Environmental Science, 15e

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Science, Matter, Energy and Systems

Core Case Study: Experimenting with a Forest

- In New Hampshire, scientists examined changes in water flow/soil nutrient content in a(n):
  - Control area of an undisturbed mature forest
  - Experimental area of a nearby deforested site
- What did the comparison of the two conditions tell the scientists?
- What does this tell us about what scientists do?

2.1 What Do Scientists Do?

- To find out how nature works, scientists:
  - Collect data
  - Develop
    - Hypothesis
    - Theories
    - Laws

Observations, Experiments, and Models Answer Questions About Nature

- Scientists discover how nature works by assuming cause and effect patterns
- To understand the patterns, scientists:
  - Make careful observations
  - Develop hypotheses
  - Take measurements
  - Experiment and create models
  - Use knowledge learned to describe and predict what happens in nature

Scientists Are Curious, Skeptical, and Demand Evidence

- Scientists are skeptical of new data
- During the peer review process, what do scientists publish?
  - Methods they used
  - Results of their experiments
  - Reasoning behind their hypotheses

Critical Thinking Is Important in Science

- What are the four steps in scientific critical thinking?
  - Be skeptical about what you read or hear
  - Look at the evidence and evaluate it
  - Be open to many viewpoints and evaluate each
  - Identify and evaluate your personal assumptions – be sure to distinguish facts from opinions

Creativity is Important in Science

- Imagination, creativity, and intuition are vital tools in science
- “There is no completely logical way to a new scientific idea”
  - – Albert Einstein

Developing Scientific Theories

- The goal of scientists is to develop theories and laws based on facts and data that explain how the physical world works
- A scientific theory:
  - Has been widely tested
  - Is supported by extensive evidence
  - Is accepted as being a useful explanation of some phenomenon by most scientists in a particular field or related fields of study

Developing Scientific Laws

- A scientific law
  - Is a well-tested and widely accepted description of events or actions of nature that are repeatable in the same way
  - Cannot be broken except by discovering new data that lead to changes in the laws

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

- Reliable science
  - Data, hypotheses, models, theories, and laws widely accepted by the field's experts
- Unreliable science
  - Has not been rigorously peer reviewed or has been discarded as a result of this peer review
- Tentative science
  - Not widely tested or accepted

Science Has Some Limitations

- Scientists cannot prove or disprove anything absolutely
  - There are inherent uncertainties in measurements, observations, and models
  - Scientists use words such as “overwhelming evidence” to clarify probability or certainty
- Being human, scientists are not free from bias, but peer review helps to reduce personal bias

The Natural World is Complex and Difficult to Measure

- Many variables cannot be tested individually
  - Scientists use mathematical models that can take these into account
- Some measurements cannot be accurately determined
  - Scientists use statistical tools to estimate these numbers

2.2 What Is Matter and What Happens When It Undergoes Change?

- Matter is organized into atoms, ions and molecules, which together make up elements and compounds
- Matter cannot be created or destroyed during physical or chemical changes (law of conservation of matter)

Matter Consists of Elements and Compounds

- Matter has mass and takes up space as:
  - Three physical states: solid, liquid, or gas
  - Two chemical forms: elements (all the same atoms) or compounds (combinations of more than one type of atom)
- Elements cannot be chemically broken down into simpler forms
  - Represented by a one- or two-letter symbol (C=carbon, Au=gold)

Chemical Elements: Mercury and Gold

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Chemical Elements Used in This Book

TABLE 2-1 Chemical Elements Used in This Book

Element	Symbol	Element	Symbol
arsenic	As	lead	Pb
bromine	Br	lithium	Li
calcium	Ca	mercury	Hg
carbon	C	nitrogen	N
copper	Cu	phosphorus	P
chlorine	Cl	sodium	Na
fluorine	F	sulfur	S
gold	Au	uranium	U

An Atom is the Basic Building Block of Matter

- The smallest building block of matter that an element can have that will still retain its chemical properties
  - Each atom has three subatomic particles
    - Protons with a positive electric charge
    - Electrons with a negative electric charge
    - Neutrons with no electric charge
  - Each atom has a small central nucleus that contains its protons and neutrons

Atomic Number, Atomic Mass, and Isotopes

- Atomic number – the number of protons in an atom's nucleus
- Mass number – the total number of neutrons and protons in an atom's nucleus
- Isotopes of an element have the same atomic number, but a different mass number (the same number of protons but a different number of neutrons)

Molecules and Ions Are Building Blocks of Matter

- Molecules
  - Two or more atoms of either the same or different elements held together by chemical bonds (forces)
- Ions
  - A group of atoms with one or more net positive or negative charges

Acidity

- The concentration (amount) of hydrogen ions ($H+$) and hydroxide ions ($OH−$) in a substance
  - Measured with a scale known as pH
  - An acidic solution has a pH below 7 and a basic solution has a pH above 7
  - A neutral solution has a pH of 7

Chemical Ions in This Book

TABLE 2-2 Compounds Used in This Book

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

Chemical Formulas

- A shorthand expression of the number of each type of atom or ion in a compound
  - Written using symbols for each element in the compound (molecule) as listed in the periodic table
  - Subscripts following letters in a chemical formula indicate the number of atoms (H_2O)

Compounds Used in This Book

TABLE 2-3 Chemical Ions Used in This Book

Positive Ion	Symbol	Components
hydrogen ion	H^+	One hydrogen atom, one positive charge
sodium ion	Na^+	One sodium atom, one positive charge
calcium ion	Ca^{2+}	One calcium atom, two positive charges
aluminum ion	Al^{3+}	One aluminum atom, three positive charges
ammonium ion	NH_4^+	One nitrogen atom, four hydrogen atoms, one positive charge
Negative Ion	**Symbol**	**Components**
chloride ion	Cl^-	One chlorine atom, one negative charge
hydroxide ion	OH^-	One oxygen atom, one hydrogen atom, one negative charge
nitrate ion	NO_3^-	One nitrogen atom, three oxygen atoms, one negative charge
carbonate ion	CO_3^{2-}	One carbon atom, three oxygen atoms, two negative charges
sulfate ion	SO_4^{2-}	One sulfur atom, four oxygen atoms, two negative charges
phosphate ion	PO_4^{3-}	One phosphorus atom, four oxygen atoms, three negative charges

Organic Compounds Are the Chemicals of Life

- Organic compounds have at least two carbon atoms and various other elements
  - Hydrocarbons: contain carbon and hydrogen atoms
  - Simple carbohydrates: contain carbon, hydrogen and oxygen
  - Polymers: simple organic compounds (monomers) chemically bonded together

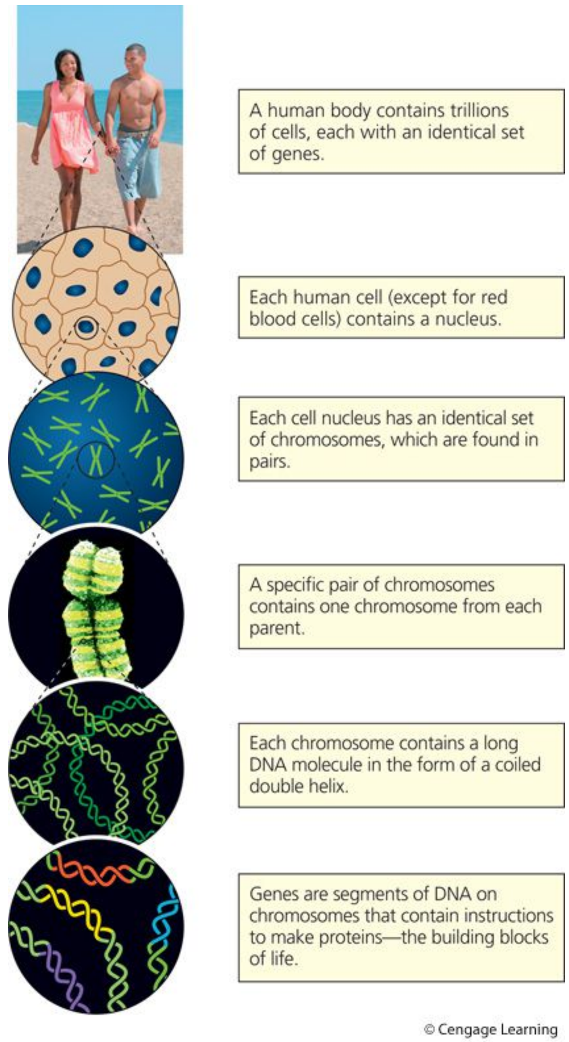
Polymers Are Essential to Life

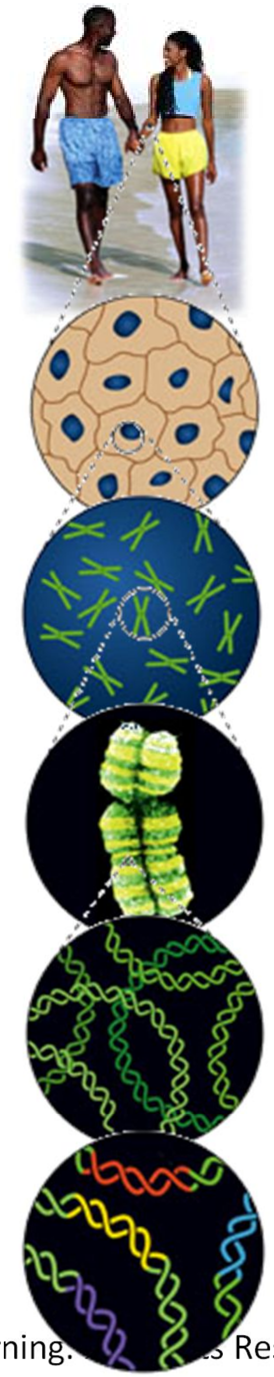
- What are the major types of polymers?
  - Complex carbohydrates: two or more monomers of simple sugars such as glucose
  - Proteins: formed by amino acids (that are monomers)
  - Nucleic acids: such as DNA and RNA that are formed by nucleotides (that are monomers)
- Lipids (fats, waxes): an essential macromolecule not made of monomers

Matter Comes To Life Through Cells, Genes, and Chromosomes

- Cells
  - The smallest units of life in all living organisms
- Genes
  - Composed of nucleotide sequences in DNA
  - Segments of DNA that code for genetic traits
- Chromosome
  - DNA molecule made up of thousands of genes

The Relationships among 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.

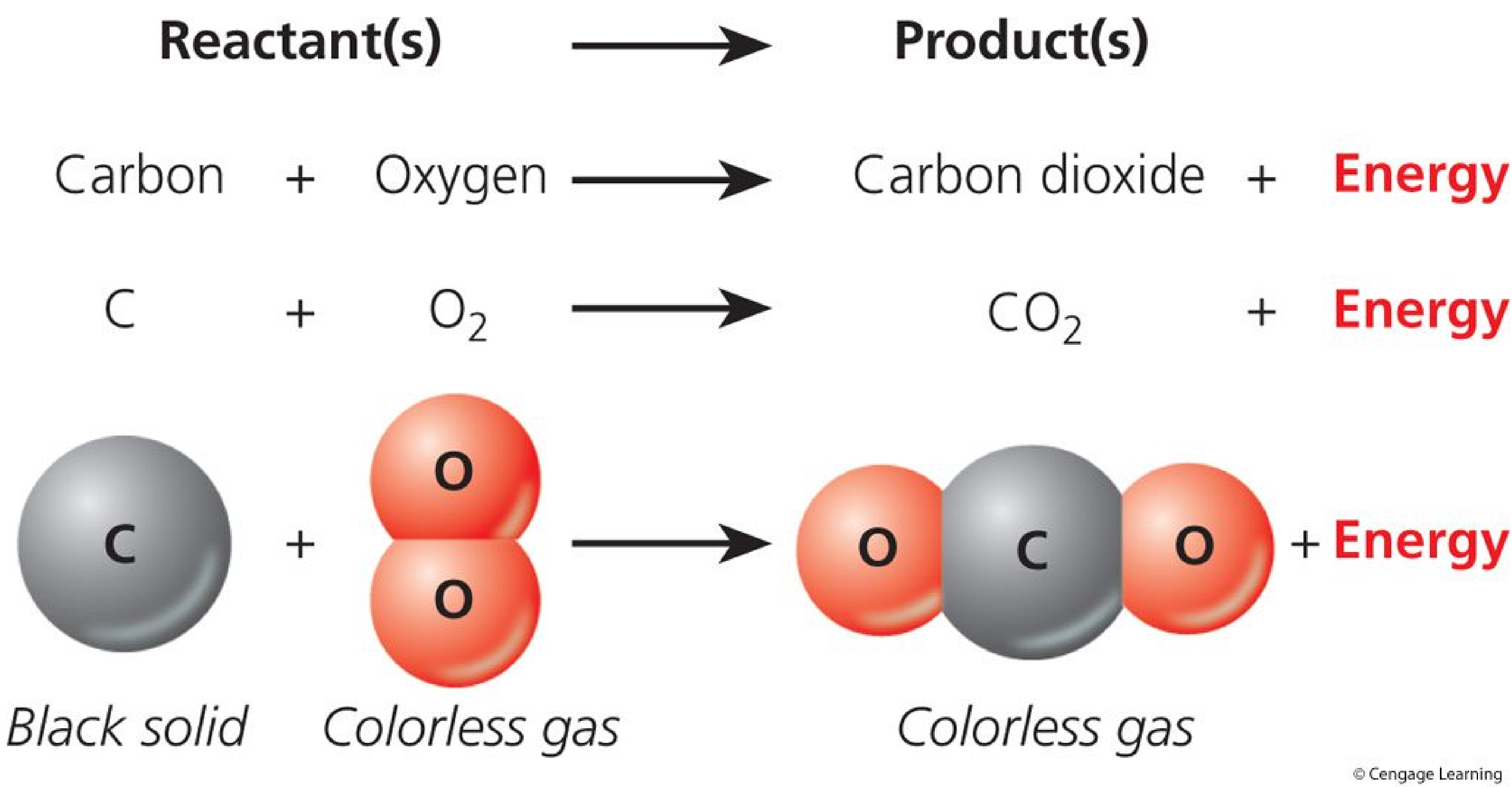
Genes are segments of DNA on chromosomes that contain instructions to make proteins—the building blocks of life.

Stepped Art

Matter Undergoes Physical, Chemical and Nuclear Changes

- Physical changes, such as changes in size or state (ice to water) do not involve changes in chemical composition
- Chemical reactions involve changes in chemical composition of the substances involved
  - Chemists use a chemical equation to show how the chemicals involved are arranged in a chemical reaction

A Chemical Equation: Coal → CO2



What Are the Three Nuclear Changes That Matter Can Undergo?

- Radioactive decay
- Nuclear fission
- Nuclear fusion

We Cannot Create or Destroy Atoms

- Law of conservation of matter
  - Physical or chemical changes can take place in chemical reactions, but no atoms are created or destroyed in the process

2.3 What Is Energy and What Happens When It Undergoes Change?

- No energy is created or destroyed when energy is converted from one form to another (first law of thermodynamics)
- Physical and chemical changes in which energy is converted from one form to another results in lower-quality or less-usable energy (second law of thermodynamics)

Energy Comes in Many Forms: Kinetic Energy

- Kinetic energy is associated with motion (wind, flowing water) and includes:
  - Heat or thermal energy: results in temperature changes of the objects involved
  - Electromagnetic energy: energy travels as waves due to changes in electric/magnetic fields

Energy Comes in Many Forms: Potential Energy

- Potential energy is stored and potentially available for use
  - Example: water stored behind a dam
- Potential energy can be changed to kinetic energy
  - Example: releasing water from behind a dam

Some Types of Energy Are More Useful Than Others

- High-quality, or concentrated energy, has a high capacity to do useful work
- Low-quality, or dispersed energy, has little capacity to do useful work

Energy Changes Are Governed By Two Scientific Laws

- First law of thermodynamics (law of conservation of energy)
  - We cannot get more energy out of a physical or chemical change than we put in
- Second law of thermodynamics
  - When energy is changed from one form to another, it always goes from a more useful to a less useful form

2.4 What Are Systems and How Do They Respond To Change?

- Sets of components that function/interact in a regular way
  - Inputs
  - Throughputs or flows
  - Outputs of both matter and energy
- Feedback loops can affect system behavior

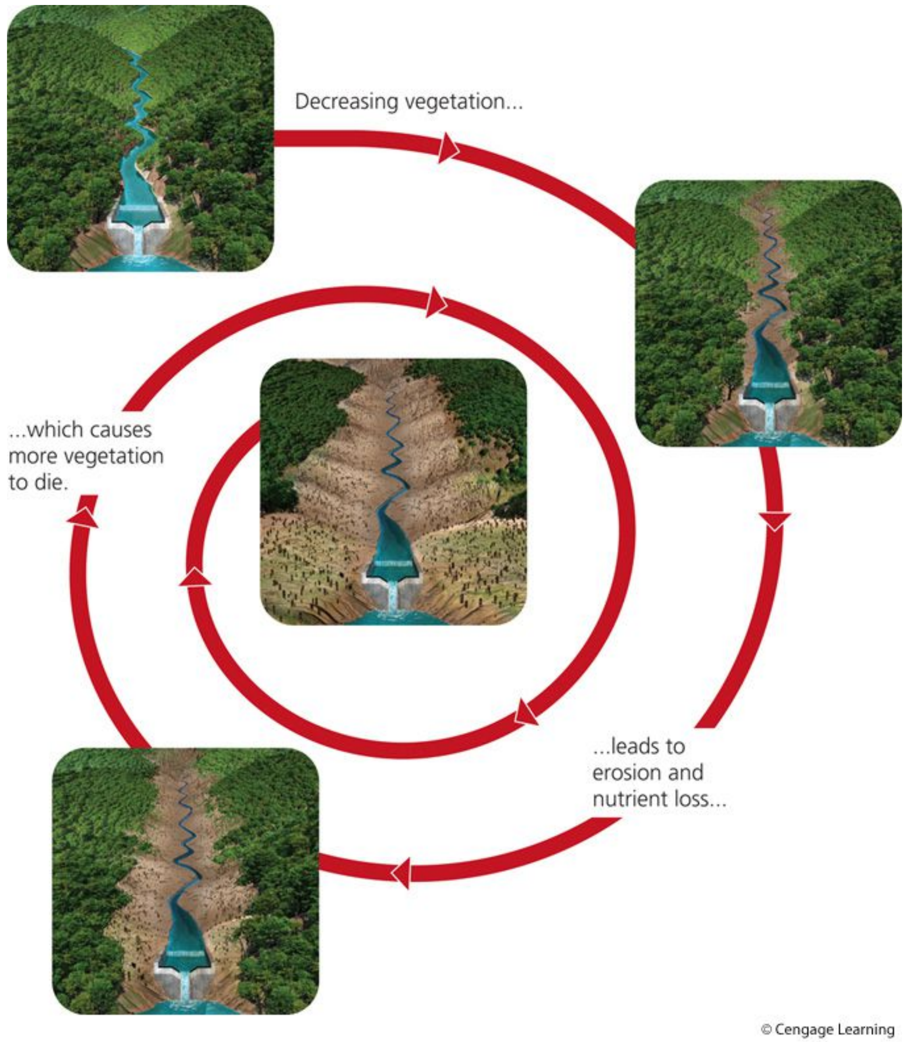
There Are Non-Living and Living Systems

- Non-living systems
  - Do not change their size or how they function in response to environmental changes
- Living systems
  - Do respond to environmental changes by changing their size, components, and behavior

Systems Respond to Change Through Feedback Loops

- Feedback
  - Any process that increases (positive feedback) or decreases (negative feedback) a change to a system
- Feedback loops
  - Occur when the output of matter or energy is fed back into the system as an input that leads to changes in that system

A Positive Feedback Loop



Additional Case Study: Powering Up America's Waterways

- Hydroelectric power generation
  - A practical application of the first two laws of thermodynamics
  - Release of water from a dam to a power plant converts potential energy to kinetic energy, spinning a turbine-powered generator to create electricity
  - A source of clean, sustainable energy

Additional Case Study: Powering Up America's Waterways – An Example

- The Grand Coulee Dam on the Columbia River in Washington State
  - "Hydropower makes up 7% of total U.S. electricity generation and continues to be the United States' largest source of renewable electricity, avoiding over 200 million metric tons of carbon emissions each year"

Additional Case Study: Powering Up America’s Waterways – Reflection

- Consider how waterways demonstrate kinetic and potential energy usage
  - How do the two laws of thermodynamics apply?
  - Why is hydropower sustainable?

America’s Waterways and Three Big Ideas

- The conservation of matter
  - No atoms of river water were created or destroyed
- Kinetic energy is converted to potential energy
  - Follows the conservation of energy and the first two laws of thermodynamics