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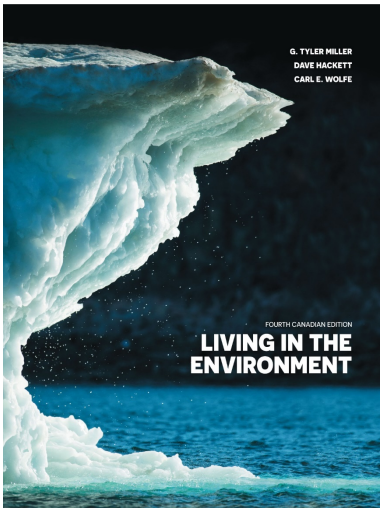

prepared by

Ian Dawe

Chapter 3

Science, Systems, Matter, and Energy

Key Concepts

What is **science**?

How and why do we **model** complex systems?

What are **matter** and **energy**?

- Different forms of matter and energy
- Physical, chemical, or nuclear changes
- Laws of conservation of matter and thermodynamics

How do these principles relate to environmental issues?

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The Nature of Science

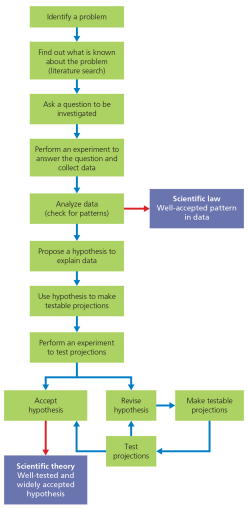
Scientific method

Reliability of results depends on

- Skepticism
- Reproducibility
- Peer review

Scientific theory

Scientific/natural law



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Notes on the Scientific Method

Scientific method relates cause and effect through systematic reasoning.

Science is based on pure reason and therefore theoretically transcends culture, language, etc.

"Proof" is a term reserved for mathematics: science provides "evidence" that supports or refutes a hypothesis.

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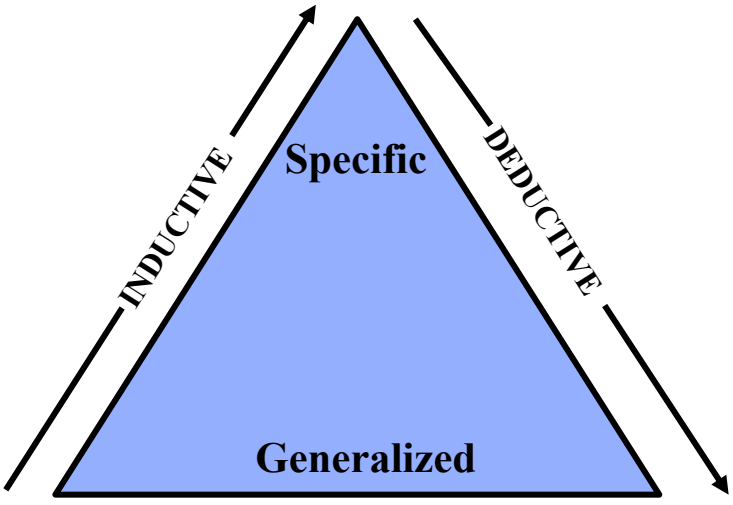
Scientific Reasoning



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How Valid Are Scientific Results?

Proof *vs*. overwhelming evidence

Frontier *vs*. consensus science

– Tentative proposal *vs*. supported and peer-reviewed

Distinguishing junk science from true science

– Reliability and objectivity of sources

– Verification by peers and experts

– Logically consistent conclusions

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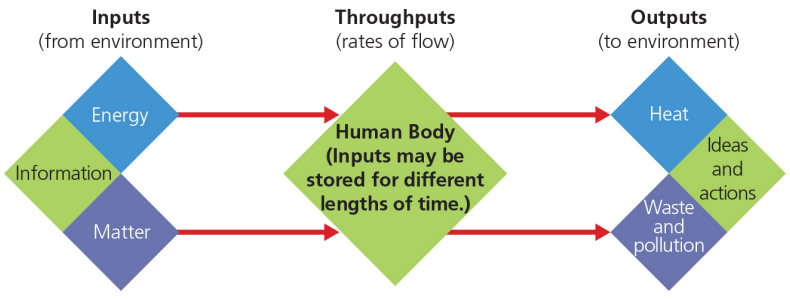
Models and Behaviour of Systems



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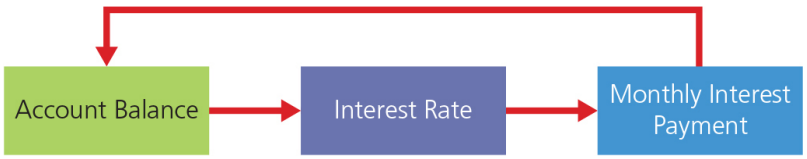
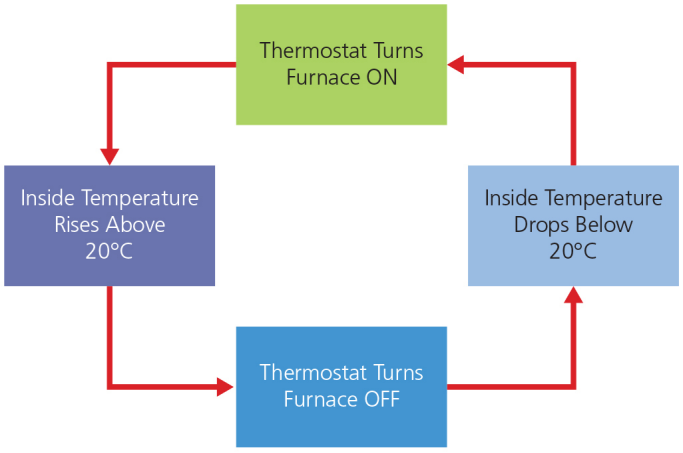
Positive Feedback



Negative Feedback



Factors Affecting Complex Systems

Time delays

– Measuring effects of inputs challenging

– Tipping point:

• Minimal changes until past a threshold

Synergy

– Combined effects > Sum of separate interactions

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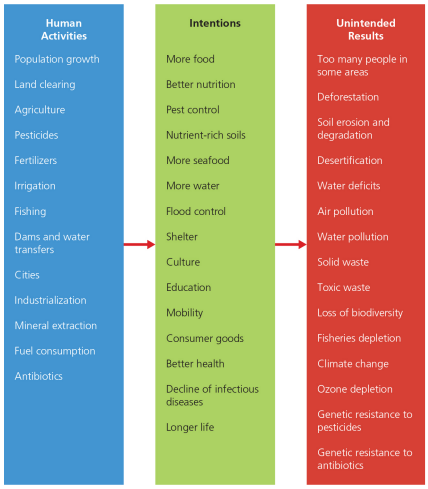
How Can We Anticipate Environmental Surprises?



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What Are Nature's Building Blocks?

Matter has mass and takes up space.

Elements ⟶ compounds

Atoms ⟶ molecules

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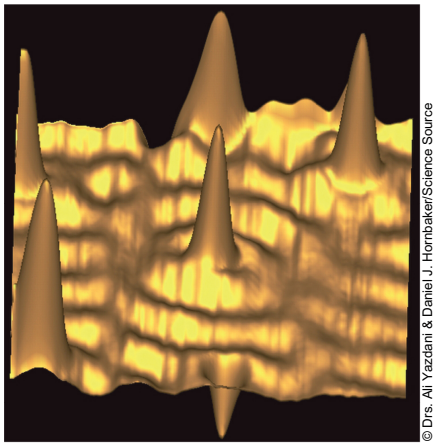
Seeing Atoms



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What Are Atoms Made Of?

Atoms are made of elementary particles, including:

Protons and neutrons - Both found in the nucleus

Electrons - Found orbiting the nucleus

Atoms have **atomic number** (# of protons) and **mass number** (# of protons + # of neutrons)

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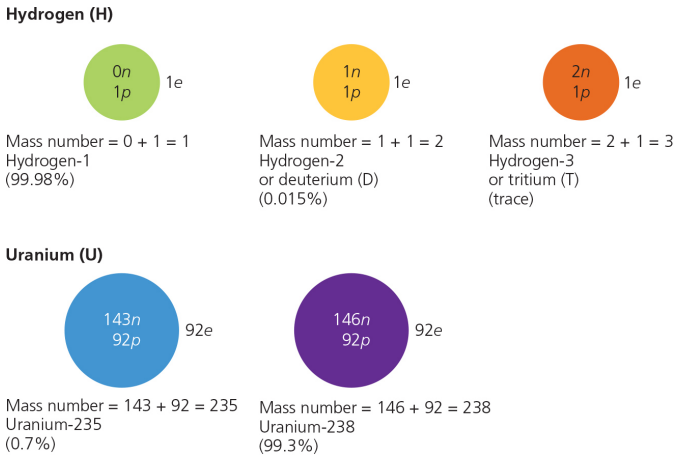
Isotopes



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Ions and Concentration

Ions

– Atoms that have lost or gained electron(s)

– Positive (+) or negative (–)

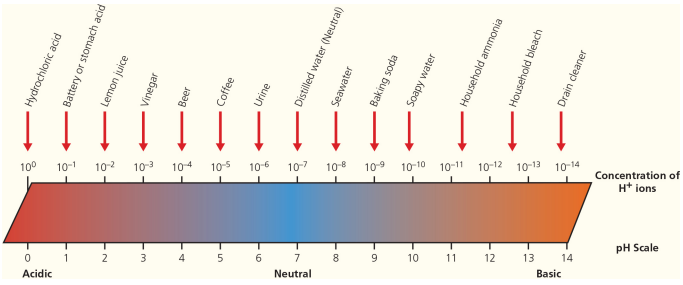
Concentration

– Amount of a substance (or ion) in a volume of air or water

The pH Scale

Acidity or basicity = concentration of H^+ ions

pH units = 10 x $[H^+]$



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Compounds

Atoms are joined together to make compounds.

Atoms in compounds are held together by (essentially) two kinds of forces:

Ionic (based on charge, i.e., NaCl)

Covalent (based on sharing of electrons in a bond, i.e., H_2O)

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Types of Compounds

Organic

Primarily built from carbon

- Hydrocarbons
- Chlorinated hydrocarbons
- Simple carbohydrates
- Biopolymers or macromolecules
  - Complex carbohydrates
  - Proteins
  - DNA

Inorganic

No C-C or C-H bonds

- Salts
- Water
- Nitrous oxide (N_2O)
- Sulfur dioxide (SO_2)
- Carbon dioxide (CO_2)
- Ammonia (NH_3)

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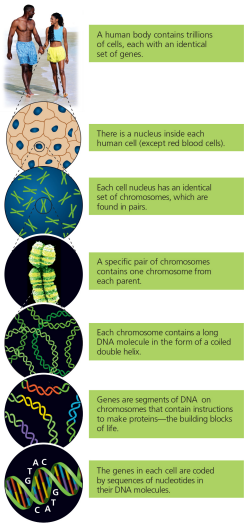
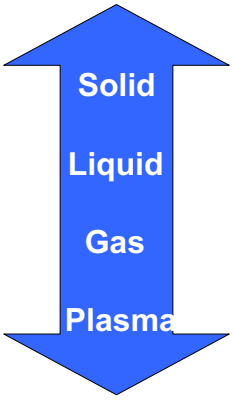
DNA and Genes



What Are Four States of Matter?

States of matter describe the arrangement and energy of molecules or atoms.



Most orderly and compact
Lowest energy

Least orderly or compact
Highest energy

What Is Matter Quality?

How useful is this form of matter as a **resource**?

- Availability
- Concentration

Material efficiency

- Or resource productivity
- Total amount of material needed to produce each unit of goods and services

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What Is Energy?

The capacity to do work and transfer heat

Comes in two major forms:

Kinetic energy, possessed by matter and shown in mass and speed

Potential energy, stored in a system for later use

Energy can be converted between these two forms.

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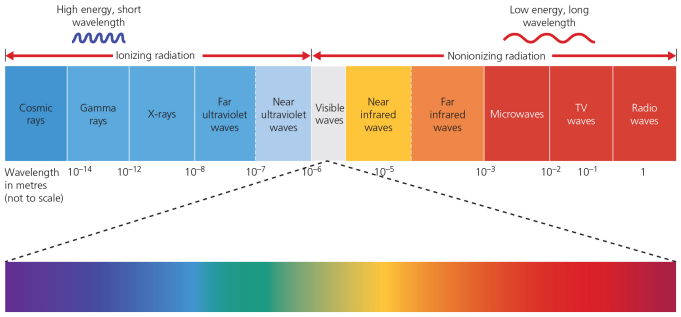
What Is Electromagnetic Radiation?

Oscillating waves of electric and magnetic fields carry energy.



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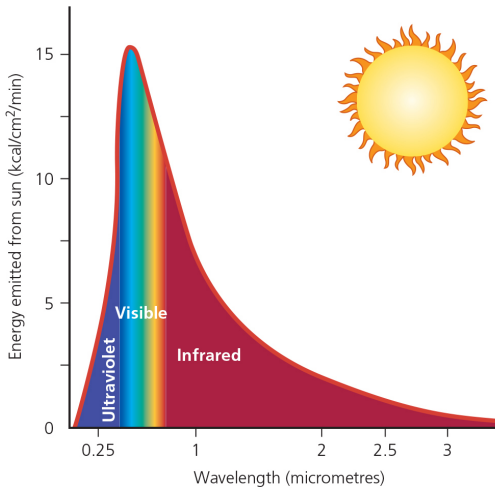
Solar Capital



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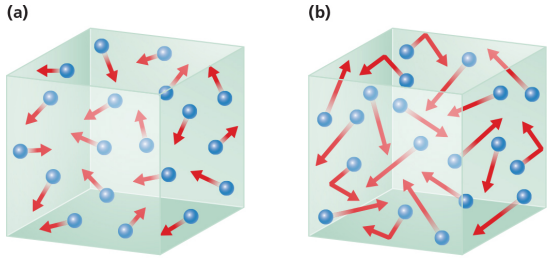
What Is Heat?

Heat is the kinetic energy of atoms moving within a substance.



Longer arrows mean higher average speed.

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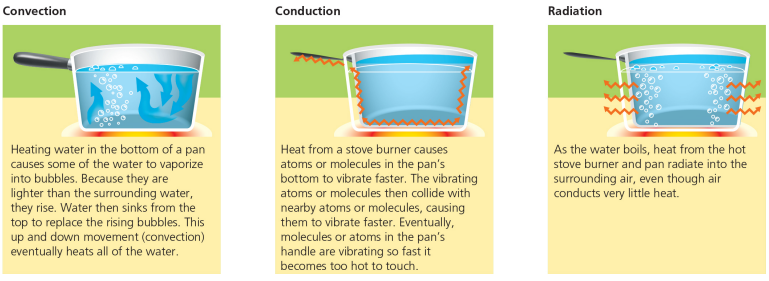
How Is Heat Transferred?

Heat: Total kinetic energy of the molecules and atoms in a substance

Temperature: Average speed of the molecules in a substance



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Edible water bottles

Why study chemistry in environmental science?

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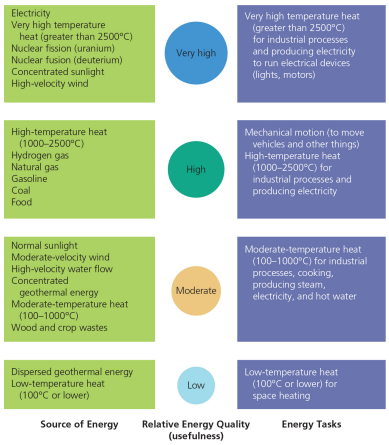
What Is Energy Quality?

Measures the ability of energy to do useful work



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Physical *vs.* Chemical Change

Conservation of Matter: Matter cannot be destroyed or created; it can only change forms!

Physical

– Same chemical compound

– Same types of bonds

– Different spatial arrangement or form

Chemical

– Different chemical compounds

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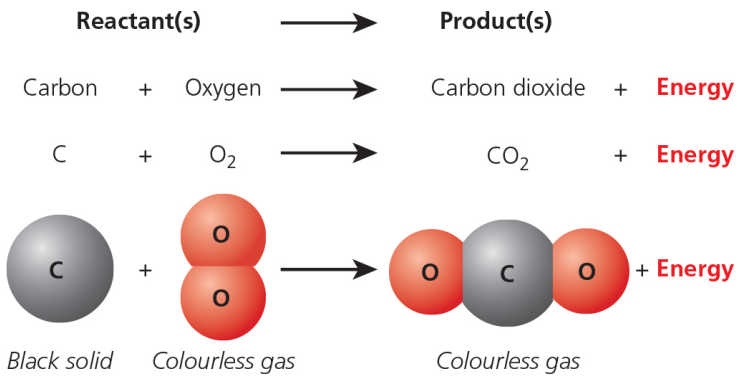
Chemical Reactions



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Balancing Chemical Equations

Must satisfy the law of conservation of matter

$H_2O \rightarrow H_2 + O_2$ — unbalanced
2 H atoms; 1 O atom → 2 H atoms; 2 O atoms

$2\,H_2O \rightarrow H_2 + O_2$ — unbalanced
4 H atoms; 2 O atom → 2 H atoms; 2 O atoms

$2\,H_2O \rightarrow 2\,H_2 + O_2$ — balanced
4 H atoms; 2 O atom → 4 H atoms; 2 O atoms

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How Harmful Are Pollutants?

Severity of harm depends on

- Chemical nature of pollutant
- Concentration (ppm *vs*. ppb)
- Persistence
  - Degradable and biodegradable
  - Persistent or slowly degradable
  - Nondegradable

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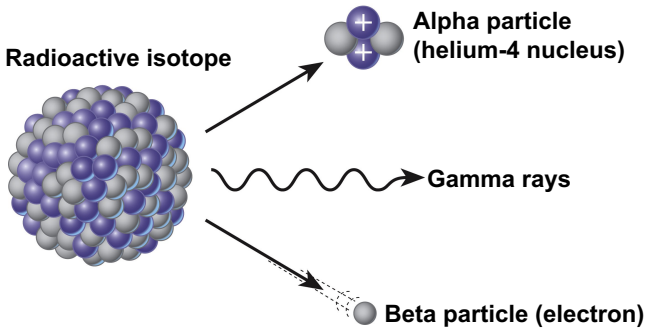
What Is Natural Radioactivity?



Spontaneous regular emission of particles or energy

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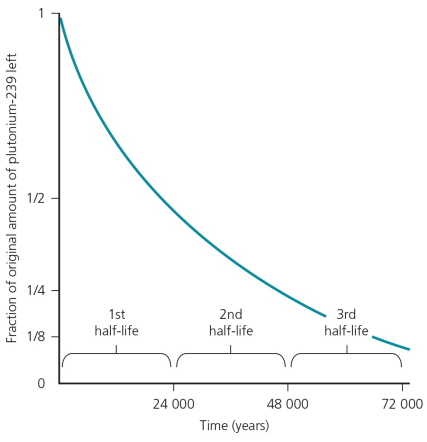
Radioactive Half-Life

The amount of time needed for half of the nuclei in a sample to decay



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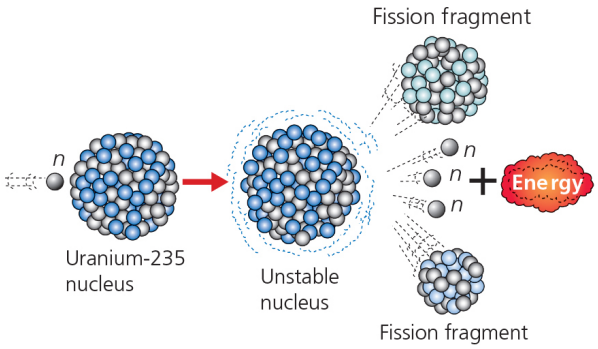
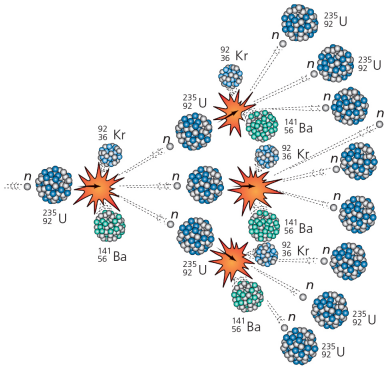
What Is Nuclear Fission?

Splitting heavy nuclei
Use neutrons to start fission



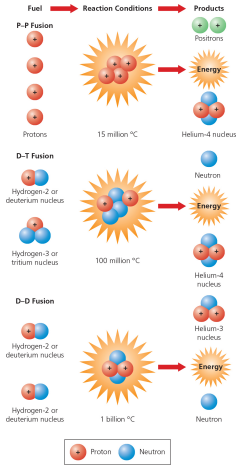
Fission: Chain Reaction

Critical mass



What Is Nuclear Fusion?

Forcing light nuclei to combine to form a heavier nucleus



The First Law of Thermodynamics

Energy can change form but cannot be created or destroyed.

You cannot get something from nothing.

This is a law that cannot be broken.

Sometimes called the law of **enthalpy**

The Second Law of Thermodynamics

As energy is transformed, some is always lost as lower quality energy (heat).

You cannot even break even.

Sometimes called the law of **entropy**

Examples:

– Gasoline-powered vehicles

– Incandescent lightbulbs

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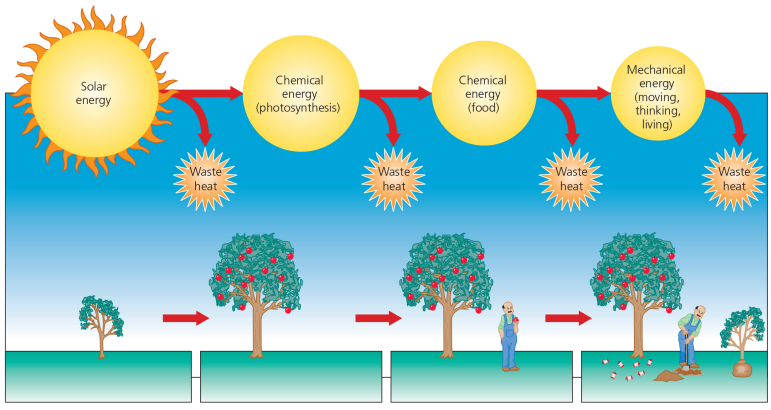
The Second Law in Natural Systems



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Matter and Energy Laws and the Environment: What Is a High-Throughput Economy?

High waste

High input of matter + high-quality energy

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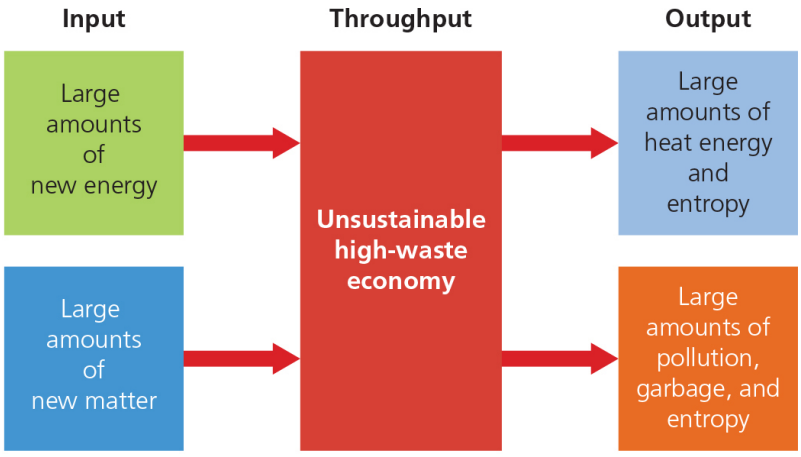
Matter and Energy Laws and the Environment: What Is a High-Throughput Economy?



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Matter and Energy Laws and the Environment: What Is a Low-Throughput Economy?

Matter recycling and reuse

Reduce overall energy throughput

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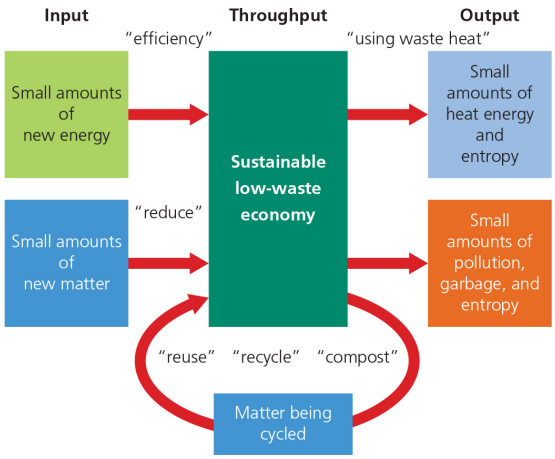
Matter and Energy Laws and the Environment: What Is a Low-Throughput Economy?



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Conclusion

Understanding science is essential to understanding environmental systems.

Matter and energy make up our world.

The interchange of these is governed by chemical/physical laws.

