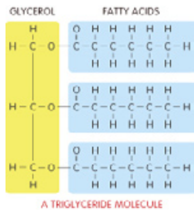
BIOLOGY

BIOCHEMISTRY

THE BUILDING BLOCKS OF LIFE

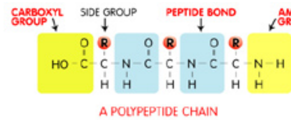
Four types of **macromolecules** (large, carbon-based organic molecules) are found in living organisms. Most are **polymers**—chains of molecules that form through **dehydration synthesis** (the loss of a water molecule).

A. Carbohydrates: Energy-storing molecules containing carbon, hydrogen, and oxygen in a 1:2:1 ratio. **Monosaccharides**, such as glucose ($C_6H_{12}O_6$), are single-sugar subunits often found as rings. **Disaccharides** have two monosaccharide subunits. **Polysaccharides**, such as starch, glycogen, and cellulose, are long chains of sugars.

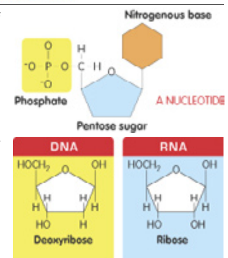


B. Lipids: Hydrocarbon-based molecules that are **hydrophobic**—insoluble in water. There are three primary families of lipids:
1. **Fats:** Large, energy-storing molecules, each built from two components:
   a. One molecule of **glycerol**, a three-carbon alcohol.
   b. Three **fatty acids**, long hydrocarbon chains that attach to the glycerol backbone. (Hence, fats are also called **triglycerides**.)
2. **Steroids:** Four fused-hydrocarbon rings, such as cholesterol.
3. **Phospholipids:** Glycerol with two fatty acids and a phosphate group attached (found in membranes).

C. Proteins: Long polymer chains called **polypeptides** built from **amino acid** subunits linked by **peptide bonds**. Every amino acid contains a central carbon with an amino group (NH_2), a carboxyl group (COOH), hydrogen (H), and one of 20 side groups (R) that define the attributes of the amino acid.



D. Nucleic acids: Polymers of **nucleotides** that encode genetic information. There are two forms: **deoxyribonucleic acid (DNA)** and **ribonucleic acid (RNA)**. Individual nucleotides are linked by phosphodiester bonds and contain three basic parts:
1. **Phosphate group**
2. **Five-carbon sugar:** deoxyribose in DNA, ribose in RNA.
3. One of four **nitrogenous bases:**
   a. **Adenine** and **guanine**, double-ringed **purines**.
   b. **Thymine** and **cytosine** single-ringed **pyrimidines**.
   c. RNA contains the pyrimidine **uracil** instead of thymine.



THERMODYNAMICS

The **first law of thermodynamics** states that energy is never created or destroyed, only transformed. The **second law of thermodynamics** states that entropy, or randomness, is always increasing. Every transformation of energy creates greater disorder. Biological life survives by relying upon high-yield energy sources (such as solar radiation) to fuel life processes before releasing that same energy as simpler, low-yield end products (such as heat).

FREE ENERGY CHANGE

All chemical reactions involve a **change in free energy**, ΔG. **Exergonic** reactions release free energy (ΔG is negative) and are spontaneous. **Endergonic** reactions absorb free energy (ΔG is positive) and are non-spontaneous. The **activation energy** of a reaction refers to the energy required to initiate the reaction.

ENZYMES

Enzymes are biological catalysts, proteins capable of speeding chemical reactions without being consumed. Enzymes lower the activation energy of a reaction (but do not affect ΔG, the free energy change). The **substrate** binds to the enzyme's **active site** in an induced fit, in which the enzyme changes its shape to wrap itself around the substrate. Enzymatic activity can be activated or inhibited by other molecules.

A. Cofactors: Some enzymes require inorganic cofactors or organic coenzymes to react.
B. Competitive inhibitors: Non-substrate molecules that block the enzyme's active site.
C. Noncompetitive inhibitors: Bind to an **allosteric site** (receptor site away from the active site) and change the enzyme's **conformational shape** so that it no longer accepts the substrate.
D. Activators: Fit into an allosteric site and open the enzyme's active site.
E. Feedback inhibition: Halts enzymatic activity by an end product that allosterically inhibits formation of an intermediate product.
F. Cooperativity: Occurs when a substrate binds to an active site, opening additional active sites.

CELLS

Every living organism is made up of **cells**, which are the lowest level of structure capable of performing all the activities of life. All cells arise from preexisting cells.

CELLULAR PRECURSORS

Conditions on the early Earth allowed for the **spontaneous abiotic synthesis** of organic compounds. This synthesis would have required an **absence of atmospheric oxygen**, because oxygen naturally breaks down compounds and because the ozone (O_3) layer today blocks the intense UV radiation that fueled such synthesis.

A. Protobionts (collections of abiotically synthesized organic compounds) formed spontaneously as the precursors to cells. Protobionts such as **coacervates** (collections of macromolecules that assemble spontaneously when shaken in water), **microspheres** (collections of proteinoids), and **liposomes** (molecules within a lipid bilayer) can combine into larger cells or bud into smaller ones, and can use enzymes to catalyze reactions.
B. The genesis of **RNA**, with its capacity to act as both a catalyst and a heredity blueprint, would have paved the way for the first real cells.

CELL STRUCTURE

A. Cell membrane: Serves as an external barrier and encloses **organelles**.
1. The basic unit is a **phospholipid molecule**, with a polar phosphate group as its hydrophilic head and two nonpolar fatty acid chains as hydrophobic tails.
2. Individual phospholipids form a fluid **phospholipid bilayer**, with hydrophilic heads facing out and hydrophobic tails facing in to form a nonpolar zone that separates the watery cell interior from the extracellular environment.
3. Cell membranes are **semipermeable**, allowing passage of gases, lipids, and small polar molecules but *not* charged molecules (ions and proteins) or large polar molecules.

B. Membrane proteins: Protein molecules embedded in the bilayer that *transport* molecules unable to cross the membrane independently, *assist* in biologically important reactions, and *interact* with membranes of neighboring cells.
C. Cytoplasm: Semifluid medium called **cytosol** and all the organelles inside the plasma membrane but outside the nucleus.
D. Cytoskeleton: A system of protein filaments in the cytoplasm, including **microtubules** and **microfilaments**, that gives the cell shape and helps direct movement.
E. Ribosomes: Proteins that work with RNA to synthesize polypeptides.
F. Cholesterol: Type of **steroid** (lipid with a carbon skeleton of four fused rings) that acts as precursor to many animal hormones. It stabilizes the lipid bilayer of animal cells, preventing solidification at low temperatures and fluidity at high temperatures.

TYPES OF CELLS

CELLS OF EUKARYOTES

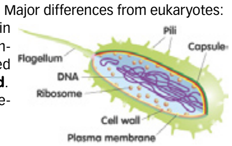
Eukaryotes include multicellular plants and animals and some unicellular protists. Their cells contain membrane-bound **organelles**, each of which performs specific functions and increases efficiency:

A. Nucleus: Membrane-bound storage site of genetic information that determines heredity and directs the activities of a cell.
B. Mitochondria: Double-membraned power plant of the cell and the location of aerobic respiration.
C. Smooth/rough endoplasmic reticulum (SER/RER): Network of membranes where lipids and proteins are synthesized. Rough ER is covered with ribosomes.
D. Golgi apparatus: Organelle that packages and exports proteins and lipids produced in the ER.
E. Vesicles: Sacs in which substances are transported or stored.
F. Lysosomes: Vesicles of digestive enzymes that degrade old cellular components.
G. Plant cells contain several additional components:
1. **Chloroplasts:** Sites of photosynthesis. Contain chlorophyll (a green pigment) and have a double membrane.
2. **Vacuole:** Vesicle used to store water, proteins, and wastes.
3. **Cell wall:** Rigid cellulose layer around the cell membrane.

CELLS OF PROKARYOTES

Prokaryotes include the simplest unicellular organisms and earliest cells to evolve (**bacteria**). Major differences from eukaryotes:

A. Genetic material floats in the cytoplasm in a concentrated but unbounded region called the **nucleoid**.
B. There are no membrane-bound organelles.



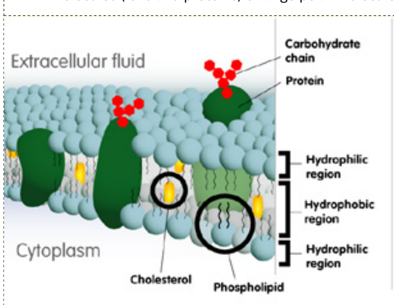
CELL TRANSPORT

PASSIVE MECHANISMS (REQUIRE NO ENERGY)

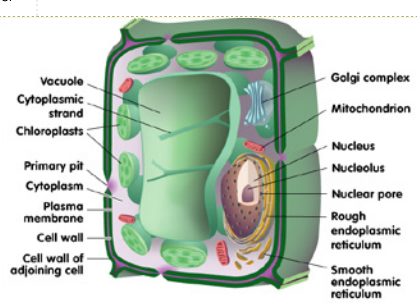
A. Diffusion: Molecules move freely across a membrane to balance a concentration gradient, from regions of high to low concentration. Diffusion of water is called **osmosis**.
B. Facilitated diffusion: Molecules cross an impermeable or semipermeable membrane down their concentration gradient but must do so via special channels.

ACTIVE MECHANISMS (REQUIRE ENERGY)

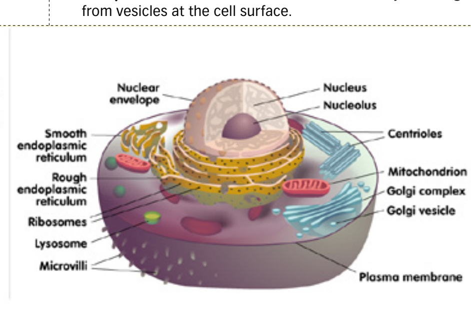
A. Active transport: Transport of molecules from low to high concentrations across a membrane using an energy-dependent transport protein.
B. Endocytosis: Enveloping of an exterior substance within a membranous vesicle for admission to the cell interior.
1. **Pinocytosis:** Endocytosis of dissolved liquid molecules.
2. **Phagocytosis:** Endocytosis of undissolved solid matter.
C. Exocytosis: Extrusion of material from a cell by discharge from vesicles at the cell surface.



CELL MEMBRANE



PLANT CELL



ANIMAL CELL

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CELLS (continued)

CELLULAR RESPIRATION

Cellular respiration is the cellular process of oxidizing glucose to obtain energy in the form of **adenosine triphosphate (ATP)**.

GLYCOLYSIS

Glycolysis is the oldest metabolic pathway, used by all cells, and a precursor to both the aerobic and anaerobic respiratory pathways. Glycolysis occurs in the cytoplasm. The six-carbon sugar **glucose** is degraded to form two molecules of three-carbon pyruvate, resulting in two NADH and two net ATP.

FERMENTATION

In the absence of oxygen, respiration relies on glycolysis to produce ATP in an anerobic process called **fermentation**. This process uses an organic molecule to accept the electron from NADH and reform NAD^+ for glycolysis to run again. Much energy remains in bonds of end-products, such as ethanol or lactic acid. There are three types of fermentation:

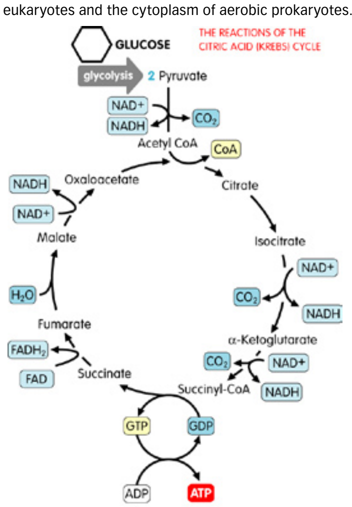
A. Homolactic: Bacteria converts pyruvate into lactic acid.
B. Alcoholic: Yeast and bacteria convert pyruvate into ethanol and CO_2.
C. Heterolactic: Organisms produce lactic acid as well as other acids and alcohols.

OXIDATIVE RESPIRATION

If oxygen is present, glycolysis leads to **aerobic respiration**, which produces a net total of 36 ATP per molecule of glucose.

A. Oxidation of pyruvate: Carbon dioxide splits off from pyruvate to produce acetyl-CoA and NADH.

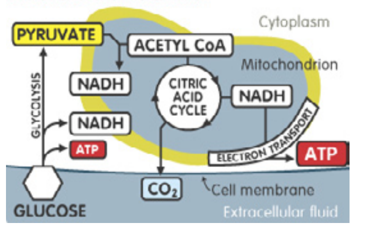
B. Citric acid cycle (Krebs cycle): Begins with acetyl-CoA joining oxaloacetic acid to form citric acid, which is oxidized to CO_2, yielding ATP, NADH, and $FADH_2$. Oxaloacetic acid is regenerated for another cycle. Occurs in the mitochondria of eukaryotes and the cytoplasm of aerobic prokaryotes.



THE REACTIONS OF THE CITRIC ACID (KREBS) CYCLE

C. Chemiosmotic (oxidative) phosphorylation: In mitochondria, electrons from NADH and $FADH_2$ flow through an **electron transport chain** from high to low energy states through energy-releasing steps, establishing an electrochemical proton gradient across the inner membrane of mitochondria. O_2 accepts the electrons to form water. ATP is synthesized when H^+ ions diffuse back across the membrane through embedded proteins.

AN OVERVIEW OF OXIDATIVE RESPIRATION



CELL REPRODUCTION

DNA is the cell's genetic material; **chromosomes** are the carriers of this genetic information. In prokaryotes, the chromosome is a single circle of DNA. In eukaryotes, each chromosome is a complex of DNA and histone proteins found in the nucleus.

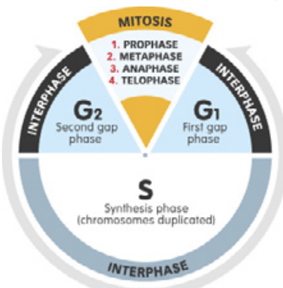
BINARY FISSION

Prokaryotic cells reproduce via **binary fission**. In this process, DNA is replicated, and the cell splits in two roughly equal parts, each with a copy of the cell's DNA.

EUKARYOTIC CELL CYCLE

Eukaryotic cells reproduce via the creation of two identical diploid cells from one **diploid** cell. Diploid (2N) refers to the total number of chromosomes in autosomal (nonsexual) cells.

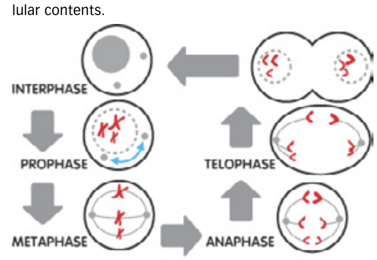
A. Interphase: The period between mitotic divisions during which chromosomes are not visible; comprised of three phases:



THE FOUR PHASES OF A EUKARYOTIC CELL CYCLE

1. **G_1 phase:** Major period of cell growth.
2. **S phase:** Chromosome replication takes place, producing pairs of sister chromatids (identical chromosomes) that are each connected by a centromere.
3. **G_2 phase:** Synthesis of cell machinery in preparation for cell division.

B. Mitosis (M) phase: The division of genetic material and cellular contents.



THE STAGES OF MITOSIS

1. **Prophase:** Replicated chromosomes condense. **Spindle** forms along cell equator. Nuclear envelope breaks down; spindle microtubules enter nuclear region, eventually attaching to centromeres of chromosomes.
2. **Metaphase:** Chromosomes align along cell equator called the **metaphase plate** but do not yet segregate to opposite poles. Centromeres divide, freeing sister chromatids.
3. **Anaphase:** Sister chromatids separate to opposite poles.
4. **Telophase:** Chromosomes uncoil at opposite ends and become enclosed by a reformed nuclear envelope.

C. Cytokinesis: Physical division of the cytoplasm into two daughter cells.

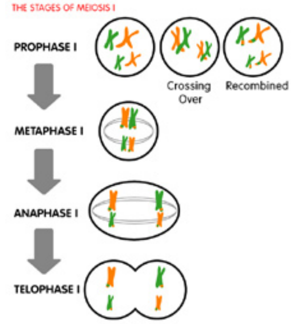
MEIOSIS

Meiosis produces four **haploid** nuclei called **gametes** from a single diploid cell. Haploid (N) is half of the diploid number. In **interphase**, chromosomes are replicated and align in **homologous pairs**. Each pair contains a maternal and paternal homologue inherited from the previous generation. An important consequence of meiosis is that the **genomes** are **mixed** and **recombined**.

A. Meiosis I:

1. **Prophase I: Crossing-over** occurs, an overlap between homologous chromosomes at x-shaped junctures called **chiasmata** and a resultant exchange of material.
2. **Metaphase I:** Spindle forms; joined homologous pairs line up at the center of the cell.
3. **Anaphase I:** Spindle shortens; chiasmata break apart, maternal/paternal chromosomes dragged to opposite poles.
4. **Telophase I:** Chromosomes are set up at each pole; new haploid nuclei form.

THE STAGES OF MEIOSIS I



B. Meiosis II: Proceeds as a mitotic division, with each daughter cell from meiosis I splitting into two haploid gametes.

CELL CYCLE REGULATION

Cells divide in order to maintain a **surface-to-volume ratio** so that the cell has enough surface area to absorb nutrients and expel wastes relative to its volume.

A. The cell cycle is regulated internally by **checkpoints** at the G_1, G_2, and M phases. The checkpoints halt cell division until overridden (e.g., when the M checkpoint halts anaphase until the sister chromatids are properly aligned).

1. **Cyclin-dependent kinases** (enzymatic complexes that activate enzymes responsible for cell division) regulate the checkpoints, activating enzymes by phosphorylating them (changing their shape and opening their active sites).
2. The kinases are in turn regulated by **cyclin**, a protein present in the cells at variable (cycling) concentrations.

B. External signals can also regulate cell division.

1. **Growth factors** are proteins that originate in one cell type and promote division in another cell type.
2. **Density-dependent inhibition** stops cells from dividing once they reach a certain density over a given surface area.
3. **Anchorage dependence** prevents cells from dividing unless they attach to specific surfaces.

C. Cancer cells are cells that ignore cell cycle regulations and divide unchecked.

MENDELIAN GENETICS

Genetics is the study of the heredity of organisms. A **gene** is the basic unit of heredity; an **allele** is one of two or more alternative forms of a specific gene.

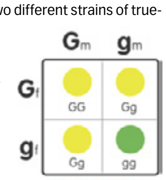
INTRODUCTION

A. Until the 20th century, scientists believed that traits from the parents would blend in the offspring (e.g., a tall father and short mother results in a child of medium height). Eventually, all members of a species would look the same.

B. Gregor Mendel, by crossing different strains of garden peas and analyzing the results, created the genetic theory still used today.

MENDEL'S FIRST LAW (LAW OF SEGREGATION)

A. Single-trait crosses: Mendel took two different strains of true-breeding pea plants, one with green peas and one with yellow peas, and crossed them. In modern terms, this **monohybrid cross** used **homozygous** plants, having the same allele inherited from each parent.



SINGLE-TRAIT CROSS
G=YELLOW, g=GREEN

1. The first-generation plants, F_1, were **heterozygous** (having inherited two different alleles of a gene) but showed only one trait. This occurred because the **dominant allele** determines the phenotype in heterozygotes by masking the **recessive allele**.
2. Then, Mendel crossed two F_1 plants. 3/4 of the plants in F_2, the second generation of peas, showed the dominant trait; 1/4 showed the recessive.

B. From these results, Mendel came up with three postulates:

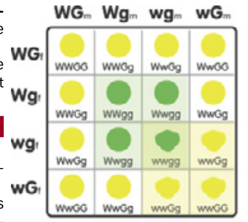
1. Alternative forms of a trait are controlled by *different alleles* of the gene responsible for that trait.
2. When **gametes** (haploid reproductive cells) form in diploid individuals, the two alternative alleles for a gene *segregate* from each other.
3. Every gamete has an *equal chance* of receiving either member of an allele pair.

MENDELIAN GENETICS (continued)

MENDEL'S SECOND LAW (LAW OF INDEPENDENT ASSORTMENT)

A. Mendel also conducted several multi-trait (**dihybrid**) crosses, in which he crossed peas that were heterozygous for two genes.

B. In each case, he observed a 9:3:3:1 phenotype ratio and concluded that genes located on different chromosomes *assort independently* of one another.



MULTI-TRAIT CROSS
G=YELLOW, g=GREEN, W=SMOOTH, w=WRINKLED

GENETICS

A. Genotype: The genes an individual has.

B. Phenotype: The physical appearance of an individual.

B. Incomplete dominance: sometimes heterozygous genotypes result in phenotypes that do not precisely resemble one parent.

1. Phenotype is intermediate between the two parental phenotypes (**incomplete dominance**).
2. Phenotype resembles homozygous dominant, but is still distinguishable from it (**partial dominance**).
3. Both parental phenotypes can be identified in the offspring (**codominance**).

C. Pleiotropy: Instance when a gene produces more than one phenotypic effect.

D. Sex chromosomes: Specific chromosomes that dictate the sex of certain organisms (the remaining chromosomes are called **autosomes**).

1. In humans, there are two sex chromosomes, **X** and **Y**.
   a. **Males** possess one each of X and Y chromosomes.
   b. **Females** possess two X chromosomes.
2. **Sex-linked inheritance:** In humans, a male expresses all traits unique to the X chromosome he inherits from his mother. Males are afflicted with **X-linked disorders** because there is no counterpart on the Y chromosome to express the functional allele.

MOLECULAR GENETICS

NUCLEIC ACIDS

A. DNA occurs most often as a **double helix,** a spiral staircase–shaped molecule composed of two nucleotide chains hydrogen-bonded to each other.

1. One of these chains always ends with a free 3′-OH group, while the other always ends with a free 5′-phosphate group.
2. The chains bind in opposing directions: the 5′ end of one chain is hydrogen-bonded to the 3′ end of its partner.

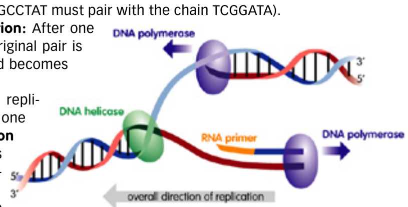
B. In double-stranded DNA, adenine hydrogen-bonds to thymine, and guanine hydrogen-bonds to cytosine.

1. Therefore, the proportion in DNA of adenine is always equal to that of thymine, and the proportion of guanine is always equal to that of cytosine: **A = T**, **G = C**.
2. There is always an equal proportion of purines (A, G) and pyrimidines (C, T).

DNA REPLICATION

A. Complementarity: The base sequence of one chain of DNA completely determines the sequence of its partner in the double helix. Each chain is a complementary mirror image of the other (e.g., the chain AGCCTAT must pair with the chain TCGGATA).

B. Semiconservative replication: After one round of replication, the original pair is not conserved. Each strand becomes part of a new duplex.



1. When a DNA molecule replicates, it separates at one end to form a **replication fork.** Each strand serves as a template for synthesis of a new strand.
2. **DNA polymerase** is the enzyme that catalyzes the replication process. It moves along each DNA strand from the 5′ to 3′ direction, so new strands are synthesized 5′ end first, 3′ end last.
3. The leading DNA strand is synthesized continuously.
4. The lagging DNA strand is synthesized discontinuously in segments of nucleotides called Okazaki fragments, which later join together with the help of DNA ligase.

GENE EXPRESSION (PROTEIN SYNTHESIS)

A. RNA transcription

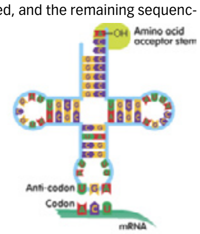
1. The region of DNA encoding the desired gene is unzipped, and the enzyme **RNA polymerase** copies the nucleotide sequence to make a strand of messenger (m)RNA. Though the two strands of DNA are complementary, only one strand (the **template strand**) is transcribed into mRNA.

TRANSCRIPTION

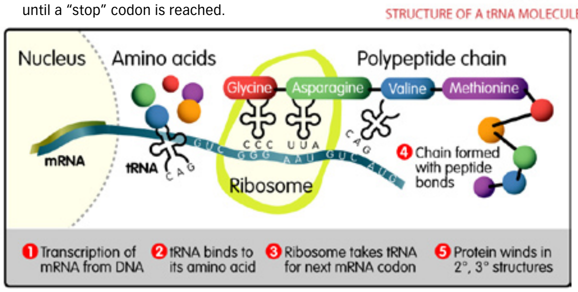
2. Noncoding sequences of mRNA called **introns** are removed, and the remaining sequences, called **exons,** are spliced together.
3. The mRNA leaves the nucleus.

B. Translation

1. A ribosome (a complex of ribosomal (r)RNA and protein) binds to an mRNA transcript and reads a triplet of nucleotides, called a **codon.**
2. The ribosome binds the matching **anticodon** of a transfer **(t)RNA** molecule, which is attached to a specific amino acid, into the ribosome's **A-site.**
3. Sequential mRNA codons call new tRNA–amino acids into the A-site, shifting previous tRNA–amino acids to the **P-site,** where they link to form a polypeptide chain until a "stop" codon is reached.



STRUCTURE OF A tRNA MOLECULE



AN OVERVIEW OF PROTEIN SYNTHESIS

THE CENTRAL DOGMA

The process of gene expression/protein synthesis follows a specific order:

A. DNA is transcribed into mRNA.

B. mRNA is then translated into protein.

GENE REGULATION

Gene regulation in prokaryotes: Prokaryotes have genes organized in an **operon** containing all the genes in a metabolic pathway, a promoter, and an **operator** (on-off switch). The operator controls whether RNA polymerase will bind to the promoter and transcribe RNA. The operator can be controlled by both negative and positive gene regulation.

A. Negative gene regulation:

1. **Repressible operons** are regulated by **repressor proteins** (encoded elsewhere than the operon). These proteins bind to the operator and prevent genetic transcription. **Corepressors** regulate the repressor proteins by binding onto an allosteric site.
   a. Repressible operons function in anabolic pathways that synthesize end products from starter reactants.
   b. The end product itself can act as the corepressor, so that once enough products are synthesized the machinery shuts off.
2. **Inducible operons** are also controlled by repressor proteins, but an **inducer** binds to an allosteric site on the repressor protein and inactivates it, triggering transcription.
   a. Inducible operons function in catabolic pathways that break down nutrients.
   b. The nutrient itself sometimes acts as the inducer, such that enzymes are only created when they will be used.

B. Positive gene regulation:

1. An activator protein binds to an operator and helps RNA polymerase attach to the promoter.
2. Molecules can control the activator by binding to an allosteric site and opening its active site, allowing the activator to bind onto the operator

Gene regulation in eukaryotes: Eukaryotic gene regulation occurs at several levels.

A. Modifications on chromatin: Chromatin is a tightly packed form of DNA. Modifications on chromatin can prevent or promote transcription by allowing or barring access to individual genes.

1. **DNA methylation** (the attachment of a CH_3 methyl group to DNA bases) inhibits genetic expression.
2. **Histone acetylation** (the addition of a $COCH_3$ acetyl group to the DNA-binding histone proteins) loosens the grip of histones on chromatin and allows transcription.

B. Control elements: Distal control elements ("enhancers") and proximal control elements are both proteins that bind to DNA at specific (non-coding) DNA binding domains. Control elements activate transcription by attaching to RNA polymerase and forming a transcription initiation complex along the promoter.

C. Steroid hormones: Steroid hormones coordinate expression of multiple related genes by binding to specific receptors that activate transcription in those genes.

D. Regulatory proteins: Regulatory proteins can control the rate of degradation of mRNA and can block mRNA translation by preventing ribosomes from binding to mRNA. **Proteastomes** are protein complexes that can recognize and degrade proteins, thereby curtailing their activity.

MUTATION

A. Point mutations: Mutations that affect single genes through a base-pair substitution, deletion, or insertion.

1. Deletions or insertions that are *not* in a multiple of three cause a **frameshift mutation**, in which all downstream codons are altered.
2. Point mutations may have no effect, may improve or damage the protein, may create a novel protein, or may create a nonfunctional one.

B. Chromosomal mutations: Mutations that affect an entire organism.

1. **Nondisjunction:** An error in chromosomal distribution during meiosis, which results in **aneuploidy**, or gametes with an abnormal chromosome count.
2. **Polyploidy:** A mutation in which gametes contain more than two full sets of chromosomes. Polyploidy is generally less fatal (or altering) than aneuploidy.
3. Mutations can also occur on individual chromosomes. These include:
   a. **Deletion:** A chromosomal fragment gets detached during cell division;
   b. **Duplication:** That same fragment joins its homologous chromosome;
   c. **Inversion:** That fragment gets reinserted backward; or
   d. **Translocation:** That fragment gets attached to a nonhomologous chromosome.
4. The effects of chromosomal mutation are often fatal or can result in genetic disease but in rare cases may improve an organism's fitness.

CONTINUED ON OTHER SIDE

VIRUSES

Viruses are intracellular parasites made up of a genome of double- or single-stranded DNA (or RNA) within a **capsid**, or protein coat. Some viruses have **viral envelopes**, lipid membranes that encase the capsid and assist in invading a **host**.

VIRUS REPLICATION

Viruses cannot **replicate** without a **host**. The **host range** refers to the specific cell type (bacterial, plant, or animal) that each type of virus may infect. Viruses generally replicate via one of two modes, both of which are best understood in bacterial viruses (or **phages**).

A. Lytic cycle:
1. The phage enters the host's cell, releases its DNA from the capsid, and then uses the host's cellular equipment to replicate.
2. The virus's genetic material is transcribed, and viral proteins (such as the capsid proteins) are translated from a viral RNA template.
3. Once the virus replicates and reassembles itself, the host cell lyses, releasing the phage copies. The cycle repeats.

B. Lysogenic cycle:
1. The phage enters the host and incorporates its genome into the host's genome at certain chromosomal locations.
2. The viral genome lies dormant and is replicated each time that the host itself replicates (with every cell division).
3. Environmental cues cause the phage genome to extricate itself from the host's DNA and begin the lytic cycle.

RETROVIRUSES

Retroviruses are animal viruses that reproduce in a manner similar to a phage lysogenic cycle aside from the fact that that the viral genome is **RNA-based**. Reverse transcriptase transcribes the RNA genome into a DNA template that is incorporated into the host's genome at specific sites.

DNA TECHNOLOGY

PLASMIDS

Plasmids are self-replicating rings of bacterial DNA. A plasmid can be used as a **cloning vector**, in which a gene of interest is spliced into that plasmid and reintroduced into the bacteria for mass replication.

A. Restriction enzymes (enzymes that cut DNA at specific sequences) cut open the plasmid and excise the gene of interest from its host DNA.

B. DNA ligase glues the cut fragments in solution with phosphodiester bonds, creating a piece of **recombinant DNA** containing both the gene and the plasmid.

C. Transformation of the plasmid reintroduces the recombinant DNA into bacteria by **electroporation**, an electric shock that temporarily makes the bacteria's plasma membrane permeable.

D. Bacterial growth in culture replicates the gene (within the plasmid). The recombinant plasmid DNA is isolated from the bacteria, and the cloned gene is re-excised using restriction enzymes.

POLYMERASE CHAIN REACTION

A **PCR (polymerase chain reaction)** can be used to clone DNA in vitro.

A. Heating the gene of interest separates it into single strands.

B. Cooling the solution allows the gene to bind with primers that are complimentary to the ends of the target gene.

C. DNA polymerase adds new nucleotides to the primers, creating new copies of the target gene.

D. Reheating the products continues in cycles such that new DNA is created in mass.

GEL ELECTROPHORESIS

Gel electrophoresis is used to isolate DNA fragments by size.

A. DNA cut with restriction enzymes is placed in wells at the end of a gel, and this gel is bathed in an aqueous solution.

B. An **electrical charge** is passed through the gel, pulling the polar DNA molecules through the gel.

C. Variations in size among DNA fragments make the fragments migrate at differential rates: shorter fragments travel farther down the gel than longer ones do.

D. A **DNA ladder** is run in one of the wells, containing fragments of benchmark sizes used to identify the sizes of the other fragments.

E. The gel is **dyed** with a solution that binds to DNA and makes it glow under ultraviolet light. The DNA glows pink under the light and can be physically cut from the gel and isolated.

BLOTTING

Southern blotting, an extension of electrophoresis, pulls DNA fragments from an electrophoresis gel onto a piece of nitrocellulose paper by the capillary action of an alkaline solution. The paper is removed, and a radioactive probe of single-stranded DNA binds to the target DNA. The radioactive DNA shows up on a piece of film placed onto the paper.

Northern blotting is similar to Southern blotting except for the fact that it analyzes whole molecules of mRNA rather than fragments of DNA cut by restriction enzyme digest.

EVOLUTION AND DIVERSITY

Evolution is the process by which species change gradually over time. It arises from processes of **selection** that favor individuals having certain favorable traits over those lacking those favorable traits.

NEO-DARWINIAN THEORY

A. Principle of variation: Variations in morphology, physiology, and behavior occur among individuals in any given population.

B. Principle of heredity: Offspring resemble parents more than they resemble other members of the population.

C. Principle of selection: Individuals with certain traits more successfully survive and reproduce, passing those traits to the next generation.

EVOLUTIONARY FACTORS

A. Mutation: A permanent change in a cell's DNA, causing diversity among individuals.

B. Genetic drift: A random change in the frequency of alleles. Two instances of genetic drift cause individuals' genes to be unnaturally overexpressed:
1. **Founder effect:** Only a few individuals of a species start a new population.
2. **Bottleneck effect:** Only a few individuals of a species survive a disaster.

C. Gene flow: Movement of genes from one population to another through migration of individuals between populations and/or mating between separate populations.

TYPES OF SELECTION

A. Natural selection: Individuals produce more offspring than can survive. Because individuals compete for limited resources, those with favorable variations and traits are more successful at passing on those traits to succeeding generations. Over time, those traits become prevalent, while disadvantageous traits occur with decreased frequency.
1. **Directional selection:** Selection favors an extreme phenotype, the frequency of which increases over time.
2. **Stabilizing selection:** Selection acts to eliminate both extreme phenotypes. The frequency of the intermediate phenotype increases over time.
3. **Disruptive selection:** Selection acts to eliminate the intermediate phenotype from a population, favoring the extremes.

B. Sexual selection: Individuals with traits that appeal to sexual partners are more likely to pass on those traits to succeeding generations. Various traits may be preserved not because they enhance survivorship but because they increase reproductive success.

C. Artificial selection: Humans intentionally breed animals to enhance specific traits.

COEVOLUTION

Coevolution is the long-term evolutionary adjustment of one group of organisms to another.

A. Predator-prey interactions: Both plants and animals develop special defenses when they interact competitively with other organisms.

B. Symbiosis: A relationship in which two kinds of organisms consistently live together.
1. **Commensalism:** A relationship in which one individual is closely associated with another and benefits without doing harm to the host.
2. **Mutualism:** A relationship that benefits both organisms involved.
3. **Parasitism:** A type of predation in which one organism lives in or on a host and benefits while harming the host.

POPULATION GENETICS

Population genetics is the study of the properties of genes in populations (as opposed to in individuals).

POPULATIONS

A. Size: Small populations are more likely to go extinct because **random events** or disturbances may affect the population disproportionately. Also, **inbreeding** may eliminate the genetic diversity necessary for the population to thrive.

B. Dispersion: Widely spaced populations may not thrive because individuals may not interact often enough to reproduce sufficiently.

POPULATION GROWTH

A. Biotic potential: $dN/dt = r_iN$; the rate at which a population increases when there are no limits on its rate of growth. N is the population size; dN/dt is the rate of change in population size over time; and r_i is the population's capacity for growth.

B. Carrying capacity: $dN/dt = rN[(K - N)/K]$; the size at which a population stabilizes in a particular environment, based on available resources, predation, competition, and niche.

HARDY-WEINBERG PRINCIPLE

In the absence of mutation, migration, genetic drift, and nonrandom selection, allele and genotype frequencies remain constant in a random-mating population. Dominant alleles do not replace recessive ones because the frequencies do not change. Mathematically:

If the frequency of allele *a* is *p*, and the frequency of allele *b* is *q*, then the genotype frequencies after one generation of random mating are represented by:

$$p^2(a) + 2pq(ab) + q^2(b) = 1$$

or

$$1 = (p + q)^2 = p^2 + 2pq + q^2$$

CLASSIFYING ORGANISMS: THE THREE-DOMAIN SYSTEM

The **five-kingdom system** of classifying organisms has given way to a **three-domain system** that better reflects current evolutionary research. **Domain Bacteria** and **Domain Archaea** are offshoots of what was once Kingdom Monera. **Domain Eukarya** contains all four other kingdoms but subdivides what was once Kingdom Protista into five separate kingdoms: Archaezoa, Euglenozoa, Alveolata, Stramenopila, and Rhodophyta.

DOMAIN ARCHAEA

Consists of those **prokaryotes** that inhabit the harshest environments. Believed to be the ancestors of Kingdom Eukarya.

A. Methanogens: Strict anaerobes (oxygen is fatal to them) that live in swamps and convert CO_2 to methane (CH_4).

B. Extreme halophiles: Live in lakes saltier than the ocean.

C. Extreme thermophiles: Live in hot deep-sea vents and sulfur springs.

DOMAIN BACTERIA

Consists of all other **prokaryotes**.

DOMAIN EUKARYA

Arose from prokaryotes through two evolutionary steps:

A. An **internal membranous system** (including a nuclear envelope) derived from infoldings of the plasma membrane.

B. Symbiosis with prokaryotes that later became mitochondria and chloroplasts.

KINGDOM ARCHAEZOA

Perhaps the oldest Eukarya; **lack mitochondria**, are flagellated, have dual nuclei and a simple cytoskeleton. **Example:** *Giardia*, a protist found in water.

KINGDOM EUGLENOZOA

Flagellated unicellular protists **with mitochondria**. **Examples:** 1. *Euglena* (which has a flagella coming from an anterior folding); 2. kinetoplastids (which have a kinetoplast, a unique organelle that houses genetic material outside the nucleus).

KINGDOM ALVEOLATA

Characterized by **alveoli** (vesicles below the plasma membrane). **Examples:** 1. dinoflagellates (photosynthetic phytoplankton that cause algal blooms known as red tides); 2. *Apicomplexa* (animal parasites such as *Plasmodium*, which causes malaria); 3. ciliates (unicellular ciliated cells capable of binary fission or conjugation, such as *Paramecium*).

KINGDOM STRAMENOPILA

Characterized by **flagella that have hairlike protrusions**. Autotrophic stramenopila have chloroplasts that more closely resemble the original prokaryotic symbionts. **Examples:** 1. diatoms (unicellular protists with silicated exoskeletons); 2. brown and golden algae.

KINGDOM RHODOPHYTA

Protists that evolved to lose their flagella. **Example:** red algae.

KINGDOM FUNGI

Decomposing organisms characterized by **absorptive nutrition**. Includes yeasts, which are unicellular, but also multicellular fungi that have the following features: 1. tubular units called **hyphae** with cell walls made of chitin, a plasma membrane, and eukaryotic organelles; 2. divisions between hyphae called **septa**, which separate hyphae into cells but also allow the passage of organelles from cell to cell; 3. multiple hyphae organized into a network called a **mycelium**.

- **Zygomycota:** Terrestrial decomposers that have spores resistant to harsh environmental changes. **Examples:** 1. bread mold; 2. mycorrhizae (symbiosis between a fungus and the roots of plants, in which the fungus absorbs minerals that it passes to the roots in exchange for sugars from the plant).
- **Ascomycota:** Terrestrial and aquatic decomposers that form spores in **asci** (which look like sacs) and have large fruiting bodies called **ascocarps** that release the asci. **Examples:** 1. truffles; 2. fruit molds; 3. lichens (symbiosis between a fungus and an algae); 4. some yeasts and also some mycorrhizae.
- **Basidiomycota:** Club-shaped, sexually-reproducing decomposers that have large fruiting bodies called **basidiocarps**. **Examples:** 1. mushrooms; 2. some yeasts.

KINGDOM PLANTAE

Muticellular eukaryotes characterized (with some exceptions) by **photosynthetic nutrition**. *For classification, see* Plants, *next page.*

KINGDOM ANIMALIA

Multicellular eukaryotes characterized by **ingestive nutrition**; generally reproduce sexually. All animals are believed to have originated from a single progenitor.

Major criteria for animal classification

A. Parazoa vs. eumetazoa

1. **Parazoa** lack true tissues; each cell is basically modular.
2. **Eumetazoa** have true tissues (i.e., specialization of cells by function).

B. Radiata vs. bilateria

1. **Radiata** have **radial symmetry**, i.e., have a top and a bottom, but bodies are shaped like circles without a front or a back end. Have only **two germ layers** (embryonic cell layers that go on to constitute adult tissues): an ectoderm and an endoderm.
2. **Bilateria** have **bilateral symmetry**, i.e., have dorsal (top), ventral (bottom), anterior (front), and posterior (back) sides. Are characterized by **cephalization** (sensory organs face the anterior end). Have **three germ layers** (including a mesoderm between the ectoderm and endoderm).

C. Acoelomates vs. pseudocoelomates vs. coelomates

1. **Acoelomates** have **no body cavity** separating the digestive tract from the rest of the body.
2. **Pseudocoelomates** have a **simple body cavity**, but it is not completely lined by mesodermal tissue.
3. **Coelomates** have a **body cavity** completely lined with mesodermal tissue that suspends the digestive tract and internal organs in fluid.

D. Protostomes vs. deuterostomes

1. **Protostomes** have embryonic cells that divide in pattern known as **spiral cleavage**. Cells are **determinate** (i.e., each dividing cell has a specific fate in forming the adult body). During embryonic cleavage, the **mouth** is formed from the **blastospore** (embryonic cellular infolding).
2. **Deuterostome** embryonic cells divide in pattern of **radial cleavage**. Cells are **indeterminate** (i.e., each cell, if separated, could form its own embryo). During embryonic cleavage, the **anus** is formed from the blastopore.

Animal phyla

- **Phylum Porifera (sponges): Sessile** (attached by a base) suspension feeders with no true tissues or organs. **Spongocoel** (central cavity) draws in water through **osculum** (large hole); food is siphoned out. **Amoebocytes** digest food, carry nutrients to other cells.
- **Phylum Cnidaria (sea anemones, jellyfish):** Have a saclike body plan with a single opening as both mouth and anus. **Polyps** are sessile with mouths facing up; **medusas** are free-floating with mouths facing down. Both have **cnidae**, organelles that shoot off **nematocysts** (stinging barbs).
- **Phylum Ctenophora (comb jellies):** Similar in appearance to cnidarians; named for comblike plates of cilia used for motion. Tentacles have **colloblasts** (sticky threads for capturing food).
- **Phylum Platyhelminthes (flatworms):** Can be terrestrial or marine; some are parasitic. Have true muscle tissue but, like radiata, have only one digestive tract opening that serves as both mouth and anus. **Examples:** planaria, tapeworms.
- **Phylum Rotifera (rotifers):** Tiny multicellular organisms with a digestive tract that has two openings (mouth and anus). Have a wheel-like crown of cilia at the mouth, used to suck in water.
- **Phylum Nematoda (roundworms):** Worms without segments. Covered with a protective cuticle. Reproduce sexually, with internal fertilization of eggs. No circulatory system, so nutrients transported through fluid of the pseudocoelom.
- **Phylum Nemertea (proboscis or ribbon worms):** Acoelomate but have a full digestive tract and closed circulatory system. Capture prey using a fluid-filled sac that operates a proboscis.
- **Phyla Bryozoa, Phoronida, Brachiopoda (lophophorates):** Sessile aquatic suspension feeders with lophophores, fold of ciliated tentacles that draw water into the mouth. No true head. **Bryozoans** look like mosses; their hard exoskeletons create reefs. **Phoronids** are aquatic worms that build hard chitinous tubes. **Brachiopods** are sessile marine creatures that look like clams and live like Bryozoa.
- **Phylum Mollusca (mollusks):** Have a three-part body: a **muscular foot** (for moving), a **visceral mass** (containing the organs), and a **mantle** (tissue covering the visceral mass that may produce a shell). Many feed using a **radula**, a scraping organ that drags for nutrients. **Examples:** 1. snails (gastropoda); 2. clams, mussels (bivalvia); 3. squids, octopus (cephalopoda).
- **Phylum Annelida (segmented worms):** True coelomates; have a digestive tract with specialized regions, nerves, and a closed circulatory system. Each segment has **metanephridia**, excretory tubes that remove wastes. **Examples:** 1. earthworms (oligochaeta); 2. leeches (hirudinea).
- **Phylum Arthropoda (arthropods):** Have a chitinous **exoskeleton**, specialized **appendages** with joints, and segmented bodies, and grow by **molting** their exoskeletons to form increasingly larger ones. Have an open circulatory system with a heart, and sensory organs for touch, smell, and sight.
  - **Subphylum Chelicerata (scorpions and spiders):** Feed with clawlike **chelicerae**. Most have simple rather than compound eyes. **Spiders** (arachnids) have **book lungs**, stacks of organs that carry out gas exchange.
  - **Subphylum Uniramia (centipedes, millipedes, insects):** Have compound rather than simple eyes. Have antennae and feed with jawlike mandibles. **Insects** (Insecta) have a **three-part body** with a head, thorax, and abdomen. Remove waste with **Malpighian tubules** and breathe using a tracheal system that lets oxygen directly into cells. Many insects can fly and also undergo **metamorphosis**, a changing of the body from a larval to an adult stage.
  - **Subphylum Crustacea (crabs, shrimp, lobsters, barnacles):** Have jawlike mandibles (as opposed to chelicerae) and two pairs of antennae. Have many pairs of appendages on the abdomen (unlike insects, which have appendages on the thorax), and can regenerate appendages.
- **Phylum Echinodermata (echinoderms):** Marine organisms radially symmetrical in adult form but bilaterally symmetrical in larval form. Endoskeletons derive from the mesoderm. Water vascular system powers **tube feet** used in movement and feeding. **Examples:** 1. sea stars (Asteroidea); 2. sea urchins, sand dollars (Echinoidea); 3. sea cucumbers (Holothuroidea).
- **Phylum Chordata (chordates):** Have an embryonic **notochord** for skeletal support and a **hollow dorsal nerve cord** (all other animals have solid ventral nerve cords) that develops into a brain and spinal chord. **Pharyngeal slits** filter out water without its continuing through the entire digestive tract: in aquatic vertebrates, these have evolved toward gas exchange; in higher animals, used for jaw support and auditory sensation. Have a **postanal tail** originally used for aquatic propulsion (other animals' digestive tracts extend throughout the body).

Vertebrate classes

- **Superclass Agnatha:** Jawless vertebrates lacking paired appendages. Skeleton made of cartilage; notochord exists throughout life. **Examples:** hagfishes, lampreys.
- **Superclass Gnathostomata:** All other vertebrates. Have hinged **jaws** and **vertebrae** that replace the notochord. Are divided between the **fish** and the **tetrapods** ("four feet").
  - **Class Chondrichthyes (cartilaginous fishes):** Have **cartilage** skeletons, jaws. Breathe using **gills** derived from the pharyngeal slits. Fertilization is internal. Lateral line system is a sensory system that detects changes in pressure or vibrations in the water. **Examples:** sharks, rays.
  - **Class Osteichthyes (bony fishes):** Have **bone** skeletons. Breathe through **gills** that are covered with a protective layer called the **operculum**. Fertilization is internal. Stay afloat via air-filled swim bladders. **Examples:** tuna, salmon.
  - **Class Amphibia (amphibians):** Oldest tetrapods; most live close to water, Have **damp skin** used in gas exchange and **shell-less eggs** that must be laid in water. Frogs undergo **metamorphosis** between an aquatic larval stage and a terrestrial adult stage. The adult stage marks the loss of gills and of the lateral line system. **Examples:** 1. frogs, toads (Anura); 2. salamanders (Urodela); 3. caecilians (Apoda).
  - **Class Reptilia (reptiles):** Eggs are **amniotic**, with a protective water-filled sac (**amnion**) in which the embryo grows alongside a repository of nutrients (**yolk**). Eggs have leathery shells and are laid on land. Have protective keratinized **scales** for skin, breathe using lungs, and are **ectothermic** (control temperature via behavioral or environmental rather than metabolic regulations). **Examples:** 1. turtles, tortoises (Chelonia); 2. lizards, snakes (Squamata); 3. crocodiles, alligators (Crocodilia).
  - **Class Aves (birds):** Evolved from reptiles. Have **wings**, specialized bones; beaks, feathers made of keratin; no teeth; instead grind food in a **gizzard**. Lay amniotic eggs with hard shells. Four-chambered heart. **Endothermic** (regulate temperature metabolically). **Examples:** pigeons, eagles.
  - **Class Mammalia (mammals):** Also evolved from reptiles. **Endothermic**; have **hair** made of keratin and make milk from **mammary glands**. Have large brains, specialized teeth, and an inner ear derived from the pharyngeal slits.
    - **Subclass Monotremata (monotremes):** Hatch from eggs. **Examples:** platypuses, echidnas.
    - **Subclass Marsupialia (marsupials):** Fertilization is internal; embryo develops inside the uterus. The embryo continues to develop after birth, as the fledgling organism nurses inside the mother's external protective pouch. **Examples:** koalas, kangaroos.
    - **Subclass Placentalia (placental mammals):** Fertilization is internal; embryo develops inside the uterus. A protective and nurturing complex called the **placenta** forms around the embryo, which develops fully inside the uterus before birth. **Examples:** mice, dogs, cats, horses, whales, humans.

HUMAN ORGAN SYSTEMS

SKELETAL AND MUSCULAR SYSTEMS

Humans have an **endoskeleton** (as opposed to an exterior exoskeleton) that supports, protects, and allows for movement at the **joints**. There are three types of muscle. **Skeletal (striated) muscle** attaches to bones and coordinates movement. The basic unit of a skeletal muscle is the **sarcomere**, where thin **actin** filaments are interspersed with thick **myosin** filaments. When the filaments slide alongside each other, the muscles contract. **Cardiac muscle**, found only in the heart, is structured like skeletal muscle but can trigger its own contraction independently of the nervous system. Also, the entire heart contracts as one unit whenever an action potential is generated in any one part of the heart. Filaments in **smooth muscle** are organized in a pattern that allows for less overall tension than in skeletal muscle but for contraction over greater lengths. Smooth muscle is found in vessels, such as the arteries and the digestive tract, that carry fluids over long distances.

NERVOUS SYSTEM

The nervous system controls sensory input and motor output. The basic unit of the nervous system is a **neuron**, each of which contains: 1. a **cell body** containing the nucleus and organelles; 2. **dendrites**, a fibrous network that receives messages; 3. an **axon**, a fibrous body that sends messages. The axon is insulated by a **myelin sheath**. The gap between the dendrites of one neuron and the axon of another neuron is called a **synapse**; messages flow through the synapse either electrically or chemically. **Sensory neurons** convey sensory input to the central nervous system, **interneurons** coordinate sensory information with motor output, and **motor neurons** convey instructions to the body. The **central nervous system (CNS)** consists of the **brain** and **spinal cord**; the **peripheral nervous system (PNS)** consists of the cranial nerves, spinal nerves, and ganglia. The **cranial nerves** connect the brain to the organs of the upper body, while **spinal nerves** connect the spinal cord to the rest of the body. **Ganglia** are clusters of nerves that are related in function. The PNS has a sensory (afferent) division responsible for incorporating outside stimuli and a motor (efferent) division responsible for responding to those stimuli. Within the motor division, the **somatic nervous system** controls voluntary functions (e.g., movement) and the **autonomic nervous system** controls involuntary functions (e.g., digestion or cardiovascular activity). The autonomic nervous system is further divided between the **parasympathetic nervous system** (which conserves energy in the body) and the **sympathetic nervous system** (which readies the body for action).

CIRCULATORY SYSTEM

Deoxygenated blood passes through the superior and inferior **vena cava** into the right atrium of the **heart**. Blood then flows into the right ventricle, which pumps it to the lungs via the **pulmonary arteries**. Oxygenated in the lungs, blood flows through the **pulmonary veins** back into the left atrium of the heart, then into the left ventricle, from which it is pumped to the entire body via the **aorta**. **Arteries** carry blood away from the heart, breaking down into a network of **arterioles**. **Veins** arise from a network of **venules** to bring blood back toward the heart. Between arterioles and venules are **capillaries**, tiny vessels where cellular exchange (gases, nutrients, wastes) occurs. The **lymphatic system** returns lost fluid to the blood. Lymph fluid can intermingle with blood along **lymph capillaries**, which run alongside circulatory capillaries. **Lymph nodes** filter the lymph fluid by the action of **white blood cells**, protective cells that sequester and isolate foreign bodies.

RESPIRATORY SYSTEM

The **larynx** controls the descent of food into the digestive system and air into the respiratory system. Air passes through the larynx into the **trachea**, where it splits into two **bronchi** that lead to the **lungs**. The bronchi branch into **bronchioles**, which have buds at the ends called **alveoli** that are the surface of respiratory exchange. In the capillaries surrounding the alveoli, carbon dioxide in the blood is exchanged for oxygen. The **diaphragm**, a wide, flat muscle at the base of the chest cavity, controls inhalation and exhalation of air in the lungs.

DIGESTIVE SYSTEM

Food passes through the **pharynx** (throat) into the **esophagus**, a long tube that brings food into the **stomach** by **paristalsis**, a rhythmic motion. The stomach breaks down food into **chyme**, a nutrient fluid. Food passes from the stomach into the **small intestine**, where enzymes further break down chyme. The small intestine is lined with **villi**, tiny projections that absorb nutrients and pass them into the bloodstream. The food then passes to the **large intestine**, where water is reclaimed. Waste matter is stored in the **rectum** until excreted from the **anus**.

EXCRETORY SYSTEM

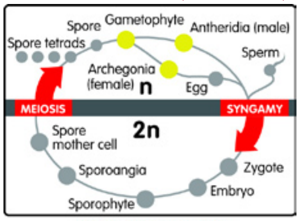
The **liver** converts toxic **nitrogen waste** (ammonia) to less toxic **urea**. The renal arteries carry urea to the **kidneys**, which filter urea out of the bloodstream and control reabsorption of important nutrients and secretion of toxic solutes. The functional unit of a kidney is the **nephron**. Blood enters the nephron in a mass of capillaries called the **glomerulus**, which filters molecules out of the blood and into the **Bowman's capsule**. The filtered material then passes through the **loop of Henle**, the site of secretion and reabsorption. The filtered blood collectively exits the kidney through the renal veins; wastes proceed to a collecting duct at each nephron. These ducts pass the urine into the **ureters**, tubes that exit the kidney and store urine in the **bladder**, where it waits to be excreted.

REPRODUCTIVE SYSTEM

The male **testes** are contained in the scrotum, a sac outside the body wall where temperatures are cooler than the internal body. **Sperm** form in the testes and pass to the **epididymis**, a tube in which the sperm become capable of fertilization and mobility. Sperm exit the epididymis through the **vas deferens**, a tube that joins with the **seminal vesicles**. The seminal vesicles contribute secretions that create **semen**, a nutrient- and enzyme-rich fluid containing the sperm. Semen exits through the **ejaculatory duct** and past the male **urethra** and into the female **vagina**. Each egg grows in the female **ovaries** within a **follicle**, a nourishing cell. Every month, one egg cell exits the follicle and can be fertilized by a male sperm cell. The follicle tissue forms a mass in the ovary called the **corpus luteum**, which secretes the hormones that line the uterus during pregnancy. The egg passes through the **oviduct**, a tube that leads to the **uterus**. The egg then lodges itself within the walls of the uterus. A **placenta** forms, which connects the fetus with the mother through an **umbilical cord** and allows for direct nourishment, gas exchange, and waste removal between the fetus and the mother's bloodstream.

PLANTS

Plants are **autotrophs**, able to synthesize their own organic nutrients (primarily via **photosynthesis**). The **plant life cycle** alternates between the diploid (**sporophyte**) and haploid (**gametophyte**) generations. The sporophyte produces spores via meiotic division; the gametophyte, formed from the spore, gives rise to haploid gametes. Reproduction occurs both sexually and asexually.

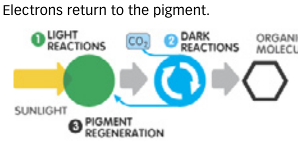


THE LIFE CYCLE OF A PLANT

PHOTOSYNTHESIS

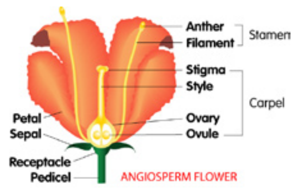
A. Plants use **chlorophyll**, **photopigments** to capture energy from sunlight. Formula: $6CO_2 + 12H_2O \rightarrow C_6H_{12}O_6 + 6H_2O + 6O_2$

B. Photosynthesis involves the following chemical processes:
   1. **Light reactions:** Transfer of light energy to electrons. Occurs on photosynthetic membranes in chloroplasts. In **primary photoevent**, pigment captures photons of light, exciting electrons within pigment. Energy breaks H_2O to release O_2 and drives **inward transport** of hydrogen ions across membrane for **chemiosmotic synthesis** of ATP.
   2. **Dark reactions (Calvin Cycle):** Enzyme-catalyzed reactions use ATP and NADPH from the light reactions to drive formation of organic molecules using CO_2. Electrons return to the pigment.



MAJOR PLANT CLASSIFICATIONS

- **Chlorophyta (green algae):** Aquatic green algae.
- **Bryophyta (nonvascular plants):** Lack vascular system to transport water and nutrients, so remain small and require moist environments. **Examples:** mosses, liverworts.
- **Tracheophyta (vascular plants):** Have highly developed vascular system to transport water and nutrients. **Xylem** carries water and dissolved materials up from roots; **phloem** distributes products of photosynthesis. **Roots** use **mycorrhizae** (symbiotic fungus) to draw water and minerals from soil and store the plant's organic nutrients. **Primary growth** (vertical) occurs due to ongoing mitosis at **apical meristem** (tip) of roots and shoots. **Secondary growth** (thickness) results as new xylem pushes old xylem inward, new phloem pushes old phloem outward.
  - **Filicopsida (ferns):** Least evolved vascular plants; reproduce by spores. Depend on moist environments.
  - **Spermatopsida (seed-bearing plants):** Reproduce by seeds.
    - **Gymnosperms (conifers):** Gametes found in **cones**; pollen grains spread by wind, which carries nonflagellated sperm. Not dependent on moisture to reproduce.
    - **Angiosperms (flowering plants):** Have nonflagellated sperm not dependent on water for dispersal. Gametes generally distributed by wind or animals. More specialized vascular network than in gymnosperms. **Stamen** (pollen-producing part of flower) consists of anther and filament; **pistil** (egg-producing central part of flower) consists of ovary, style, and stigma.

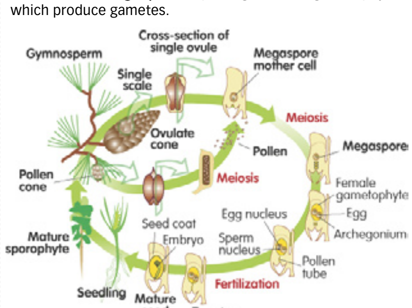


ANGIOSPERM FLOWER

- **Monocots:** A **single cotyledon** (seed leaf) forms during embryonic development. Leaf veins are **parallel**. Flower parts occur in multiples of **three**. Vascular tissue **scattered** throughout stem. **Fibrous root** system. **Examples:** grasses, grains, spring-flowering bulbs.
- **Dicots:** **Two cotyledons** form during embryonic development. Leaf veins in **network** pattern. Flower parts occur in multiples of **four** or **five**. Vascular tissue arranged in **tubular** pattern in stem. **Taproot** system. **Examples:** roses, sunflowers, most trees.

GYMNOSPERM LIFE CYCLE

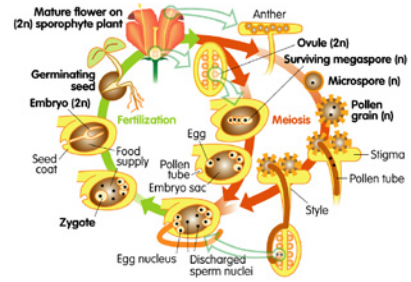
Diploid sporophyte is dominant. Males make **microspores**; females make **megaspores**. Spores give rise to gametophytes, which produce gametes.



GYMNOSPERM LIFE CYCLE

ANGIOSPERM LIFE CYCLE

Diploid sporophyte dominant. Diploid plant produces male and female haploid spores, which give rise to gametophytes (**flowers**) that produce gametes. Gametes form a diploid zygote via **self-pollination** or **cross-pollination**.



ANGIOSPERM LIFE CYCLE

C4 AND CAM PLANTS

Photorespiration occurs when a plant avoids water loss by closing **stomata** on hot, dry days. The plant, unable to take in airborne CO_2 for the **Calvin cycle**, instead incorporates internal O_2—reducing efficiency of photosynthesis by creating energetically useless compounds. C4 and CAM plants resist photorespiration.

- **C4 plants:** Named for tendency to fix carbon into a 4-carbon compound rather than 3-carbon compound of most (C3) plants. **Fixation** occurs in loosely placed mesophyll cells beneath leaf surface, using an enzyme (PEP carboxylase) that is more efficient at fixing carbon than the C3 plant enzyme (rubisco). Calvin cycle occurs in tightly packed bundle sheath cells beneath mesophyll, where 4-carbon compound releases carbon as CO_2. By localizing Calvin cycle in bundle sheath cells and by saturating those cells with CO_2, C4 plants prevent photorespiration. **Example:** corn.
- **CAM (crassulacean acid metabolism) plants:** Resist water loss by closing stomata during day, opening at night. At night, take in CO_2, convert to organic acids that are stored until daytime. Acids release CO_2 for Calvin cycle (powered by ATP generated in light reactions of photosynthesis). **Example:** cacti.

PLANT TROPISMS

Plants respond to various stimuli by a differential growth of cells on one side of the plant or the other such that the plant moves toward or away from the stimulus.

A. **Phototropism:** Plant shoots grow toward a source of light.

B. **Gravitropism:** Roots grow downward, shoots grow upward in response to gravity.

C. **Thigmotropism:** Plant grows in response to touch (e.g., climbing plants that coil around support structures).

ECOLOGY AND THE BIOSPHERE

ECOSYSTEMS AND BIOMES

A. **Population:** An interbreeding group of the same species.
   1. Every species has a **niche** defined by its lifestyle factors (e.g., behavior, habitat, predation).
   2. Overlap of niches results in **competition** until competitors are eliminated or displaced into a different niche.

B. **Community:** All the populations (biotic factors) in an area.

C. **Ecosystem:** All the biotic *and* abiotic factors in an area.

D. **Biome:** A large region with distinct plant and animal life.
   1. **Tropical rain forest:** Infertile soil but heavy rainfall; dense vegetation. Greatest biodiversity of any biome.
   2. **Savanna:** Open grassland with scattered trees; transitional between rain forest and desert; found primarily in Africa.
   3. **Desert:** Sparse, arid; large daily fluctuation in temperature.
   4. **Chaparral:** Coastal area with short evergreen shrubs; mild, rainy winter; hot, dry summer.
   5. **Temperate grassland:** Rich soils, abundant precipitation, agriculturally productive; covers much of the Americas.
   6. **Temperate deciduous forest:** Deciduous trees (drop leaves every winter); warm, rainy summer; cool winter.
   7. **Taiga:** Northern coniferous forest with long, cold winter.
   8. **Tundra:** Cold; little precipitation or vegetation; permafrost exists near the surface; covers ~20% of Earth's land area.
   9. **Marine:** Salt water; covers ~75% of Earth's surface; home to 10% of living species. Divided into zones:
      a. **Intertidal/littoral zone:** Shorelines and coasts; subject to periods of wet and dry.
      b. **Neritic zone:** Shallow waters to the continental shelf.
      c. **Oceanic/pelagic zone:** Surface layers of the open ocean.
      d. **Aphotic/abyssal zone:** Deep-water areas; no sunlight.
   10. **Freshwater:** Ponds, lakes, rivers; tied closely to terrestrial habitats. Lakes in temperate regions see thermal stratification. <3% of the Earth's surface.

ECOLOGICAL SUCCESSION

Communities change through an orderly process of **succession**.

A. **Pioneer organisms** move into an uninhabited area.

B. With succession, the community's biomass, complexity, species diversity, and capacity to process nutrients all increase.

C. The result is a stable **climax community**.

ENERGY FLOW

Energy in an ecosystem flows among organisms of different **trophic levels**. **Primary producers** (plants, chemosynthetic bacteria) have the most biomass, followed by **primary consumers** (herbivores) and **secondary and tertiary consumers** (carnivores, omnivores). Finally, **decomposers (saprophytes)** break down organic remains and excretions. Only 10% of a trophic level's energy flows to the next; the rest is lost to respiration, heat, and so on.

CYCLES IN THE ENVIRONMENT

- **Water cycle:** Solar energy causes water to **evaporate** from oceans into atmosphere. Plants **transpire**, also sending water into atmosphere as vapor. Water vapor **condenses** into clouds and **precipitates** into rain. Rain falls back to Earth, collects on land as **runoff** or **groundwater**, and runs back into oceans.
- **Carbon cycle:** Plants incorporate **airborne CO_2** into organic compounds. Primary consumers eat plants. When organisms die, their carbon is locked into **fossil fuels** or decomposed by microbes. **Burning** of fossil fuels, **decomposition** of organisms, and **cellular respiration** all release CO_2 back into the air.
- **Nitrogen cycle:** **Nitrogen-fixing bacteria** convert atmospheric N_2 gas into ammonium (NH_4^+). **Nitrifying bacteria** convert ammonium into nitrites (NO_2^-) and nitrates (NO_3^-), which are assimilated by plants, which are then eaten by animals. After plant or animal death, **decomposers** (bacteria, fungi) convert nitrogen back to ammonium (NH_4^+). **Denitrifying bacteria** process nitrogenous compounds back into atmospheric N_2 gas.
- **Phosphorous cycle:** **Phosphorous-containing rocks** weather into soil; plants take up phosphates (PO_4^{3-}) from soil. Animals eat plants; **decomposers** break down dead plants and animals, returning phosphates to soil. **Leaching** removes phosphates from soil via water that runs into lakes and streams. **Sedimentation** forms new phosphorous-containing rocks.

SPARKCHARTS™

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