Supplementary Notes (PJ Shlachtman, Miller book)

Experiment Design; Matter and Energy Resources

Science, Technology, and Environmental Science

Science is a pursuit of knowledge about how the world works, an attempt to discover order in nature and use that knowledge to make predictions.
Scientific data (or facts) are used to make observations and solve problems.
Experiment - a procedure a scientist uses (in lab or in nature) to study some phenomenon.
Reproducibility is important in science to detect errors in experimentation.
Scientific Hypothesis (a testable statement) is a possible explanation for a particular observation
A **model** is an approximate representation or simulation of a system being studied and may be used to test a hypothesis.
Models include:

- **Mental -** perceive the world, control their bodies and think about things
- **Conceptual -** describe the general relationships among components of a system
- **Graphic -** compile and display data in meaningful patterns (map)
- **Physical -** try out designs and ideas (scale models of airplanes, buildings)
- **Mathematical -** consist of one or more mathematical equations to describe the behavior of a system (rule of 70).

Data is subject to **review** by other scientists and usually falls into this pattern:
observe---> hypothesize---> argue---> test---> hypothesize---> argue---> test

A **scientific theory** is an idea, principle, or model that usually ties together and explains many facts that previously appeared to be unrelated and is supported by a great deal of evidence. (Big Bang Theory, John Dalton- Atomic Theory of Matter- all matter is made up of small particles called atoms that cannot be destroyed, created, or subdivided by physical and chemical changes.)

A **scientific law** is a description of what we find happening in nature over and over in the same way, without known exception. (Law of Gravity, the Law of Conservation of Matter states that we can change matter from one physical or chemical form to another, but no matter is created or destroyed by such processes).

Accuracy is the extent to which a measurement agrees with the accepted or correct value for that quantity.
Precision is a measure of reproducibility, or how closely a series of measurements of the same quantity agree with one another.
Controlled experiment - to test a hypothesis. Consists of two groups:

1. **experimental group**, in which the variable is changed in a known way
2. **control group**, in which the variable is not changed

A double blind experiment in which a group of patients is given a placebo, and a new drug is tested on another group.
Scientists cannot prove a hypothesis to be true in all cases. They can only prove it to be false under specific conditions.

Types of reasoning

Inductive - uses observations and facts to arrive at generalizations or hypotheses.
Deductive - uses logic to arrive at a specific conclusion based on a generalization or premise. From general to specific.
Frontier Science is controversial because it has not been widely tested and accepted.
Consensus Science consists of data, theories, and laws that are widely accepted by scientists considered experts in the field involved.
Technology is the creation of new products and processes intended to improve our efficiency, chances for survival, comfort level, and quality of life.
Environmental Science is the study of how the biotic (living) environment interacts with one another and with the nonliving environment (abiotic). Where as ecology is a pure science – environmental science is an applied science using chemistry, biology, ecology geology, physics and mathematics.

Systems and System Models

System - is a set of components that function and interact in some regular and theoretically predictable manner.
A system has

- **structure -** consists of components or parts that fit together to make a whole, and
- **function -** what the system does. (e.g., circulatory system)

Models are used as approximate representations or simulations of real systems to find out which ideas or hypotheses work. Mathematical models require three steps:

1. Make a guess and write down some equations,
2. Compute the predictions implied by the equations, and
3. Compare the predictions with observations, the predictions of mental models, existing experimental data, and scientific hypotheses, laws, and theories.

Mathematical models are important because they can give us improved perceptions and predictions, especially concerning matters for which our mental models are weak.

Some Basic Components and Behaviors of System Models

Any system being studied has one or more **inputs** (such as matter, energy or information). Inputs accumulate in the environment, such as population. Inputs flow through a system at a certain rate. Such flows or throughputs of matter, energy, or information through a system are represented using arrows. Anything flowing out of a system is called an **output**.

- A **feedback loop** occurs when one change produces some other change, which reinforces or slows the original change. They occur when an output of matter, energy or information is fed back into the system as input.
- **Positive feedback loop** is a runaway cycle in which a change in a certain direction provides information that causes a system to change further in the same direction.
- **Negative feedback loop** occurs when one change leads to a lessening of that change.
- **Homeostasis -** the maintenance of favorable internal conditions despite fluctuations in external conditions. Homeostatic systems consist of one or more negative feedback loops that help maintain constant internal conditions when changes occur.

Most systems contain one or a series of coupled positive and negative feedback loops. The idea that life on earth helps sustain its own environment is a modified version of the **Gaia hypothesis**, proposed in the early 1970s by James Lovelock and Lynn Margulis.

Some Behaviors of Complex Systems

Complex systems often show **time delays** between the input of a stimulus and the response to it. A long delay can mean that the corrective action comes too late. (e.g., smoker who quits but already has lung cancer)
Synergistic reactions occur when two or more processes interact so that the combined effect is greater than the sum of their separate effects. Synergy amplifies the action of positive feedback loops and thus can amplify a change we believe is favorable. Can also bring about harmful changes.
Some systems are now appearing to be random, chaotic, and unpredictable. This behavior of systems comes from within the system itself, and is said to be generating **chaos**.

Matter: Forms, Structure, and Quality

matter – anything that has mass and takes up space
Four states of matter:

1. solid
2. liquid
3. gas
4. plasma

Two chemical forms:

1. **elements** – distinctive building blocks of matter that make up every substance
2. **compounds** – two or more different elements held together in fixed proportions by attractive forces (chemical bonds)
3. **mixtures** – various elements, compounds, or both
4. **atoms**
   - smallest unit of matter that's unique to a particular element
   - "ultimate building blocks for matter"
   - made of subatomic particles – 3 fundamental particles:
     - **protons** – positively charged; located in the nucleus
     - **neutrons** – neutral/no charge; located in the nucleus
     - **electrons** – negatively charged, found in electron clouds

ions – electrically charged particles or combinations of atoms (monatomic or polyatomic)

molecules – combinations of two or more atoms of the same or different elements held together by covalent bonds (O_2, CO_2, CH_4)
atomic number – number of protons in the nucleus (equal to the number of electrons in a neutral atom)
mass number – total number of neutrons plus protons in the nucleus
isotopes – various forms of an element with the same atomic number but different mass numbers(same number of protons but a different of neutrons)
periodic table – classification of elements according to chemical behavior(based on electron configurations)

- **period** – horizontal row
- **group** – vertical column
- **metals** – usually conduct heat and electricity, strong
- **nonmetals** – don't conduct heat and electricity very well, and usually aren't shiny
- **metalloids** – substance with metallic and nonmetallic properties (ex. Si)
- **nutrients** – required for all or some forms of life

chemical formula – shorthand way to show the number of atoms (or ions) in the basic structural unit of a compound. E.g., H_2O, NaCl, $C_6H_{12}O_6$
ionic compounds – compounds made of oppositely charged ions (ionic bonds – strong forces of attraction between opposite charges)
covalent (molecular) compounds

- compounds of molecules of uncharged atoms e.g.. H_2O
- covalent bonds-atoms share 1 or more pairs of electrons
- usually gases or liquids

hydrogen bonds – forces of attraction between molecules; hydrogen bonding only occurs between H and one of the following elements → O, N, F
organic compounds

- contain carbon atoms combined with each other and with atoms of 1 or more other elements, such as: H, O, N, S, P, Cl, F (does not include the carbonate series)
- molecular compounds held together by covalent bonds (almost all)
- **polymers** – larger and more complex organic compounds, consist of a number of basic structural or molecular units (monomers), linked by chemical bonds
  1. **complex carbohydrates**– made by linking a number of simple carbohydrates. Molecules (e.g. Complex starches in rice and potatoes)
  2. **proteins**
     a. produced in living cells by linking different sequences of about 20 different monomers (amino acids) whose number and sequence in each protein are specified by genetic code found in DNA molecules in an organism's cells. (C,H,O,N)
     b. **essential amino acids**
        i. the 10 amino acids that must be obtained from food (cannot be synthesized)
        ii. can act as enzymes to control the rate at which chemical reactions take place in a cell
  3. **nucleic acids**
     a. made by linking hundreds to thousands of five different monomers
     b. nucleotides – have 1 phosphate group, 1 sugar molecule, 5 carbon atoms [deoxyribose in DNA and ribose in RNA], and 1 of 4 nucleotide bases [A, G, C, T])
     c. **DNA** – instructions for new cells and proteins for each cell
     d. **RNA** – instructions for proteins within cells
     e. genes – specific sequences of nucleotides in DNA molecules;
        i. approx. 75, 000 in each cell
        ii. carries codes required to make various proteins
        iii. **gene mutations** – changes of the nucleotide bases in a gene sequence
        iv. **chromosomes** – combinations of genes that make up a single DNA molecule together with a number of proteins
        v. **human cell** – 46 chromosomes
  4. **lipids**
     a. biologically important molecules, not polymers, include molecules of fat, oils, waxes
     b. phospholipids, and various substances
     c. serve as energy storage molecules, regulators of certain cellular functions, nutrients, and water proof coverings around cells

inorganic compounds – all other compounds; e.g., ionic and covalent

Earth's crust

- outermost layer, made of inorganic materials and rocks
- must contain at least 2 minerals
  - **mineral** – element or inorganic compound that occurs naturally, is solid; usually has crystalline internal structure made of 3-d arrangement of atoms or ions.
- rock – any material that makes up a large, natural, continuous part of the earth's crust

matter quality – measurement of how useful a matter resource is; availability and concentration

- high-quality matter – organized, concentrated, and usually found near the earth's surface; has great potential for use as a matter resource
- low-quality matter – disorganized, dilute, and often deep underground or dispersed in the ocean or atmosphere; has little potential as a matter resource

entropy – measurement of disorder or randomness of a system; high disorder = high entropy

Energy: Forms and Quality

energy – capacity to do work and transfer heat

- many forms: light, heat, electricity; chemical, mechanical, nuclear energy
- kinetic
  - energy that matter has b/c of its mass and speed (velocity)
  - energy in action or motion
  - wind, flowing water, falling rocks, electricity
  - electromagnetic radiation – consists of wide band (spectrum) of electromagnetic waves that differ in wavelength and energy content e.g., radio waves, TV waves
  - **heat** – total kinetic energy($KE = \frac{1}{2} mv^2$) of all moving atoms, ions, molecules with a given substance; excluding the motion of the whole object
  - **temperature** – measurement of the average kinetic energy of an atom, ion, molecule in a sample of matter at a given moment
- potential energy – stored energy that's potentially available for use ($PE=mgh$)
  - rock, dynamite, still water behind dam
  - can be changed to kinetic energy

energy quality – measurement of energy source's ability to do useful work

- high energy quality – organized or concentrated and can perform much useful work (e.g., electricity, coal, gas)
- low energy quality – disorganized, dispersed and has little ability to do useful work (e.g., heat in atoms)

Physical and Chemical Changes and the Law of Conservation of Matter

physical change – involves no change in chemical composition (e.g., cutting, changing states)

chemical change (reaction) – chemical compositions are altered

-chemical equation: reactants → products ($CO_2 + H_2O \rightarrow C_6H_{12}O_6 + O_2$)

Law of Conservation of Matter

- we may change elements and compounds from one physical of chemical form to another, but we cannot create or destroy the atoms involved
- there is no away

Nuclear Changes

Law of Conservation of Matter and Energy – In any nuclear change, the total amount of matter and energy involved remains the same

nuclear changes – nuclei of certain isotopes spontaneously change or are made to change into one or more different isotopes; 3 types:

1. **natural radioactive decay** – nuclear change in which unstable isotopes (radioisotopes) spontaneously emit fast-moving particles, high-energy radiation, or both at a fixed rate, continues until isotopes are stable and not radioactive
   - **gamma rays** – most common; form of high energy radiation, can be stopped with a sheet of lead (γ rays)
   - **alpha particles** – fast-moving, positively charged chunks of matter with 2 protons and 2 neutrons; equivalent to a helium nucleus, weakest form (α particles; $^{4}_{2}He$)
   - **beta particles** – equivalent to an electron; slightly stronger than alpha particles(β particles; $_{-1}^{0}e$)
   - **half-life** – time needed for half of the nuclei in radioisotopes to decay and emit their radiation to form different isotopes
   - **radiocarbon dating** – using carbon-14 to estimate ages of fossils, etc.
   - **tracers** – used in pollution detection, agriculture, industry
   - **nuclear medicine** – uses radioisotopes for diagnosis and treatment
2. **nuclear fission** – nuclear change in which the nuclei of certain isotopes with large mass numbers are split into lighter nuclei when struck by neutrons
   - each fission releases 2 or 3 neutrons and energy
   - for multiple fissions, enough critical mass must be present
   - forms chain reaction – releases huge amounts of energy
3. nuclear fusion – nuclear change in which 2 isotopes of light elements are forced together (usually at extremely high temperatures and pressure) until they fuse to form a heavier nucleus and release energy (ex. The sun)
   - uncontrolled nuclear fusion – used to develop extremely powerful thermonuclear weapons

Laws of Energy - Thermodynamics

1st law of energy (thermodynamics) – in all physical and chemical changes, energy is neither created nor destroyed, but may be converted from one form to another. Energy input = energy output

2nd law of energy – when energy is changed from one form to another, some of the useful energy is always degraded to low quality, more dispersed, less useful energy

- can never recycle or reuse high quality energy to perform useful work
- all forms of life are tiny pockets of order (low entropy) maintained by creating a sea of disorder (high entropy) in their environment.

Connections: Matter and Energy Laws and Environmental Problems

high-waste or high-throughput societies – attempt to sustain ever-increasing economic growth by increasing throughput of matter and energy resources in the economic system; will eventually become unsustainable

matter recycling society – allow economic growth to continues without depleting matter resources or producing excess pollution and environmental degradation; will but some time

low-waste society – recycling and reusing discarded matter, preventing pollution, conserving matter and energy resources; reducing