# ECOLOGY AND SUSTAINABILITY

# Chapter 2

# Science, Systems, Matter, and Energy

### 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.

### Key Questions and Concepts

**2-1 What is science?**

**CORE CASE STUDY**. Controlled experiments involve an experimental group, in which a known variable is changed, and a control group, in which the variable is not changed. The example involves two drainages that were dammed. One was deforested and one left forested. The deforested landscape showed an increase in erosion and an increase in water flow carrying dissolved nutrients.

A. Science assumes that events in the natural world follow orderly patterns and that, through observation and experimentation, these patterns can be understood.

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.

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

D. There are many types of scientific methods used to gather data, formulate hypotheses, state theories and laws and, then test them. Observation leads to a hypothesis, then to an experiment that produces results, which lead to a conclusion.

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. **Science Focus**: Easter Island Revisited—an example of how a once accepted hypothesis has been replaced as a result of new evidence.

1. Scientists use both inductive reasoning and deductive reasoning.

a. Inductive reasoning uses specific observations and measurements to arrive at a general conclusion.

b. Deductive reasoning uses logic to arrive at a specific conclusion based on a generalization.

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. **Science Focus**: Global Warming—how global warming can be made to look like frontier science.

H. Environmental science has limitations.

a. Scientists can disprove things, but not prove anything absolutely.

b. Scientists are sometimes biased.

c. Environmental scientists often rely on estimates.

d. Environmental phenomena often involve a multitude of interacting variables.

e. **Science Focus**: Statistics and Probability—understanding how statistics work.

**2-2 What is 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.

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. Electron(s) 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. The mass number of an atom equals the total number of neutrons and protons in its nucleus.

5. Isotopes 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. Hydrogen ions (H+) in a solution are a measure of how acidic or basic the solution is. 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. Ionic compounds are made up of oppositely charged ions, (Na+ and Cl-).

2. Compounds made of uncharged atoms are called covalent compounds (CH4).

F. Organic compounds contain carbon atoms combined with one another and with various other atoms.

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.

G. Polymers are larger and more complex organic compounds that have molecular units.

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.

a. Genes: specific sequences of nucleotides in a DNA molecule.

b. Chromosomes: combinations of genes that make a single DNA molecule, plus some proteins.

c. 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. 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.

**2-3 How can matter change?**

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 change.

C. The Law of Conservation of Matter states that no atoms are created/destroyed during a physical or chemical change.

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

E. Radioactive isotopes emit high-energy radiation at a fixed rate until the original unstable isotope is changed into a stable isotope.

1. Nuclei of certain isotopes with large mass numbers (uranium-235) are split apart into lighter nuclei

when struck by neutrons. This is nuclear fission.

F. Nuclear fusion occurs at extremely high temperatures and involves the fusion of two isotopes of light elements (H).

**2-4 What is energy and how can it be changed?**

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 ,for example.

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.

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

E. 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.

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.

* 1. **What are systems and how do they respond to change?**

1. A system is a set of components that interact. **Science Focus**: The Usefulness of Models—how models can be used to understand a system?

1. Most systems have inputs from the environment, throughputs of matter and energy within the system,

and outputs to the environment.

1. Systems are affected by feedback and feedback loops (positive and negative).
2. Systems often show time delays between input and response
3. Problems can build slowly in systems until reaching a tipping point.
4. Synergy is when processes interact such that the combined effect is greater than the individual effects.

### Key Terms

**atomic number** (p. 36)

**atom** (p. 35)

**cells** (p. 38)

**chemical change** (p. 40)

**chemical formula** (p. 37)

**chemical reaction** (p. 40)

**chromosome** (p. 38)

**compounds** (p. 35)

**deductive reasoning** (p. 32)

**electromagnetic radiation** (p. 42)

**electrons** (p. 36)

**elements** (p. 35)

**energy** (p. 4)

**energy efficiency** (p. 43)

**energy productivity** (p. 43)

**energy quality** (p. 42)

**experiments** (p. 30)

**feedback loop** (p. 44)

**first law of thermodynamics**   
(p. 42)

**flows** (p. 44)

**frontier science** (p. 33)

**genes** (p. 38)

**heat** (p. 41)

**high-quality energy** (p. 42)

**high-quality matter** (p. 39)

**inductive reasoning** (p. 32)

**inorganic compounds** (p. 38)

**inputs** (p. 44)

**isotopes** (p. 36)

**kinetic energy** (p. 40)

**law of conservation of energy**   
(p. 42)

**law of conservation of matter**   
(p. 40)

**low-quality energy** (p. 42)

**mass number** (p. 36)

**matter** (p. 35)

**matter quality** (p. 39)

**molecule** (p. 37)

**natural radioactive decay** (p. 40)

**negative feedback loop** (p. 45)

**neutrons** (p. 36)

**nuclear change** (p. 40)

**nuclear fission** (p. 40)

**nuclear fusion** (p. 40)

**nucleus** (p. 36)

**organic compounds** (p. 38)

**paradigm shift** (p. 32)

**pH** (p. 37)

**physical change** (p. 39)

**positive feedback loop** (p. 45)

**potential energy** (p. 42)

**protons** (p. 36)

**radioactive isotopes** (**radioisotopes**) (p. 40)

**science** (p. 29)

**scientific** (**natural**) **law** (p. 32)

**scientific hypothesis** (p. 30)

**scientific theory** (p. 31)

**second law of**

**thermodynamics** (p. 43)

**synergistic interaction** (p. 46)

**synergy** (p. 46)

**system** (p. 44)

**throughputs** (p. 44)

**time delays** (p. 46)