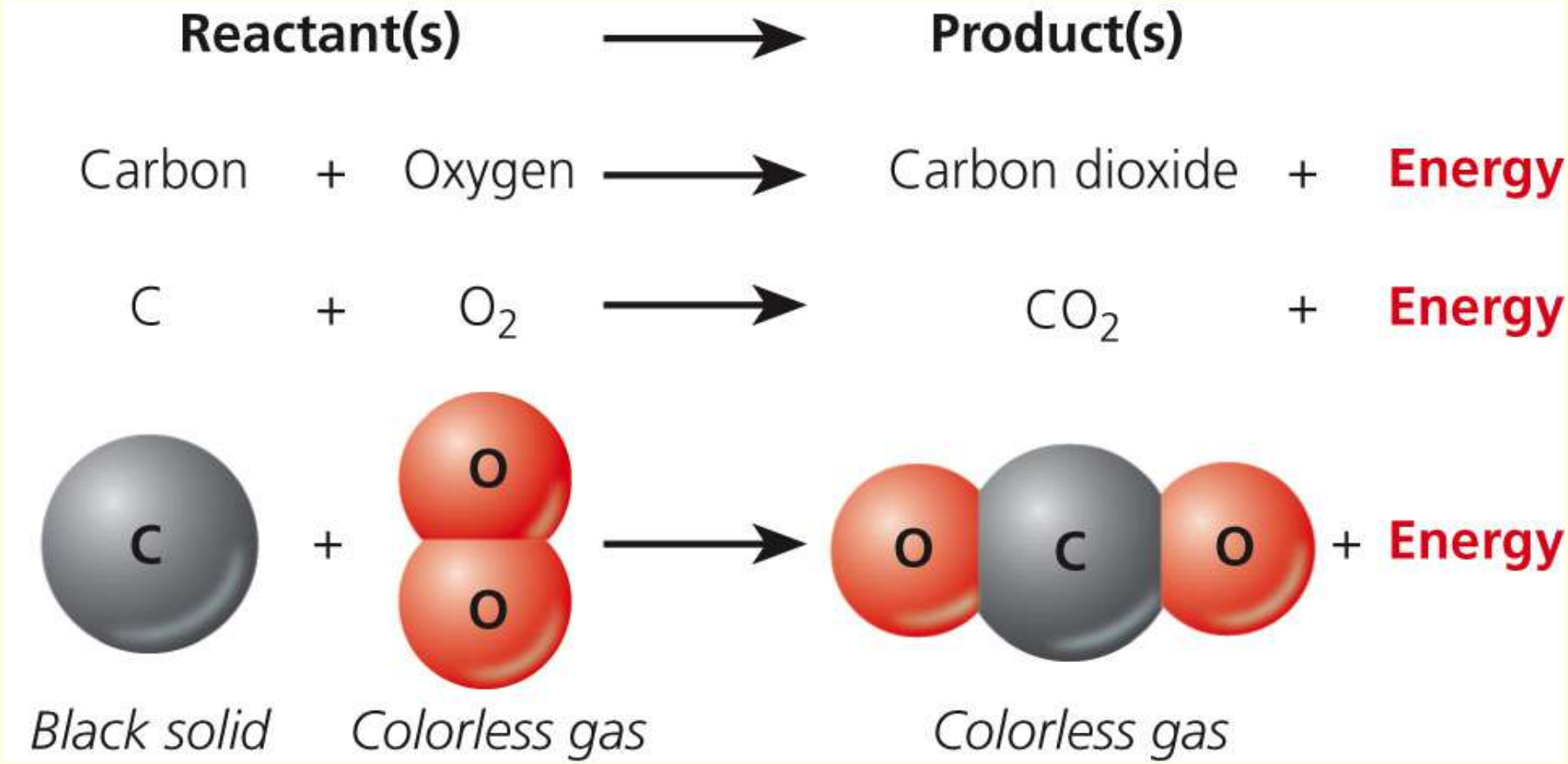
Aluminum can

Aluminum ore

Fig. 2-5, p. 32

Changes in Matter

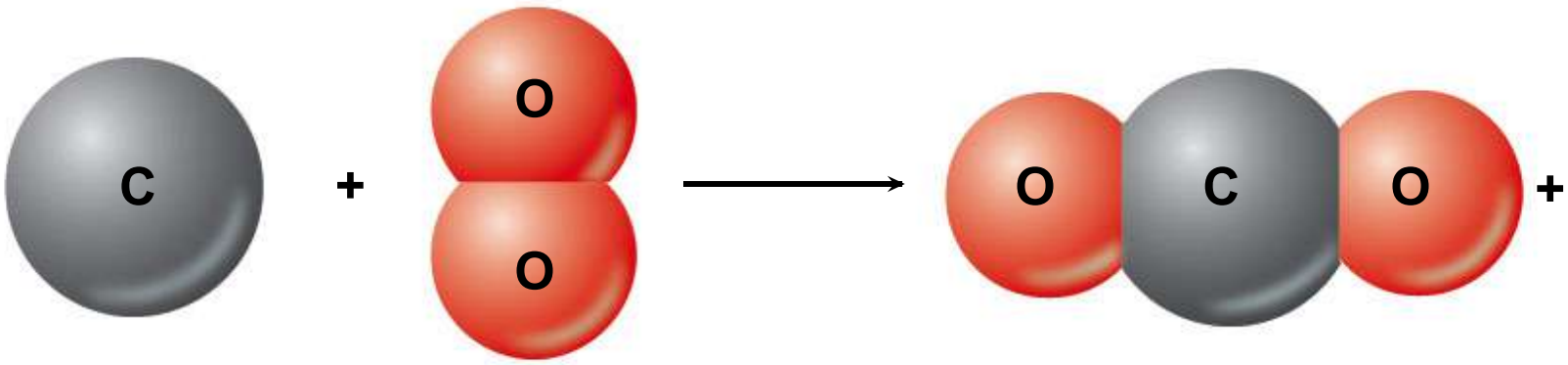
- **Physical**
- **Chemical**
- **Law of Conservation of Matter**
  - Matter only changes from one form to another


Reactant(s)
Product(s)
Carbon + Oxygen
Carbon dioxide + Energy
C + O_2
CO_2 + Energy
C
O
O
O
C
O
+ Energy
Black solid
Colorless gas
Colorless gas

Reactant(s) ⟶ Product(s)

Carbon + Oxygen ⟶ Carbon dioxide + Energy

C + O_2 ⟶ CO_2 + Energy



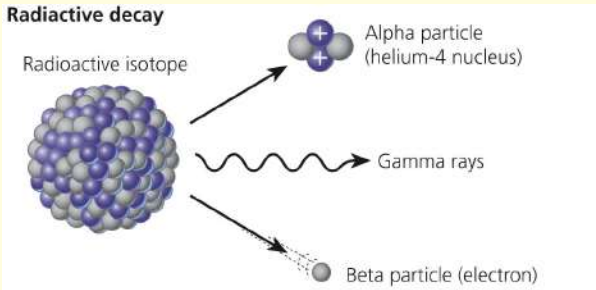
Black solid *Colorless gas* *Colorless gas*

Nuclear Changes (1)

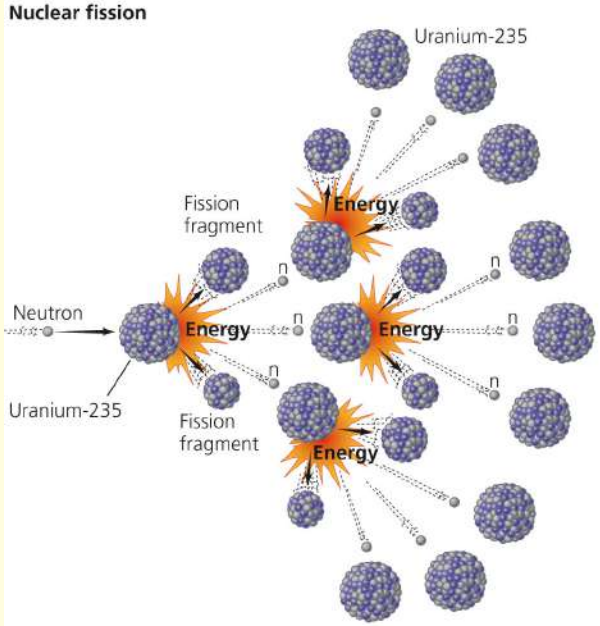
- **Radioactive decay** – unstable isotopes
  - Alpha particles
  - Beta particles
  - Gamma rays

Nuclear Changes (2)

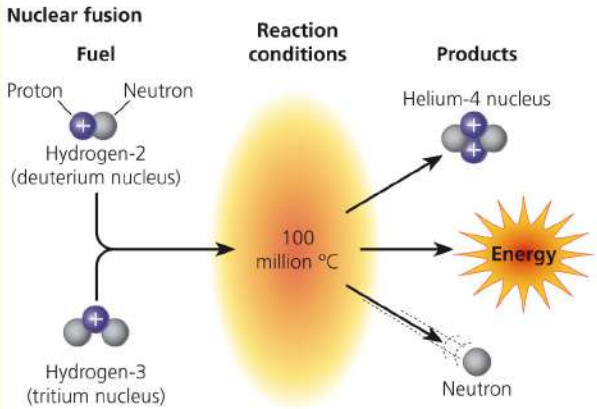
- **Nuclear fission**
  - Large mass isotopes split apart
  - Chain reaction
- **Nuclear fusion**
  - Two light isotopes forced together
  - High temperature to start reaction
  - Stars



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.



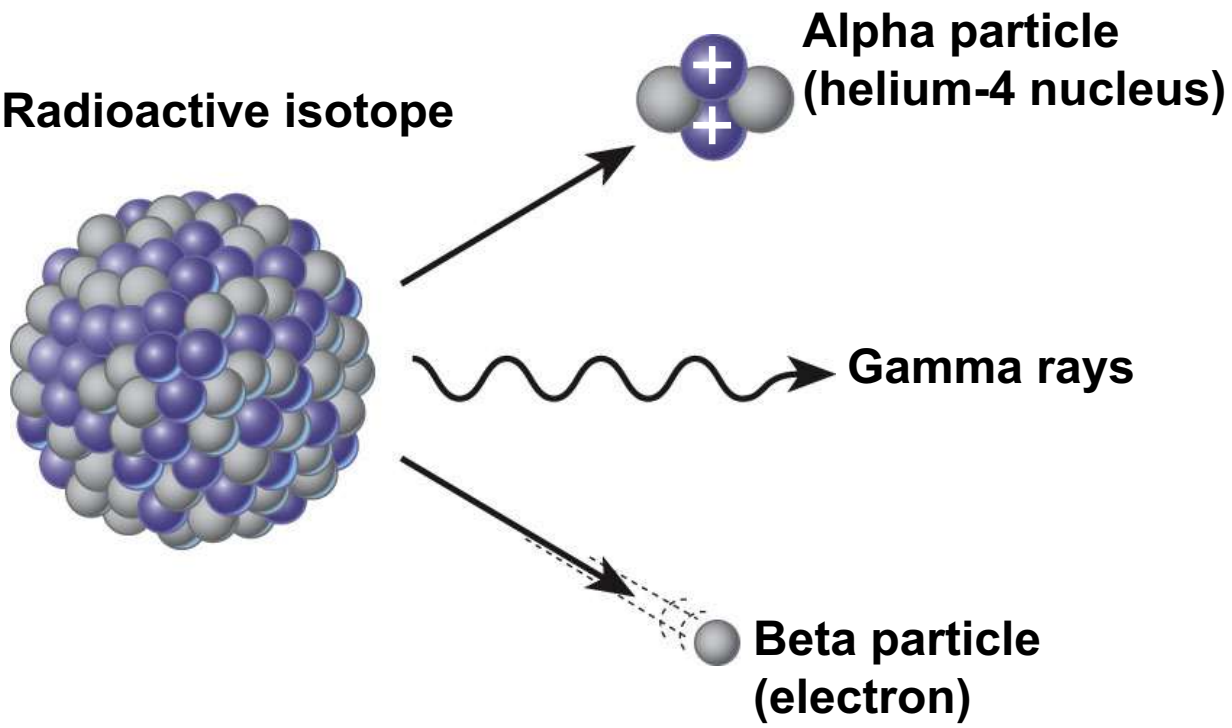
Nuclear fission occurs when the nuclei of certain isotopes with large mass numbers (such as uranium-235) are split apart into lighter nuclei when struck by a neutron and release energy plus two or three more neutrons. Each neutron can trigger an additional fission reaction and lead to a *chain reaction*,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

Fig. 2-6, p. 33

Radioactive decay



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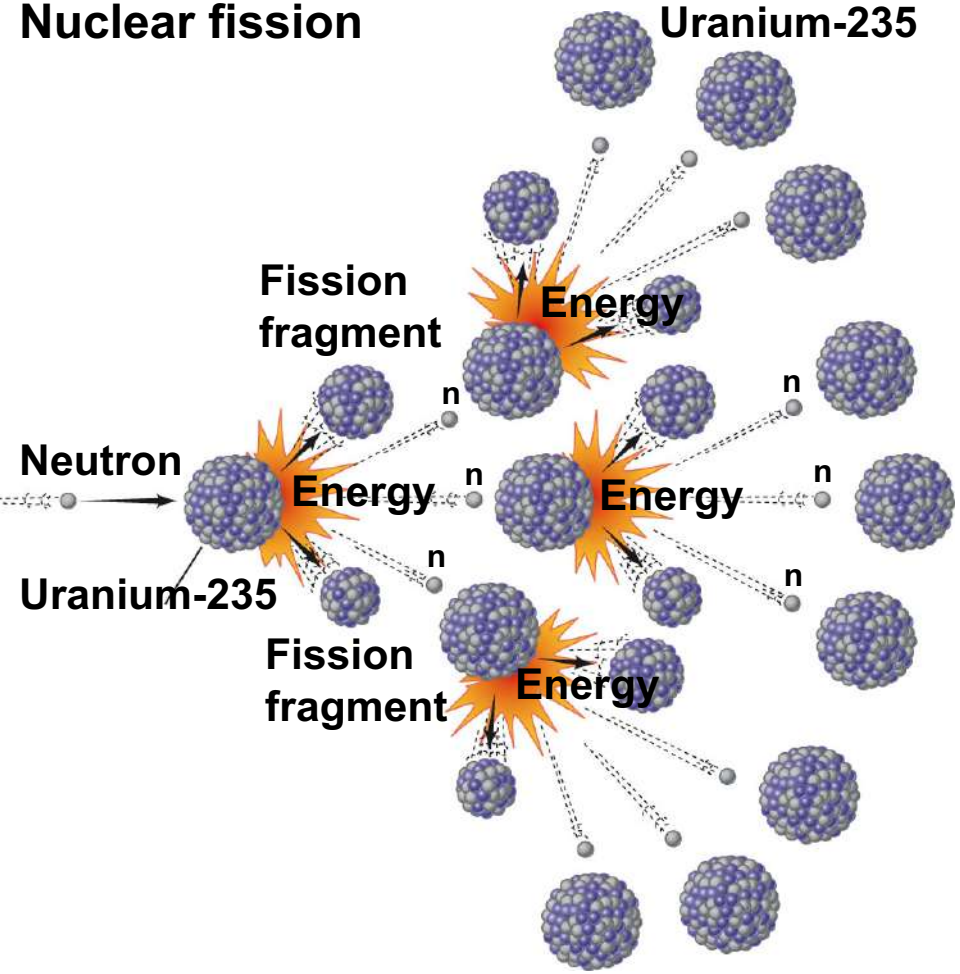

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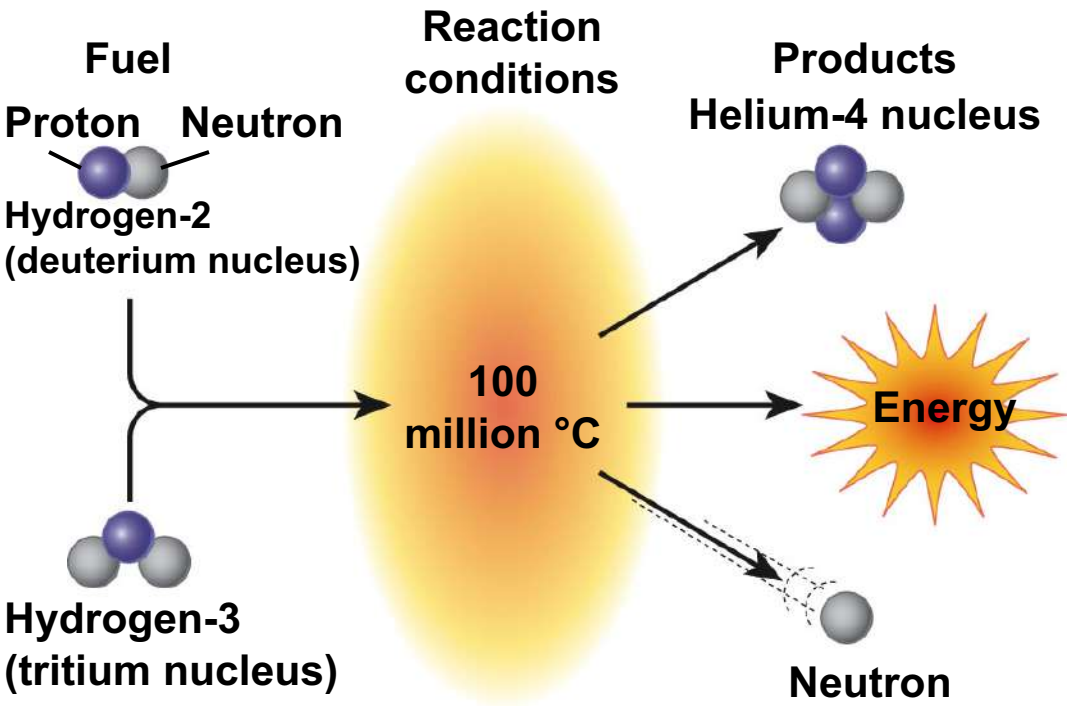
Nuclear fusion



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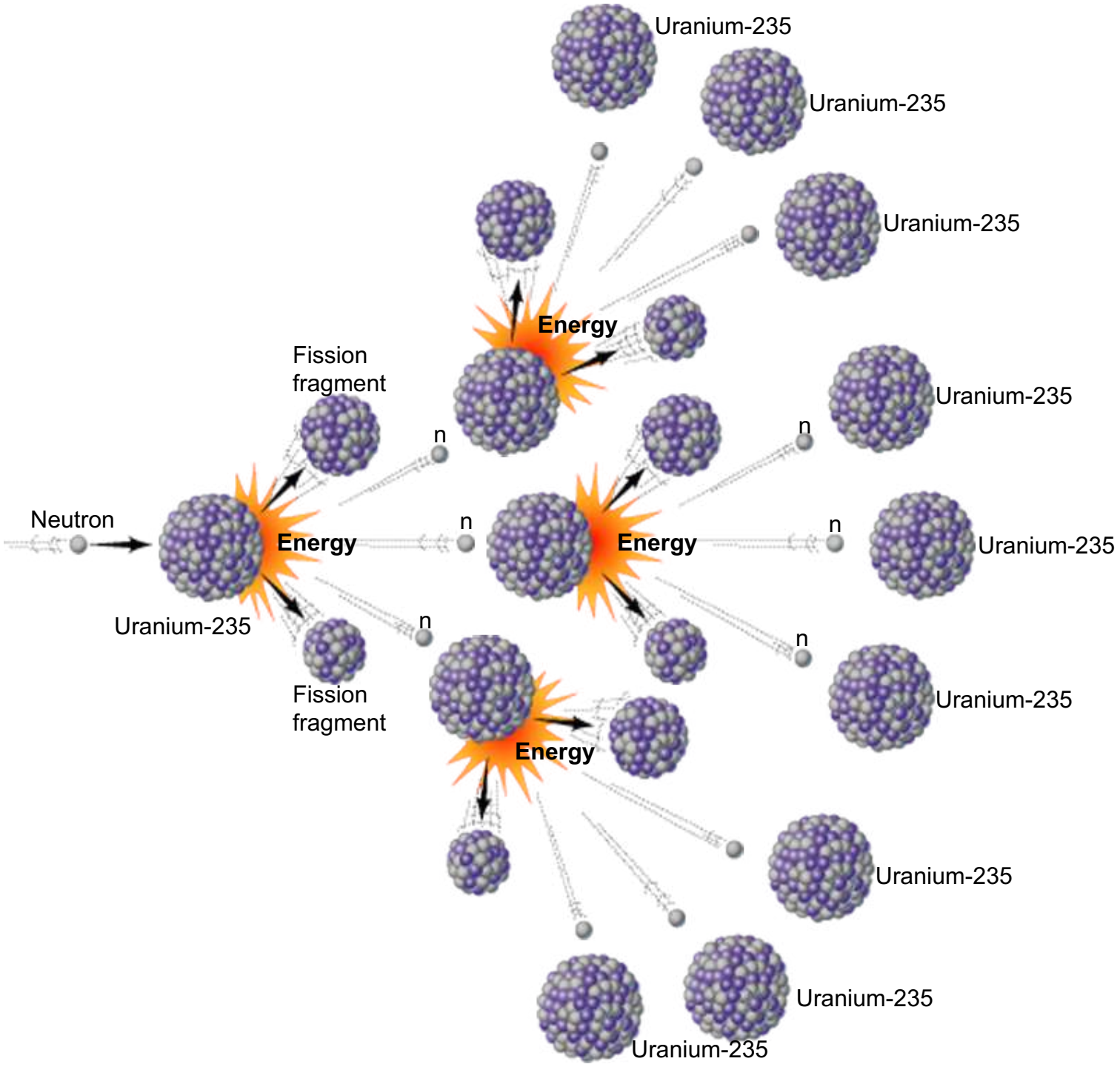

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Fig. 2-6, p. 33

2-3 What Is Energy and How Do Physical and Chemical Changes Affect It?

- ***Concept 2-3A*** *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 2-3B*** *Whenever energy is converted from one form to another in a physical or chemical change, we end up with lower quality or less usable energy than we started with (second law of thermodynamics).*

What Is Energy?

- **Energy** – the capacity to do work or transfer heat

Types of Energy

- **Potential energy** – stored energy
  - Gasoline
  - Water behind a dam
- **Kinetic energy** – energy in motion
  - Wind, flowing water, electricity
  - Heat – flow from warm to cold
  - Electromagnetic radiation
    - wavelength and relative energy

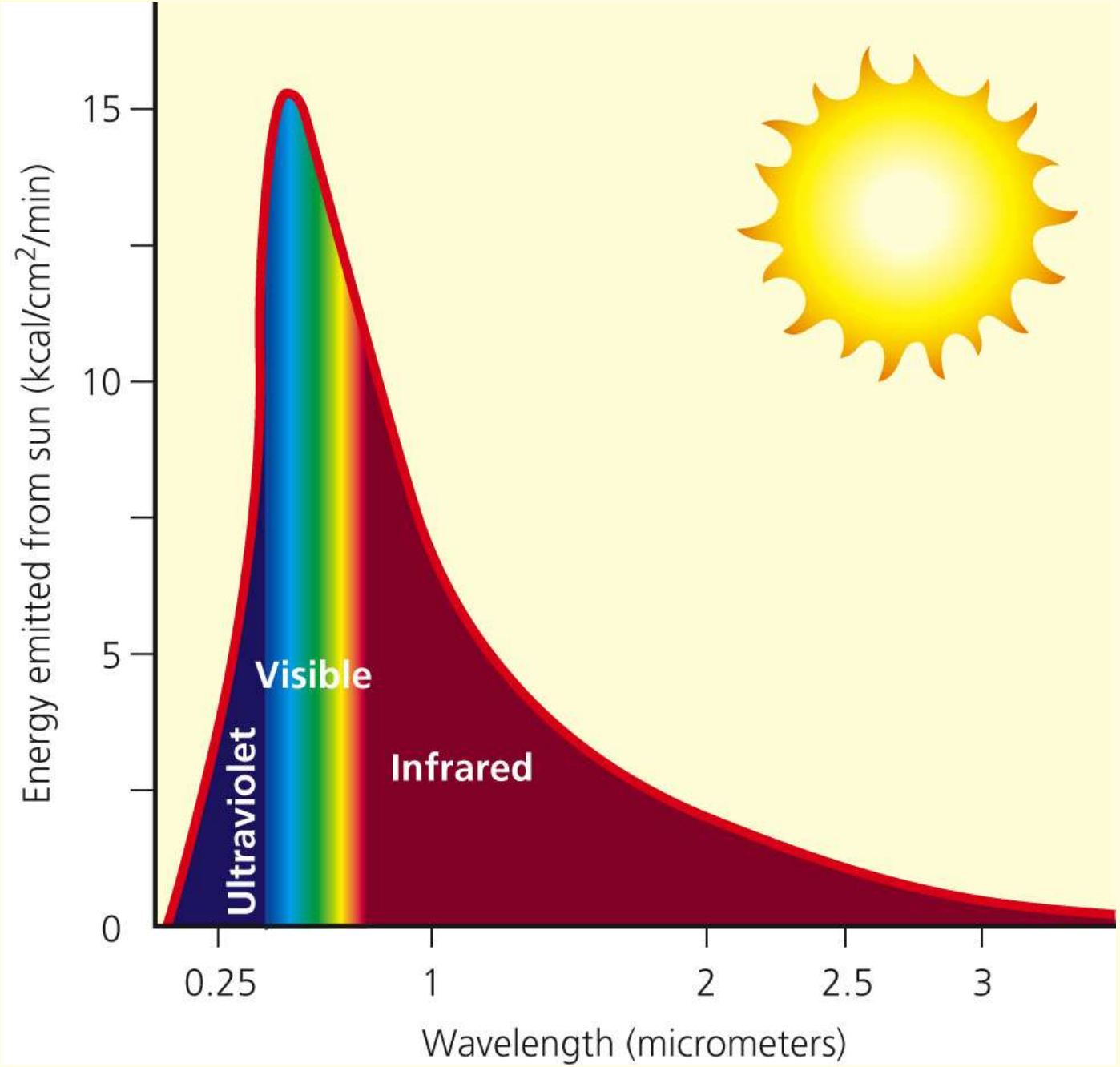

Energy emitted from sun (kcal/cm²/min)
15
10
5
0
Visible
Ultraviolet
Infrared
0.25
1
2
2.5
3
Wavelength (micrometers)

Fig. 2-7, p. 34

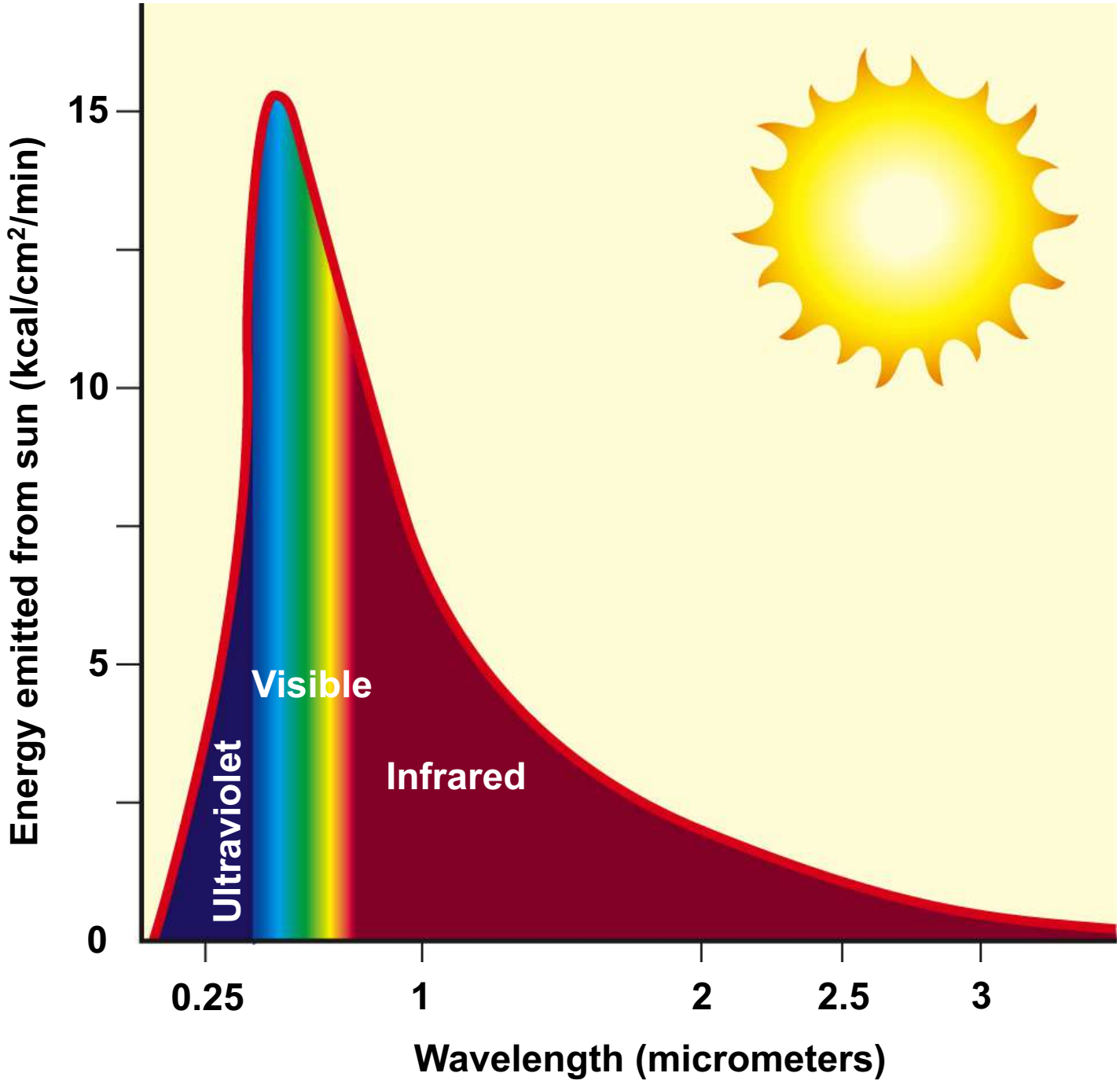

Energy emitted from sun (kcal/cm²/min)
15
10
5
0
Ultraviolet
Visible
Infrared
0.25
1
2
2.5
3
Wavelength (micrometers)

Fig. 2-7, p. 34

Energy Quality (1)

- **High-quality energy**
  - Concentrated, high capacity to do work
  - High-temperature heat
  - Nuclear fission
  - Concentrated sunlight
  - High-velocity wind
  - Fossil fuels

Energy Quality (2)

- **Low-quality energy**
  - Dispersed
  - Heat in atmosphere
  - Heat in ocean

Laws of Thermodynamics

- **First law of thermodynamics**
  - Energy input = Energy output
  - Energy is neither created or destroyed
  - Energy only changes from one form to another
- **Second law of thermodynamics**
  - Energy use results in lower-quality energy
  - Dispersed heat loss

Consequences of the Second Law of Thermodynamics

- Automobiles
  - ~13% moves car
  - ~87% dissipates as low-quality heat into the environment
- Incandescent light bulb
  - ~5% useful light
  - ~95% heat

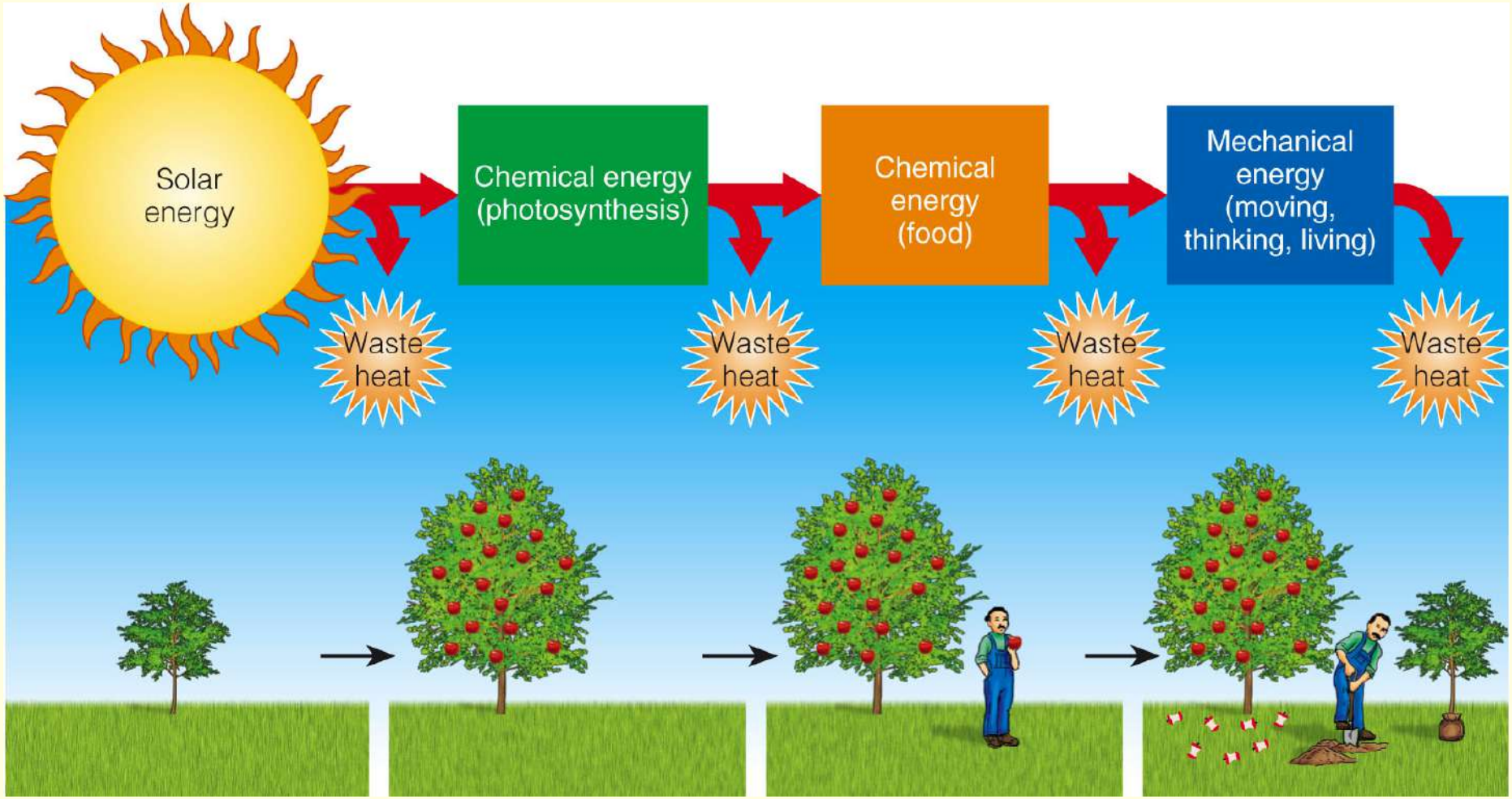

Solar energy
Chemical energy (photosynthesis)
Chemical energy (food)
Mechanical energy (moving, thinking, living)
Waste heat
Waste heat
Waste heat
Waste heat

Fig. 2-8, p. 36

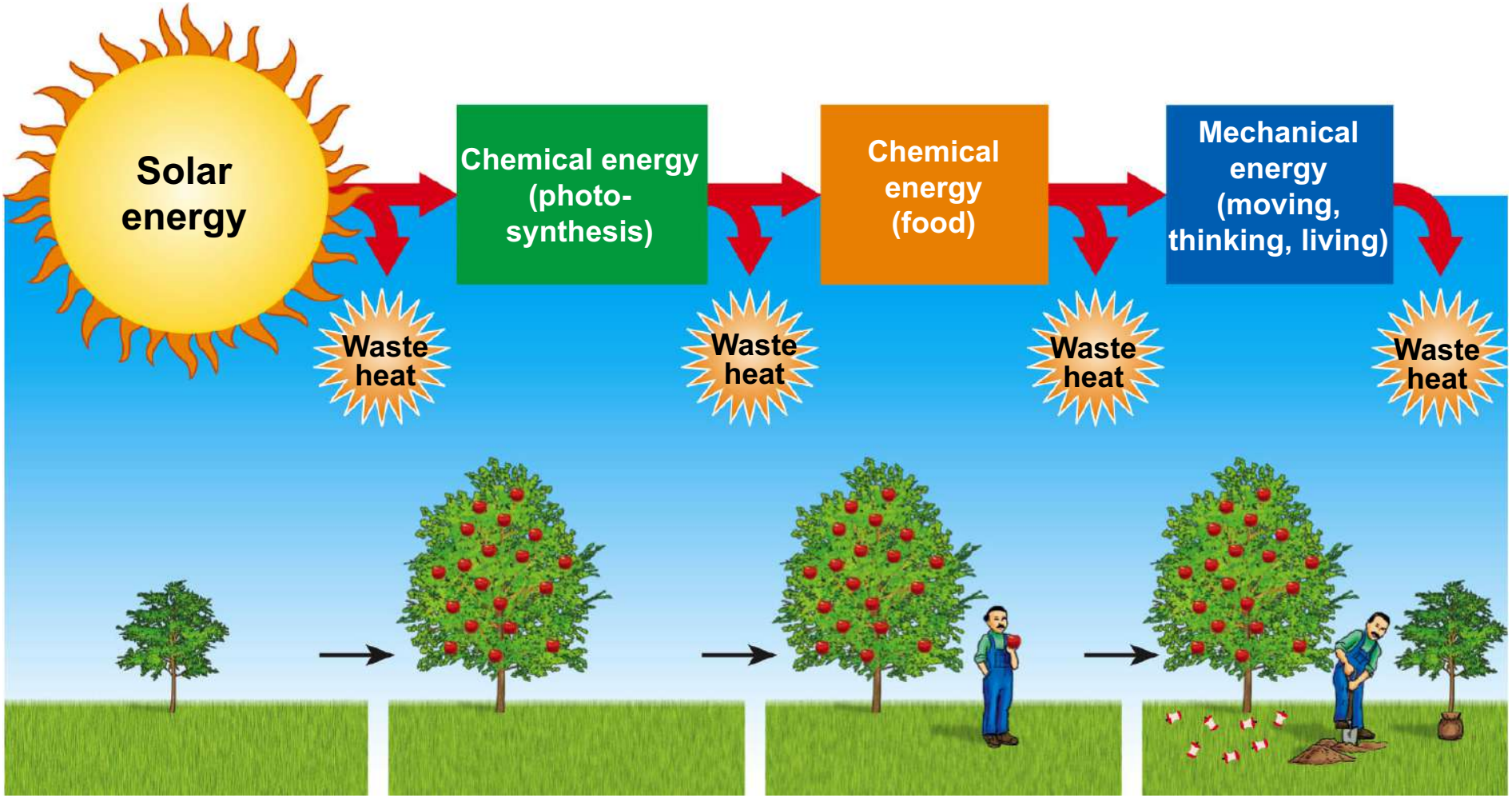
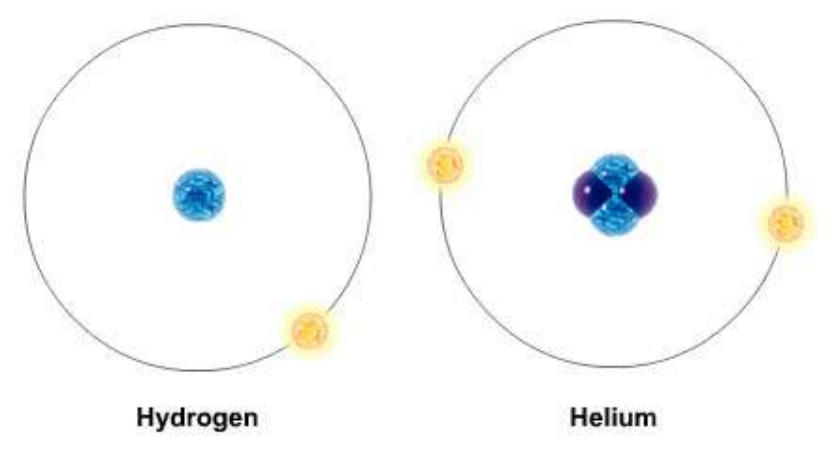

Solar energy
Chemical energy (photo-synthesis)
Chemical energy (food)
Mechanical energy (moving, thinking, living)
Waste heat
Waste heat
Waste heat
Waste heat

Fig. 2-8, p. 36

Three Big Ideas of This Chapter

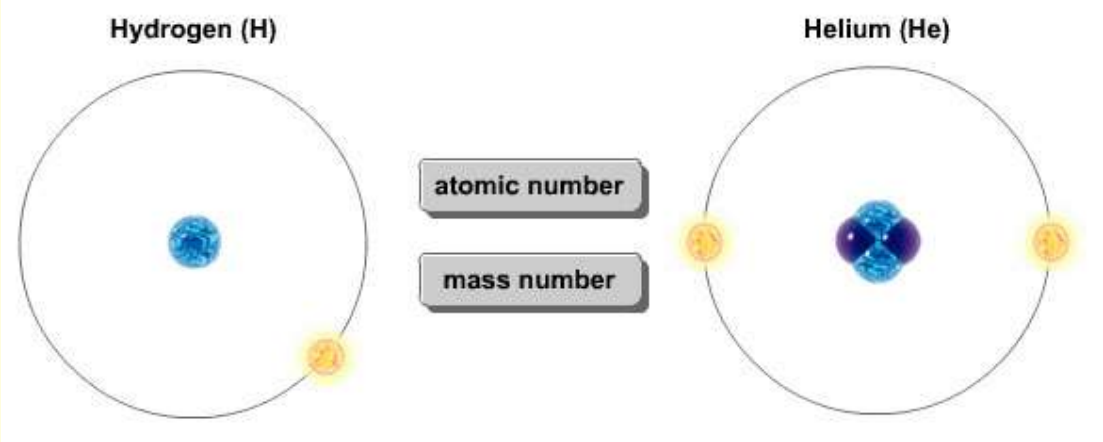
- There is no away
  - Law of conservation of matter
- You cannot get something for nothing
  - First law of thermodynamics
- You cannot break even
  - Second law of thermodynamics

Animation: Subatomic particles



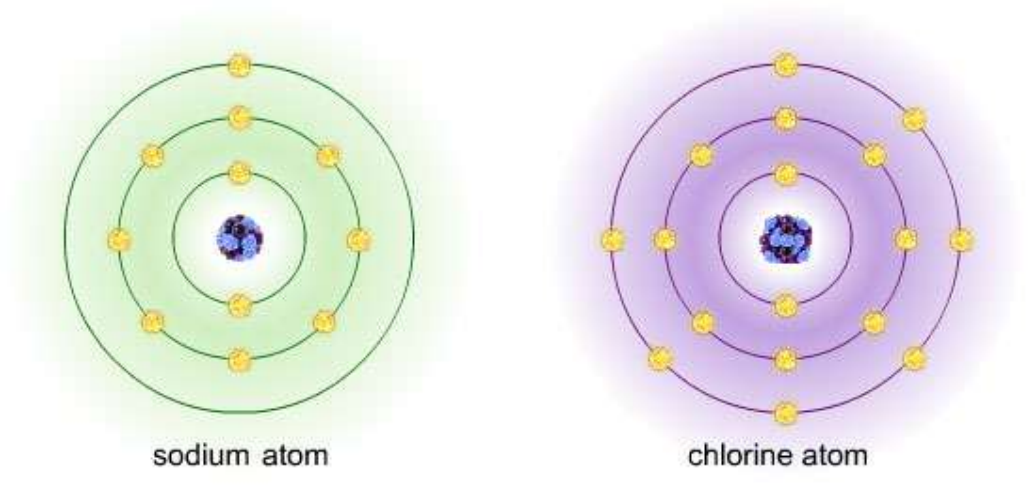
PLAY ANIMATION

Animation: Atomic number, mass number



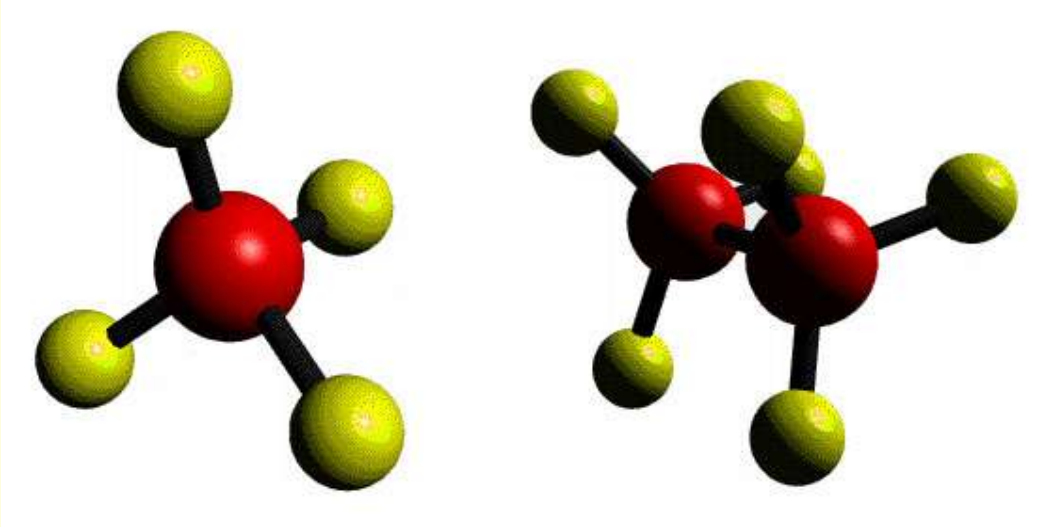
PLAY ANIMATION

Animation: Ionic bonds



PLAY ANIMATION

Animation: Carbon bonds



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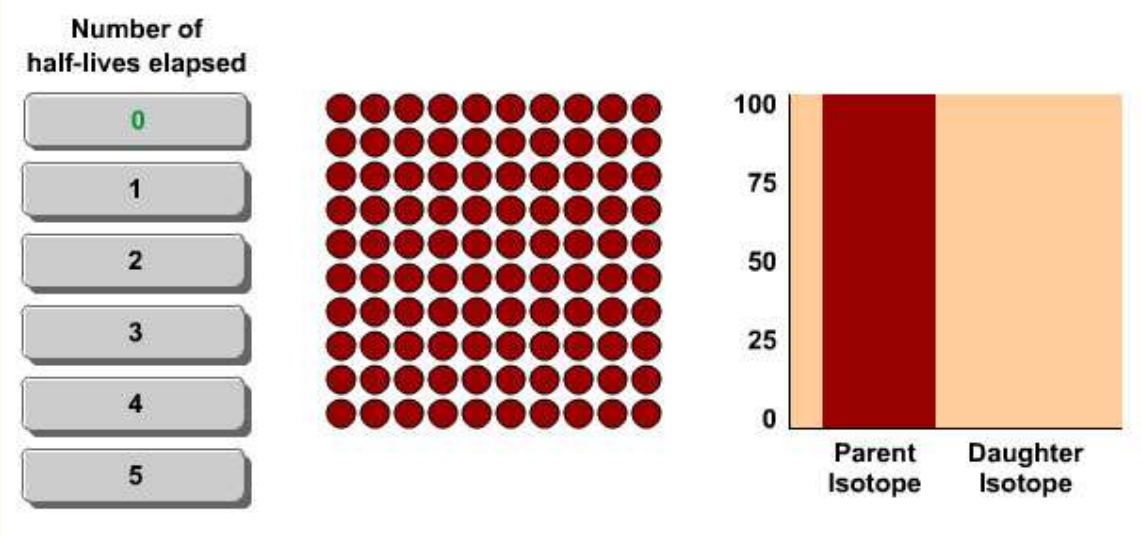
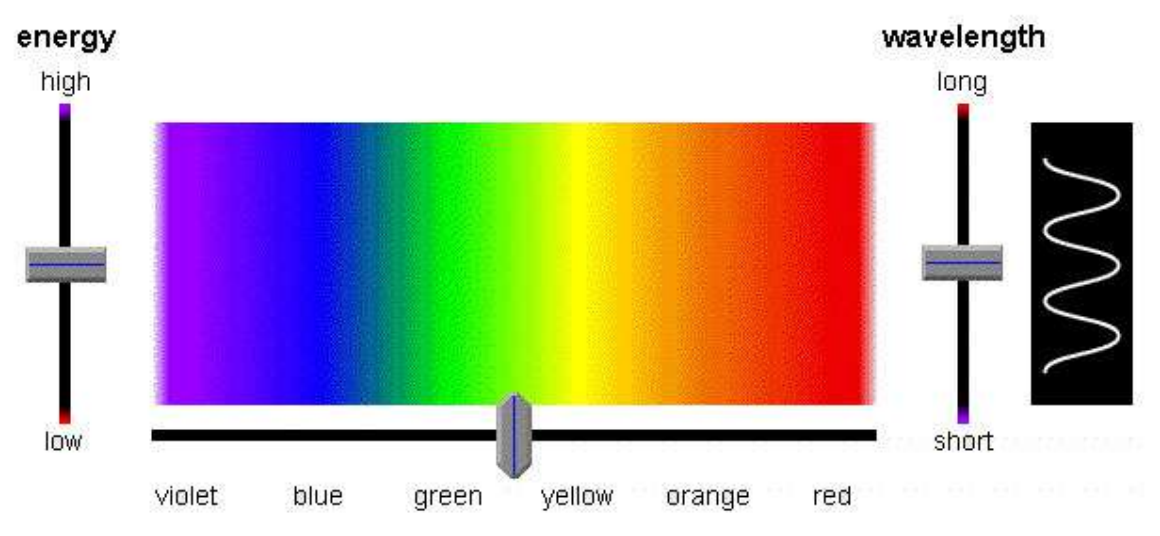
Animation: Half-life



PLAY ANIMATION

Animation: Visible light

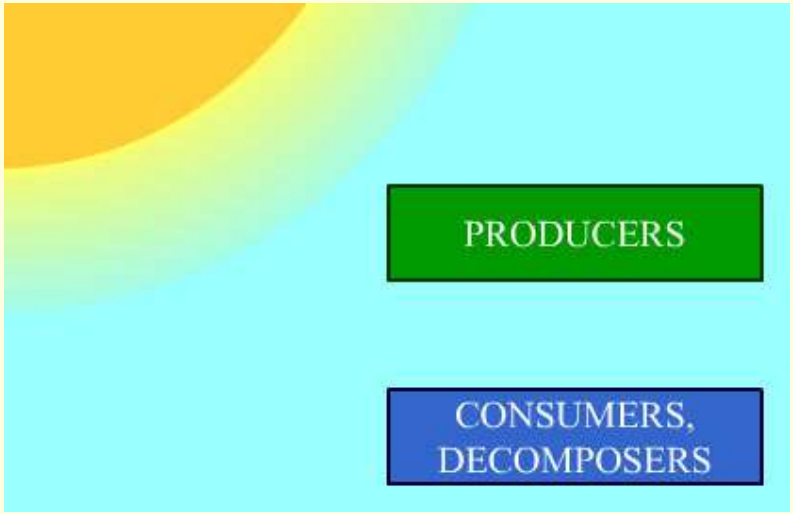


PLAY ANIMATION

Animation: Total energy remains constant

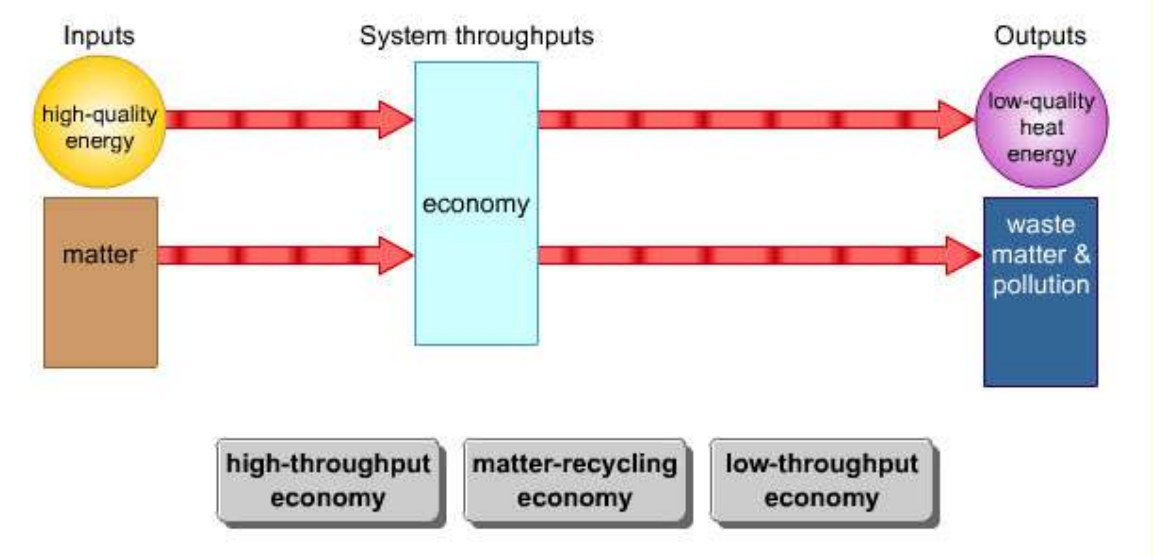
PLAY ANIMATION

Animation: Energy flow



PLAY ANIMATION

Animation: Economic types

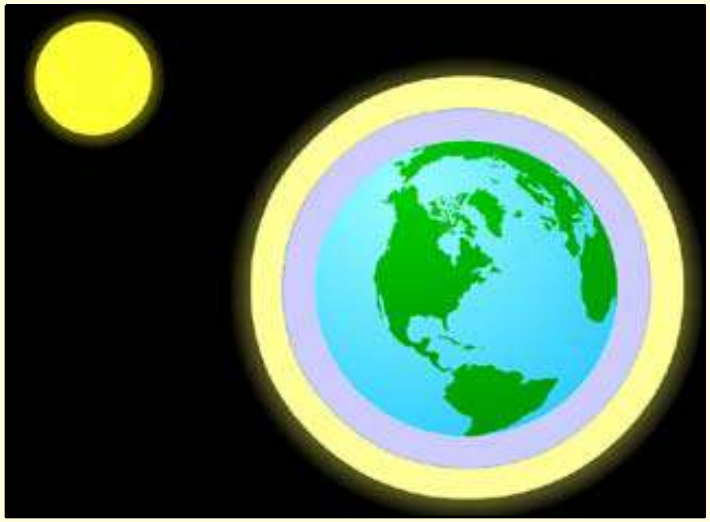


PLAY ANIMATION

Animation: Martian doing mechanical work

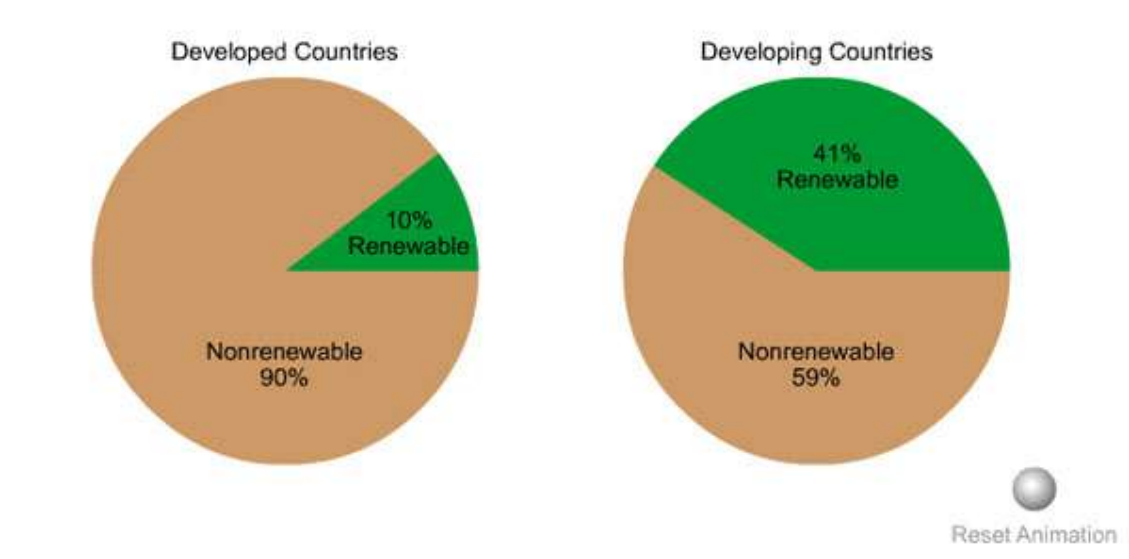
PLAY ANIMATION

Animation: Energy flow from Sun to Earth



PLAY ANIMATION

Animation: Energy Use

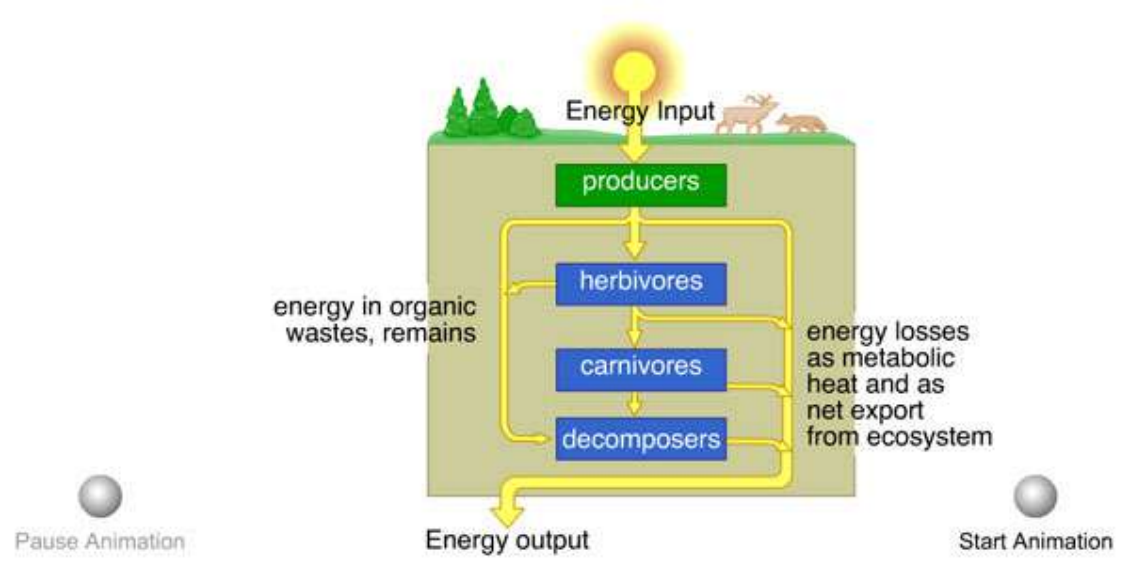


PLAY ANIMATION

Animation: Hubbard Brook Experiment

PLAY ANIMATION

Animation: Categories of Food Webs



PLAY ANIMATION