ECOLOGY AND SUSTAINABILITY
Chapter 2
Science, Systems, Matter, and Energy

"It's A Small World After All"

Outline

The Nature of Science

A. Science assumes that events in the natural world follow orderly patterns and that, through observation and experimentation, these patterns can be understood. Scientists collect data, form hypotheses and develop theories, models and laws to explain how nature works.
   1. Scientists collect facts or scientific data.
   2. Based on observations of phenomenon, scientists form a scientific hypothesis—an unconfirmed explanation of an observed phenomenon to be tested.
   3. Parts of the scientific process are skepticism, reproducibility, and peer review.

B. A scientific theory is a verified, believable, widely accepted scientific hypothesis or a related group of scientific hypotheses.
   1. Theories are explanations that are likely true, supported by evidence.
   2. Theories are the most reliable knowledge we have about how nature works.

C. A scientific/natural law describes events/actions of nature that reoccur in the same way, over and over again.

D. There are many types of scientific methods used to gather data, formulate hypotheses, state theories and laws and, then, text them. Observation leads to a hypothesis, then to an experiment that produces results that lead to a conclusion. Variables/factors influence the gathering of data. In a controlled experiment, the scientist attempts to isolate and study the effect of one variable.
   1. In an experimental group, one chosen variable is changed.
   2. In a control group, the chosen variable is not changed.
   3. Multivariable analysis uses mathematical models to analyze interactions of many variables.

E. Scientists try to establish that a particular theory/law has a high probability of being true. They always include a degree of uncertainty.
   1. Scientists use both inductive reasoning and deductive reasoning to arrive at a general conclusion or hypothesis.
      a. Inductive reasoning uses specific observations and measurements to arrive at a general conclusion or hypothesis.
      b. Deductive reasoning uses logic to arrive at a specific conclusion based on a generalization or premise.

F. Paradigm shifts occur when new discoveries overthrow well-accepted scientific theory.

G. Frontier science is scientific results that have not been confirmed; sound science or consensus science results from scientific results that have been well tested and are widely accepted. Frontier science represents tentative results in the process of being validated.

H. Junk science is scientific results/hypotheses that have not been reviewed by peer scientists, which is scientists with competencies and skills comparable to the researcher describing his/her findings.
   1. Junk science is sometimes used as a label if it does not uphold/support a particular person's view.
   2. Media people mislead us in seeming to provide support from one who is not an expert in the field being discussed or who does not accept the consensus science.
   3. Consider the reliability of the individuals presenting the data, any particular point that they may be promoting; their scientific credentials; their funding sources. Determine if their conclusions are valid, if there has been impartial peer review, and the consensus view of experts in the field.

Models and Behavior of Systems

A. Scientists project the behavior of complex systems by developing a model of its inputs, throughputs (flows), and outputs of matter, energy, and information.
   1. Mathematical models consist of one or a series of equations to describe the likely behavior of a system
   2. They are useful when there are many interacting variables, a long time from and when controlled experiments are not feasible.

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3. They are used to answer a series of "if-then" questions.

B. Feedback loops can cause a system to do more of what it was doing (positive feedback) or less (negative feedback).

C. Prolonged time delays in a complex system may cause a weakening or failure of the feedback mechanisms.

D. A synergistic interaction results in the combined effects of a process being greater than the sum of the separate effects. Social science research suggests that 5-10% of a population working together influence other people.

E. Any action in a complex system has multiple effects that may be unintended and often have unpredictable effects. Crossing an environmental threshold can lead to a sudden shift in balance.

Types and Structure of Matter

A. Matter is anything that has mass and takes up space, living or not. It comes in chemical forms, as an element or a compound.
   1. An element is the distinctive building block that makes up every substance; chemically, elements are represented by a one- or two-letter symbol.
   2. Chemists classify elements by their chemical behavior by arranging them in a periodic table of elements.

B. The building blocks of matter are atoms, ions, and molecules.
   1. An atom is the smallest unit of matter that exhibits the characteristics of an element.
   2. An ion is an electrically charged atom or combinations of atoms.
   3. A molecule is a combination of two or more atoms/ions of elements held together by chemical bonds.

C. Each atom has a nucleus containing protons and neutrons. One or more electrons orbit the nucleus of an atom.
   1. A proton (p) is positively charged, a neutron (n) is uncharged and the electron (e) is negatively charged.
   2. Each atom has an equal number of positively charged protons in the nucleus and negatively charged electrons outside the nucleus, so the atom has no net electrical charge.
   3. Each element has a specific atomic number that is equal to the number of protons in the nucleus.
   4. Most of the mass of an atom is concentrated in the nucleus. The mass number of an atom equals the total number of neutrons and protons in its nucleus.
   5. Isotopes of an element are various forms of an element that have the same atomic number, but different mass number.

D. Atoms of some elements can lose or gain one or more electrons to form ions with positive or negative electrical charges.
   1. Elements known, as metals tend to lose one or more electrons, they are electron givers.
   2. Elements known, as nonmetals tend to gain more electrons, they are known as electron receivers.
   3. Positive or negative ions are shown as a superscript after the symbol.
   4. The amount of a substance in a unit volume of air, water, or other medium is its concentration.
   5. Hydrogen ions (H+) in a solution are a measure of how acidic or basic the solution. Neutral pH is 7, acid solutions are below 7, and basic solutions are above 7.

E. Chemical formulas are a type of shorthand to show the type and number of atoms/ions in a compound.
   1. Each element in the compound is represented by a symbol: H = hydrogen, N = nitrogen.
   2. Subscripts show the number of atoms/ions in the compound.
   3. Ionic compounds are made up of oppositely charged ions, (Na^+ and Cl^-).
   4. Compounds made of uncharged atoms are called covalent compounds (CH_4).

F. Organic compounds contain carbon atoms combined with one another and with various other atoms. Only methane (CH_4) has only one carbon atom.
   1. Hydrocarbons: compounds of carbon and hydrogen atoms
   2. Chlorinated hydrocarbons: compounds of carbon, hydrogen, and chlorine atoms
   3. Simple carbohydrates: specific types of compounds of carbon, hydrogen and oxygen atoms.

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G. Polymers are larger and more complex organic compounds which have molecular units, linked by chemical bonds; three major types are complex carbohydrates, proteins, and nucleic acids.
   1. Complex carbohydrates contain two or more monomers of simple sugars linked together.
   2. Proteins are formed by linking monomers of amino acids together.
   3. Nucleic acids are made of sequences of nucleotides linked together.
   4. Genes: specific sequences of nucleotides in a DNA molecule.
   5. Chromosomes: combinations of genes that make a single DNA molecule, plus some proteins.
   6. Genome: the complete sequence of DNA base pairs that combine to make up the chromosomes in a typical member of each species.

H. All compounds without the combination of carbon atoms and other elements' atoms are inorganic compounds.

I. All living things are composed of cells.
   1. Cells of eukaryotic organisms have a membrane, nucleus, and organelles.
   2. Cells of prokaryotic organisms have a membrane but no defined nucleus or organelles.
   3. Organic molecules are the building blocks of life.

J. Matter exists in four states, solid, liquid, and gaseous physical states and a fourth state known as plasma.
   1. Water exists as ice, liquid, or water vapor depending on its temperature.
   2. Plasma is a high-energy mixture of positively charged ions and negatively charged electrons. It is the most abundant form of matter in the universe, but very little is found on earth.
   3. Scientists make artificial plasmas in fluorescent light, arc lamps, neon signs, gas discharge lasers, TV and computer screens.

K. According to the usefulness of matter as a resource, it is classified as having high or low quality.
   1. High-quality matter is concentrated with great potential for usefulness and is usually found near the earth's surface.
   2. Low-quality matter is dilute and found deep underground and/or dispersed in air or water.
   3. Material efficiency/resource productivity describes the total amount of material needed to produce a unit of good/service.

Changes in Matter

A. When matter has a physical change, its chemical composition is not changed; the molecules are organized in different patterns.

B. In a chemical change, the chemical composition of the elements/compounds changes. Shorthand chemical equations represent what happens in the reaction.

C. The Law of conservation of matter states that no atoms are created/destroyed during a physical or chemical change. The same is true for energy.
   1. Atoms are re-arranged into different patterns/combinations.
   2. Atoms can have physical or chemical changes but they are never created/destroyed.

D. Chemical equations are used to verify that no atoms are created or destroyed in a chemical reaction. The number of atoms on one side of the equation must equal the number of atoms on the other side of the equation.

E. We will always have some pollutants, but can produce less and clean up some that we do produce.
   1. Three factors determine the severity of a pollutant's harmful effects: chemical nature, concentration and persistence.
   2. Dilution of concentration of a pollutant is only a partial answer.
   3. Pollutants are classified into 4 categories based on persistence: degradable, biodegradable, slowly degradable, and non-degradable.

F. Matter can undergo a change known as a nuclear change. Three types of nuclear change are radioactive decay, nuclear fission, and nuclear fusion.

G. Radioactive isotopes emit high-energy radiation at a fixed rate until the original unstable isotope is changed into a stable isotope.
   1. Alpha particles are fast-moving, positively charged; consist of two protons and two neutrons.
   2. Beta particles are high-speed electrons.
   3. Rate of decay into a stable isotope is expressed in terms of half-life: the time needed for one-half of the nuclei of a given quantity to form a different isotope.

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4. Half-life time is used to estimate storage time needed in a safe container to reach a safe level.
5. Exposure to ionizing radiation from alpha particles, beta particles or gamma rays damages cells in two possible ways: genetic damage (mutation of DNA molecules), somatic damage to tissues that harm quality of life.

H. Nuclei of certain isotopes with large mass numbers (uranium-235) are split apart into lighter nuclei when struck by neutrons. This is nuclear fission
1. A critical mass of fissionable nuclei must be present.
2. Multiple fissions within the critical mass results in a chain reaction with release of enormous amounts of energy.
3. Nuclear fission is used to produce high-pressure steam to generate electricity.

I. Nuclear fusion occurs at extremely high temperatures and involves the fusion of two isotopes of light elements (H). It is difficult to initiate, but once started, releases more energy per unit than fission. This technology is still in the laboratory stage after 50 years of research.

Energy

A. Energy is the capacity to do work and transfer heat; it moves matter.
1. Kinetic energy has mass and speed: wind, electricity are examples
2. Potential energy is stored energy, ready to be used: unlit match, for example.
3. Potential energy can be changed to kinetic energy: drop an object.

B. Electromagnetic radiation is energy that travels as a wave, a result of changing electric and magnetic fields.
1. Each form of electromagnetic radiation has a different wavelength and energy content.
2. The electromagnetic spectrum describes the range of electromagnetic waves that have different wavelengths and energy content.

C. Heat is the total kinetic energy of all moving atoms, ions, or molecules in a substance.
1. It can be transferred from one place to another by convection, conduction and radiation.
2. Temperature is the average speed of motion of atoms, ions, or molecules in a sample of matter.
3. Energy quality is measured by its usefulness; high energy is concentrated and has high usefulness. Low energy is dispersed and can do little work.

Energy Laws: Two Rules We Cannot Break

A. The First Law of Thermodynamics states that energy can neither be created/destroyed, but can be converted from one form to another.

B. The Second Law of Thermodynamics states that when energy is changed from one form to another, there is always less usable energy. Energy quality is depleted.
1. In changing forms of energy, there is a loss in energy quality; heat is often produced and lost.
2. Changing forms of energy produces a small percentage of useful energy; much is lost in the process, energy not used by the application.
3. In living systems, solar energy is changed to chemical energy, then to mechanical energy. High quality energy degraded to low quality heat.
4. High-quality energy cannot be recycled/reused.
5. Energy efficiency/productivity measures the amount of useful work by a specific input of energy. Overall, energy efficiency is very poor—about 16% of the energy produces useful work.
6. Forty-one percent is unavoidable waste energy, 43% is unnecessarily wasted energy. A change in habits can further reduce this waste.

Sustainability and Matter and Energy Laws

A. Resource use automatically adds some waste heat/waste matter to the environment.

B. Advanced industrialized countries have high-throughput (high waste) economies.
1. Resources flow into planetary sinks (air, water, soil, organisms) with accumulation to harmful levels.
2. Eventually consumption will exceed capacity of the environment to dilute/degrade wastes.

C. Recycling and reusing more of earth's matter resources slows depletion of nonrenewable resources, reduces environmental impact.

D. Waste heat is added to environment even with recycling/reuse, but does slow the process and buys some time.
E. Shifting to a more sustainable, low-throughput (low-waste) economy is the best long-term solution to environmental/resource problems. Waste less matter, live more simply, slow population growth.

Summary

1. Science is an attempt to discover the natural world's order and use that in describing what is likely to happen in nature. Scientists ask a question or identify a problem to investigate. Then, they collect scientific data through observation and measurement. Experiments may be used to study specific phenomena.

2. The major components of complex systems are environmental inputs, flows within the system, and outputs to the environment.

3. The basic forms of matter are elements and compounds. Matter is useful to us as a resource because it makes up every material substance.

4. The major forms of energy are kinetic energy and potential energy. Energy is useful to us as a resource because it moves matter.

5. The Law of conservation of Matter states that matter is neither created nor destroyed when a physical or chemical change occurs.

6. Matter can undergo three types of nuclear changes: natural radioactive decay, nuclear fission, and nuclear fusion.

7. The First Law of Thermodynamics states that in all physical and chemical changes, energy may be converted from one form to another but it is neither created nor destroyed. The Second Law of Thermodynamics states that when energy is changed from one form to another, there is always less usable energy left.

8. These laws, then, show that energy goes from a more useful to a less useful form and that high-quality energy cannot be recycled. So, the quality as well as the quantity of our resources and our environment will be reduced.

Objectives

1. Describe how science works. Distinguish between frontier and consensus science. Summarize the limits of environmental science.

2. Define *matter*. Distinguish between forms of matter and quality of matter.

3. Define *energy*. Distinguish between forms of energy and quality of energy.

4. Define and explain mathematical models and how they are useful in predicting the behavior of a complex system.

5. Describe synergistic interactions within a complex system.

6. Describe how the law of conservation of matter and the law of conservation of energy govern normal physical and chemical changes. Briefly describe the second law of energy (thermodynamics).

7. Define *radioactivity*. Distinguish between natural radioactivity, nuclear fission and nuclear fusion.

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8. Define *high-throughput economy*. Explain where you would expect to see this type of economy.

9. Define *low-throughput economy*. Explain where you would expect to see this type of economy.

10. Compare the sustainability of the two different types of economies for future generations of people.

Key Terms **(Terms are listed in the same font style as they appear in the text.)**

acidic solution (p. 36)	*concentration* (p. 40)
atomic number (p. 35)	**consensus science** (p. 32)
atoms (p. 35)	*control group* (p. 31)
basic solution (p. 36)	*controlled experiment* (p. 31)
biodegradable pollutants (p. 40)	*controlled nuclear fusion* (p. 41)
cells (p. 37)	**critical mass** (p. 41)
chemical bonds (p. 34)	**deductive reasoning** (p. 31)
chemical change (p. 39)	**degradable (nonpersistent) pollutants** (p. 40)
chemical energy (p. 42)	*discontinuity* (p. 34)
chemical formula (p. 36)	*electrical energy* (p. 42)
chemical nature (p. 40)	**electromagnetic radiation** (p. 43)
chemical reaction (p. 39)	**electrons** (p. 35)
chlorinated hydrocarbons (p. 37)	**elements** (p. 34)
chromosomes (p. 38)	**energy** (p. 42)
complex carbohydrates (p. 37)	**energy efficiency** (p. 46)
compounds (p. 34)	**energy productivity** (p. 46)
energy quality (p. 44)	**nuclear fission** (p. 40)
environmental threshold (p. 34)	**nuclear fusion** (p. 41)
eukaryotic (p. 37)	*nucleic acids* (p. 42)
experimental group (p. 31)	**nucleus** (p. 35)
experiments (p. 29)	*nucleus* (p. 37)
feedback loop (p. 33)	*organelles* (p. 37)
first law of thermodynamics (p. 45)	**organic compounds** (p. 36)
flows (p. 33)	**paradigm shifts** (p. 31)
frontier science (p. 32)	*parts per million* (ppm) (p. 40)
genes (p. 37)	*peer review* (p. 30)
half-life (p. 40)	*periodic table of elements* (p. 34)
heat (p. 42)	**persistence** (p. 40)
high-quality energy (p. 44)	**pH** (p. 36)
high-quality matter (p. 38)	**physical change** (p. 39)
high-throughput economies (p. 46)	***plasma*** (p. 38)
hydrocarbons (p. 37)	*polymers* (p. 37)
inductive reasoning (p. 31)	**positive feedback loop** (p. 33)
inorganic compounds (p. 36)	**potential energy** (p. 43)
inputs (p. 33)	*probability* (p. 32)
ion (p. 35)	**prokaryotic** (p. 37)
isotopes (p. 35)	*proteins* (p. 37)
junk science (p. 32)	**protons** (p. 35)
kinetic energy (p. 42)	**radioactive isotopes (radioisotopes)** (p. 40)
law of conservation of energy (p. 45)	*reproducibility* (p. 330)
law of conservation of matter (p. 39)	**resource productivity** (p. 38)
light (electromagnetic) energy (p. 42)	**science** (p. 29)
lipids (p. 37)	**scientific (natural) law** (p. 30)

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low-quality energy (p. 44) **low-quality matter** (p. 38) **low-throughput economy** (p. 46) **macromolecules** (p. 37) **mass number** (p. 35) **material efficiency** (p. 38) **matter** (p. 34) **matter quality** (p. 38) **matter-recycling economy** (p. 46) *mechanical energy* (p. 42) *model* (p. 30) **molecule** (p. 36) *monomers* (p. 37) *multivariable analysis* (p. 31) **natural radioactive decay** (p. 40) **negative feedback loop** (p. 33) **neutral solution** (p. 36) **neutrons** (p. 35) **nondegradable pollutants** (p. 40) **nuclear change** (p. 40)	**scientific hypotheses** (p. 30) *scientific hypothesis* (p. 30) **scientific theory** (p. 30) **second law of thermodynamics** (p. 45) *simple carbohydrates* (p. 37) *single variable analysis* (p. 31) *sinks* (p. 46) *skepticism* (p. 30) **slowly degradable** (**persistent**) **pollutants** (p. 40) *subatomic particles* (p. 35) *syllogism* (p. 31) **synergistic interaction** (p. 34) **synergy** (p. 34) **system** (p. 33) *threshold level* (p. 33) **throughputs** (p. 33) **time delays** (p. 33) *uncontrolled nuclear fusion* (p. 41) *variables* (*factors*) (p. 31)