EOC BIOLOGY STUDY GUIDE NOTES

B-1.1 Generate hypotheses on the basis of credible, accurate, and relevant sources of scientific information.

It is essential for students to

- Know that a hypothesis is a reasonable explanation of an observation or experimental result or a possible answer to a scientific question that can be tested. The hypothesis may or may not be supported by the experimental results. It is often stated in terms of an independent and a dependent variable—or a "cause-effect relationship." Examples of hypotheses might include:
  - If a leaf has a greater surface area, then the rate at which it produces oxygen may increase.
  - As the volume of the lungs increases, the rate at which breathing occurs decreases.
  - At warmer temperatures, mold will grow faster on bread

  Know that the results of an experiment cannot prove that a hypothesis is correct. Rather, the results support or do not support the hypothesis. Valuable information is gained even when the hypothesis is not supported by the results. For example, it would be an important discovery to find that lung capacity is not related to breathing rate. When hypotheses are tested over and over again and not contradicted, they may become known as laws or principles.

- Use *credible* (trustworthy), *accurate* (correct – based on supported data), and *relevant* (applicable, related to the topic of the investigation) sources of scientific information in preparation for generating a hypothesis. These sources could be previous scientific investigations-science journals, textbooks, or other credible sources, such as scientifically reliable internet sites.

***B-1.2 Use appropriate laboratory apparatuses, technology, and techniques safely and accurately when conducting a scientific investigation.**

- Use appropriately and identify the following laboratory apparatuses and materials:
  Apparatuses and materials appropriate for biology investigations:
  - Balances, triple beam or electronic
  - Beakers (50mL, 100 mL, 250mL)
  - Burners (Bunsen), flint strikers
  - Chemicals & other consumable materials depending on planned laboratory investigations
  - Erlenmeyer flasks
  - Evaporating dishes
  - Filter paper
  - Forceps
  - Funnels
  - Graduated cylinders (10 mL & 100 mL)
  - Hand lenses (magnifiers)
  - Hot plates
  - Measuring tools (rulers, meter stick, meter tapes, stop watch or timer)
  - Microscopes (compound & dissecting)
  - Microscope slides & cover slips, light source, lens paper
  - Lab aprons, safety goggles, gloves
  - Measuring tools: clear metric rulers, meter sticks, and meter tapes; stop watch or timer
  - pH indicator paper, pH buffer solution
  - Prepared slides of normal cells, cancerous cells, human cheek cells, onion root cells, bacteria, protists, fungi, sickle cell blood, chromosome smear, whitefish blastula, etc.
  - Pipettes / droppers
  - Petri dishes
  - Ring stand, ring clamp, and test tube clamp
  - Stirring rods, spatulas, scissors, chemical scoop
  - Stoppers – rubber, cork
  - Test tubes, clamp, holder, and rack
  - Test tube brushes
  - Thermometers (alcohol, digital)
  - Tongs (crucible, beaker)
  - Watch glasses, spot plate
  - Wire gauze with ceramic centers
  - Wood splints
- Use the identified laboratory apparatuses in an investigation safely and accurately with
  - Associated technology, such as

        - computers, calculators and other devices, for data collection, graphing, and analyzing data, or
        - probe ware and meters to gather data; and
    - Appropriate techniques that are useful for understanding biological concepts, such as
      Using a microscope appropriately

B-1.3 Use scientific instruments to record measurement data in appropriate metric units that reflect the precision and accuracy of each particular instrument.

- Read scientific instruments such as graduated cylinders, balances, spring scales, thermometers, rulers, meter sticks, and stopwatches using the correct number of decimals to record the measurements in appropriate metric units.
- The measurement scale on the instrument should be read with the last digit of the recorded measurement being estimated.
- Record data using appropriate metric units (SI units). They should be able to use prefixes; milli, centi, kilo. (Conversions should be made using dimensional analysis – see PS 1-5)
- Understand that the more decimals in the recorded measurement, the greater the precision of the instrument.
    - An instrument that can be read to the hundredths place is more precise than an instrument that can be read to the tenths place.
    - A 100 mL graduated cylinder that is marked in 1 mL increments can be read exactly to the ones place with the tenths place being estimated in the recorded measurement.
    - A 10 mL graduated cylinder that is marked in 0.1 mL increments can be read exactly to the tenths place with the hundredths place being estimated in the recorded measurement.
    - The 10 mL graduated cylinder, therefore, is more precise than the 100 mL graduated cylinder.
- Understand that the terms *precision* and *accuracy* are widely used in any scientific work where quantitative measurements are made**.**
    - ***Precision*** is a measure of the degree to which measurements made in the same way agree with one another.
    - The ***accuracy*** of a result is the degree to which the experimental value agrees with the true or accepted value.
    - It is possible to have a high degree of precision with poor accuracy. This occurs if the same error is involved in repeated trials of the experiment.

B-1.4 Design a scientific investigation with appropriate methods of control to test a hypothesis (including independent and dependent variables), and evaluate the designs of sample investigations.

- Design a controlled scientific investigation in which one variable at a time is deliberately changed and the effect on another variable is observed while holding all other variables constant.
  The steps in designing an investigation include:

    - Stating the purpose in the form of a testable question or problem statement
    - Researching information related to the investigation
    - Stating the hypothesis
    - Describing the experimental process
        - Planning for independent and dependent variables with repeated trials
        - Planning for factors that should be held constant (controlled variables)
        - Setting up the sequence of steps to be followed
        - Listing materials
        - Planning for recording, organizing and analyzing data
    - Planning for a conclusion statement that will support or not support the hypothesis
- Understand that scientific investigations are designed to answer a question about the relationship between two variables in a predicted “cause-effect relationship.”
- Understand that the statement that predicts the relationship between an independent and dependent variable is called a *hypothesis*.
- Understand that the *independent variable* is the variable that the experimenter deliberately changes or manipulates in an investigation.
- Understand that the *dependent variable* is the variable that changes in an investigation in response to changes in the independent variable.
- Understand that the independent variable is the “cause” and the dependent variable is the “effect” in the “cause-effect” relationship that is predicted.

- Understand that all the other possible variables in the investigation should be held constant so that only one variable (the independent) is tested at a time. The variables which are held constant are called *controlled variables*.
- Understand that the investigator should conduct repeated trials to limit random error in measurements.
- Understand that, when appropriate, a *control group* is set up as a basis of comparison to test whether the effects on the dependent variable came from the independent variable or from some other source.
- Evaluate the design of an experiment by assessing whether the steps of the investigation are presented.
- Evaluate the methods by which the investigation was conducted to determine:
  - Whether independent and dependent variables are appropriate for testing the hypothesis;
  - Whether only one variable is changed at a time by the investigator;
  - Which variables are, or should have been, controlled;
  - Whether data was collected with adequate repeated trials, organized and analyzed properly;
  - Whether the conclusion is logical based on the analysis of collected data.

B-1.5 Organize and interpret the data from a controlled scientific investigation by using mathematics (including formulas and dimensional analysis), graphs, models, and/or technology.

- Organize data which is collected from a controlled scientific investigation.
  - Data should be organized in charts which list the values for the independent variable in the first column and list the values for the dependent variable in a column to the right of the independent variable.

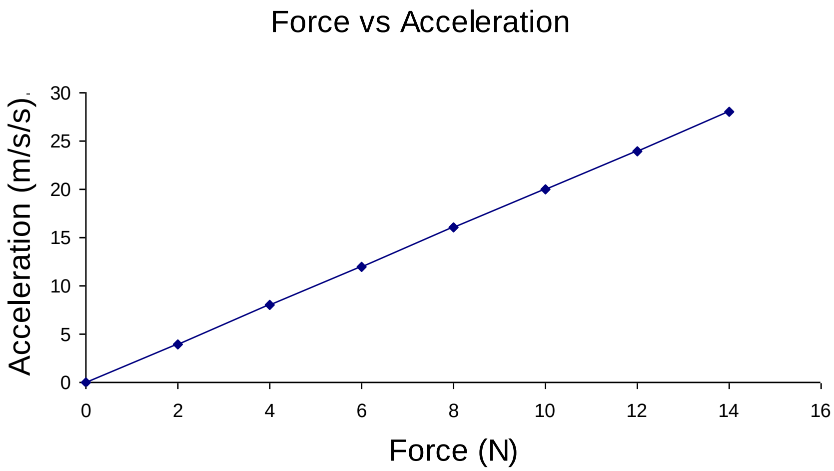
Example Charts:

Independent Variable	Dependent Variable

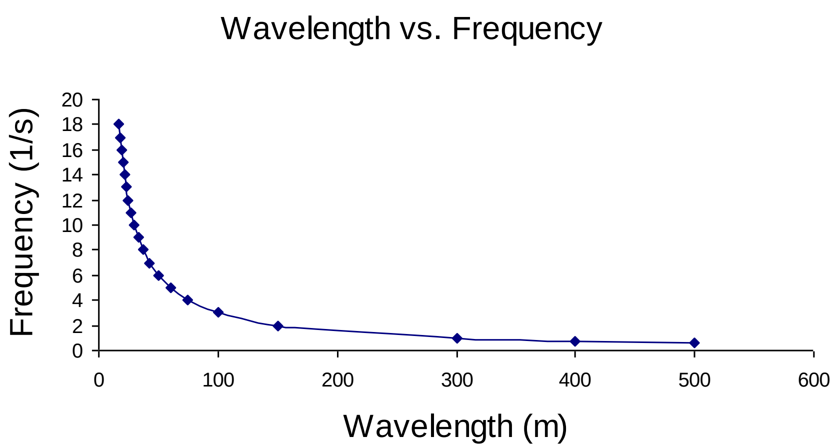
(Or)

Independent Variable				Dependent Variable
	Trial 1	Trial 2	Trial 3	
First value				
Second value				
Third value				
(other values)				

- Use graphs to organize data from controlled investigations.
  - Data should be recorded on a graph with the independent variable plotted on the "X" axis and the dependent variable plotted on the "Y" axis.
  - Choose scales for both the horizontal axis and the vertical axis.
    - There should be two data points more than is needed on the vertical axis.
    - The horizontal axis should be long enough for all of the data points to fit.
    - The intervals on each axis should be marked in equal increments.
  - Label each axis with the name of the variable and the unit of measure.
  - Title the graph.
- Use the graphs to analyze and interpret data to determine a relationship between the dependent and independent variables.
  - A line graph is used for continuous quantitative data.
  - A bar graph is used for non-continuous data which is usually categorical.
  - A circle graph shows a relationship among parts of a whole. Circle graphs often involve percentage data.
- Recognize the implications of various graphs
  - A *direct variation* (or proportion) is one in which, one variable increases as the other increases or as one variable decreases the other decreases. A straight line with a positive slope indicates a direct relationship that changes at a constant rate. A greater slope indicates an increased rate of change.



- An *inverse variation* (or proportion) is one in which the product of two quantities is a constant. For example the product of the frequency and the wavelength is equal to the velocity of a wave ($v = f\lambda$). Frequency and wavelength are inversely proportional. As one quantity increases the other quantity decreases.



Use a *formula* to solve for one variable if given the value for the other variables.

- Use *dimensional analysis* to change the units of the measurement determined, <u>not</u> the value of the measurement itself.
  - It is very important in science to express all numbers <u>with</u> *units of measurement* when appropriate, not just the number as is sometimes done in purely mathematical problems.
  - To change a measurement from liters to milliliters, or grams to kilograms, for example, the measurement can be multiplied by a "conversion factor" that expresses the relationship between the given and asked- for value.
  - This conversion factor is a fraction equal to <u>one</u> and, therefore, the *value* of the original measurement does <u>not</u> change---only the *unit* changes.

15 ~~liters~~ X <u>1000 milliliters</u> = 15,000 milliliters

1 ~~liter~~

(conversion factor)

- Understand that a *scientific model* is an idealized description of how phenomena occur and how data or events are related. A scientific model is simply an idea that allows us to create explanations of how we think some part of the world works. *Models* are used to represent a concept or system so that the concept may be more easily understood and predictions can be made.

  - The model of the atom helps us understand the composition, structure, and behavior of atoms. Models for the atom can change as new information and theories explain the atom more completely.
  - No model is ever a perfect representation of the actual concept or system. Models may change over time as scientific knowledge advances.
- Understand that *technology* (tools/machines or processes) can be used to develop better understanding of the science concepts studied. As technology improves, science concepts are studied more completely and more accurately.
- Understand how to organize and analyze data using technology such as graphing calculators or computers.

B-1.6 Evaluate the results of a controlled scientific investigation in terms of whether they refute or verify the hypothesis.

- Understand that in a controlled scientific investigation the *hypothesis* is a prediction about the relationship between an independent and dependent variable with all other variables being held constant.
- Understand that results of a controlled investigation will either refute the hypothesis or verify it by supporting the hypothesis.
  - After the hypothesis has been tested and data is gathered, the experimental data is reviewed using data tables, charts, or graphical analysis.
  - If the data is consistent with the prediction in the hypothesis, the hypothesis is supported.
  - If the data is not consistent with the prediction in the hypothesis, the hypothesis is refuted.
- Understand that the shape of a graph can show the relationship between the variables in the hypothesis. (See graph shapes in PS-1.5)
- Understand that if the data does support the relationship, the hypothesis is still always tentative and subject to further investigation. Scientists repeat investigations and do different investigations to test the same hypothesis because the hypothesis is always tentative, and another investigation could refute the relationship predicted.
- Understand that scientific laws express principles in science that have been tested and tested and always shown to support the same hypothesis. Even these laws, however, can be shown to need revision as new scientific evidence is found with improved technology, advanced scientific knowledge, and more controlled scientific investigations based on these.

B-1.7 Evaluate a technological design or product on the basis of designated criteria (including cost, time, and materials).

- Understand that technological designs or products are produced by the application of scientific knowledge to meet specific needs of humans. The field of engineering focuses on these processes.
- Understand that there are four stages of technological design:
  - Problem identification
  - Solution design (a process or a product)
  - Implementation
  - Evaluation
- Understand that common requirements within the solution design stage of all technological designs or products include:
  - Cost effectiveness or lowest cost for production;
  - Time effectiveness or the least amount of time required for production, and
  - Materials that meet <u>specific criteria</u>, such as:
    - Solves the problem
    - Reasonably priced
    - Availability
    - Durability
    - Not harmful to users or to the environment
    - Qualities matching requirements for product or solution
    - Manufacturing process matches characteristics of the material
- Understand that benefits need to exceed the risk.
- Understand that there are tradeoffs among the various criteria. For example, the best material for a specific purpose may be too expensive.

B-1.8 Compare the processes of scientific investigation and technological design.

- Understand that *science* is a process of inquiry that searches for relationships that explain and predict the physical, living and designed world.
- Understand that *technology* is the application of scientific discoveries to meet human needs and goals through the development of products and processes.
- Understand that the processes of *scientific investigation* are followed to determine the relationship between an independent and dependent variable described by a hypothesis. The results of scientific investigations can advance science knowledge.
- Understand that the processes of *technological design* are followed to design products or processes to meet specified needs. The results of technological designs can advance standard of living in societies.
- Understand that, in general, the field of engineering is responsible for technological designs or products by applying science to make products or design processes that meet specific needs of mankind.
- The process of controlled scientific investigations:
  - Asks questions about the natural world;
  - Forms hypotheses to suggest a relationship between dependent and independent variables;
  - Investigates the relationships between the dependent and independent variables;
  - Analyzes the data from investigations and draws conclusions as to whether or not the hypothesis was supported.
- The technological design process is used to design products and processes that people can use. The process may involve:
  - A problem or need is identified
  - A solution is designed to meet the need or solve the problem identified.
  - The solution or product is developed and tested.
  - The results of the implementation are analyzed to determine how well the solution or product successfully solved the problem or met the need.

Some ways that the two processes might be compared:

Scientific Investigation	Technological Design
Identifies a problem – asks a question	Identifies a problem or need
Researches related information	Researches related information
Designs an investigation or experiment	Designs a process or a product
Conducts the investigation or experiment – repeated trials	Implements the design or the process – repeated testing
Analyzes the results	Analyzes the results
Evaluates the conclusion – did the results refute or verify the hypothesis	Evaluates the process or product – did it meet the criteria
Communicates the findings	Communicates the product or process

B-1.9 Use appropriate safety procedures when conducting investigations.

- Practice the safety procedures stated in every scientific investigation and technological design problem conducted in the laboratory and classroom. Follow safety procedures regarding
  - Personal safety – follow only the designated lab procedures; be sure to understand the meaning of any safety symbols shown, wear proper clothing and shoes for the lab, use protective equipment (goggles, aprons,…), tie back loose hair, never eat or drink in lab room, use proper technique for touching or smelling materials, be careful when using sharps (any item that can puncture, cut, or scrape the skin.)
  - Work area safety – use only designated chemicals or equipment, keep work area clear and uncluttered, do not point heated containers at yourself or anyone else, be sure all burners or hot plates are turned off when the lab is finished, know the location and use of the fire extinguisher, safety blanket, eyewash station, safety shower, and first aid kit, disconnect electrical devices, follow clean-up procedures as designated by the teacher.
- Safely and accurately practice appropriate techniques associated with the equipment and materials used in the activities conducted in the laboratory and classroom (see B-1.2 for materials lists).
- Abide by the safety rules in the course safety contract.
- Report any laboratory safety incidents (spills, accidents, or injuries) to the teacher.

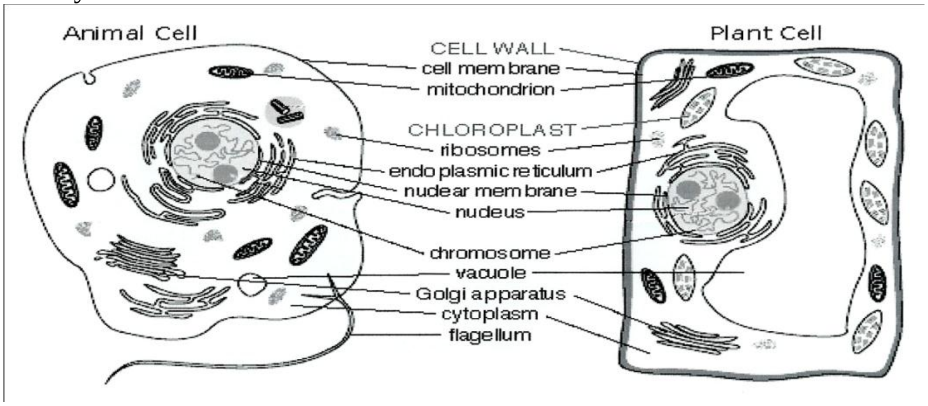
B-2.1 Recall the three major tenets of cell theory (all living things are composed of one or more cells; cells are the basic units of structure and function in living things; and all presently existing cells arose from previously existing cells).

- All living things are composed of one or more cells.
- Cells are the basic unit of structure of all living things.
  - The lowest level of structure capable of performing all the activities of life is the cell.
  - A *unicellular organism* is composed of one cell and all of life's activities occur within that single cell.
  - In a *multicellular organism,* each cell carries on most of the major functions of life.
- All presently existing cells arose from previously existing cells.
  - The ability of cells to divide to form new cells is the basis for all reproduction (both sexual and asexual) and for the growth and repair of all multicellular organisms.

B-2.2 Summarize the structures and functions of organelles found in a eukaryotic cell (including the nucleus, mitochondria, chloroplasts, lysosomes, vacuoles, ribosomes, endoplasmic reticulum [ER], Golgi apparatus, cilia, flagella, cell membrane, nuclear membrane, cell wall, and cytoplasm).

An *organelle* is a cell structure that performs a specialized function within a eukaryotic cell. Organelles found in a eukaryotic cell include:

- *Nucleus* contains the chromosomes which are composed of DNA (a chemical compound called deoxyribonucleic acid); functions in the genetic control of the cell.
- *Mitochondria* are the sites of cellular respiration, a process which supplies the cell with energy.
- *Chloroplasts* are found only in plant cells, contain the green pigment, *chlorophyll,* which absorbs energy from the Sun to convert carbon dioxide and water into sugar through the process of photosynthesis.
- *Lysosomes* contain chemicals called *enzymes* necessary for digesting certain materials in the cell.
- *Vacuoles* store materials such as water, salts, proteins, and carbohydrates; vacuoles in animal cells (if they are present) are much smaller than those in plant cells.
- *Ribosomes* are the sites of protein synthesis; some are located on the ER, others are found in the cytoplasm.
- *Endoplasmic reticulum (ER)* is a complex, extensive network that transports materials throughout the inside of a cell.
  - Rough ER has ribosomes attached to the surface is ribosome-studded.
  - Smooth ER has no attached ribosomes.
- *Golgi apparatus* modifies, collects, packages, and distributes molecules within the cell or outside the cell.
- *Cilia* are short hair-like projections responsible for the movement of animal cells or protists.
- *Flagella* are long whip-like projections responsible for the movement of some animal cells, bacteria, or protists.
- *Cell membrane* (sometimes called the plasma membrane) is the cell structure that encloses the cell and regulates the passage of materials between the cell and its environment; the cell membrane also aids in protection and support of the cell.
- *Nuclear membrane* (sometimes called nuclear envelope) is the membrane that surrounds the nucleus of the cell and regulates the passage of materials between the nucleus and the cytoplasm.
- *Cell wall* is the cell structure that surrounds the cell membrane for protection and support in plant cells, bacteria, fungi, and some protists, and allows for specific substances to pass in and out of the cell.
- *Cytoplasm* is the semi-fluid material inside the cell containing molecules and the organelles, exclusive of the nucleus; is bound by the cell membrane.

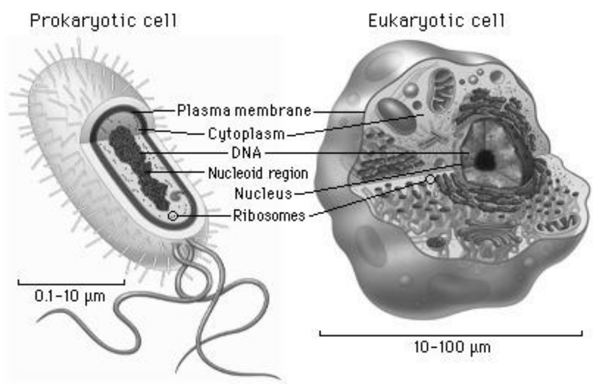


B-2.3 Compare the structures and organelles of prokaryotic and eukaryotic cells.

The major difference between prokaryotic cells and eukaryotic cells is the presence of a nucleus.

- *Prokaryotic cells* do not have a true nucleus; the DNA in prokaryotic cells is not completely separated from the rest of the cell by a nuclear membrane (envelope) and is not arranged in strands called chromosomes.
  - *DNA (deoxyribonucleic acid)* is a chemical compound that stores and transmits genetic information
- In *eukaryotic cells*, the DNA is organized into structures called chromosomes and the chromosomes are separated from the cytoplasm by a nuclear membrane.

Prokaryotic cells differ from eukaryotic cells in other ways:
- Prokaryotic cells lack most of the other organelles which are present in the cytoplasm of eukaryotic cells.
- Prokaryotic cells do not contain mitochondria but they can obtain energy from either sunlight or from chemicals in their environment.
- Prokaryotic cells, however, do contain ribosomes, the site of protein synthesis.
- Most prokaryotes are unicellular organisms, such as bacteria.



B-2.4 Explain the process of cell differentiation as the basis for the hierarchical organization of organisms (including cells, tissues, organs, and organ systems).

- In the development of most multicellular organisms, a single cell (fertilized egg) gives rise to many different types of cells, each with a different structure and corresponding function.
  - The fertilized egg gives rise to a large number of cells through *cell division*, but the process of cell division alone could only lead to increasing numbers of identical cells.
  - As cell division proceeds, the cells not only increase in number but also undergo *differentiation* becoming specialized in structure and function. (Cell division is covered in B-2.6.)
  - The various types of cells (such as blood, muscle, or epithelial cells) arrange into tissues which are organized into organs, and, ultimately, into organ systems.
- Nearly all of the cells of a multicellular organism have exactly the same chromosomes and DNA.
  - During the process of differentiation, only specific parts of the DNA are activated; the parts of the DNA that are activated determine the function and specialized structure of a cell.
  - Because all cells contain the same DNA, all cells initially have the potential to become any type of cell.
  - Once a cell differentiates, the process can not be reversed.
- *Stem cells* are unspecialized cells that continually reproduce themselves and have, under appropriate conditions, the ability to differentiate into one or more types of specialized cells.
  - Embryonic cells, which have not yet differentiated into various cell types, are called embryonic stem cells.
  - Stem cells found in adult organisms, for instance in bone marrow, are called adult stem cells.
  - Scientists have recently demonstrated that stem cells, both embryonic and adult, with the right laboratory culture conditions, differentiate into specialized cells.

- **B-2.5 Explain how active, passive, and facilitated transport serve to maintain the homeostasis of the cell.**

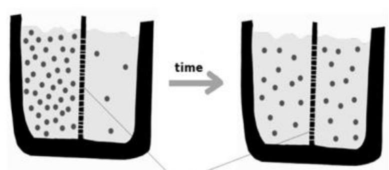
Homeostasis refers to the necessity of an organism to maintain constant or stable conditions. In order to maintain homeostasis, all organisms have processes and structures which respond to stimuli in ways that keep conditions in their bodies conducive for life. Homeostasis depends in part on appropriate movement of materials across the cell membrane.

- Materials needed for cellular processes must pass into cells so they can be utilized. For example, oxygen and glucose are continuously needed for the process of cellular respiration.
- Waste materials from cellular processes must pass out of cells as they are produced. For example, carbon dioxide is continuously produced within the cell during the process of cellular respiration.
- The cell membrane regulates the passage of material into and out of the cell. Depending on the needs of the cell, excess substances must move out of the cell and needed substances must move into the cell.
- Each individual cell exists in a fluid environment, and the cytoplasm within the cell also has a fluid environment. The presence of a liquid makes it possible for substances (such as nutrients, oxygen, and waste products) to move into and out of the cell.
- A cell membrane is *semi-permeable (selectively permeable)*, meaning that some substances can pass directly through the cell membrane while other substances can not.
- Materials can enter or exit through the cell membrane by passive transport or active transport.

Passive transport is a process by which substances move across a cell membrane but do not require energy from the cell. Types of passive transport are diffusion, osmosis, and facilitated diffusion.

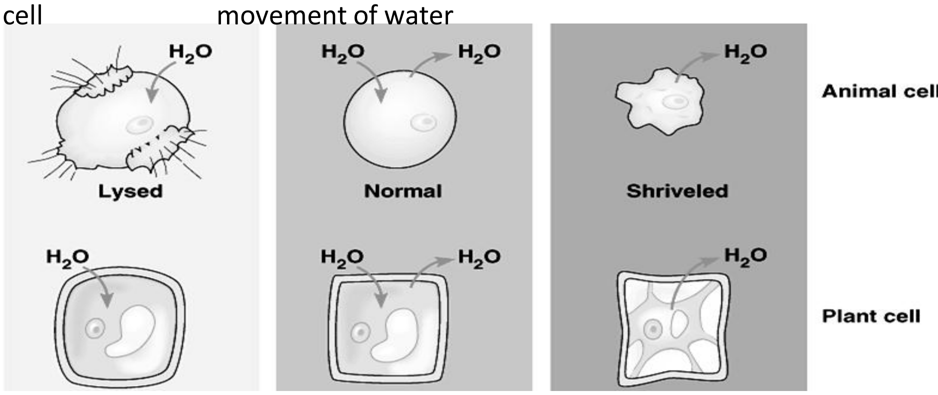
- *Diffusion* is the spreading out of molecules across a cell membrane until they are equally concentrated. It results from the random motion of molecules and occurs along a *concentration gradient* (molecules move from an area of higher concentration to an area of lower concentration); substances that are able to pass directly across the cell membrane can diffuse either into a cell or out of a cell.

Diffusion across a semi-permeable membrane



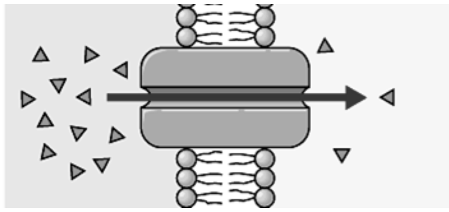
- *Osmosis* is the diffusion of water molecules through a selectively permeable membrane from an area of greater concentration of water to an area of lesser concentration of water.
  - If two solutions with the same solute concentration are separated by a selectively permeable membrane, water molecules will pass through the membrane in both directions at the same rate so the concentration of the solutions will remain constant.
  - The diffusion of water molecules is a passive transport process because it does not require the cell to expend energy.
  - If cells are placed in solutions that are very different in concentration from that of the cell, the cells may be damaged and even shrivel or burst (*lyse*).

Water concentration greater outside the cell than inside so water moves into the cell	Water concentration the same inside and outside the cell so there is no net movement of water	Water concentration greater inside the cell than outside so water moves out of the cell



- *Facilitated diffusion (transport)* is the process by which some substances that are not able to pass directly through a cell membrane are able to enter the cell with the aid of *transport proteins*. Facilitated diffusion occurs along a concentration gradient and does not require energy from the cell.
  - Some substances have chemical structures that prevent them from passing directly through a cell membrane. The cell membrane is not permeable to these substances.
  - Transport proteins provide access across the cell membrane.
  - Glucose is an example of a substance that passes through the cellular membrane using facilitated diffusion.

Facilitated Diffusion



Active transport is another one way that substances can move through a cell membrane. However, molecules move against the concentration gradient (from an area of low concentration to an area of high concentration) and require the cell to expend energy.

- One process of active transport happens when cells pump molecules through the cell membrane.
  - Unlike the process of facilitated diffusion, in active transport, molecules are "pumped" across the cell membrane by transport proteins. This pumping process requires an expenditure of chemical energy.
  - Because this process does not depend on diffusion, cells can use this process to concentrate molecules within the cell, or to remove waste from a cell.
  - Calcium, potassium, and sodium ions are examples of materials that must be forced across the cell membrane using active transport.
- Another process of active transport happens when molecules are too large to pass through a cell membrane even with the aid of transport proteins. These molecules require the use of *vesicles* to help them through the membrane.
  - If the large molecule is passing into the cell, the process is called *endocytosis*.
  - If the large molecule is passing out of the cell, the process is called *exocytosis*.

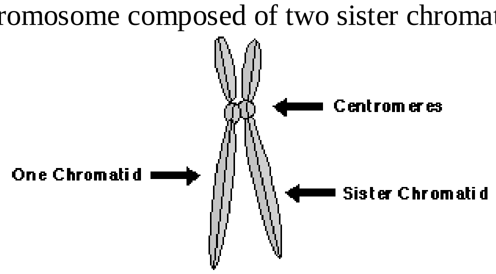
B-2.6 Summarize the characteristics of the cell cycle: interphase (called G1, S, G2); the phases of mitosis (called prophase, metaphase, anaphase, and telophase); and plant and animal cytokinesis

The *cell cycle* is a repeated pattern of growth and division that occurs in eukaryotic cells. This cycle consists of three phases. The first phase represents cell growth while the last two phases represent cell division.

Interphase

- Cells spend the majority of their cell cycle in interphase. The purpose of interphase is for cell growth. By the end of interphase a cell has two full sets of DNA (chromosomes) and is large enough to begin the division process.
- Interphase is divided into three phases. Each phase is characterized by specific processes involving different structures.
  - During the *G1 (gap 1) phase*, the cell grows and synthesizes proteins.
  - During the *S (synthesis) phase*, chromosomes replicate and divide to form identical sister *chromatids* held together by a *centromere.*
  - During the *G2 (gap 2) phase*, cells continue to grow and produce the proteins necessary for cell division.

Chromosome composed of two sister chromatids



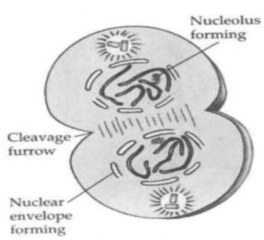
Mitosis

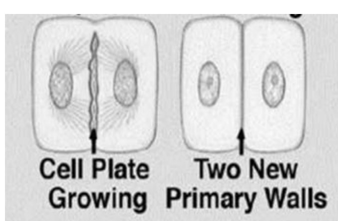
- The purpose of mitosis is cell division: making two cells out of one. Each cell has to have its own cytoplasm and DNA. The DNA that replicated in Interphase when two chromosome strands became four strands (two strands per chromatid). In mitosis the four strands (two sister chromatids) have to break apart so that each new cell only has one double-stranded chromosome.
- Mitosis, which follows Interphase, is divided into four phases. Each phase is characterized by specific processes involving different structures.
  - *Prophase* is characterized by four events:
    - Chromosomes condense and are more visible.
    - The nuclear membrane (envelope) disappears.
    - By the end of prophase the centrioles (cell organelles that produce spindle fibers) have separated and taken positions on the opposite poles of the cell.
    - Spindle fibers form and radiate toward the center of the cell.
  - *Metaphase* (the shortest phase of mitosis) is characterized by two events:
    - Chromosomes line up across the middle of the cell.
    - Spindle fibers connect the centromere of each sister chromatid to the poles of the cell.
  - *Anaphase* is characterized by three events:
    - Centromeres that join the sister chromatids split.
    - Sister chromatids separate becoming individual chromosomes.
    - Separated chromatids move to opposite poles of the cell.
  - *Telophase* (the last phase of mitosis) consists of four events:
    - Chromosomes (each consisting of a single chromatid) uncoil.
    - A nuclear envelope forms around the chromosomes at each pole of the cell.
    - Spindle fibers break down and dissolve.
    - Cytokinesis begins.

Cytokinesis

Cytokinesis is the division of the cytoplasm into two individual cells. The process of cytokinesis differs somewhat in plant and animal cells.

- In animal cells the cell membrane forms a *cleavage furrow* that eventually pinches the cell into two nearly equal parts, each part containing its own nucleus and cytoplasmic organelles.
- In plant cells a structure known as a *cell plate* forms midway between the divided nuclei, which gradually develops into a separating membrane. The cell wall forms in the cell plate.





Animal Cell Telophase/Cytokinesis   Plant Cell Telophase/Cytokinesis

B-2.7 Summarize how cell regulation controls and coordinates cell growth and division and allows cells to respond to the environment, and recognize the consequences of uncontrolled cell division.

The cell cycle is driven by a *chemical control system* that both triggers and coordinates key events in the cell cycle. The cell cycle control system is regulated at certain checkpoints.

- Signals from inside the cell (internal signals) and from outside the cell (external signals) are involved in turning the process of cell division off and on.
  - An *internal signal* involves the cell sensing the presence of chemicals, called enzymes, which are produced inside the cell
  - An *external signal* involves the cell sensing the presence of a chemical (such as a growth factor) which was produced in other specialized cells.
- Cells can also respond to physical signals from their environment.
  - Cells sense when they are too closely packed and cell division is turned off.
  - Cells sense when they are not in contact with a surface and cell division is turned on.

A *checkpoint* in the cell cycle is a critical control point where stop and go signals can regulate the cycle. The cell division mechanism in most animal cells is in the "off" position when there is no stimulus present. Specific stimuli are required to start the processes

- *Cancer cells* are an example of cells that do not heed the normal signals which shut down the cell division process; they continue to divide even when they are very densely packed and/or there is no growth factor present.
- Cancer begins when a single cell is transformed into a cancer cell, one that does not heed the regulation mechanism.
  - Normally the body's immune system will recognize that the cell is damaged and destroy it, but if it evades destruction, it will continue to divide and each daughter cell will be a cancer cell.
  - A mass of these cells that invades and impairs the functions of one or more organs is called a *malignant tumor*.
  - A *benign tumor* is a mass of abnormal cells that remains at the original site.
- Cancer cells may also separate from the original tumor, enter the blood and lymph vessels of the circulatory system, and invade other parts of the body, where they grow to form new tumors.

B-2.8 Explain the factors that affect the rates of biochemical reactions (including pH, temperature, and the role of enzymes as catalysts).

Biochemical reactions allow organisms to grow, develop, reproduce, and adapt. A chemical reaction breaks down some substances and forms other substances. There are several factors that affect the rates of biochemical reactions.
- Chemical reactions (including biochemical reactions) can occur when reactants collide with sufficient energy to react. The amount of energy that is sufficient for a particular chemical reaction to occur is called the *activation energy*.
  - Sometimes a chemical reaction must absorb energy for the reaction to start; often, but not always, this energy is in the form of heat.
  - Energy, as heat or light, can also be given off as a result of biochemical reactions, such as with cellular respiration or bioluminescence.
- Changes in temperature (gaining or losing heat energy) can affect a chemical reaction.
- *pH* (a measure of the acidity of a solution) in most organisms needs to be kept within a very narrow range. *Buffers* within an organism are used to regulate pH so that pH homeostasis can be maintained. A small change in pH can disrupt cell processes.
- A *catalyst* is a substance that changes the rate of a chemical reaction or allows a chemical reaction to occur (activate) at a lower than normal temperature. Catalysts work by lowering the activation energy of a chemical reaction. A catalyst is not consumed or altered during a chemical reaction, so, it can be used over and over again. *Enzymes* are proteins which serve as catalysts in living organisms.
  - Enzymes are very specific. Each particular enzyme can catalyze only one chemical reaction by working on one particular reactant (substrate).
  - Enzymes are involved in many of the chemical reactions necessary for organisms to live, reproduce, and grow, such as digestion, respiration, reproduction, movement and cell regulation.
  - The structure of enzymes can be altered by temperature and pH; therefore, each catalyst works best at a specific temperature and pH.

B-3.1 Summarize the overall process by which photosynthesis converts solar energy into chemical energy and interpret the chemical equation for the process.

All organisms need a constant source of energy to survive. The ultimate source of energy for most life on Earth is the Sun. *Photosynthesis* is the overall process by which sunlight (solar energy) chemically converts water and carbon dioxide into chemical energy stored in simple sugars (glucose). This process occurs in two stages.

- The first stage is called the *light-dependent reactions* because they require solar energy.
  - During the light-dependent reactions, solar energy is absorbed by chloroplasts (see B-2.2) and two energy storing molecules (ATP and NADPH) are produced.
  - The solar energy is used to split water molecules which results in the release of oxygen as a waste product, an essential step in the process of photosynthesis.
- The second stage is called the *dark (light-independent) reactions* because they do not require solar energy.
  - During the dark (light-independent) reactions, energy stored in ATP and NADPH is used to produce simple sugars (such as glucose) from carbon dioxide. These simple sugars are used to store chemical energy for use by the cells at later times.
  - Glucose can be used as an energy source through the process of cellular respiration or it can be converted to organic molecules (such as proteins, carbohydrates, fats/lipids, or cellulose) by various biologic processes.

The process photosynthesis is generally represented using a balanced chemical equation. However, this equation does not represent all of the steps that occur during the process of photosynthesis.

$$6CO_2 + 6H_2O \xrightarrow{\text{Solar energy}} C_6H_{12}O_6 + 6O_2$$

- In general, six carbon dioxide molecules and six water molecules are needed to produce one glucose molecule and six oxygen molecules.
- Each of the reactants (carbon dioxide and water) is broken down at different stages of the process.
- Each of the products (oxygen and glucose) is formed in different stages of the process.
  - Solar energy is needed to break down the water molecules.

B-3.2 Summarize the basic aerobic and anaerobic processes of cellular respiration and interpret the chemical equation for cellular respiration.

The ultimate goal of *cellular respiration* is to convert the chemical energy in nutrients to chemical energy stored in *adenosine triphosphate (ATP)*. ATP can then release the energy for cellular metabolic processes, such as active transport across cell membranes, protein synthesis, and muscle contraction.

- Any food (organic) molecule, or nutrient, including carbohydrates, fats/lipids, and proteins can be processed and broken down as a source of energy to produce ATP molecules.

$$\text{nutrients} + \text{oxygen} \longrightarrow \text{water} + \text{energy (ATP)} + \text{carbon dioxide}$$

To transfer the energy stored in glucose to the ATP molecule, a cell must break down glucose slowly and capture the energy in stages.

- The first stage is *glycolysis*.
  - In the process of glycolysis a glucose molecule is broken down into pyruvic acid molecules and ATP molecules.

- Glycolysis is a series of reactions using enzymes that takes place in the cytoplasm.

- If oxygen is available, the next stage is the two-step process of *aerobic respiration*, which takes place primarily in the mitochondria of the cell.
  - The first step of aerobic respiration is called the *citric acid* or *Krebs cycle.*
    - The pyruvic acid formed in glycolysis travels to the mitochondria where it is chemically transformed in a series of steps, releasing carbon dioxide, water, and energy (which is used to form 2 ATP molecules)

$$\text{Pyruvic acid} \longrightarrow \text{carbon dioxide} + \text{water} + \text{energy (2 ATP)}$$

  - The second step of aerobic respiration is the *electron transport chain*.
    - Most of the energy storing ATP molecules is formed during this part of the cycle.
    - The electron transport chain is a series of chemical reactions ending with hydrogen combining with oxygen to form water. Carbon dioxide is released as a waste product as it is formed in several stages of the Krebs cycle.
    - Each reaction produces a small amount of energy, which by the end of the cycle produces many (up to 36) ATP molecules.
    - The ATP synthesized can be used by the cell for cellular metabolism

The process aerobic respiration is generally represented using a balanced chemical equation. However, this equation does not represent all of the steps that occur during the process of aerobic respiration.

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{energy}$$

- In general, one glucose molecule and six oxygen molecules are needed to produce six carbon dioxide molecules and six water molecules.
- Each of the reactants (glucose and oxygen) is used during different stages of aerobic respiration.
- Each of the products (carbon dioxide and water) is formed during different stages of the process.
- The energy that is released is primarily used to produce approximately 34 to 36 molecules of ATP per glucose molecule.

If no oxygen is available, cells can obtain energy through the process of *anaerobic respiration.* A common anaerobic process is *fermentation*.

- Fermentation is not an efficient process and results in the formation of far fewer ATP molecules than aerobic respiration.
- There are two primary fermentation processes:
  - *Lactic acid fermentation* occurs when oxygen is not available, for example, in muscle tissues during rapid and vigorous exercise when muscle cells may be depleted of oxygen.
    - The pyruvic acid formed during glycolysis is broken down to lactic acid, and in the process energy is released (which is used to form ATP).

$$\text{Glucose} \rightarrow \text{Pyruvic acid} \rightarrow \text{Lactic acid} + \text{energy}$$

    - The process of lactic acid fermentation replaces the process of aerobic respiration so that the cell can continue to have a continual source of energy even in the absence of oxygen, however this shift is only temporary and cells need oxygen for sustained activity.
    - Lactic acid that builds up in the tissue causes a burning, painful sensation.

- *Alcohol fermentation* occurs in yeasts and some bacteria.
  - In this process, pyruvic acid formed during glycolysis is broken down to produce alcohol and carbon dioxide, and in the process energy is released (which is used to form ATP).

Glucose → Pyruvic acid → alcohol + carbon dioxide + energy

B-3.3 Recognize the overall structure of adenosine triphosphate (ATP)—namely, adenine, the sugar ribose, and three phosphate groups—and summarize its function (including the ATP-ADP [adenosine diphosphate] cycle).

Adenosine triphosphate (ATP) is the most important biological molecule that supplies energy to the cell. A molecule of ATP is composed of three parts:

- A *nitrogenous base (adenine)*
- A sugar *(ribose)*
- Three *phosphate groups* (therefore the name triphosphate) bonded together by "high energy" bonds

ATP-ADP cycle.

- Cells break phosphate bonds as needed to supply energy for most cellular functions, leaving adenosine diphosphate (ADP) and a phosphate available for reuse.
  - When any of the phosphate bonds are broken or formed, energy is involved.
    - Energy is released each time a phosphate is removed from the molecule.
    - Energy is used each time a phosphate attaches to the molecule.
  - To constantly supply the cell with energy, the ADP is recycled creating more ATP which carries much more energy than ADP.
- The steps in the ATP-ADP cycle are
  - To supply cells with energy, a "high energy" bond in ATP is broken. ADP is formed and a phosphate is released back into the cytoplasm.

    ATP → ADP + phosphate + energy

  - As the cell requires more energy, ADP becomes ATP when a free phosphate attaches to the ADP molecule. The energy required to attach the phosphate to ADP is much less than the energy produced when the phosphate bond is broken.

    ADP + phosphate + energy → ATP

B-3.4 Summarize how the structures of organic molecules (including proteins, carbohydrates, and fats) are related to their relative caloric values.

All organisms are composed of *organic molecules* which contain carbon atoms. Most organic molecules are made of smaller units that bond to form larger molecules. Energy is stored in the bonds that link these units together. The amount of energy stored in these bonds varies with the type of molecule formed. As a result, not all organic molecules have the same amount of energy available for use by the organism. The energy stored in organic molecules determines its *caloric value*. Proteins, carbohydrates, and fats/lipids are three organic molecules with different structures and different caloric values based on those structures.

- *Proteins* are molecules composed of chains of *amino acids.*
  - Amino acids are molecules that are composed of carbon, hydrogen, oxygen, nitrogen, and sometimes sulfur.
  - There are 20 amino acids that chemically bond in various ways to make proteins. Twelve of these amino acids are made in the body; others must be consumed from foods such as nuts, beans, or meat.

  - Although proteins are more important as a source of building blocks, amino acids may be used by the body as a source of energy (through the process of cellular respiration), but first they must be converted by the body to carbohydrates. This process does not happen as long as there is a carbohydrate or lipid available.
  - As a source of energy, proteins have the same caloric value per gram as carbohydrates.
- *Carbohydrates* (sugars and starches) are molecules composed of carbon, hydrogen, and oxygen.
  - The basic carbohydrates are simple sugars (*monosaccharides*) such as glucose. These simple sugars can bond together to make larger, complex carbohydrate molecules, for example starch or cellulose.
  - Carbohydrates are important because they the main source of energy for the cell.
    - ♦ When carbohydrates are synthesized during the process of photosynthesis, the plants or other photosynthetic organisms use them as a source of energy or they are stored in the cells.
    - ♦ When complex carbohydrates are consumed, the process of digestion breaks the bonds between the larger carbohydrate molecules so that individual simple sugars can be absorbed into the bloodstream through the walls of the intestines.
      - ∗ The bloodstream carries the simple sugars to cells throughout the body where they cross into the cells through the cell membrane.
      - ∗ Once inside the cells, simple sugars are used as fuel in the process of cellular respiration, releasing energy which is stored as ATP.
  - The caloric value of carbohydrates is dependent on the number of carbon-hydrogen bonds. If an organism has a greater supply of carbohydrates than needed for its energy requirements, the extra energy is converted to fats and stored by the body.
- *Lipids,* including *fats,* are organic molecules composed of carbon, hydrogen, and oxygen.
  - Lipid molecules are made of two component molecules (*glycerols* and *fatty acids*) so they are structurally different from carbohydrates. Fats/lipids have more carbon-hydrogen bonds than carbohydrates.
  - Fats are important to organisms for energy when carbohydrates are scarce, but when there is no shortage of food, stored fat accumulates.
    - ♦ When fats are consumed, the molecules are broken down during the process of digestion so that individual glycerol and fatty acid molecules are absorbed into the bloodstream through the walls of the intestines.
    - ♦ The blood stream carries the glycerol and fatty acid molecules to cells throughout the body where the molecules cross into the cells through the cell membrane.
    - ♦ Once inside the cell, glycerols and fatty acids are stored for later use or used as fuel for cellular respiration if there are no carbohydrates available.
    - ♦ The process of cellular respiration releases the energy that is held in the chemical bonds of the glycerol and fatty acid molecules.

Due to the structure and number of the carbon-hydrogen bonds that hold the different types of molecules (proteins, carbohydrates, or fats) together, fats contain more energy (ATP) per gram than carbohydrates or proteins, which explains why fats have a greater caloric value.

B-3.5 Summarize the functions of proteins, carbohydrates, and fats in the human body.

Proteins, carbohydrates, and fats have important functions within the human body.

- *Proteins* are involved in almost every function in the human body. For example, they serve as the basis for structures, transport substances, regulate processes, speed up chemical reactions, and control growth.
  - Proteins are more important as a source of building blocks than as a source of energy. Proteins can function as an energy source only if there is a shortage of carbohydrates or lipids.
    - ♦ When proteins are consumed, the bonds that hold the amino acids together are broken during the process of digestion so that individual amino acids are absorbed into the bloodstream through the walls of the intestines.
    - ♦ The amino acids are carried by the blood stream to cells throughout the body where they cross into the cells through the cell membrane.
    - ♦ Once inside the cell, they are used as raw materials to make all of the proteins required by the organism.
  - Because of their structures, proteins serve different functions. For example,
    - ♦ Structural proteins are used for support such as connective tissue and keratin that forms hair and finger nails.

        - ♦ Transport proteins transport many substances throughout the body such as hemoglobin which transports oxygen from the lungs to the other parts of the body to be used by cells in cellular respiration.
        - ♦ Hormone proteins coordinate body activities such as insulin which regulates the amount of sugar in the blood.
        - ♦ Contractile proteins help control movement such as proteins in the muscles which help control contraction.
        - ♦ Enzymatic proteins accelerate the speed of chemical reactions such as digestive enzymes which break down food in the digestive tract.
- *Carbohydrates* are important as an energy source for all organisms and as a structural molecule in many organisms.
    - Carbohydrates are a primary source of fuel for cellular respiration.
    - Carbohydrates are also used to store energy for short periods of time.
    - The carbon, hydrogen, and oxygen that compose carbohydrates serve as raw materials for the synthesis of other types of small organic molecules, such as amino acids and fatty acids.
    - Some carbohydrates (such as cellulose) are used as structural material in plants.
        - ♦ For most animals, foods that contain these carbohydrates are important as fiber which stimulates the digestive system.
- *Fats (lipids)* are important to organisms for energy when carbohydrates are scarce since they are the primary way to store energy.
    - Fats serve a variety of functions in humans, such as providing long-term energy storage, cushioning of vital organs, and insulation for the body.
    - Fats also serve as a major component of cell membranes and are one of the raw materials necessary for the production of some vitamins and hormones.

B-3.6 Illustrate the flow of energy through ecosystems (including food chains, food webs, energy pyramids, number pyramids, and biomass pyramids).

Flow of energy through ecosystems can be described and illustrated in food chains, food webs, and pyramids (energy, number, and biomass).

Food Chain

A *food chain* is the simplest path that energy takes through an ecosystem. Energy enters an ecosystem from the Sun. Each level in the transfer of energy through an ecosystem is called a *trophic level*. The organisms in each trophic level use some of the energy in the process of cellular respiration, lose energy due to heat loss, and store the rest.

- The first trophic level consists of *primary producers* (green plants or other *autotrophs*).
    - Primary producers capture the Sun's energy during photosynthesis, and it is converted to chemical energy in the form of simple sugars.
    - The autotroph uses some of the simple sugars for energy and some of the simple sugars are converted to organic compounds (carbohydrates, proteins, and fats) as needed for the structure and functions of the organism.
    - Examples of primary producers include land plants and phytoplankton in aquatic environments.
- The second trophic level consists of *primary consumers (heterotrophs)*.
    - Primary consumers that eat green plants are called *herbivores*.
    - The herbivore uses some of the organic compounds for energy and some of the organic compounds are converted into the proteins, carbohydrates and fats that are necessary for the structure and functions of the herbivore. Much of the consumed energy is lost as heat.
    - Examples of primary consumers include grasshoppers, rabbits and zooplankton.
- The third trophic level, or any higher trophic level, consists of *consumers*.
    - Consumers that eat primary consumers are called *carnivores*; consumers that eat both producers and primary consumers are called *omnivores*.
    - The carnivores or omnivores use some of the organic compounds for energy and some of the organic compounds are converted into the proteins, carbohydrates and fats that are necessary for their body structures and functions. Much of the consumed energy is lost as heat.
    - Examples of consumers include humans, wolves, frogs, and minnows.
- A heterotroph that decomposes organic material and returns the nutrients to soil, water, and air making the nutrients available to other organisms is called a *detritivore*.

The energy available for each trophic level in an ecosystem can be illustrated with a food chain diagram. The size of the arrow in a diagram may indicate that the energy is smaller at each trophic level because each organism uses some of the energy for life processes or lost as heat.

Food Web

A *food web* represents many interconnected food chains describing the various paths that energy takes through an ecosystem. The energy available in an ecosystem can be illustrated with a food web diagram.

Ecological Pyramids

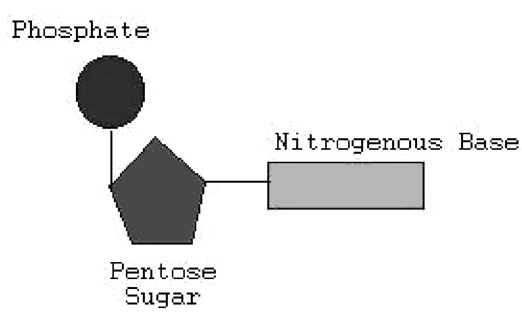
Ecological pyramids are models that show how energy flows through ecosystems. Pyramids can show the relative amounts of energy, biomass, or numbers of organisms at each trophic level in an ecosystem. The base of the pyramid represents producers. Each step up represents a different level of consumer. The number of trophic levels in the pyramid is determined by the number of organisms in the food chain or food web.

- An *energy pyramid* represents the energy available for each trophic level in an ecosystem.
  - The energy needs of organisms are greater from level to level in an ecosystem.
  - Therefore, the total amount of energy available at each level decreases in an ecosystem.
  - Each successive level in an ecosystem can support fewer numbers of organisms than the one below. With each level of the pyramid, only 10% of the energy available is used by organisms while there is an energy loss of about 90% to the environment.
- A *number pyramid* represents the number of individual organisms available for energy at each trophic level in an ecosystem. It can be used to examine how the population of a certain species affects another.
  - The autotrophic level is represented at the base of the pyramid. This represents the total number of producers available to support the energy needs of the ecosystem.
  - The total numbers of individual organisms tend to decline as one goes up trophic levels.
- A *biomass pyramid* represents the total mass of living organic matter (biomass) at each trophic level in an ecosystem.
  - Since the number of organisms is reduced in each successive trophic level, the biomass at each trophic level is reduced as well.
  - Even though a biomass pyramid shows the total mass of organisms available at each level, it does not necessarily represent the amount of energy available at each level. For example, the skeleton and beak of a bird will contribute to the total biomass but are not available for energy.

B-4.1 Compare DNA and RNA in terms of structure, nucleotides, and base pairs.

Nucleic acids are organic molecules that serve as the blueprint for proteins and, through the action of proteins, for all cellular activity.

- There are two types of nucleic acids.
  - *Deoxyribonucleic acid (DNA)*
  - *Ribonucleic acid (RNA)*
- Both DNA and RNA are composed of small units called *nucleotides.* The nucleotides that compose nucleic acids have three parts:
  - A *nitrogenous base*
    - Cytosine (C)
    - Guanine (G)
    - Adenine (A)
    - Thymine (T) (DNA only)
    - Uracil (U) (RNA only)
  - A simple (pentose) *sugar*
    - Deoxyribose (DNA only)
    - Ribose (RNA only)
  - A *phosphate group*



The basic structure of the two molecules is different.

- DNA consists of two single chains which spiral around an imaginary axis to form a double helix with nitrogenous bases from each strand of DNA chemically bonded through the axis of the helix.
  - When the nitrogenous bases of two strands of DNA chemically bond through the center of the helix, each base can bond to only one type of base. Bases that bond are called *complementary bases.*
    - ♦ Guanine (G) will only bond with Cytosine (C).
    - ♦ Thymine (T) will only bond with Adenine (A).
- RNA consists of a single chain of nucleotides with nitrogenous bases exposed along the side.
  - When the nitrogenous bases of RNA chemically bond to a strand of DNA, each RNA base can bond with only one type of DNA base. Bases that bond are called *complementary bases.*
    - ♦ Guanine (G) will only bond with Cytosine (C).
    - ♦ Uracil (U) will only bond with Adenine (A).

B-4.2 Summarize the relationship among DNA, genes, and chromosomes.

DNA, genes, and chromosomes compose the molecular basis of heredity.

- A *chromosome* is a structure in the nucleus of a cell consisting essentially of one long thread of DNA that is tightly coiled.
- *DNA*, composed of nucleotides, provides the blueprint for the synthesis of proteins by the arrangement of nitrogenous bases.
  - The code for a particular amino acid (the base unit of proteins) is determined by a sequence of three base pairs on the DNA molecule.
- A *gene* is a specific location on a chromosome, consisting of a segment of DNA, that codes for a particular protein.
  - The particular proteins coded by the DNA on the genes determine the characteristics of an organism.
  - Each chromosome consists of hundreds of genes determining the many proteins for an individual organism.

B-4.3 Explain how DNA functions as the code of life and the blueprint for proteins.

DNA, which comprises the organism's chromosomes, is considered the "code of life" (*genetic code*) because it contains the code for each protein that the organism needs.

- The specificity of proteins is determined by the order of the nitrogenous bases found in DNA.
  - In order to construct the specific proteins needed for each specific purpose, cells must have a blueprint that reveals the correct order of amino acids for each protein found in the organism (thousands of proteins).
  - A gene is a segment of DNA that codes for one particular protein.
- Each cell in an organism's body contains a complete set of chromosomes.
  - The number of chromosomes varies with the type of organism. For example, humans have 23 pairs of chromosomes; dogs have 39 pairs; potatoes have 24 pairs.
  - One pair of chromosomes in an organism determines the sex (male, female) of the organism; these are known as *sex chromosomes*. All other chromosomes are known as autosomal chromosomes, or *autosomes*.
  - Cells (except for sex cells) contain one pair of each type of chromosome.
    - ♦ Each pair consists of two chromosomes that have genes for the same proteins.
    - ♦ One chromosome in each pair was inherited from the male parent and the other from the female parent. In this way traits of parents are passed to offspring.
    - ♦ For example, human cells have 46 chromosomes (23 pairs).
- Each chromosome consists of thousands of genes. This is because there are so many unique proteins that each organism needs to produce in order to live and survive.
  - Organisms that are closely related may have genes that code for the same proteins that make the organisms similar. For example, all maple trees have many of the same genes.
  - Each individual organism has unique characteristics and those unique characteristics arise because of the differences in the proteins that the organism produces.
  - Organisms that are not closely related share fewer genes than organisms that are more closely related. For example, red maple trees share more genes with oak trees than with earthworms.

DNA can function as the code of life for protein synthesis or the process of DNA replication, which ensures that every new cell has identical DNA.

- *DNA replication* is carried out by a series of enzymes. The first enzyme unzips the two strands of DNA that compose the double helix, separating paired bases.
- Each base that is exposed can only bond to its complementary base.
  - Adenine (A) can only bond to thymine (T)
  - Cytosine (C) can only bond to guanine (G)
- Each of the separated strands serves as a template for the attachment of complementary bases, forming a new strand, identical to the one from which it was "unzipped".
- The result is two identical DNA molecules.

B-4.4 Summarize the basic processes involved in protein synthesis (including transcription and translation).

When a particular protein is needed, the cell must make the protein through the process of *protein synthesis.* DNA molecules (which contain the code) do not leave the nucleus of the cell, but protein synthesis must occur in the ribosomes which are located outside of the nucleus in the cytoplasm. Therefore, the code must be carried from the nucleus to the cytoplasm.

Transcription

Transcription is the process by which a portion of the molecule of DNA is copied into a complementary strand of RNA. Through the process of transcription, the DNA code is transferred out of the nucleus to the ribosomes.

- Through a series of chemical signals, the gene for a specific protein is turned on. An enzyme attaches to the exact location on the DNA molecule where the gene is found, causing the two strands of DNA to separate at that location.
- Complementary RNA nucleotide bases bond to the bases on one of the separated DNA strands.

DNA nucleotide bases exposed on the separated strand	RNA nucleotide which bonds
Adenine (A)	Uracil (U)
Thymine (T)	Adenine (A)
Cytosine (C)	Guanine (G)
Guanine (G)	Cytosine (C)

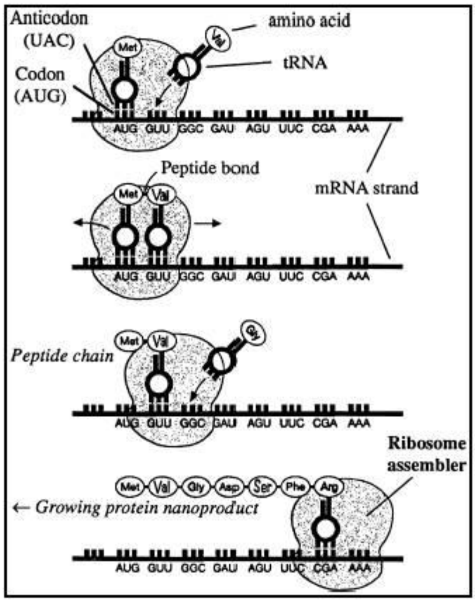
- Nucleotides of RNA bond together, forming a single-stranded molecule of RNA that peels away from the DNA strand and the two DNA strands rejoin. This is called *messenger RNA* (*mRNA*).
- The messenger RNA (mRNA) is formed complementary to one strand of DNA.
- The mRNA strand leaves the nucleus and goes through the nuclear membrane into the cytoplasm of the cell.

Translation

Translation is the process of interpreting the genetic message and building the protein and begins when the mRNA attaches to a ribosome, which contains proteins and *ribosomal RNA (rRNA),* in the cytoplasm.

- The function of ribosomes is to assemble proteins according to the code that the mRNA brings from the DNA.
- Each three-base nucleotide sequence on the mRNA is called a *codon*. Each codon specifies a particular amino acid that will be placed in the chain to build the protein molecule.
  - For example, if the DNA sequence was GAC, then the RNA sequence becomes CUG and the amino acid that is coded is Leucine.
  - The sequence of mRNA nucleotides determines the order of the amino acids in the protein chain which, in turn, distinguishes one protein from another in structure and function.
- Another type of RNA, *transfer RNA (tRNA)*, is vital in assembling amino acids into the correct sequence for the required protein by transferring amino acids to the ribosomes when needed. There are twenty different types of tRNA molecules, one for each amino acid.
  - At one end of each tRNA is an *anticodon site,* which has the 3-nucleotide bases complementary to the codon of mRNA.
  - The other end of the tRNA molecule has a specific amino acid attached determined by the anticodon.
- The translation process takes place as follows:
  - The tRNA with its attached amino acid pairs to the codon of the mRNA attached to a ribosome.

- When a second tRNA with its specific amino acid pairs to the next codon in sequence, the attached amino acid breaks from the first tRNA and attaches to the amino acid of the second tRNA.
- The ribosome forms a *peptide bond* between the amino acids, and an amino acid chain begins to form.
- The empty tRNA moves off and picks up another matching amino acid from the cytoplasm in the cell.
- This sequence is repeated until the ribosome reaches a *stop codon* on the mRNA, which signals the end of protein synthesis.

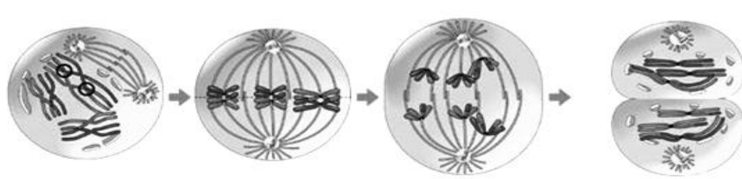


B-4.5 Summarize the characteristics of the phases of meiosis I and II.

The process of meiosis and its importance to sexual reproduction just as mitosis is to asexual reproduction (see B-2.6). In order for the offspring produced from sexual reproduction to have cells that are *diploid* (containing two sets of chromosomes, one set from each parent), the egg and sperm cells must be *haploid* (contain only one of each type of chromosome). The division resulting in a reduction in chromosome number is called *meiosis.*
Meiosis occurs in two steps:

- *Meiosis I*, in which the chromosome pairs replicate, results in two haploid *daughter cells* with duplicated chromosomes different from the sets in the original diploid cell.
- *Meiosis II*, in which the haploid daughter cells from Meiosis I divide, results in four haploid daughter cells called *gametes*, or sex cells (eggs and sperm), with undoubled chromosomes.

Meiosis I



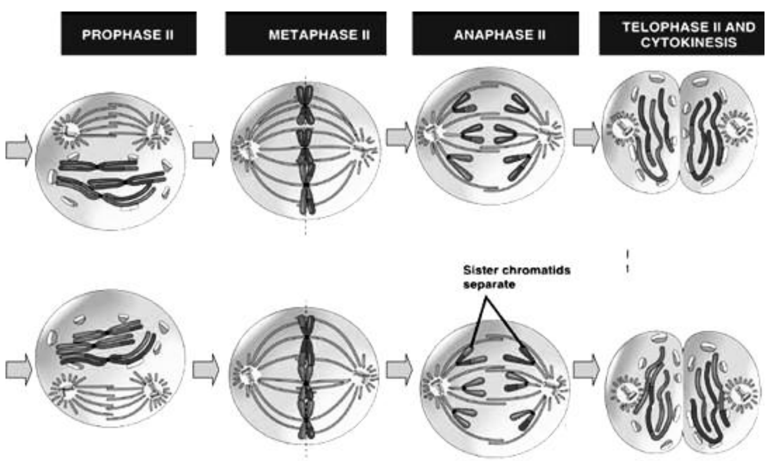
A prophase I **B metaphase I** **C anaphase I** **D telophase I**

Meiosis I begins with *interphase*, like in mitosis (see B-2.6), in which cells: (1) increase in size, (2) produce RNA, (3) synthesize proteins, and (4) replicate DNA

- *Prophase I* (as in figure "A" above)
  - The nuclear membrane breaks down; centrioles separate from each other and take up positions on the opposite sides of the nucleus and begin to produce spindle fibers.
  - Chromosomes pair up and become visible as a cluster of four chromatids called a *tetrad.*
    - A *homologous* chromosome pair consists of two chromosomes containing the same type of genes.

- the paternal chromosome in the pair contributed by the organism's male parent
  - the maternal chromosome in the pair contributed by the organism's female parent
    - Each chromosome consists of two *sister chromatids* attached at a point called the *centromere.*
    - Because the homologous chromosome pairs are in close proximity, an exchange of chromosome genetic material between pairs often occurs in a process called "*Crossing over.*" (see also B-4.7)
- *Metaphase I* (as in figure "B" above)
  - The chromosomes are attached to the spindle fiber at the centromere and are pulled into the mid-line (or equator) of the cell in pairs.
- *Anaphase I* (as in figure "C" above)
  - The chromosome pairs separate, one chromosome to each side of the cell.
    - Each daughter cell will receive only one chromosome from each homologous chromosome pair.
    - Sister chromatids remain attached to each other.
- *Telophase I & Cytokinesis* (as in figure "D" above)
  - Chromosomes gather at the poles, nuclear membrane may form, and the cytoplasm divides.
  - Cytokinesis that occurs at the end of telophase I is the division of the cytoplasm into two individual daughter cells.
- Each of the two daughter cells from meiosis I contains only one chromosome (consisting of two sister chromatids) from each parental pair. Each daughter cell from meiosis I proceeds to undergo meiosis II.

Meiosis II



(E) **(F)** **(G)** **(H)**

- *Prophase II* (as in figure "E" above)
  - Spindle fibers form in each of the daughter cells from meiosis I and attaches to the centromeres of the sister chromatids
  - The chromosomes progress towards the midline of each cell.
  - The nuclear membrane breaks down.
- *Metaphase II* (as in figure "F" above)
  - Chromosomes, made up of two sister chromatids, line up across the center of the cell.
  - Spindle fibers from opposite poles of the cell attach to one of each pair of chromatids.

- *Anaphase II* (as in figure "G" above)
  - The chromosomes separate so that one chromatid from each chromosome goes to each pole.
- *Telophase II* & *Cytokinesis* (as in figure "H" above)
  - Nuclear member forms around each set of chromosomes.
  - The resulting daughter cells are haploid, containing one single chromosome from each pair of chromatids, either from the maternal or paternal contributor.

B-4.6 Predict inherited traits by using the principles of Mendelian genetics (including segregation, independent assortment, and dominance).

Genetics is the study of patterns of inheritance and variations in organisms. Genes control each trait of a living thing by controlling the formation of an organism's proteins.

- Since in all cells (except gametes) chromosomes are diploid (exist as a pair of chromosomes), each cell contains two genes for each trait, one on the maternal chromosome and one on the paternal chromosome.
- The two genes may be of the same form or they may be of different forms.
  - These forms produce the different characteristics of each trait. For example, a gene for plant height might occur in a tall form and a short form.
  - The different forms of a gene are called *alleles*.
  - The two alleles are segregated during the process of gamete formation (meiosis II).

Law (Principle) of Dominance

The *law (principle) of dominance* states that some alleles are dominant whereas others are recessive.

- An organism with a dominant allele for a particular trait will always have that trait expressed (seen) in the organism.
- An organism with a recessive allele for a particular trait will only have that trait expressed when the dominant allele is not present.

Since organisms received one gene for a chromosome pair from each parent, organisms can be heterozygous or homozygous for each trait.

- When an organism has two identical alleles for a particular trait that organism is said to be *homozygous* for that trait.
  - The paternal chromosome and the maternal chromosome have the same form of the gene; they are either both dominant or both recessive.
- When an organism has two different alleles for a particular trait that organism is said to be *heterozygous* for that trait.
  - The paternal chromosome and the maternal chromosome have different forms of the gene; one is dominant and one is recessive.

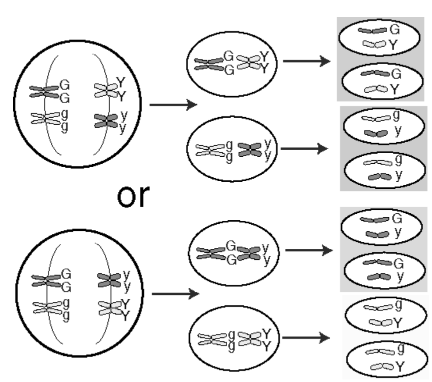
The *genotype* (genetic makeup) of an organism reveals the type of alleles that an organism has inherited for a particular trait. The genotype for a particular trait is usually represented by a letter, the capital letter representing the dominant gene and the lower-case letter representing the recessive gene.

- TT represents a homozygous dominant genotype.
- tt represents a homozygous recessive genotype.
- Tt represents a heterozygous genotype.

The *phenotype* (physical characteristics) of an organism is a description of the way that a trait is expressed in the organism.

- Organisms with genotypes of TT or Tt would have a phenotype of tall.
- Organisms with a genotype of Tt would have a phenotype of short.

Law (Principle) of Segregation



The *law (principle) of segregation* explains how alleles are separated during meiosis.

- Each gamete receives one of the two alleles that the parent carries for each trait. Each gamete has the same chance of receiving either one of the alleles for each trait.
- During fertilization (when sperm and egg unite), each parent organism donates one copy of each gene to the offspring.

Law (Principle) of Independent Assortment

The *law (principle) of independent assortment* states that the segregation of the alleles of one trait does not affect the segregation of the alleles of another trait.

- Genes on separate chromosomes separate independently during meiosis.
- This law holds true for all genes unless the genes are *linked*. In this case, the genes that do not independently segregate during gamete formation, usually because they are in close proximity on the same chromosome.

The principles of Mendelian genetics can be used to predict the inherited traits of offspring. A *Punnett square* can be used to predict the probable genetic combinations in the offspring that result from different parental allele combinations that are independently assorted.

- A *monohybrid cross* examines the inheritance of one trait. The cross could be homozygous-homozygous, heterozygous-heterozygous, or heterozygous-homozygous.
- The Punnett square example represents the probable outcome of two heterozygous parents with the trait for height: T = dominant tall, t = recessive short (Tt x Tt). The parents are the *F_1 generation*; the resulting offspring possibilities are the *F_2 generation*.

  The square shows the following genotypes are possible:
  - there is a 1:4 ratio (25%) that an offspring will carry two dominant alleles.
  - there is a 1:4 ratio (25%) that an offspring will carry two recessive alleles.

    there is a 2:4 or 1:2 ratio (50%) that an offspring will carry one dominant allele and one recessive allele.

  The square also shows the following phenotypes are possible:
  - there is a 3:4 ratio (75%) that an offspring will express the tall trait.
  - There is a 1:4 ratio (25%) that an offspring will express the short trait.

	T	t
T	TT	Tt
t	Tt	tt

- A *dihybrid cross* examines the inheritance of two different traits.
- The following Punnett square example represents the probable outcome of two traits of homozygous parents with the traits for shape and color: R = dominant round, r = recessive wrinkled; Y = dominant for yellow, y = recessive green (rryy x RRYY). The parents are the *F_1 generation*; the resulting offspring possibilities are the *F_2 generation*.

	ry	ry	ry	ry
RY	RrYy	RrYy	RrYy	RrYy
RY	RrYy	RrYy	RrYy	RrYy
RY	RrYy	RrYy	RrYy	RrYy
RY	RrYy	RrYy	RrYy	RrYy

  - All of the offspring for this generation would predictably have the same genotype, heterozygous for both traits (RrYy).
  - All of the offspring for this generation would predictably have the same phenotype, round and yellow (16/16 will be round and yellow).

B-4.7 Summarize the chromosome theory of inheritance and relate that theory to Gregor Mendel's principles of genetics.

The current *chromosome theory of inheritance* is a basic principle in biology that states genes are located on chromosomes and that the behavior of chromosomes during meiosis accounts for inheritance patterns, which closely parallels predicted Mendelian patterns. The principles of Mendelian genetics (segregation, independent assortment, and dominance) support the chromosome theory of inheritance (see B-4.6). Due to advances in technology since Mendel, inheritance patterns and genetic variations that could not be explained by Mendelian genetics are now understood using the chromosome theory of inheritance. The following are new developments since Mendel's principles of genetics:

Gene Linkage and Crossing-over

- *Gene linkage* simply means that genes that are located on the same chromosome will be inherited together. These genes travel together during gamete *formation* (see B-4.5).

- This is an exception to the Mendelian principle of independent assortment because linked genes do not segregate independently.

- *Crossing-over* is a process in which alleles in close proximity to each other on homologous chromosomes are exchanged. This results in new combinations of alleles.
  - When chromosomes pair up during meiosis I, sometimes sections of the two chromosomes become crossed. The two crossed sections break off and usually reattach.
  - When the genes are rearranged, new combinations of alleles are formed (see B-4.5).
- Crossing-over explains how linked genes can be separated resulting in greater genetic diversity that could not be explained by Mendel's principles of genetics.

Incomplete Dominance and Codominance

- *Incomplete dominance* is a condition in which one allele is not completely dominant over another. The phenotype expressed is somewhere between the two possible parent phenotypes.
- *Codominance* occurs when both alleles for a gene are expressed completely. The phenotype expressed shows evidence of both alleles being present.
- These conditions go beyond Mendel's principle of dominance.

Multiple Alleles and Polygenic Traits

- *Multiple alleles* can exist for a particular trait even though only two alleles are inherited. For example, three alleles exist for blood type (A, B, and O), which result in four different blood groups.
- *Polygenic traits* are traits that are controlled by two or more genes. These traits often show a great variety of phenotypes, e.g. skin color.
- Mendel's principles of genetics did not explain that many traits are controlled by more than one gene.

Sex-Linked Traits

- *Sex-linked traits* are the result of genes that are carried on either the X or the Y chromosome.
- This is an exception to the Mendel's principle of independent assortment, which does not explain sex-linked traits.
- In organisms that undergo sexual reproduction, one pair of chromosomes (the sex chromosomes) determines the sex of the organism.
  - The pair of sex chromosomes in females consists of two X chromosomes, each carrying the same genes; the pair of sex chromosomes in males consists of one X chromosome and one Y chromosome.
  - During meiosis I, when chromosome pairs separate, each gamete from the female parent receives an X chromosome, but the gametes from the male parent can either receive an X chromosome or a Y chromosome.
- A Punnett square for the cross shows that there is an equal chance of offspring being male (XY) or female (XX).

	X	Y
X	XX	XY
X	XX	XY

- In humans, the Y chromosome carries very few genes; the X chromosome contains a number of genes that affect many traits. Genes on sex chromosomes are called *sex-linked genes*. Sex-linked genes are expressed differently from an autosomal gene.
  - If a gene is linked on the X chromosome (X-linked),
    - Female offspring will inherit the gene as they do all other chromosomes (X from the father and X from the mother). The principles of dominance will apply.
    - Male offspring will inherit the gene on their X chromosome, but not on the Y chromosome.
    - Since males have one X chromosome, they express the allele whether it is dominant or recessive; there is no second allele to mask the effects of the other allele.

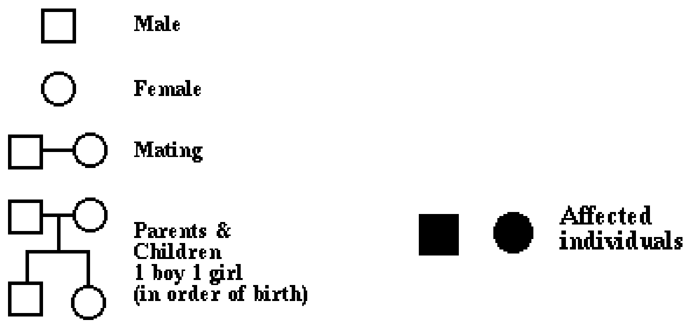
- For example, the trait for color blindness is located on the X chromosome:
  - X chromosomes carrying a gene for normal vision can be coded X^C
  - X chromosomes carrying a gene for color-blindness can be coded X^c
  - Y chromosomes that all lack this gene can be coded Y
  - Only offspring that have the X^C gene will have normal vision.
- Hemophilia is also a sex-linked trait.
- In rare cases, a female can express the sex-linked, recessive trait.

	X^C	Y
X^C	$X^C X^C$	$X^C Y$
X^c	$X^c X^C$	$X^c Y$

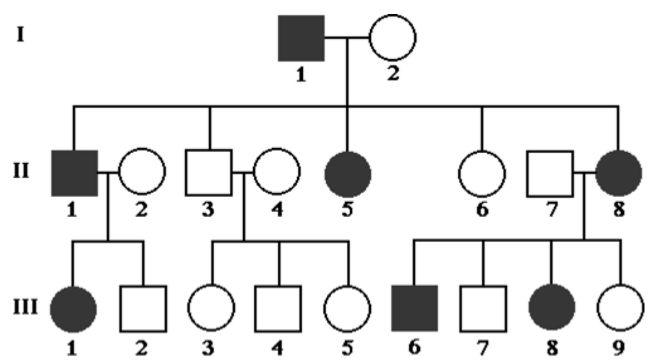
Pedigree

A *pedigree* is a chart constructed to show an inheritance pattern (trait, disease, disorder) within a family through multiple generations. Through the use of a pedigree chart and key, the genotype and phenotype of the family members and the genetic characteristics (dominant/recessive, sex-linked) of the trait can be tracked.

An example of a pedigree key:



<u>Pedigree Example I:</u>



(Family with a dominant autosomal genetic trait)

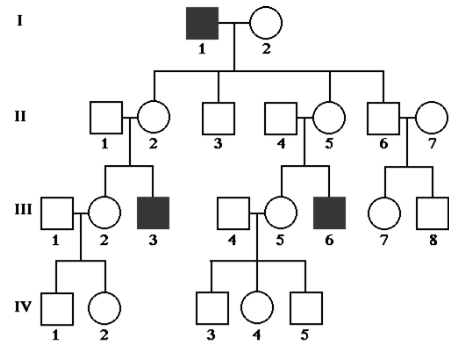
The gene for this particular genetic trait does not occur on the sex chromosomes; it occurs on an autosomal chromosome because both males and females have the trait. This information can be inferred from two facts:

(1) Because the father has the trait, if the trait were sex-linked (on the father's X chromosome), then all females would have the trait. However, because some females do not have the trait, it is not a sex-linked trait.
(2) Individual III-7 who is a male did not inherit the trait from his mother, who has the trait. He received his only X chromosome from his mother.

- This particular gene is a dominant gene because
  - each of the people who have the trait has only one parent who has the trait.
  - if only one parent has the trait and the trait is not sex-linked, then the individuals who have the trait must be heterozygous for the gene.

Pedigree Example II

(Family with a recessive sex-linked genetic trait)



The gene for this particular trait is sex-linked and recessive. This information can be inferred because only males have the trait.

- This is common in X-linked, recessive traits because females who receive the gene for the trait on the X chromosome from their fathers also receive an X chromosome from their mothers which hides the expression of the trait.
- The trait skips a generation.
  - In generation II, all of the offspring receive an X chromosome from their mother.
    - Because the males only receive the X chromosome from their mother, they do not receive the gene carrying the trait.
    - Because the females receive an X chromosome from their mother and father, they are heterozygous and do not express the recessive trait, but they are carriers.
  - In generation III, the offspring of all of the females from generation II have a 50/50 chance of passing a trait-carrying gene to their children.
    - If the males receive the trait-carrying gene, they will express the trait.
    - If the females receive the trait-carrying gene, they will again be carriers.

B-4.8 Compare the consequences of mutations in body cells with those in gametes.

A *mutation* is the alteration of an organism's DNA. Mutations can range from a change in one base pair to the insertion or deletion of large segments of DNA. Mutations can result from a malfunction during the process of meiosis or from exposure to a physical or a chemical agent, a *mutagen.*

Most mutations are automatically repaired by the organism's enzymes and therefore have no effect. However, when the mutation is not repaired, the resulting altered chromosome or gene structure is then passed to all subsequent daughter cells of the *mutant cell*, which may have adverse or beneficial effects on the cell, the organism, and future generations.

- If the mutant cell is a body cell (somatic cell), the daughter cells can be affected by the altered DNA, but the mutation will not be passed to the offspring of the organism.
  - Body cell mutations can contribute to the aging process or the development of many types of cancer.
- If the mutant cell is a gamete (sex cell), the altered DNA will be transmitted to the embryo and may be passed to subsequent generations. Gamete cell mutations can result in *genetic disorders*.
  - If the mutation affects a single gene, it is known as a *gene mutation*.
    - For example, the genetic basis of sickle-cell disease is the mutation of a single base pair in the gene that codes for one of the proteins of hemoglobin.
    - Other examples of genetic disorders are Tay-Sachs disease, Huntington's disease, cystic fibrosis, or albinism.
  - If the mutation affects a group of genes or an entire chromosome, it is know as a *chromosomal mutation.*
    - *Nondisjunction* results in an abnormal number of chromosomes, usually occurring during meiosis.
      - Examples of abnormalities in humans due to nondisjunction of sex chromosomes are Klinefelter's syndrome (male) and Turner's syndrome (female).
      - Examples of abnormalities in humans due to nondisjunction of autosomal chromosomes include Down syndrome.

In some cases mutations are beneficial to organisms. *Beneficial mutations* are changes that may be useful to organisms in different or changing environments. These mutations result in phenotypes that are favored by natural selection and increase in a population.

B-4.9 Exemplify ways that introduce new genetic characteristics into an organism or a population by applying the principles of modern genetics.

The knowledge of genes and chromosomes enables the manipulation of the genotypes and phenotypes of organisms rather than allowing them to be left to natural processes.

Genetic Engineering

Genetic engineering is the process of replacing specific genes in an organism in order to ensure that the organism expresses a desired trait. Genetic engineering is accomplished by taking specific genes from one organism and placing them into another organism.

- Genetic engineering can only occur when scientists know exactly where particular genes for particular traits occur on specific chromosomes.
  - A *gene map* shows the relative location of each known gene on a chromosome.
  - *Genome* refers to all the genetic material in an organism. The Human Genome Project that mapped the DNA sequence of human genes is useful in identifying genes for specific traits.
- In *cloning*, an identical copy of a gene or an entire organism is produced. This may occur naturally or may be engineered. Cloning brings benefits such as organ transplants or saving endangered species, but it may also result in an organism with genetic disorders or health problems.
- In *gene therapy*, scientists insert a normal gene into an absent or abnormal gene. Once inserted the normal gene begins to produce the correct protein or enzyme, eliminating the cause of the disorder. However, gene therapy has had limited success because the host often rejects the injected genetic material.
- *Stem cells* are undifferentiated cells that have the potential to become specialized in structure or function. Although primarily found in embryos, they are also found all over the adult human body (for example bone marrow) but may be harder to isolate. Therapy using stem cells can replace tissue that is deficient due to disease or damage.
- Results of genetic engineering may include:
  - The development of plants that manufacture natural insecticides, are higher in protein, or spoil more slowly.
  - The development of animals that are bigger, are faster growing, or are resistant to disease.
  - The development of bacteria that produce hormones such as human insulin or human growth hormone.
  - In humans, it is theoretically possible to transplant copies of normal genes into the cells of people suffering from genetically carried diseases such a Tay-Sachs disease, cystic fibrosis, and sickle-cell anemia.

Selective Breeding

Selective breeding is the method of artificially selecting and breeding only organisms with a desired trait to produce the next generation. Almost all domesticated animals and most crop plants are the result of selective breeding.

- The process works because in order for the parents to show strong expression for the trait, they must carry at least one gene for the trait.
  - Once the breeder has successfully produced offspring with the desired set of characteristics, *inbreeding* (crossing individuals who are closely related) continues.
  - Over several generations, the gene for the trait will become more and more prevalent in the offspring.
  - The drawback to this method is that recessive gene defects often show up more frequently after several generations of inbreeding.
- *Hybridization*, which is another form of selective breeding, is the choosing and breeding organisms that show strong expression for two different traits in order to produce offspring that express both traits. This occurs often between two different (but similar) species. The offspring are often hardier than either of the parents.

Compare the structure of the two types of nucleic acid.

	DNA	**RNA**
Type of base composing nucleotides	Cytosine (C) Adenine (A) Guanine (G) Thymine(T)	Cytosine(C) Adenine (A) Guanine (G) Uracil (U)
Type of sugar composing nucleotides	deoxyribose	ribose
Molecule structure and shape	Double helix	Single chain

B-5.1 Summarize the process of natural selection.

Biological evolution describes all of the changes that have transformed life on Earth from the earliest beginnings to the diversity of organisms in the world today. Biological evolution is the unifying theme of biology. Biological evolution can occur on a small scale affecting a single population (*microevolution*) or on a large scale affecting changes in species across populations (*macroevolution*).

One way to explain how biological evolution occurs is through natural selection. *Natural selection* occurs because the individual members of a population have different traits which allow them to interact with the environment either more or less effectively than the other members of the population. Natural selection results in changes in the inherited traits of a population over time. These changes often increase a species' fitness in its environment. There are four main principles to natural selection.

Overproduction of Offspring

- The ability of a population to have many offspring raises the chance that some will survive but also increases the competition for resources.

Variation

- Within every population, variation exists within the *inherited traits* of the individuals.
- Variation exists in the phenotypes (body structures and characteristics) of the individuals within every population.
- An organism's phenotype may influence its ability to find, obtain, or utilize its resources (food, water, shelter, and oxygen) and also might affect the organism's ability to reproduce.
- Phenotypic variation is controlled by the organism's genotype and the environment.
    - Those individuals with phenotypes that do not interact well with the environment are more likely to either die or produce fewer offspring than those that can interact well with the environment.

Adaptation

- The process of *adaptation* leads to the increase in frequency of a particular structure, physiological process, or behavior in a population of organisms that makes the organisms better able to survive and reproduce.
    - With every generation, organisms with specific beneficial inherited traits (that arose in a previous generation due to genetic variation) become more prevalent.
    - As each generation progresses, those organisms that carry genes that hinder their ability to meet day to day needs become less and less prevalent in the population.
        - ♦ Organisms that have a harder time finding, obtaining, or utilizing, food, water, shelter, or oxygen will be less healthy and more likely to die before they reproduce or produce less viable or fewer offspring.
    - In this manner, the gene pool of a population can change over time.
- The concept of *fitness* is used to measure how a particular trait contributes to reproductive success in a given environment and results from adaptations.
    - Natural selection has sometimes been popularized under the term *survival of the fittest*.

Descent with modification

- As the environment of a population changes, the entire process of natural selection can yield populations with new phenotypes adapted to new conditions.
- Natural selection can produce populations that have different structures, live in different niches or habitats from their ancestors. Each successive living species will have descended, with adaptations or other modifications, from previous generations.
- More individuals will have the successful traits in successive generations, as long as those traits are beneficial to the environmental conditions of the organism.

B-5.2 Explain how genetic processes result in the continuity of life-forms over time.

The continuity of life-forms on Earth is based on an organism's success in passing genes to the next generation. Many organisms that lived long ago resemble those still alive today because the same genetic processes have passed along the genetic material of life. Based on scientific evidence, most scientists attribute the continuity of life-forms over time to the genetic processes that all organisms share.

- All life that has ever existed on Earth, share at least the same two structures:
  (1) Nucleic acids (RNA or DNA) that carry the code for the synthesis of the organism's proteins (see B-4.1)
  (2) Proteins (composed of the same twenty amino acids in all life forms on Earth)
- The process by which nucleic acids code for proteins (transcription and translation) is the same in all life forms on Earth. The same sequences of nucleotides code for the same specific amino acids. (see B-4.4)

All organisms have reliable means of passing genetic information to offspring through reproduction. The reproductive processes of organisms, whether sexual or asexual, result in offspring receiving essentially the same genetic information as the parent or parents, though there may be some genetic variability.

Sexual Reproduction

Sexual reproduction uses the process of meiosis to create gametes. (see B-4.5) Fertilization results in the embryo receiving alleles from each parent for each trait. The new individual will express a combination of traits allowing for variation within the offspring. (see B-4.7)

- Genetic variability may also be due to gene shuffling, crossing-over, recombination of DNA, or mutations. (see B-4.7 and B-4.8) When gametes are produced, each parent's alleles may be arranged in new ways in the offspring.
- Genetic changes or variability result in the transcription and translation of new or different proteins that will result in changes in the phenotype of an individual organism.
- Reproduction that results in allele combinations producing traits that improve an individual's chance of survival ensures the continuity of that life form over time.

Asexual Reproduction

Asexual reproduction involves only one parent that produces the offspring that are for the most part genetically identical to that parent.

- Genetic variability can only occur through mutations in the DNA passed from parent to offspring, which is another way these organisms achieve variations as the populations continue over time.
- This may be accomplished by cell division: binary fission (reproduction of single-celled organisms) or mitosis (reproduction in multi-celled organisms).
- Examples of asexual reproduction are budding, fragmentation, and vegetative propagation.
- The asexual reproduction rate is much higher than sexual reproduction and produces many offspring that are suited to continuing life in the present environment.
- Asexual reproduction may have a disadvantage in changing conditions because genetically identical offspring respond to the environment in the same way. If a population lacks traits that enable them to survive and reproduce, the entire population could die off.

The genetic view of evolution includes the transfer of the genetic material through these processes of reproduction. The continuity of a species is contingent upon these genetic processes. If an organism can reproduce both sexually and asexually, they have an adaptive advantage for survival.

B-5.3 Explain how diversity within a species increases the chances of its survival.

A *species* is a group of organisms that share similar characteristics and can interbreed with one another to produce fertile offspring.

- Species that interbreed share a common *gene pool* (all genes, including all the different alleles, of all of the individuals in a population).
- Because of the shared gene pool, a genetic change that occurs in one individual can spread through the population as that individual and its offspring mate with other individuals.
- If the genetic change increases fitness, it will eventually be found in many individuals in the population.

Within a species there is a variability of phenotypic traits leading to diversity among the organisms of the species. The greater the diversity, the greater the chances are for that species to survive during environmental changes.

If an environment changes, organisms that have phenotypes which are well-suited to the new environment will be able to survive and reproduce at higher rates than those with less favorable phenotypes. Therefore, the alleles associated with favorable phenotypes increase in frequency and become more common and increase the chances of survival of the species.

- Favorable traits (such as coloration or odors in plants and animals, competitive strength, courting behaviors) in male and female organisms will enhance their reproductive success. Non-random mating results in the gene pool of a population that can change over time and a species that can become increasingly adapted to its environment.
- Organisms with inherited traits that are beneficial to survival in its environment become more prevalent. For example, resistance of the organism to diseases or ability of the organism to obtain nutrients from a wide variety of foods or from new foods.
- Organisms with inherited traits that are detrimental to survival in its environment become less prevalent.

B-5.4 Explain how genetic variability and environmental factors lead to biological evolution.
Taxonomy Level:

Genetic variation is random and ensures that each new generation results in individuals with unique genotypes and phenotypes. This *genetic variability* leads to biological evolution.

Factors that influence genetic variability within a population may be:

- *Genetic drift* is the random change in the frequency of alleles of a population over time. Due to chance, rare alleles in a population will decrease in frequency and become eliminated; other alleles will increase in frequency and become fixed. The phenotypic changes may be more apparent in smaller populations than in larger ones.
- *Gene flow* is the movement of genes into or out of a population. This occurs during the movement of individuals between populations (such as migration) thus increasing the genetic variability of the receiving population.
- *Non-random mating* limits the frequency of the expression of certain alleles. (see B-5.3)
- *Mutations* increase the frequencies and types of allele changes within the population. (see B-5.2)
- *Natural selection* allows for the most favorable phenotypes to survive and thus be passed on to future generations. (see B-5.1)

When there is no change in the allele frequencies within a species, the population is said to be in *genetic equilibrium*. This concept is known as the *Hardy-Weinberg principle*. Five conditions that are required to maintain genetic equilibrium are:

- The population must be very large, no genetic drift occurs
- There must be no movement into or out of a population
- There must be random mating
- There must be no mutations within the gene pool
- There must be no natural selection

Speciation is the process of forming of a new species (or other taxonomic groups) by biological evolution from a preexisting species.

- New species usually form when organisms in the population are isolated or separated so that the new population is prevented from reproducing with the original population, and its gene pools cease to blend.

- Once isolation (reproductive or temporal, behavioral, geographic) occurs, genetic variation and natural selection increase the differences between the separated populations.
- As different traits are favored in the two populations (original and new) because of isolation, the gene pools gradually become so different that they are no longer able to reproduce. At this point the two groups are by definition different species.

  - Environmental factors (such as catastrophic events, climatic changes, continental drift) can also lead to biological evolution. Results from environmental factors may affect biological evolution on a grand scale over many generations (macroevolution). Some *patterns of evolution* are:

Gradualism
- Gradual changes of a species in a particular way over long periods of time, such as a gradual trend toward larger or smaller body size.

Punctuated equilibrium
- Periods of abrupt changes in a species after long periods of little change within the species over time, such as sudden change in species size or shape due to environmental factors.

Adaptive radiation/Divergent evolution
- In adaptive radiation (divergent evolution), a number of different species diverge (split-off) from a common ancestor.
- This occurs when, over many generations, organisms (whose ancestors were all of the same species) evolve a variety of characteristics which allow them to survive in different niches.

Convergent evolution
- In convergent evolution, evolution among different groups of organisms living in similar environments produces species that are similar in appearance and behavior.
- Convergent evolution has produced many of the *analogous structures* in organisms today. Analogous structures are similar in appearance and function, but have different evolutionary origins.

Coevolution
- With coevolution, when two or more species living in close proximity change in response to each other. The evolution of one species may affect the evolution of the other.

Extinction
- Extinction is the elimination of a species often occurring when a species as a whole cannot adapt to a change in its environment. This elimination can be gradual or rapid.
- *Gradual extinction* usually occurs at a slow rate and may be due to other organisms, changes in climate, or natural disasters. Speciation and gradual extinction occur at approximately the same rate.
- *Mass extinction* usually occurs when a catastrophic event changes the environment very suddenly (such as a massive volcanic eruption, or a meteor hitting the earth causing massive climatic changes). It is often impossible for a species to adapt to rapid and extreme environmental changes.

B-5.5 Exemplify scientific evidence in the fields of anatomy, embryology, biochemistry, and paleontology that underlies the theory of biological evolution.

Scientific studies in the fields of anatomy, embryology, biochemistry, and paleontology have contributed scientific evidence for the theory of evolution.

Field of Anatomy
The field of *anatomy* (the study of the structures of organisms) provides one type of data for the support of biological evolution.
- Scientists study homologous structures as one form of evidence to determine the possible relationship between the evolutionary paths of two species. (see B-5.4)
  - Organisms which have diverged from a common ancestor often have *homologous structures* (similar characteristics resulting from common ancestry). The greater the numbers of shared structures between two species, the more closely the species are related.
  - Many species have *vestigial organs* (structures with little or no function to the organism) that are remnants of structures that had important functions in ancestors of the species. The vestigial organs of one species are often homologous with structures in related species where the structure has remained functional.
- Also, the study of the anatomy of species located in different geographical locations reveals that species living in different locations under similar ecological conditions developed similar structures and behaviors.

- If a species encountered a different ecosystem due to a change in geographical location, favorable anatomical traits become established. A new species evolves with a shared common ancestor from the original population.

Field of Embryology

The field of *embryology* (the study of the embryonic development of organisms) provides another type of data for the support of biological evolution by comparing the anatomies of embryos (an early stage—pre-birth, pre-hatching, or pre-germination—of organism development).

- Sometimes similarities in patterns of development or structures that are not obvious in adult organisms become evident when embryonic development is observed.
- The embryos of vertebrates are very similar in appearance early in development but may grow into different structures in the adult form.
- These similar structures of these embryos may suggest that these species evolved from common ancestors.

Field of Biochemistry

The field of *biochemistry* (the study of the chemical processes in organisms) studies genes and proteins to provide support for biological evolution.

- The more similar the DNA and amino acid sequences in proteins of two species, the more likely they are to have diverged from a common ancestor.
- Biochemistry provides evidence of evolutionary relationships among species when anatomical structures may be hard to use. For example,
  - when species are so closely related that they do not appear to be different, or
  - when species are so diverse that they share few similar structures.

Field of Paleontology

Paleontology (the study of prehistoric life) is another tool that scientists use to provide support for biological evolution.

- The fossil record provides valid evidence of life forms and environments along a timeline and supports evolutionary relationships by showing the similarities between current species and ancient species.
- Comparing current and ancient species shows a pattern of gradual change from the past to the present.
- Examining the fossil record of Earth reveals a history that tells a story of the types of organisms that have lived on Earth (including those that are extinct) and the relative ages of those fossils.
- The fossil record is not complete because most organisms do not form fossils. Many of the gaps in the fossil record have been filled in as more fossils have been discovered.
- The older the fossils, the less resemblance there is to modern species.

B-5.6 Summarize ways that scientists use data from a variety of sources to investigate and critically analyze aspects of evolutionary theory.

Scientists study data to trace the *phylogeny* (evolutionary history) of a species or a group of related species. Based on this study of data, an evolutionary theory has been developed that states all forms of life on Earth are related because the ancestry of organisms can be traced back to a common origin. Evidence of the shared history is found in all aspects of living and fossil organisms (physical features, structures of proteins, sequences found in RNA and DNA). Scientists must use multiple sources of evidence in drawing conclusions concerning the evolutionary relationship among groups of organisms. For example:

Field of Anatomy:

- Phylogenies can be constructed by assuming that anatomical differences increase with time. The greater the anatomical similarity, the more recently a pair of species shares a common ancestor.
  - The accumulation of evolutionary differences over time is called divergence. (see B-5.7)
  - Anatomical structures that share a common evolutionary history but not necessarily the same function are termed homologous. (see B-5.5)
- Evolutionary biologists make observations on as many anatomical structures as possible to construct phylogenies.
- Sometimes individual structures may suggest evolutionary relationships that differ from the bulk of the evidence. This may result from *convergence*, structures becoming more similar with time.
  - Convergence occurs when organisms with different evolutionary histories adapt to similar environments.

- Anatomical structures that have different evolutionary origins but similar functions are said to be analogous. (see B-5.4)

Field of Embryology:

- Characters of embryonic development allow scientists to reconstruct the phylogenies of highly divergent taxa, such as phyla and classes, that may have evolved so many anatomical differences that they are difficult to compare otherwise.
- One mechanism by which evolution may have proceeded is by selection for successive new stages at the end of embryonic development. If this has been the case, ontogeny (growth and development of an individual organism) will recapitulate phylogeny.

Field of Paleontology:

- The fossil record provides information regarding the dates and order of divergence for phylogenies.
- *Transitional fossils* (fossils that show links in traits between groups of organisms used to document intermediate stages in the evolution of a species) confirm evolutionary relationships.
- The primary challenge for using the fossil record as a map of evolutionary history is that the record is incomplete.
  - Even though millions of fossils have been discovered by scientists, many environmental conditions must be met in order for a fossil to form, and the chance of all of these conditions coming together at one time is rare.
  - The fossil record favors the preservation of species that existed for a long time, were abundant and widespread, and had hard shells or skeletons.
  - Gaps do not indicate weakness in the evolutionary theory, but rather point out opportunities for additional research. Fossils that allow scientists to fill gaps in the record are continually being discovered.

Field of Biochemistry:

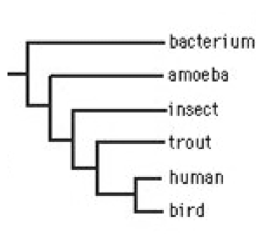
- Phylogenies can be constructed by assuming that differences in DNA, proteins, and other molecules increase over time. The greater the overall genetic similarity, the more recently a pair of species shares a common ancestor.
- The time since a pair of species has diverged can be estimated under the assumptions of a "molecular clock."
- Even though a comparison of the DNA sequences of two species provides some of the most reliable evidence, there are challenges inherent in this approach as well.
  - Because genes evolve at different rates, it may be difficult for scientists to identify the molecules that yield information about the group of organisms at the scale under study.
  - Insertions and deletions result in homologous genes of different lengths, which may introduce difficulties in aligning them for comparison. (see B-4.8)
  - Different assumptions about the details of molecular evolution can yield different phylogenetic trees. (see B-5.7)
  - Natural selection can cause convergence in molecules, just as it causes convergence in anatomical structures. (see B-5.1)

Students should also understand that one piece of evidence does not ensure an accurate picture of the history of the evolution of a particular group of organisms, but as scientists collect many pieces of evidence from many fields, the reliability of a particular hypothesis becomes greater and greater.
The more evidence scientists can gather from different fields of science, the more reliable their information becomes in regards to evolutionary relationships. The evolutionary theory is a well-tested explanation that accounts for a wide range of observations made by scientists in many fields of science. No scientist suggests that all evolutionary processes are understood; many unanswered questions remain to be studied and analyzed.

B-5.7 Use a phylogenetic tree to identify the evolutionary relationships among different groups of organisms.

A *phylogenetic tree* is a scientific diagram that biologists use to represent the phylogeny (evolutionary history of a species) of organisms. It classifies organisms into major *taxa* (groups) based on evolutionary relationships. Phylogenetic trees are used to classify species in the order in which they descended from a common ancestor using physical characteristics. Speciation could be thought of as a branching of a family tree then extinction is like the loss of one of the branches.

- Some phylogenetic trees only express the order of divergence of a species. They do not attempt to show relative or absolute time frames.



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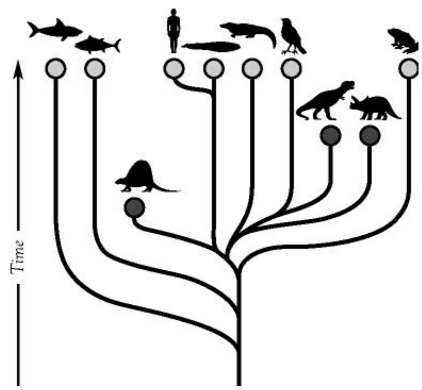
- Some phylogenetic trees indicate an estimated time of divergence. The tree below shows the relative time that species diverged.
  - The branch between humans and whales is almost at the top of the line, while the branch between birds and tyrannosaurs happens about midway up the line, indicating that birds and tyrannosaurs diverged much sooner than humans and whales diverged.



From phylogenetic trees, the following information can be determined:

- Which groups are most closely related?
- Which groups are least closely related?
- Which group diverged first (longest ago) in the lineage?

One of the main challenges that biologists concerned with biodiversity have recently face is in classifying organisms because species are becoming extinct at an increasing pace. As knowledge of biodiversity increases, revisions to taxonomic systems are continually being proposed. Biologists regularly revise the many branches of the phylogenetic tree to reflect current hypotheses of the evolutionary relationships between groups. The most recent classification scheme includes

- three domains (Bacteria, Archaea, and Eukarya)
- six kingdoms (Eubacteria, Archaebacteria, Protista, Fungi, Plantae, and Animalia).

A different way of classifying organisms is by using a cladogram, which represents a hypothesis using derived characteristics to determine evolutionary relationships.

B-6.1 Explain how the interrelationships among organisms (including predation, competition, parasitism, mutualism, and commensalism) generate stability within ecosystems.

An *ecosystem* is defined as a community (all the organisms in a given area) and the abiotic factors (such as water, soil, or climate) that affect them. A *stable ecosystem* is one where

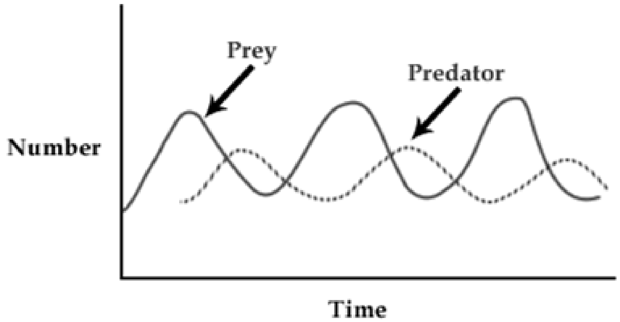
- the population numbers of each organism fluctuate at a predictable rate.
- the supply of resources in the physical environment fluctuates at a predictable rate.
- energy flows through the ecosystem at a fairly constant rate over time.

These fluctuations in populations and resources ultimately result in a stable ecosystem.

Organisms in an ecosystem constantly interact. The interactions among the organisms generate stability within ecosystems.

Predation
Predation is an interaction between species in which one species (the *predator*) eats the other (the *prey*). This interaction helps regulate the population within an ecosystem thereby causing it to become stable. Fluctuations in predator–prey populations are predictable. At some point the prey population grows so numerous that they are easy to find.

- A graph of predator–prey density over time shows how the cycle of fluctuations results in a stable ecosystem.
  - As the prey population increases, the predator population increases.
  - As the predator population increases, the prey population decreases.



Competition
Competition is a relationship that occurs when two or more organisms need the same resource at the same time.

- Competition can be among the members of the same or different species and usually occurs with organisms that share the same niche.
  - An ecological *niche* refers to the role of an organism in its environment including type of food it eats, how it obtains its food and how it interacts with other organisms.
  - Two species with identical ecological niches cannot coexist in the same habitat.
- Competition usually results in a decrease in the population of a species less adapted to compete for a particular resource.

Symbiotic Relationships
A *symbiotic relationship* exists between organisms of two different species that live together in direct contact. The balance of the ecosystem is adapted to the symbiotic relationship. If the population of one or other of the symbiotic organisms becomes unbalanced, the populations of both organisms will fluctuate in an uncharacteristic manner. Symbiotic relationships include parasitism, mutualism, and commensalism.

Parasitism is a symbiotic relationship in which one organism (the parasite) benefits at the expense of the other organism (the host). In general, the parasite does not kill the host.

- Some parasites live within the host, such as tape worms, heartworms, or bacteria.
- Some parasites feed on the external surface of a host, such as aphids, fleas, or mistletoe.
- The parasite-host populations that have survived have been those where neither has a devastating effect on the other.
- Parasitism that results in the rapid death of the host is devastating to both the parasite and the host populations. It is important that the host survive and thrive long enough for the parasite to reproduce and spread.

Mutualism is a symbiotic relationship in which both organisms benefit. Because the two organisms work closely together, they help each other survive. For example,

- bacteria, which have the ability to digest wood, live within the digestive tracts of termites;
- plant roots provide food for fungi that break down nutrients the plant needs.

Commensalism is a symbiotic relationship in which one organism benefits and the organism is not affected. For example,

- barnacles that attach to whales are dispersed to different environments where they can obtain food and reproduce;
- burdock seeds that attach to organisms and are carried to locations where they can germinate.

B-6.2 Explain how populations are affected by limiting factors (including density-dependent, density-independent, abiotic, and biotic factors).

A *population* is a group of organisms belonging to the same species that live in a particular area. Populations can be described based on their size, density, or distribution. *Population density* measures the number of individual organisms living in a defined space. Regulation of a population is affected by limiting factors that include density-dependent, density-independent, abiotic and biotic factors.

Density-dependent
Limiting factors that are density-dependent are those that operate more strongly on large populations than on small ones. Density-dependent limiting factors include competition, predation, parasitism, and disease. These limiting factors are triggered by increases in population density (crowding).

Density-independent
Limiting factors that are density-independent are those that occur regardless of how large the population is and reduce the size of all populations in the area in which they occur by the same proportion. Density-independent factors are mostly abiotic (such as weather changes), human activities (such as pollution), and natural disasters (such as fires).

Abiotic and biotic factors
Limiting factors can change within an ecosystem and may affect a population.

- *Abiotic factors* may be chemical or physical. Some examples are water, nitrogen, oxygen, salinity, pH, soil nutrients and composition, temperature, amount of sunlight, and precipitation.
- *Biotic factors* include all of the living components of an ecosystem. Some examples are bacteria, fungi, plants, and animals.

A change in an abiotic or biotic factor may decrease the size of a population if it cannot acclimate or adapt to or migrate from the change. A change may increase the size of a population if that change enhances its ability to survive, flourish or reproduce.

B-6.3 Illustrate the processes of succession in ecosystems.

Ecological succession is the series of changes in an ecosystem when one community is replaced by another community as a result of changes in abiotic and biotic factors. There are two types of succession, primary and secondary.

Primary succession occurs in an area that has not previously been inhabited: for example, bare rock surfaces from recent volcanic lava flows, rock faces that have been scraped clean by glaciers, or a city street.

- The beginning of primary succession depends on the presence of unique organisms that can grow without soil and also facilitate the process of soil formation.
  - Lichens (mutualistic relationships between fungi and algae) and some mosses, which break down rock into smaller pieces, are among the most important *pioneer species* (the first organisms) in the process of primary succession. At this stage of succession there are the fewest habitats for organisms in the ecosystem.
  - Once there is enough soil and nutrients, small plants, such as small flowers, ferns, and shrubs, grow. These plants break down the rock further, and provide more soil.
  - Then seeds of other plants and small trees are able to germinate and grow.
  - Over time more species grow and die. Their decomposed bodies add nutrients to the soil and larger plant species are able to populate the area.
- As the species of plants change, the species of animals that are able to inhabit the area also change. The organisms in each stage may alter the ecosystem in ways that hinder their own survival but make it more favorable for future organisms. In this way, one community replaces another over time.
- Eventually a mature community (*climax community*) results where there is little change in the composition of species and perpetuates itself as long as no disturbances occur.
  - The climax community of a particular area is determined by the limiting factors of the area. (see B-6.2)
- As scientists have studied changes in ecosystems, they have found that the processes of succession are always changing ecosystems.

Secondary succession begins in an area where there was a preexisting community and well-formed soil: for example, abandoned farmland, vacant lots, clear-cut forest areas, or open areas produced by forest fires.

- It is similar to primary succession in the later stages, after soil has already formed.
- Something halts the succession, such as a fire, a hurricane or human activities, and destroys the established community but the soil remains intact.
- When the disturbance is over, the ecosystem interacts to restore the original condition of the community.

Succession is a continual process.

- Some stages (and the organisms that compose the communities that characterize these stages) may last for a short period of time, while others may last for hundreds of years.
- Any disturbance to the ecosystem will affect the rate of succession in a particular area. Usually secondary succession occurs faster than primary succession because soil is already present.
  - When disturbances are frequent or intense, the area will be mostly characterized by the species that are present in the early stages of succession.
  - When disturbances are moderate, the area will be composed of habitats in different stages of succession.
- The process of succession occurs in all ecosystems (i.e., forest succession, pond succession, coral reef or marine succession and desert succession).

B-6.4 Exemplify the role of organisms in the geochemical cycles (including the cycles of carbon, nitrogen, and water).

The role of organisms in the *geochemical cycles* (the movement of a particular form of matter through the living and nonliving parts of an ecosystem) since Earth is a closed system and must continually cycle its essential matter. Matter changes form but is neither created nor destroyed; it is used over and over again in a continuous cycle. Organisms are an important part of this cycling system. Matter placed into biological systems is always transferred and transformed. Matter, including carbon, nitrogen, and water, gets cycled in and out of ecosystems.

Carbon Cycle

- Carbon is one of the major components of the biochemical compounds of living organisms (proteins, carbohydrates, lipids, nucleic acids).
- Carbon is found in the atmosphere and also in many minerals and rocks, fossil fuels (natural gas, petroleum, and coal) and in the organic materials that compose soil and aquatic sediments.
- Organisms play a major role in recycling carbon from one form to another in the following processes:
  - Photosynthesis: Photosynthetic organisms take in carbon dioxide from the atmosphere and convert it to simple sugars. (see B-3.1)
  - Respiration: Organisms break down glucose and carbon is released into the atmosphere as carbon dioxide. (see B-3.2)
  - Decomposition: When organisms die, decomposers break down carbon compounds which both enrich the soil or aquatic sediments and are eventually released into the atmosphere as carbon dioxide.
  - Conversion of biochemical compounds: Organisms store carbon as carbohydrates, proteins, lipids, and nucleic acids in their bodies. For example, when animals eat plants and animals, some of the compounds are used for energy; others are converted to compounds that are suited for the predator’s body (see B-3.6), other compounds, (such as methane and other gases) are released to the atmosphere.
- Other methods of releasing stored carbon may be:
  - Combustion: When wood or fossil fuels (which were formed from once living organisms) are burned, carbon dioxide is released into the atmosphere.
  - Weathering of carbonate rocks: Bones and shells fall to the bottom of oceans or lakes and are incorporated into sedimentary rocks such as calcium carbonate. When sedimentary rocks weather and decompose, carbon is released into the ocean and eventually into the atmosphere.

Nitrogen Cycle

- Nitrogen is the critical component of amino acids which are needed to build proteins in organisms.

- Nitrogen is found in the atmosphere as *elemental nitrogen* (N_2), in living organisms (in the form of proteins and nucleic acids), or in organic materials that compose soil and aquatic sediments.
- Organisms play a major role in recycling nitrogen from one form to another in the following processes:
  - Nitrogen-fixation: Nitrogen-fixing bacteria, which are found in the soil, root nodules of plants, or aquatic ecosystems, are capable of converting elemental nitrogen found in the air or dissolved in water into the forms that are available for use by plants (*nitrogen fixation*).
  - Intake of nitrogen into the organisms: Plants take in the nitrogen through their root systems in the form of ammonia or nitrate and in this way, nitrogen can enter the food chain. (see B-3.6)
  - Decomposition: When an organism dies or from animal waste products, decomposers return nitrogen to the soil.
  - Denitrification: *Denitrifying bacteria* break down the nitrogen compounds in the soil and release elemental nitrogen, N_2, into the atmosphere.

Water Cycle (Hydrologic cycle)

- Water is a necessary substance for the life processes of all living organisms.
- Water is found in the atmosphere, on the surface of Earth and underground, and in living organisms.
- The water cycle, also called the *hydrologic cycle*, is driven by the Sun's heat energy, which causes water to evaporate from water reservoirs (the ocean, lakes, ponds, rivers) on Earth and also from organisms.
- Organisms play a role in recycling water from one form to another in water cycle. For example,
  - Intake of water into the organisms: Organisms take in water and use it to perform life functions (such as photosynthesis or transport of nutrients).
  - Transpiration: Plants release water back into the atmosphere through the process of transpiration (the evaporative loss of water from plants).
  - Respiration: All organisms metabolize food for energy and produce water as a by-product of respiration.
  - Elimination: Most organisms need water to assist with the elimination of waste products.

B-6.5 Explain how ecosystems maintain themselves through naturally occurring processes (including maintaining the quality of the atmosphere, generating soils, controlling the hydrologic cycle, disposing of wastes, and recycling nutrients).

There are naturally occurring Earth processes that help ecosystems maintain the materials necessary for the organisms in the ecosystem. The portion of Earth that is inhabited by life (the biosphere) is interconnected with other Earth systems: the atmosphere, the hydrosphere, and the geosphere. All of these systems must interact efficiently in order for an ecosystem to maintain itself.

Maintaining the Quality of the Atmosphere
The composition of Earth's *atmosphere* is mostly the result of the life processes of the organisms which inhabit Earth (past and present).
- Plants and other photosynthetic organisms need to produce enough oxygen for themselves and all other organisms on Earth to maintain a balance of atmospheric carbon dioxide and oxygen.
- The oxygen that is produced through the process of photosynthesis is also responsible for the *ozone layer* in the atmosphere and prevents much of the Sun's ultraviolet radiation from reaching Earth's surface and protects the biosphere from the harmful radiation.
- The normal cycling of oxygen and carbon dioxide occurs as plants produce more oxygen through photosynthesis than they consume through respiration, while animals use this oxygen in cellular respiration and release carbon dioxide used by the plants in photosynthesis.
- Nitrogen is maintained in the atmosphere through the nitrogen cycle. (see B-6.4)
- Water is maintained in the atmosphere through the water cycle. (see B-6.4)
  - As water vapor condenses in the atmosphere, impurities (such as dust and particulates) are removed from the atmosphere and fall to Earth with precipitation. In this manner, the air is cleaned after a rain or snow fall.

The *greenhouse effect* is the normal warming effect when gases trap heat in the atmosphere.

- Greenhouse gases (such as carbon dioxide, oxygen, methane, and water vapor) trap heat energy and maintain Earth's temperature range.
- Greenhouse gases do not allow heat to pass through very well. Therefore, the heat that Earth releases stays trapped under the atmosphere.
- The amount of carbon dioxide in the atmosphere cycles in response to the degree to which plants and other photosynthetic organisms cover Earth and absorb carbon dioxide.

Amount of CO_2 in the atmosphere	Greenhouse effect	Average Global Temperature	Plant cover on Earth	Rate of photosynthesis	Amount of CO_2 absorbed by plants	Amount of CO_2 in the atmosphere
higher	increases	increases	increases	increases	increases	decreases
lower	decreases	decreases	decreases	decreases	decreases	increases

- The amount of carbon dioxide in the atmosphere also cycles in response to the degree to which oceans cover Earth. The salt water of oceans acts as a *sink* for carbon dioxide, absorbing what plants do not use and converting it to various salts such as calcium carbonate.

Generating Soils

As part of the *geosphere*, the soils on Earth are constantly being generated and eroded.

- All soils are composed of four distinct components – inorganic minerals, organic matter, water, and air.
- As the weathering of inorganic materials from wind, water, and ice and the decaying of organic materials continue, the process of soil generation continues.
- *Soil erosion* and *deposition* are natural processes that move soil from one location to another due to water, wind, ice and other agents.
- In most areas, the presence of plants allows the process of soil production to be consistent with the process of soil erosion so that the overall amount of soil remains constant.
- The presence of soil in an ecosystem allows for succession to take place. (see B-6.3)

Controlling the Hydrologic Cycle:

The *hydrologic cycle* is maintained by the energy of the Sun and the effect of weather. (see B-6.4)

The hydrologic cycle purifies water in several ways:

- Evaporated water is pure water containing no impurities.
- As water seeps down through the soil and rock it is physically filtered of impurities.
- As water flow slows, heavier particles of sediment settle out, leaving purified water to travel toward the oceans.

Disposing of Waste & Recycling Nutrients

- Waste materials from organisms are decomposed by bacteria or other organisms in the soil or in aquatic ecosystems. (see B-6.4)
- Nutrients are cycled through an ecosystem from organisms to the environment and back through series of specific processes known as geochemical cycles. (see B-6.4)

B-6.6 Explain how human activities (including population growth, technology, and consumption of resources) affect the physical and chemical cycles and processes of Earth.

Humans play a role in ecosystems and geochemical cycles. People depend on the resources and geochemical cycles of Earth to provide clean water, breathable air, and soil that is capable of supporting crops. Human activities, including population growth, technology, and consumption of resources, can affect the cycles and processes of Earth.

- The *carrying capacity* of an environment is defined as the maximum population size that can be supported by the available resources.
- Various factors (such as energy, water, oxygen, nutrients) determine the carrying capacity of Earth for the human population.

In order to meet the needs of humans to survive indefinitely (*sustainability*), there needs to be a balance between Earth's resources and carrying capacity, the needs of humans, and the needs of other species on Earth. Factors that affect the sustainability of humans include:

Population Growth

- Population growth world-wide has grown exponentially. Based on current trends, scientists predict that the population will continue to grow at a rapid rate.
- The natural slowing of population growth as it nears Earth's carrying capacity is due to an increase in the death rate and a decrease in the birth rate as a result of:
  - Food and water shortages
  - Pollution of the environment
  - Spread of diseases
- An increasing population can have an effect on the amount of available clean water.
  - If clean water is being depleted at a greater rate than it can be purified, it is not considered renewable in our lifetime.
- An increasing population can have an effect on the amount of waste that is produced.
  - Although there are mechanisms in place to control the disposal of some waste products, more waste is produced than can be managed effectively.
  - Some waste products require complicated and costly means for removal once they are introduced into the environment.
- An increasing population can have an effect on the amount of available fertile soil for agriculture (food resources).
  - Soil is often lost when land is cleared, making the land unsuitable for agriculture.
  - Worldwide demand for land (for agriculture or habitation) has led to deforestation.
    - ♦ As forests are cut down, there are fewer trees to absorb atmospheric carbon dioxide. The increase in atmospheric carbon dioxide contributes to global warming by preventing heat from radiating back into space. (see B-6.5)
    - ♦ Deforestation can increase the rate of erosion (both wind and water) and decrease the rate of soil generation. (see B-6.5)
- Human population growth has depleted the amount of fertile soil, clean water and available land in many areas of the world. When these resources become scarce, many natural processes (such as the water cycle, the carbon cycle, the nitrogen cycle, and the physical process of soil regeneration) are affected.

Technology

Different types of technology have applied scientific knowledge in order to either find solutions to problems or develop products to help meet the needs of humans. Although technology has benefited humankind, it has also contributed to the pollution of the air, water, and land. For sustainability, humans depend on technology to now provide cleaner energy sources, safer ways to deal with waste, and better methods for cleaning up pollution. Technological advances in agriculture, industry, and energy can have a positive or negative impact on Earth.

Agricultural technology

- Advances in agricultural methodology, tools, and biotechnology have improved the ability to grow crops to sustain a growing world population.
- Sustainable agricultural practices can help conserve fertile soil and reduce soil erosion.
- Farm machinery (such as tractors and combines) consumes nonrenewable resources and can contribute to erosion and air pollution.
- The addition of substances (such as fertilizers, pesticides, fungicides, livestock waste) to the environment can alter the composition of soil and can have a positive or negative effect on the water, carbon or nitrogen cycles.

Industrial technology

- Advances in industrial technology have changed the world and have lead to developments in communication, transportation, and industry.
- The development of certain chemicals, such as CFCs (chlorofluorohydrocarbons), contributes to the depletion of the ozone layer, which results in increased ultraviolet rays reaching Earth. CFCs are used in producing foam packing materials, for cleaning electrical components, and refrigeration chemicals (Freon).

- Technological advances have revolutionized the communication industry; however, the disposal of outdated or damaged equipment is becoming an increasing concern.
- The burning of fossil fuels for industry and transportation increases sustainability of the growing human population; however, it also:
  - increases the greenhouse gases released in the atmosphere (mainly carbon dioxide), which increases global temperatures (global warming) that affect sea levels, climate and atmospheric composition (see B-6.5)
  - produces acid rain (pollutants in the air combining with water to cause the normal water pH to be lowered)
    - ♦ Acid rain decreases the pH of the soil and can leach nutrients from soils or destroy plant life.
    - ♦ Acid rain changes the pH of aquatic ecosystems and therefore affects the types of organisms that can survive there.

Alternative energy technology

- Using natural renewable energy sources (such as wind, water, geothermal, or solar energy) decreases the burning of fossil fuels, which increases the quality of the atmosphere and the cycles involved.
- Using nuclear energy technology provides an alternative energy source that does not impact the atmosphere. However, the waste produced from nuclear energy use is becoming an increasing concern.

Consumption of Resources

- As the population increases and technology expands, the demand for Earth resources also increases. However, there is a limited supply of these resources available to sustain the human population.
- Some resources (such as food, clean water, and timber) are considered *renewable resources*, those that can be produced at roughly the same rate that they are consumed.
  - Renewable resources have factors that limit their production, for example the amount of grain that can be produced is limited by the amount of land available for farming, fertility of the land, productivity of the grain, or availability of clean water.
- Other resources, such as fossil fuels, are *nonrenewable resources*, those that cannot be produced at the same rate that they are consumed. For example,
  - The demand for minerals, metals, and ores increases because these strategic materials are vital to industry but are decreasing in availability.
  - Minerals are regarded as nonrenewable because mineral deposits that can be extracted economically are formed so slowly by geological processes that their formation as a means of replacing what we are using is of no practical use to us.
- Sustainable use of resources can be accomplished by reducing consumption, reusing products rather than disposing of them, or recycling waste to protect the environment.