Biology (1)

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The Hashemite kingdom of JORDAN

The Deposit Number at The National Library

(2020/9/3810)

Index

Preface

Biology is the science of life; it gives an in-depth understanding of the living world and the ways its species function and interact.

This booklet provides the core of certain topics that are involved in medicine, agriculture, biotechnology, and many other areas.

It gives the student a concise review of many biological subjects to help them recall material taught during their lectures.

It is not intended to substitute for comprehensive textbooks; it is a useful adjunct to biology lectures.

The material is extracted from “Campbell Biology Book”, epitomized, and organized into nine chapters.

Difficult concepts are explained clearly, with appropriate tables and diagrams.

Mnemonics and many strategies are used to enhance memory of complex words or points and promote better retention of material to be learned.

Arabic translation of certain words and ideas is provided to ensure full understanding and to help students who have difficulties in studying in English.

Best of luck! Hadeel Abdullah Alkayed.

Chapter 3

Water and Life

Concept 3.1: Polar covalent bonds in water molecules result in hydrogen bonding

1. Polar covalent bonds in water molecules result in hydrogen bonding.
2. The water molecule is shaped like a wide V.
3. It has two hydrogen atoms joined to the oxygen atom by single bonds.
4. Oxygen is more electronegative than hydrogen (electrons spend more time closer to oxygen than hydrogen; these are polar covalent bonds).
5. The (1) unequal sharing of electrons and (2) water's V-shape make it a polar molecule (why polar? 1+2), meaning that its overall charge is unevenly distributed.
6. The partially positive hydrogen of one water molecule is attracted to the partially negative oxygen of a nearby water molecule. The two molecules are thus held together by a hydrogen bond.
7. The oxygen of the molecule has two regions of partial negative charge (-), and each hydrogen has one partial positive charge (+), that's why each water molecule can form hydrogen bonds with four other water molecules.
8. When water is in its liquid form, its hydrogen bonds are very fragile, each only about 1/20 as strong as a covalent bond. The hydrogen bonds form, break, and re-form with great frequency.

Concept 3.2: Four emergent properties of water contribute to Earth's suitability for life

(1) Cohesive behavior

1. **Cohesion** phenomenon: the **hydrogen** bonds **hold** the substance (water molecules) together.
2. Cohesion due to hydrogen bonding contributes to the **transport** of water and dissolved nutrients **against gravity** in **plants, and this needs water to evaporate from leaves at first then it's transported through** a network of **water-conducting cells.**
3. **Adhesion**: the clinging of one substance to **another** substance.
4. **Adhesion** of **water** by **hydrogen bonds** to the molecules of **cell walls** also plays a role in the transport of water in plants **against** gravity.
5. Cohesion occurs between water molecules. It helps hold together the column of water within the cells.
6. Adhesion occurs between water molecules and cell walls. It helps resist the downward pull of gravity.
7. Related to **cohesion** is **surface tension**, a measure of how **difficult** it is to **stretch** or break the **surface** of a liquid. It happens at the **interface** between water and air, due to water molecules' arrangement and hydrogen-bonding to one another and to the water below, but not to the air above. (E.g. when you overfill a cup of water, the water will stand above the rim, and spiders can walk across a pond without breaking the surface, etc…)

(2) Ability to moderate air temperature

1. **Water moderates air temperature** by absorbing heat from air that is warmer and releasing the stored heat to air that is cooler.
2. The specific heat of a substance: the amount of heat that must be absorbed or lost for 1 g of that substance to change its temperature by 1°C.
3. The specific heat of water is high and it equals 1 calorie per gram and per degree Celsius $\frac{\text{Cal}}{\text{g.°C}}$. Thus, Water resists changing its temperature and when it does change its temperature, it absorbs or loses a relatively large quantity of heat for each degree of change.
4. The reason that water has high specific heat is hydrogen bonds; heat must be absorbed in order to break hydrogen bonds before the water molecules can begin moving faster and must be released when hydrogen bonds form.
5. The high specific heat of water also tends to stabilize ocean temperatures, creating a favorable environment for marine life.
6. The transformation of any substance from a liquid to gas is called **vaporization,** or **evaporation** and it happens when molecules move fast enough to **overcome** and **break** the inter-molecular attractions (hydrogen bonds in the case of water) and depart the liquid to enter the air as a gas (vapor). Even at low temperatures, the speediest molecules can escape into the air. If a liquid is heated, the average kinetic energy of molecules increases and the liquid evaporates more rapidly.
7. **Heat of vaporization:** the quantity of heat a liquid must absorb for 1 g of it to be converted from the liquid to the gaseous state. Due to hydrogen bonds, water also has a relatively high heat of vaporization. To evaporate 1 g of water at 25°C, about 580 cal of heat is needed -which is double the amount needed to vaporize a gram of alcohol or ammonia-.
8. **Evaporative cooling** of water contributes to the stability of temperature in lakes and ponds and also provides a mechanism that prevents terrestrial organisms from overheating (evaporation of sweat).

(3) Expansion upon freezing

1. While other materials contract and become denser when they solidify, **water expands** and becomes less dense (10 % less dense) due to hydrogen bonds.
2. At temperatures above 4°C, water behaves like other liquids, expanding as it warms and contracting as it cools. As the temperature falls from 4°C to 0°C, water begins to freeze because more and more of its molecules are moving too slowly to break hydrogen bonds. At 0°C, the molecules become locked into a crystalline lattice; each water molecule can hydrogen bonded to four partners. When ice absorbs enough heat for its temperature to rise above 0°C, hydrogen bonds between molecules are disrupted. As the crystal collapses, the ice melts and molecules have fewer hydrogen bonds, allowing them to slip closer together.
3. **Water reaches its greatest density at 4°C and then begins to expand as the molecules move faster.**
4. The floating ice (due to its low density) insulates the liquid water below, preventing it from freezing and allowing life to exist under the frozen surface.

(4) Versatility as a solvent

1. Due to the polarity of water, it is **a very versatile solvent**.
2. Ions and regions of partial charges in water molecules become attracted to each other due to their opposite charges. (Partial negative charges of water molecules attract positive ions, and partial negative charges attract positive ions)
3. **Hydration shell:** water molecules surround the individual dissolved ions, separating and shielding them from one another (it is the sphere of water molecules around each dissolved ion).
4. **Ionic (e.g. NaCl) and non-ionic polar molecules (e.g. sugar) and large molecules as proteins (e.g. lysozyme) can dissolve in water.**

Hydrophilic substances have affinity for water (e.g. ionic and polar substances). Some hydrophilic substances don't dissolve in water (e.g. cotton which consists of giant molecules of cellulose which is a compound with numerous regions of partial positive and partial negative).

Hydrophobic substances do not have affinity for water (e.g. non-ionic and nonpolar substances and substances that cannot form hydrogen bonds). The hydrophobic behavior of the oil molecules results from the presence of C-H nonpolar covalent bonds (C & H share electrons almost equally).

- **Kinetic energy:** the energy of motion (the faster a molecule moves, the greater its kinetic energy).
- **Thermal energy:** the kinetic energy associated with the random movement of atoms or molecules.
- **Thermal energy vs. Temperature**
  1. Temperature represents the **average** kinetic energy of the molecules in a body of matter, regardless of **volume**, whereas the thermal energy of a body of matter reflects the **total** kinetic energy, and thus depends on the **matter's volume**.
  2. Whenever two objects of different **temperature** are brought together, **thermal energy** passes from the warmer to the cooler object until the two are the same **temperature**; an ice cube cools a drink not by adding coldness to the liquid, but by absorbing thermal energy from the liquid as the ice itself melts.
- **Heat:** thermal energy in the transfer from one body of matter to another.

- The **concentration** of solutes in an aqueous solution: the number of solute molecules in a volume of solution.
- **Molecular mass**: is the sum of the masses of all the atoms in a molecule.
- **Molecular mass** (daltons) = (number of C atoms* atomic mass) + (number of O atoms * atomic mass) + (number of H atoms * atomic mass).
- A mole (mol) represents an exact number of objects ($6.02 * 10^{23}$) which is called Avogadro's number.
- There are **$6.02 * 10^{23}$** daltons in 1 g.
- Once we determine the molecular mass of a molecule, we can use the same number but with the unit gram, to represent the mass of $6.02 * 10^{23}$ molecules (1 mol); this is called **the molar mass**.
- If the molecular mass of substance A is 342 daltons and that of substance B is 10 daltons, then 342 g of A will have the same number of molecules (one mol or $6.02 * 10^{23}$) as 10 g of B.
- **Molarity**: the number of moles of solute per liter of solution. It is the unit of concentration most often used for aqueous solutions. (1 M = 1 mol/1L)

Acidification: A Threat to Our Oceans

- Burning of fossil fuels results in an increase in the atmospheric CO^2 levels which has caused global warming and other aspects of climate change. In addition, about 25% of human-generated CO^2 is absorbed by the oceans; when CO_2 dissolves in seawater, it reacts with water to form carbonic acid, which lowers ocean pH. This process, known as ocean acidification, alters the delicate balance of conditions for life in the oceans.
- The drop in pH happens because carbonic acid provides additional protons that react with carbonate ion (CO_3^{-2}) forming HCO^{3-} ; this decreases CO_3^{-2} levels that's needed for calcification (the production of calcium carbonate ($CaCO^3$) by many marine organisms in order to build reef and shells).

➲ ***Test your understanding:***

1. Water molecules are able to form hydrogen bonds with____

A) Chloride ions.
B) Oxygen gas (02) molecules.
C) Oils.
D) Compounds that have polar covalent bonds. ←
E) Any compound that is not soluble in water

2. Liquid water's high specific heat is mainly a consequence of the____

A) Absorption and release of heat when hydrogen bonds break and form. ←
B) Higher density of liquid water than solid water (ice).
C) Fact that water is a poor heat conductor.
D) Small size of the water molecules.
E) High specific heat of oxygen and hydrogen atoms.

3. An aqueous solution is one in which the solvent is__

A) Water. ←
B) Alcohol.
C) Sugar.
D) Na+.
E) Any liquid.

4. Which property of water is shown in the image below?

A) Cohesion of water molecules.←
B) Moderation of temperature.
C) High specific heat.
D) Evaporate cooling.
E) The image doesn't show any property.

5. When water vaporizes, which of the following bonds is broken?

A) Ionic.
B) Hydrogen. ←
C) Polar covalent.
D) Nonpolar covalent.
E) Hydrophobic.

6. Which of the following is not a property of liquid water?

A) More dense than ice.
B) Has a specific heat lower than that of metals. ←
C) Has a heat of vaporization that is high.
D) Has high surface tension.
E) Can form hydrogen bond with ethanol.

7. The thermal energy of a hot cup of water is expected to be _____ the thermal energy of an ocean___

A) Less than. ←
B) More than.
C) Equal to.
D) Twice.
E) Three times.

8. Ice is less dense than liquid water because its hydrogen bonds_____

A) Break and reform.
B) Are weak bonds.
C) Are ordered and stable in the crystals. ←
D) Are minimal in number.
E) None of the above.

9. Hydrogen bond is an attraction between___

A) Hydrogen and oxygen only.
B) Hydrogen and an electronegative atom.←
C) Hydrogen and nitrogen only.
D) Hydrogen and carbon.
E) None of the above.

Chapter 5

Biological Macromolecules and Lipids

Concept 5.1: Macromolecules are polymers, built from monomers

There are four main classes of large biological molecules:

1. Carbohydrates
2. Lipids
3. Proteins
4. Nucleic Acids

A polymer is a long molecule consisting of many similar or identical building blocks linked by covalent bonds. Large carbohydrates, proteins and nucleic acids are polymers. Lipids are not polymers.

Monomers: small molecules, the repeating units that serve as the building blocks of a polymer.

Diversity of polymers is generally due to their arrangement: (Noor Talks Openly)

1. Number of monomers.
2. Type of monomers.
3. Order or monomers.

- Polymerization (building polymers) of a polymer occurs by a dehydration reaction; molecules are covalently bonded to each other with the loss of a water molecule. The reaction is repeated as monomers are added to the chain one by one, making a polymer.

- Polymers are disassembled to monomers by hydrolysis (the reverse of the dehydration reaction); it means water breakage; the bond between monomers is broken by the addition of a water molecule.

- Number of water molecules needed to breakdown a polymer = number of broken bonds = number of monomers - 1

Concept 5. 2: Carbohydrates serve as fuel and building material

Monosaccharides (the simplest carbohydrates)

1. They have molecular formulas that are some multiple of the unit $(CH_2O)_n$.

2. They have a carbonyl and multiple hydroxyl groups.

3. Glucose is the most common.

4. Classification depends on (1) the location of the carbonyl group (either an aldose a ketose), (2) the size of the carbon skeleton (3C-7C), and the arrangement around the asymmetric carbon.

5. In aqueous solutions, most of them form rings, because it's their most stable form. In glucose, the ring structure forms when the aldehyde group (at C1) reacts with the oxygen of the hydroxyl group attached to (C5). Carbon number 1 is positioned either below (alpha (α) glucose) or above (beta (β) glucose) the plane of the ring.

6. Functions include that they are major nutrients (fuel) for cells, their carbon skeletons serve as raw material for the synthesis of other types of small organic molecules (such as amino acids and fatty acids), and they can be incorporated as monomers into disaccharides or polysaccharides.

Disaccharide (double sugars, consisting of two monosaccharides)

1. A disaccharide consists of two monosaccharides joined by a glycosidic linkage (covalent bond formed between two monosaccharides by a dehydration reaction).
2. Maltose (Malt Sugar) = 2 Glucose molecules joined by 1-4 glycosidic linkage.
3. Sucrose (Table Sugar) = Glucose and fructose joined by 1-2 glycosidic linkage. The most prevalent disaccharide. Plants generally transport carbohydrates in the form of sucrose.
4. Lactose (Milk Sugar) = Glucose and galactose joined by β-1,4-glycosidic linkage.
5. Disaccharides must be broken down into monosaccharides to be used for energy by organisms. Lactose intolerance: is a common condition in humans who lack lactase, the enzyme that breaks down lactose.

Polysaccharides' architecture and function are determined by their sugar monomers and by the positions of their glycosidic linkages.

1. Storage polysaccharides (starch and glycogen)

Plants store starch in plastids. Amylose (simplest form of starch) is an unbranched polymer of α-glucose monomers joined by 1-4 glycosidic linkage. Amylopectin (complex starch) is a branched polymer; it has 1-4 glycosidic linkages with 1-6 linkages at the branching points. Starch molecules are largely helical, fitting their function of efficiently storing glucose units. Glycogen is a polymer of α -glucose that is like amylopectin but more extensively branched. Vertebrates store glycogen mainly in liver and muscle cells. Its extensively branched structure gives more free ends for hydrolysis (into glucose monomers).

2. Structural polysaccharides (cellulose and chitin)

- Cellulose is a major component of the plant cells' walls. It is the most abundant organic compound on Earth. It's an unbranched polymer of β-glucose with 1-4 glycosidic linkages. Some hydroxyl groups on its glucose monomers are free to hydrogen-bond with the hydroxyls of other cellulose molecules lying parallel to it forming "microfibrils".

It is used (1) a strong building material for plants and (2) an important substance for humans (for paper and cotton). Almost all animals, including humans, **do not** have enzymes that can digest cellulose; the cellulose in our food (insoluble fibers) passes through the digestive tract and is eliminated with the feces. Some fungi and prokaryotes (which are present in the guts of cows and termites) can digest cellulose, breaking it down into glucose monomers.

- Chitin is the carbohydrate used by arthropods to build their **exoskeletons**. Fungi use chitin rather than cellulose for their cell walls. Chitin is similar to cellulose, with ß linkages, except that the glucose monomer of chitin has a nitrogen-containing attachment.

Concept 5.3: Lipids are a diverse group of hydrophobic molecules

- Lipids are not true polymers, and they are not big enough to be considered macromolecules.
- Lipids mix poorly, if at all, with water. The hydrophobic behavior of lipids is based on their molecular structure. Although they may have some polar bonds associated with oxygen, lipids consist mostly of hydrocarbon regions.
- Types of lipids are (1) fats (aka. triacylglycerol or triglyceride) (2) phospholipids and (3) steroids.

- **Phospholipids** are major constituents of cell membranes. They consist of glycerol, two fatty acids and a phosphate group. The phosphate group has a negative electrical charge. An additional small charged or polar molecule can be linked to the phosphate group, such as a choline molecule.
- The two ends of phospholipids show different behaviors with respect to water. The hydrocarbon tails are hydrophobic and are excluded from water. However, the phosphate group and its attachments form a hydrophilic head that has an affinity for water (it's kept in contact with the aqueous solutions inside and outside of the cell). When phospholipids are added to water, they self-assemble into a double-layered sheet called a "bilayer" that shields their hydrophobic fatty acid tails from water (this happens at the cell surface).

- A **fat** molecule consists of a glycerol molecule (an alcohol with three –OH) and three fatty acids (16-18 carbons in length) joined by ester bonds (covalent bonds formed by dehydration reactions between the hydroxyl groups of the glycerol and the carboxyl groups in the fatty acids).
- The relatively nonpolar C-H bonds in the hydrocarbon chains of fatty acids are the reason fats are hydrophobic.
- There are (1) saturated fatty acids (saturated with hydrogen) with no double bonds, and (2) unsaturated fatty acids with one or more double bonds and one fewer hydrogen atom on each double-bonded carbon. Fat made from saturated fatty acids is called a saturated fat, and fat made from unsaturated fatty acids is called an unsaturated fat.
- Nearly every double bond in naturally occurring fatty acids is a cis double bond, which creates a kink in the hydrocarbon chain wherever it occurs. These kinks prevent the molecules from packing together closely enough to solidify at room temperature (they are liquid; such as plant and fish oils).
- Saturated fat molecules lack double bonds and this allows the fat molecules to pack together tightly (examples are animal fats such as lard and butter).
- Hydrogenated vegetable oils are unsaturated fats that have been synthetically converted to saturated fats by adding hydrogen, allowing them to solidify. This process produces not only saturated fats but also unsaturated fats with trans double bonds; trans fats causes coronary heart disease and atherosclerosis.

- Fats store energy as twice as polysaccharides, such as starch. Humans and other mammals stock their long-term food reserves in adipose cells. Adipose tissue also cushions vital organs as the kidneys, and a layer of fat beneath the skin insulates the body (this layer is especially thick in whales, seals, and most other marine mammals, insulating their bodies in cold ocean water).

- **Steroids** are lipids characterized by a carbon skeleton consisting of four fused rings. Different steroids are distinguished by the chemical groups attached to these rings.

Cholesterol is a type of steroid which is crucial molecule in animals. It is a common component of animal cell membranes, and the precursor from which other steroids (such as the vertebrate sex hormones) are synthesized. It is synthesized in the liver and is also obtained from the diet. A high level of cholesterol in the blood may contribute to atherosclerosis.

Concept 5.4 : Proteins include a diversity of structures, resulting in a wide range of functions

- Proteins account for more than 50% of the dry mass of most cells.
- Enzymes are (mostly) proteins that speed up chemical reactions by acting as catalysts (chemical agents that selectively speed up reactions without being consumed).

Types of proteins based on their shape

- **Globular proteins (spherical)**
- **Fibrous proteins (long fibers)**

- An amino acid is an organic molecule with a central asymmetric carbon atom called the alpha (α) carbon; its four different partners are an amino group, a carboxyl group, a hydrogen atom, and a variable group symbolized by R.The R group (aka. the side chain) may be as simple as a hydrogen atom, as in the amino acid glycine, or it may be a carbon skeleton with various functional groups attached, as in glutamine.

- There are 20 amino acids that cells use to build their thousands of proteins. The amino groups and carboxyl groups exist in ionized form at the pH found in a cell.

- Amino acids are grouped according to their side chains into (1) amino acids with nonpolar side chains and are hydrophobic, (2) amino acids with polar side chains such as (OH, NH2, SH), and are hydrophilic, and (3) amino acids with charged side chains, and are either acidic (negative, like when R=COO-) or basic (positive, like when R=NH3+) which are also hydrophilic.

- The carboxyl group of one amino acid can be joined to the amino group of another amino acid by a dehydration reaction, with the removal of a water molecule. **The resulting covalent bond is called a peptide bond**. Thus, a polypeptide is an unbranched polymer which consists of a chain of amino acids (monomers) linked by peptide bonds.
- Chemical nature of the protein as a whole is determined by the **kind** and **sequence** of the **side chains**, which determine how a polypeptide folds and thus its final shape and chemical characteristics.
- **The polypeptide backbone** includes the amino nitrogen, alpha carbon, and carboxyl carbon of each amino acid.
- One end of the polypeptide chain has a free amino group (the N-terminus of the polypeptide), while the opposite end has a free carboxyl group (the C-terminus).

Side chains aren't considered part of the polypeptide backbone because they're variable.

! The term polypeptide is <u>not</u> synonymous with the term protein; a functional protein is one or more polypeptides twisted, folded, and coiled into a molecule of unique shape, which can be shown in several different types of models.

- Intrinsically disordered proteins are mammalian proteins that do not have a distinct 3-D structure until they interact with a target protein or other molecule, which makes it hard to study their structures and functions (20%-30% of mammalian proteins).

- The method most commonly used to determine the 3-D structure of a protein and to study its function is X-ray crystallography (it depends on the diffraction of an X-ray beam by the atoms of a crystallized molecule). Nuclear magnetic resonance (NMR), spectroscopy, and bioinformatics are also used.

Protein functions include selective acceleration of chemical reactions, protection against disease, storage of amino acids (e.g. casein protein in milk and ovalbumin in eggs), transport of substances (e.g. hemoglobin and membrane channels), coordination of body's activities (e.g. insulin hormone), response to chemicals (e.g. cellular receptors), movement (e.g. contractile proteins (actin and myosin)), and support (e.g. keratin, silk fibers, collagen, and elastin).

Levels of protein structure; the primary, secondary, and tertiary structures

The Quaternary structure arises from association of two or more polypeptides, and not all proteins have a quaternary structure, examples are (1) transthyretin which consists of four polypeptides, (2) collagen which has three identical helical polypeptides, and (3) hemoglobin which consists of four polypeptides, two (alpha) and two (beta), that consist primarily of alpha-helical secondary structure and each has a non-polypeptide component, called heme, with an iron atom that binds oxygen.

The tertiary structure is the overall (3d) shape of a polypeptide resulting from interactions between the side chains (R groups) of the various amino acids. These interactions can be: **(Dareen Hit Her Iphone Very Hard)**
1. Hydrophobic interactions; as a polypeptide folds into its final shape, amino acids with hydrophobic (nonpolar) side chains cluster at the core of the protein, out of contact with water (i.e. water exclusion of hydrophobic molecules results in these interactions).
2. Van der Waals interactions between nonpolar amino acid side chains.
3. Hydrogen bonds between polar **amino acid side chains.**
4. Ionic bonds between positively and negatively charged side chains.
5. Covalent bonds called Disulfide bridges reinforce the protein; two cysteine monomers which have sulfhydryl groups (SH) on their side chains are brought close together by the folding the protein.

The secondary structure is characterized by regions stabilized by hydrogen bonds between atoms of the polypeptide backbone. Within the backbone, the oxygen atoms have partial negative charges, and the hydrogen atoms attached to the nitrogen have partial positive charges, so hydrogen bonds form between them. Some types of secondary structures are (1) the alpha helix coils (e.g. transthyretin protein has only one alpha helix while hemoglobin has multiple alpha helices, and some fibrous proteins, such as α-keratin, have the α helix formation over most of their length), and (2) the beta - pleated sheets (aka. beta strands), which are two or more segments of the polypeptide chain lying side by side. β-pleated sheets make up the core of many globular proteins, as is the case for transthyretin, and these sheets dominate some fibrous proteins, including the silk protein of a spider's web.

The primary structure of a protein is its sequence of amino acids. The precise primary structure of a protein is determined by inherited genetic information. It dictates secondary and tertiary structure, due to the chemical nature of the backbone and the side chains (R groups) of the amino acids along the polypeptide.

If the environment is changed (pH, temperature...), the weak chemical bonds and interactions within a protein may be destroyed, causing the protein to lose its shape, this is called denaturation. Denatured protein is biologically inactive.

Denatured proteins can **sometimes** return to its functional shape when the denaturing agent is removed.

Sickle-Cell Disease is an inherited blood disorder caused by the substitution of one amino acid (valine) for the normal one (glutamic acid) at the position of the sixth amino acid **in the primary structure of hemoglobin**, the protein that carries oxygen in red blood cells. Due to this substitution, abnormal β subunits form. In sickle-cell disease, the abnormal hemoglobin molecules tend to aggregate into chains, deforming some of the cells into a sickle shape. Patients have periodic "sickle-cell crises" when the angular cells clog tiny blood vessels, impeding blood flow. 💀!

Examples on denaturizing agents

- Transferring proteins to a nonpolar solvent, such as ether or chloroform, so that the polypeptide chain refolds and its hydrophobic regions face outward toward the solvent.
- Chemicals that disrupt the hydrogen bonds, ionic bonds, and disulfide bridges that maintain a protein's shape.
- Excessive heat, which agitates the polypeptide chain enough to overpower the weak interactions that stabilize the structure.

Mis-folding of polypeptides in cells is a serious problem: cystic fibrosis, Alzheimer's, Parkinson's, and mad cow disease—are associated with an accumulation of mis-folded proteins. Mis-folded versions of the transthyretin protein have been implicated in several diseases, including one form of senile dementia.

Concept 5.5: Nucleic acids store, transmit, and help express hereditary information

All about nucleic acid and nucleotides structures!

Nucleic acids (DNA & RNA) are polymers made of nucleotides; each nucleotide consists of a five carbon sugar (pentose), a nitrogenous **base** (it acts as a base by taking up H+) and one to three phosphate groups .The beginning monomer used to build a polynucleotide has three phosphate groups, but two are lost during the polymerization.

Pyrimidine nitrogenous base has one six-membered ring of carbon and nitrogen atoms; it includes cytosine (C), thymine (T), and uracil (U). Purine nitrogenous base has a six-membered ring fused to a five-membered ring; it includes adenine (A) and guanine (G)).

Nucleic acid synthesis

Adjacent nucleotides are joined by a dehydration reaction forming a covalent bond between a phosphate group of one nucleotide and the 3'C of another nucleotide; it's called a phosphodiester bond.

The direction of polynucleotide synthesis: from 5' (which has the phosphate group) → 3' end (which has the –OH group). **Thus, a new nucleotide can be added only to the 3' end.**

- ✓ DNA provides directions for its own replication.
- ✓ Each chromosome contains one long DNA molecule, carrying several genes.
- ✓ Prokaryotic cells lack nuclei but still use mRNA for gene expression.

- ✓ The nitrogenous bases aren't part of the backbone; the backbone includes the sugar and the phosphate groups only.

- ✓ The nitrogenous base is attached to the 1'C of the sugar.
- ✓ The phosphate group is attached to the 5'C of the sugar.
- ✓ At the 3'C, an OH group is attached.

NucloSide → only Sugar + nitrogenous base

NucleoTide → there is a phosphaTe!

- ✓ In RNA: the sugar is ribose.
- ✓ In DNA: the sugar is deoxyaribose (lacks an oxygen atom on the second carbon).

Gene expression → → DNA → RNA → protein

Deoxy-ribonucleic acid (DNA)

1. RNA molecules are more variable in shape (exist as a single strand that coils and forms different shapes).

2. Uracil is found only in RNA, and Adenine pairs with Uracil.

Ribo-nucleic acid (RNA)

1. DNA molecules have two polynucleotides (strands) joined together by hydrogen bonds between the nitrogenous bases, they wind around an imaginary axis, forming a double helix due to hydrogen bonding.

2. Thymine is found only in DNA, and Adenine pairs with Thymine.

✓ **Complementary base pairing:** the two strands of the double helix are complementary; each is the predictable counterpart of the other; Adenine base pairs with thymine by two hydrogen bonds, and Guanine base pairs with cytosine by three hydrogen bonds.

✓ **Antiparallel strands:** it means that the two strands of the nucleic acid run in opposite directions; if one strand runs from 5' to 3', the opposite strand runs from 3' to 5'.

**Complementary base pairing can occur between regions of two RNA molecules or even between two stretches of nucleotides in the same RNA molecule; this allows it to take on a particular three-dimensional shape necessary for its function. For example, a tRNA molecule is about 80 nucleotides in length, and its functional shape results from base pairing between nucleotides where complementary stretches of the molecule can run antiparallel to each other.

➲ ***Test your understanding:***

1. What aspects of protein structure are stabilized or assisted by hydrogen bonds?

A. Primary structure.
B. Secondary structure.
C. Tertiary structure.
D. Quaternary structure.
E. Secondary, tertiary, and quaternary structures, but not primary structure.←

2. The structural level of a protein least affected by a disruption in hydrogen bonding ____

A. All are equally affected.
B. Quaternary .
C. Secondary.
D. Tertiary.
E. Primary.←

3. What is a distinguishing feature of most naturally occurring fats?

A. Nearly all naturally occurring unsaturated fats have cis double bonds.←
B. All organisms share an equal ratio of saturated and unsaturated fatty acids.
C. They all share four fused rings as a carbon skeleton.
D. They are distinguished from other lipid forms by their chief role as components of cell membranes.

4. The subunits (monomers) in cellulose are linked together by _____

A. Glycosidic linkages.←
B. Ionic bonds.
C. Peptide bonds.
D. Phosphodiester linkages.
E. Oster linkages.

5. Which of the following biological macromolecules can be described as saturated, unsaturated, or polyunsaturated?

A. Steroids.
B. Chitin.
C. Fats.←
D. Proteins.
E. Amylopectin.

6. If ^{14}C-labeled uracil is added to the growth medium of cells, what macromolecules will be labeled?

A. RNA.←
B. Proteins.
C. Both DNA and RNA.
D. DNA.

7. Which of the following molecules possesses glycosidic bonds?

A. Amylose.
B. Glycogen.
C. Cellulose.
D. Chitin.
E. All are correct.←

8. Which of the following are pyrimidines found in the nucleic acid DNA?

A. Thymine and Cytosine.←
B. Guanine and Cytosine.
C. Thymine and Adenine.
D. Uracil and Guanine.
E. Adenine and Guanine.

9. What is the term used for a protein molecule that assists in the proper folding of other proteins?

A. Tertiary protein.
B. Denaturing protein.
C. Renaturing protein.
D. Chaperon. ←

10. A glycosidic linkage is analogous to which of the following in proteins?

A. A disulfide bond.
B. An amino group.
C. A beta-pleated sheet.
D. A peptide bond.←

11. Which of the following are pyrimidines?

A. Guanine and Cytosine.
B. Thymine and Guanine.
C. Cytosine and Uracil. ←
D. Guanine and Adenine.
E. Adenine and Thymine.

12. If a DNA sample were composed of 10% Thymine, what would be the percentage of Guanine?

A. 10%
B. 80%
C. 40% ←
D. It is impossible to tell from the information given.

13. What is the process by which monomers are linked together to form polymers?

A. Coiling.
B. Protein formation.
C. Monomerization.
D. Hydrolysis.
E. Dehydration reactions.←

14. All the following contain amino acids EXCEPT _____

A. Hemoglobin.
B. Enzymes.
C. Cholesterol. ←
D. Insulin.

15. What is the difference between an aldose sugar and a ketose sugar?

A. The number of carbons.
B. The position of the carbonyl group. ←
C. The position of the hydroxyl groups.
D. One is a ring form, the other is a linear chain.

16. Cooking oil and gasoline (a hydrocarbon) are not amphipathic molecules because they _____

A. Do not have a polar or charged region.←
B. Are highly reduced molecules.
C. Have hydrophobic and hydrophilic regions.
D. Do not have a nonpolar region.

17. Which of the following is the strongest evidence that protein structure and function are correlated?

A. Proteins function best at certain temperatures.
B. Denatured (unfolded) proteins do not function normally.←
C. Proteins have four distinct levels of structure and many functions.
D. Enzymes tend to be globular in shape.

18. You disrupt all hydrogen bonds in a protein. What level of structure will be preserved?

A. Primary structure.←
B. Secondary structure.
C. Tertiary structure.
D. Quaternary structure.

19. The hydrolysis of DNA results in _____

A. Amino acids.
B. Nucleotides. ←
C. Fatty acids.
D. Monosaccharides.

20. Which of the following is true regarding nucleotides?

A. Nucleotide without the phosphate group is called a nucleoside. ←
B. The nucleotides of the pyrimidine family have a six-membered ring fused to a five-membered ring.
C. The nucleotides of DNA are identical to those of RNA.
D. Nucleotides are polymers.
E. All are correct.

21. Which of the following polymers contain nitrogen?

A. Cellulose.
B. Amylopectin.
C. Starch.
D. Glycogen.
E. Chitin.←

22. Which of the following statements is true for the class of biological molecules known as lipids?

A. They are made by dehydration reactions.
B. They contain nitrogen.
C. They contain less energy than proteins and carbohydrates.
D. They are insoluble in water. ←
E. They are made from glycerol, fatty acids, and phosphate.

23. What maintains the secondary structure of a protein?

A. Hydrogen bonds between the amino group of one peptide bond and the carboxyl group of another peptide bond.←
B. Hydrogen bonds between the R groups.
C. Disulfide bonds.
D. Peptide bonds.
E. Hydrophobic interactions.

24. What kind of chemical bond is found between paired bases of the DNA double helix?

A. Ionic.
B. Hydrogen.←
C. Double or triple covalent.
D. Phosphodiester.
E. Coordinate.

25. A sample of normal double stranded DNA was found to have a Thymine content of 27%. What is the expected proportion of Guanine ?

A. 23% ←
B. 73%
C. 9%
D. 32%
E. 36%

26. A molecule with the chemical formula $C_6H_{12}O_6$ is probably a _____

A. Carbohydrate only.
B. Lipid only.
C. Carbohydrate and monosaccharide.
D. Carbohydrate and lipid.
E. Monosaccharide only.←

27. Which of these classes of biological molecules consist of both small molecules and macromolecular polymers?

A. Nucleic acids.
B. Proteins.
C. Lipids.
D. Lipids, carbohydrates, proteins, and nucleic acids all consist of only macromolecular polymers.
E. Carbohydrates. ←

28. The nitrogenous base Adenine is found in all members of which group?

A. Carbohydrates and lipids.
B. Proteins, ATP and DNA.
C. ATP, RNA and DNA.←
D. Carbohydrates, ATP and DNA.
E. Proteins, carbohydrates and ATP.

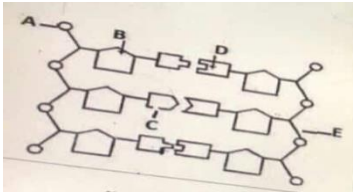
29. In sucrose the linkage between glucose and fructose is a_____ linkage.

A. 1-4 glycosidic
B. 1-6 glycosidic
C. 1-2 peptidic
D. 1-2 glycosidic ←

30. Cytosine makes up 38% of the nucleotide bases in a sample of DNA from an organism. Approximately what percentage of the Thymine nucleotides in this sample will be?

A. 12%←
B. 24%
C. 31%
D. 38%
E. It cannot be determined from the information given.

31. In this figure showing part of the DNA molecule, which letter represents ribose sugar?

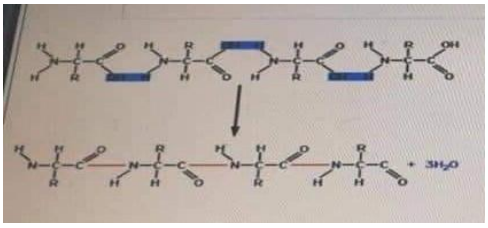


A. A
B. B ←
C. C
D. D
E. E

32. Cholesterol is a _____

A. Triglyceride.
B. Phospholipid.
C. Steroid. ←
D. A and B are correct.
E. A and C are correct.

33. What bonds are formed in the reaction shown?

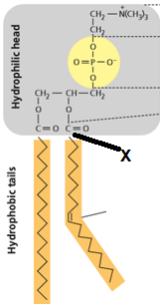


A. Glycosidic bonds.
B. Ester bonds.
C. Peptide bonds.←
D. Hydrogen bonds.
E. Ionic bonds.

34. The tertiary structure of a protein is the:

A. Bonding together of several polypeptide chains by weak bonds.
B. Order in which amino acids are joined in a polypeptide chain.
C. Unique three-dimensional shape of the fully folded polypeptide.←
D. Organization of a polypeptide chain into an alpha helix or beta pleated sheet.
E. Over all protein structure resulting from the aggregation of two more polypeptide subunits.

35. The bond pointed at (x) is described as a _____ bond.



A. Glycosidic
B. Ester ←
C. Peptide
D. Ionic
E. Hydrogen

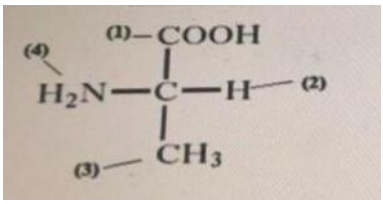
36. How many molecules of water are needed to completely hydrolyze a polymer that is 4 monomers long?

A. 4
B. 3 ←
C. 2
D. 1
E. 5

37. Which of the following are nitrogenous bases of the purine type?

A. Guanine and Cytosine.
B. Adenine and Thymine.
C. Guanine and Adenine.←
D. Thymine and Cytosine.
E. Uracil and Cytosine.

38. The diagram represents the structure of an amino acid. In this diagram, the R group is represented by number_____



A. 1
B. 2
C. 3 ←
D. 4
E. None of these.

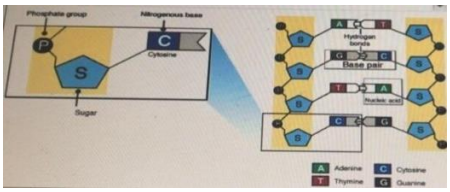
39. Which of the following refers to a hydrophilic "insoluble fiber"?

A. Polypeptides.
B. Cellulose.←
C. Starch.
D. Amylose.
E. Amylopectin.

40. DNAase is an enzyme that breaks the covalent bonds between nucleotides. Which bonds are broken?

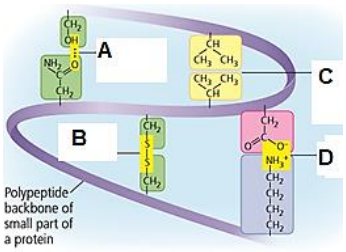
A. The OH group on carbon no. 2 of the ribose.
B. The phosphodiester bonds between deoxyribose sugars would be broken.←
C. The purines would be separated from the deoxyribose sugar.
D. The pyrimidines would be separated from the deoxyribose sugar.
E. All bases would be separated from the deoxyribose sugar.

41. In this figure, the monomers are called_____



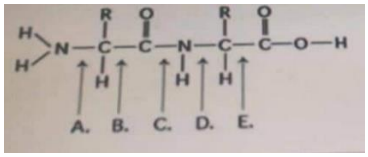
A. Nucleosides.
B. Nucleotides. ←
C. Nucleoside diphosphates.
D. Nucleoside triphosphates.
E. Purines and pyrimidines.

42. Van Der Waal forces in the figure are represented by the letter ____



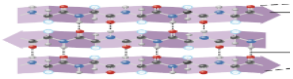
A. B
B. C ←
C. D
D. E

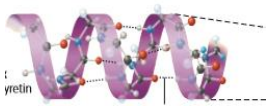
43. Which bond is closest to the amino terminus of the molecule?



A. A←
B. B
C. C
D. D
E. E

44. Which bonds support the level of protein structure shown in the figure?





A. H-bonds between the amino acid R groups.
B. Disulfide bonds.
C. Ionic bonds.
D. H-bonds between H and O of the peptide back done. ←
E. Hydrophobic interactions.

45. A phospholipid molecule has_____

A. A hydrophobic acid.
B. A hydrophilic head.←
C. Three fatty acids.
D. A phosphate group.
E. All except C.

46. The molecular formula for a ribose molecule is_____

A. $C_6 H_{12} O_6$
B. $C_5 H_{10} O_5$ ←
C. $C_6 H_{120} O_{60}$
D. $C_6 H_{102} O_{51}$
E. $C_5 H_{82} O_{41}$

47. Which of the following is not a polymer?

A. Steroid.←
B. Starch.
C. Cellulose.
D. Chitin.
E. DNA.

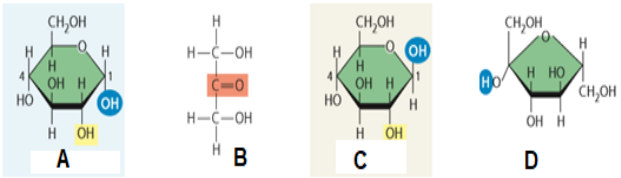
48. All the following contain amino acids except_____

A. Hemoglobin.
B. RNA.←
C. Polypeptide.
D. Enzymes.
E. Collagen.

49. Oils are liquid at room temperature because they_____

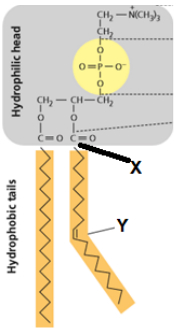
A. Are small molecules.
B. Have hydrophobic acid.
C. Contain unsaturated fatty acids.←
D. Are not polymers.
E. All are correct.

50. Which of the molecules shown in the figure is the monomer of cellulose?



A. A
B. B
C. C ←
D. D

51. The part (Y) is said to be_____



A. Saturated.
B. Unsaturated. ←
C. Completely hydrogenated.
D. Triglyceride.
E. Monoglyceride.

52. Which of the following is true about cellulose?

A. It contains alpha glucose.
B. It is a storage polysaccharide.
C. Humans cannot digest it. ←
D. It contains alpha galactose.

Chapter 6

Energy and life " الطاقة والحياة "

Concept 6.2: The free energy-change of a reaction tells us whether or not the reaction occurs spontaneously

- Free energy: is the portion of a system's energy that can perform work when temperature and pressure are uniform throughout the system (as in a living cell). **[$\Delta G = \Delta H - T\Delta S$] [$\Delta G = G_{final} - G_{initial}$]**
- ΔH is the change in the system's enthalpy, ΔS is the change in the system's entropy, and T is the absolute temperature in Kelvin (K) unit ' s (K = °C+273).
- **In order for ΔG to be negative** (1) ΔH must be negative (the system gives up enthalpy and H decreases) or (2) $T\Delta S$ must be positive (the system gives up order and S increases), or both. ΔG can be negative only when the process involves a loss of free energy during the change from initial state to final state. Free energy is a measure of a system's instability—its tendency to change to a more stable state.

- **Spontaneous reactions** occur when ΔG is negative (from more free energy (higher G) to less free energy (lower G); from less stable to more stable; from greater work capacity to less work capacity.
- At equilibrium, G is at its lowest possible value in that system; going away from equilibrium **increases** free energy (ΔG is positive)**.**

- **Standard conditions** are (1) having 1 M of each reactant and product, (2) T= 25°C, and (3) pH=7.

- Exergonic spontaneous **reactions** occur with a net release of free energy (ΔG is negative). An example is cellular respiration.
- Endergonic nonspontaneous **reactions** absorb free energy from its surroundings (ΔG is positive). An example is the reverse process of cellular respiration (the conversion of carbon dioxide and water to glucose and oxygen).
- Breaking bonds requires energy, while forming bonds releases energy.
- If a reaction is endergonic, its reverse reaction is exergonic.

Concept 6.3: ATP powers cellular work by coupling exergonic reactions to endergonic reactions

Cellular work

A cell does three main kinds of work: (1) chemical work which pushes endergonic reactions that would not occur spontaneously, such as the synthesis of polymers from monomers, (2) transport work like pumping substances across membranes against the direction of spontaneous movement, and (4) mechanical work, such as the beating of cilia, the contraction of muscle cells, and the movement of chromosomes during cellular reproduction.

ATP (adenosine triphosphate nucleotide) consists of a ribose sugar, nitrogenous base (adenine), and three phosphate groups.

ATP hydrolysis

- ✓ By addition of a water molecule **(a hydrolysis reaction),** the terminal phosphate bond breaks and a molecule of inorganic phosphate ($HOPO_3^{2-}$, abbreviated ~ Pi) leaves the ATP, which becomes adenosine diphosphate, or ADP. It's an exergonic and releases 7.3 kcal of energy per mole of ATP hydrolyzed.The release of energy during the hydrolysis of ATP comes from the chemical change of the system to a state of lower free energy, not from the phosphate bonds themselves.
- ✓ In the cell, conditions do not conform to standard conditions (reactant and product concentrations differ from 1 M). The actual ΔG produced = -13 kcal/mol; 78% **greater** than the energy released by ATP hydrolysis under standard conditions.

ATP regeneration

- ✓ ATP is a renewable resource that can be regenerated by the addition of phosphate to ADP in an endergonic reaction. The free energy required to phosphorylate ADP comes from **exergonic** breakdown reactions (**catabolism**) in the cell (e.g. cellular respiration and plants' use of light energy).

Energy coupling: the use of an exergonic process to drive an endergonic one by ATP.

- ✓ If ΔG of an endergonic reaction is less in amount than the energy released by ATP hydrolysis, then the two reactions can be **coupled** so that, overall, **the coupled reactions are exergonic (the net effect is energy release).** This usually involves phosphorylation (the transfer of a phosphate group from ATP to some other molecule, such as the reactant). The recipient **molecule with the phosphate group** covalently bonded to it is then called a phosphorylated **intermediate**. An example of energy-coupling is the conversion of glutamic acid to glutamine.
- ✓ **Transport** and **mechanical** work in the cell are also nearly always powered by the hydrolysis of ATP. Direct phosphorylation of a transporter protein changes its shape and ability to bind solutes (transport work). Also, ATP can bind non-covalently (indirectly) to a motor protein, and gets hydrolyzed releasing ADP and ~ Pi; at each stage, the motor protein changes its shape and ability to bind the cytoskeleton, resulting in the movement of the protein (mechanical work).

Concept 6.4: Enzymes speed up metabolic reactions by lowering energy barriers

Why do we need enzymes?

A spontaneous chemical reaction occurs without any requirement for energy, but it may occur so slowly that it is imperceptible, that's why we need enzymes that accelerate these reactions. An example is the hydrolysis of sucrose (table sugar) which requires "sucrose" enzyme although it's an exergonic reaction.

An enzyme is a macromolecule that acts as a catalyst; it speeds up a reaction without being consumed. Most of enzymes are proteins; however, some RNA molecules (called ribozymes) function as enzymes.

The Activation Energy Barrier

- Changing one molecule into another generally involves contorting the starting molecule into a highly **unstable state** before the reaction can proceed. To reach the **contorted *unstable* state** where bonds can change, reactant molecules must absorb energy from their surroundings.
- When the new bonds of the product molecules form, energy is released as heat ☀, and the molecules return to stable shapes with lower energy **than the contorted state**.
- **Activation energy E_A:** the initial investment (use) of energy for starting a reaction; it's the energy required to **contort the reactant** molecules so the bonds can break. It is often supplied by heat in the form of **thermal energy.** *How does it work?* The absorption of thermal energy accelerates the reactant molecules and agitates the atoms within the molecules, making the breakage of bonds more likely. When the molecules have absorbed enough energy for the bonds to break, the reactants are in an unstable condition known as the **transition state.**

‼ In most cases, E_A is **so high** and the transition state is reached so rarely that the reaction will hardly proceed at all, in these cases, the reaction will occur at a noticeable rate only if:

1. Energy is provided, usually by heat. Heat can increase the rate of a reaction by allowing reactants to attain the transition state more often, but this would not work well in biological systems ; high temperature denatures proteins and kills cells, also, it would speed up all reactions, not just those that are needed (it's not specific).
2. OR catalytic agents are used. Catalytic agents (e.g. enzymes) speed up reactions by lowering the E_A barrier; enzymes do not change Gi, Gf, or ΔG; they cannot make an endergonic reaction exergonic.
   The enzyme binds to one or more specific substrates (reactants) forming an enzyme-substrate complex (sucrase will act only on sucrose).

Active site: a pocket or groove on the surface of the enzyme where catalysis occurs formed by only a few of the enzyme's amino acids **(as the substrate enters the active site, the enzyme changes shape slightly due to interactions between the substrate's chemical groups and chemical groups on the side chains (R groups) of the amino acids that form the active site; the R groups can then catalyze the reaction).** This so-called induced fit brings chemical groups of the active site into positions that enhance their ability to catalyze the chemical reaction.

➲ **Quick notes on enzymes:**

1. An enzyme can catalyze either the forward **or** the reverse reaction, depending on which direction has a negative ΔG. Distorting the substrate helps it approach the transition state and thus reduces the amount of free energy that must be absorbed to achieve that state.
2. The active site is the same after the reaction as it was before; steps in the reaction restore the side chains to their **original** states.

Enzyme saturation

- The rate at which a **particular amount of enzyme** converts substrate to product depends on the initial concentration of the substrate; the more substrate, the more frequently they access the active sites of the enzyme molecules.
- Sometimes, the concentration of substrate will be high enough that all enzyme molecules have their active sites **engaged** *(all chairs are full).* At this substrate concentration:

  1. The enzyme is said to be saturated.
  2. The rate of the reaction is determined by the **speed at which the active site converts substrate to product** *(not the initial concentration of the substrate).*
  3. The only way to increase the rate of product formation is to add more enzymes.

Does the environment affect enzymes?

Increasing **temperature** increases the speed of molecules resulting in more collision between substrates and active sites of enzymes. Thus, **the rate of the reaction** increases until we reach the optimal temperature. Above that temperature, however, the speed of the enzymatic reaction drops sharply. ⤵

* Each enzyme has an optimal temperature at which its reaction rate is greatest (optimal temperature for human enzymes is 35 - 40 °C, and for thermophile bacteria, it's 70°C or higher).
*Each enzyme also has an optimal pH value at which it is **most active** (the optimal pH values for most enzymes is 6-8; pepsin (in the stomach) works best at pH 2, and trypsin (in the intestine) works best at pH 8).

Cofactors 👇 are non-protein helpers for catalytic activity for the enzymes. There are **(1) inorganic cofactors** (e.g. metals like zinc, iron, and), and **(2) organic cofactors** which are called coenzymes (e.g. vitamins).

Enzyme inhibitors 😣 can be **irreversible** (attach to enzymes by covalent bonds), or **reversible** (bind to enzymes by weak interactions). Many antibiotics are inhibitors of specific enzymes in bacteria. For instance, penicillin blocks the active site of an enzyme that bacteria use to build their cell walls.

Reversible inhibitors can be (1) competitive inhibitors which resemble the normal substrate molecule and compete for admission into the active site (i.e. they reduce the productivity of enzymes by blocking substrates from entering active sites), and this kind of inhibition can be overcome by increasing the concentration of substrate, or (2) noncompetitive inhibitors which do not bind to the active site but to another part of the enzyme, and this interaction causes the enzyme to change its shape in a way that the **active site** becomes less effective.

Irreversible inhibitors include toxins and poisons such as (1) "Sarin" which is a nerve gas that binds covalently to the amino acid serine, which is found in the active site of acetylcholinesterase [AchE] (an enzyme that works in the nervous system), (2) pesticides, (3) DDT, and (4) parathion.

Concept 6.5: Regulation of enzyme activity & control metabolism

Allosteric regulation of enzymes

In cells, there are regulatory molecules that naturally regulate enzyme by acting like reversible noncompetitive inhibitors.

Allosteric regulation describes any case in which a protein's function at one site is affected by the binding of a regulatory molecule to a separate site.

Most enzymes can be allosterically regulated *(called allosteric enzymes)* **are constructed from two or more subunits, and each subunit is composed of a polypeptide chain with its own active site.**

- An allosteric enzyme has two different shapes; one is **active** and the other is **inactive**. The binding of an activator *(regulatory molecule)* to a regulatory site stabilizes the shape that has functional active sites, whereas the binding of an inhibitor *(regulatory molecule)* stabilizes the inactive form of the enzyme.
- A single activator or inhibitor molecule that binds to one regulatory site will affect the active sites of all subunits.

- A **substrate** molecule binding to one **active site** in a multi-subunit enzyme triggers a shape change in all the subunits and **increases** the catalytic activity at the other active sites; this is called **cooperativity** *(a type of allosteric regulation);* it amplifies the response of enzymes to substrates; one substrate molecule primes an enzyme to act on additional substrate molecules **more readily** (e.g. **hemoglobin transporter** which has four subunits, each with an oxygen-binding site, the binding of an oxygen molecule to one binding site **increases** the affinity for oxygen of the remaining binding sites).

Feedback inhibition: happens when a metabolic pathway is halted by the inhibitory binding of its end product to an enzyme that acts **early** in the pathway (e.g. isoleucine synthesis from threonine by threonine deaminase; as isoleucine accumulates, it slows down its own synthesis by allosterically inhibiting isoleucine deaminase).

➲ ***Test your understanding:***

1. Allosteric enzyme regulation is usually associated with_____

A. The need for cofactors.
B. Lack of cooperativity.
A. Feedback inhibition.
C. Activating activity.
D. An enzyme with more than one subunit.←

2. A chemical reaction that has a positive ΔG is correctly described as_____

A. Spontaneous.
B. Enthalpic.
C. Exothermic.
D. Endothermic.
E. Endergonic. ←

3. Why is ATP an important molecule in metabolism?

A. It has only 2 phosphate groups.
B. Its terminal phosphate group contains a strong covalent bond.
C. All choices are correct.
D. Its hydrolysis provides an input of free energy for exergonic reactions.
E. It provides energy coupling between exergonic and endergonic reactions.←

4. Which of the following statements is true concerning catabolic pathways?

A. They build up complex molecules such as protein from simpler compounds.
B. They convert molecules into more energy-rich molecules.
C. They supply energy, primarily in the form of ATP, for the cell's work. ←
D. They are endergonic.
E. They are spontaneous and do not need enzyme catalysis.

5. The active site of an enzyme is the region that_____

A. Is involved in the catalytic reaction of the enzyme.←
B. Binds products of the reaction.
C. Binds noncompetitive inhibitors of the enzyme.
D. Binds allosteric regulators of the enzyme.
E. Is inhibited by the presence of a coenzyme or a cofactor.

6. Which of the following is most similar in structure to ATP?

A. An amino acid with three phosphate groups attached.
B. A phospholipid.
C. A DNA nucleotide.
D. An RNA nucleotide. ←
E. A pentose sugars.

7. A mutation results in a defective enzyme A. Which of the following would result because of that mutation?

A. An accumulation of A, and no production of B and C. ←
B. An accumulation of A and B, and no production of C.
C. An accumulation of B, and no production of A and C.
D. An accumulation of B and C, and no production of A.
E. An accumulation of C, and no production of A and B.

8. Coenzymes are usually_____

A. Inorganic.
B. Organic.
C. Vitamins.
D. Allosteric regulators.
E. Both B and C are correct.←

9. Reactants capable of interacting to form products in a chemical reaction must first overcome a thermodynamic barrier known as the reaction's_____

A. Entropy.
B. Activation energy.←
C. Endothermic level.
D. Equilibrium point.
E. Free energy.

10. In a spontaneous change_____

A. The free energy of a system decreases.
B. The system becomes more stable.
C. The released free energy can be harnessed to do work.
D. Always move away from equilibrium.
E. All the above is true except D. ←

11. The active site of an enzyme is the region that_____

A. Bind to a noncompetitive inhibitor.
B. Binds to an allosteric inhibitor.
C. Binds to an allosteric activator.
D. Binds to a heme group.
E. Binds to substrate(s).←

12. The minimum amount of energy needed for a process (reaction) to occur is called the_____

A. Potential energy.
B. Process energy.
C. Kinetic energy.
D. Activation energy.←
E. Exergonic energy.

13. What are allosteric enzymes?

A. Enzymes that have one subunit.
B. Enzymes that are unable to be denatured.
C. Enzymes that change shape between active and inactive forms. ←
D. Enzymes that can be only activated but not inhibited.
E. None of these.

Chapter 7

Cell structure and function

"بنية الخلية ووظيفتها"

Concept 7.1: Biologists use microscopes and biochemistry to study cells

Microscopes are the most important tools of cytology, the study of cell structure. The two main types of microscopes; (1) light microscopes and (2) electron microscopes.

In a light microscope (LM), visible light is passed through the specimen and then through glass lenses. The lenses refract (bend) the light in such a way that the image of the specimen is magnified as it is projected into the eye or into a camera. However, the electron microscope (EM) focuses a beam of electrons through the specimen or onto its surface.

- Organelles can't be seen with standard light microscopy because of its resolution (we use EM instead).

- Specimen preparation for EM kills the cells; that's why we use LM to study living cells.

Parameters of microcopy:

1. **Magnification**: the ratio of an object's image size to its real size, light microscopes can magnify effectively to about 1,000 times. (at greater magnifications, additional details cannot be seen clearly)
2. **Resolution**: a measure of the clarity of the image; it is the minimum distance two points can be separated and still be distinguished as separate points. *(it is inversely related to the wavelength of the light (or electrons), and electron beams have much shorter wavelengths than visible light)*
3. **Contrast**: the difference in brightness between the light and dark areas of an image. There are methods to enhance the contrast, such as (1) staining and (2) labeling cell components.

SEM	TEM
1. It's used for detailed study of the specimen's topography. 2. Specimen is coated by thin layer of gold. 3. It gives 3D images.	1. Used to study the internal structure of cells. 2. It needs very thin section of the specimen. 3. The specimen has been stained with atoms of heavy metals, which attach to certain cellular structures, thus enhancing the electron density.

Both use electromagnets as lenses to bend the paths of the electrons.

Types of light microscope:

1. Bright-field (unstained specimen).
2. Bright-field (stained specimen).
3. Phase contrast
4. Differential-interference-contrast.
5. Fluorescence.
6. Confocal.
7. De-convolution.
8. Super-resolution.

- *Confocal and deconvolution microscopy have produced sharper images of three-dimensional tissues and cells.*

Types of electron microscope

1. Scanning electron microscope (SEM).
2. Transmission electron microscope (TEM).

Cell fractionation is a useful technique for studying cell structure and function, which takes cells apart and separates major organelles and other subcellular structures from one another.

- *Cells are homogenized in a blender to break them up. The resulting mixture (homogenate) is centrifuged using a centrifuge which spins test tubes holding mixtures of disrupted cells at a series of **increasing speeds.** At each speed, the resulting force causes a subset of the cell components to settle to the bottom of the tube, forming a pellet. The other components of the tube (the liquid above the pellet) are called supernatant, which is poured into another tube and centrifuged at a higher speed for a longer period.*
- At lower speeds, the pellet consists of larger components, and higher speeds result in a pellet with smaller components.

Concept 7.2: Eukaryotic cells have internal membranes that compartmentalize their functions

The cell is the basic structural and functional unit of every organism. There are two types of cells; prokaryotic cells (bacteria and archaea) and eukaryotic cells (protists (unicellular), fungi, animals, and plants).
Both types have **plasma membrane (cell membrane), cytosol, chromosomes, and ribosomes**. The main difference between them is **the location of their DNA**; in a eukaryotic cell, DNA is in an organelle called the **nucleus**, which is bounded by a double membrane, however, in a prokaryotic cell, the DNA is concentrated in a region that is not membrane-enclosed, called the **nucleoid**.

A prokaryotic cell is rod-shaped; it has fimbriae, nucleoid, ribosomes, plasma membrane, cell wall, glycocalyx, and flagella (locomotion organelles)

The cytoplasm in eukaryotic cells, is the region between the nucleus and the plasma membrane (cytoplasm= cytosol + **organelles**; organelles are **absent** in prokaryotic cells).

Eukaryotic cells are generally much larger than prokaryotic cells, and the smallest cells known are bacteria called mycoplasmas.

The plasma membrane

At the boundary of every cell, the plasma membrane functions as a selective barrier that allows passage of enough oxygen, nutrients, and wastes to service the entire cell.

The plasma membrane and the membranes of organelles consist of a double layer (bilayer) of phospholipids with various proteins attached to or embedded in it.The hydrophobic parts of phospholipids and proteins are in the interior of the membrane and the hydrophilic parts are in contact with aqueous solutions on either side. Carbohydrate side chains may be attached to proteins or lipids on the outer surface of the plasma membrane. *However, each type of membrane has a unique composition of enzymes, lipids, proteins, etc.*

Concept 7.3: The eukaryotic cell's genetic instructions are housed in the nucleus and carried out by the ribosome

Two cellular components involved in the genetic control of the cell; (1) the nucleus and (2) the ribosomes.
*The nucleus contains **most** of the genes in the eukaryotic cell; some are located in the mitochondria and chloroplasts.*

- The nuclear envelope separates the nucleus from the cytoplasm. It is a double membrane (two membranes separated by a space). It has pores and at the lip of each pore, the inner and outer membranes of the nuclear envelope are continuous.
- Pore complex: a protein structure lines each pore and regulates the entry and exit of proteins, RNAs, as well as large complexes of macromolecules.
- The nuclear lamina is a netlike array of protein filaments (in animal cells, called intermediate filaments) that lines the nuclear side of the membrane and maintains the shape of the nucleus by mechanically supporting the nuclear envelope.
- The nuclear matrix is a framework of protein fibers extending throughout the nuclear interior.

Within the nucleus, the DNA is organized into discrete units called chromosomes, structures that carry the genetic information. Each chromosome consists of one long DNA molecule associated with many proteins (some proteins reduce the length of the DNA molecule allowing it to fit into the nucleus). The **complex** of DNA and proteins making up chromosomes is called chromatin.

When a cell is not dividing, chromatin appears as a diffuse mass and the chromosomes cannot be distinguished from one another, even though discrete chromosomes are present. As a cell prepares to divide, however, the chromosomes coil (condense) further, becoming thick enough to be distinguished as separate structures.

- Each eukaryotic species has a characteristic number of chromosomes (human cell has 46 chromosomes except the sex cells (eggs and sperm), which have only 23 chromosomes).

The **nucleolus** is a prominent structure within the non-dividing nucleus; a mass of densely stained granules and fibers adjoining part of the chromatin. There, ribosomal RNA (rRNA) synthesis occurs -from instructions in the DNA-, and then proteins imported from the cytoplasm are assembled with rRNA into large and small subunits of ribosomes. These subunits then exit the nucleus through the nuclear pores to the cytoplasm, where a large and a small subunit can assemble into a ribosome. Sometimes there are two or more nucleoli; the number depends on the species and the stage in the cell's reproductive cycle.

1. Synthesizing messenger RNA (mRNA) according to instructions provided by the DNA (transcription).
2. The mRNA is then transported to the cytoplasm via the nuclear pores.
3. In the cytoplasm, ribosomes translate the mRNA's genetic message into the primary structure of a specific polypeptide (translation).

Ribosomes (protein factories) are the cellular components that carry out protein synthesis. **Ribosomes are not membrane bounded and thus are not considered organelles**. Cells that have high rates of protein synthesis have large numbers of ribosomes as well as prominent nucleoli (e.g. pancreatic cells).
Free ribosomes are suspended in the cytosol; they synthesize proteins that function within the cytosol. Bound ribosomes are attached to the outside of the endoplasmic reticulum or nuclear envelope; they synthesize membrane proteins, lysosomal proteins, and **secretory proteins**. Bound and free ribosomes are structurally identical, and ribosomes can play either role at different **times**.

Concept 7.4: The endomembrane system regulates protein traffic and performs metabolic functions

The endomembrane system is composed of:

1. Golgi apparatus.
2. Plasma membrane.
3. Nuclear envelope.
4. Endoplasmic reticulum.
5. Lysosomes.
6. Vesicles.
7. Vacuoles.

Its functions:

1. Protein synthesis and transport.
2. Lipid metabolism and movement
3. Detoxification of poisons.

Relations between its parts:

1. Direct physical continuity.
2. Tiny membranous vesicles (sacs).

Detoxification: Adding hydroxyl groups to drug molecules, making them more soluble and easier to flush from the body (e.g. sedative phenobarbital and other barbiturates).

- ✓ The endoplasmic reticulum (ER) accounts for more than half the total membrane in many eukaryotic cells. It consists of a network of membranous tubules and sacs called cisternae.
- ✓ The ER membrane separates the internal compartment of the ER, called the ER lumen (cavity) or cisternae space, from the cytosol.

The smooth ER lacks ribosomes (appears smooth).
Smooth ER functions: **(**Sara Likes Doing Some Magic Tricks)

1. **Lipid synthesis (oils, steroids, new membrane phospholipids).** The cells that synthesize and secrete these lipids (e.g. testes and ovaries, which secrete sex steroidal hormones, are rich in smooth ER).
2. **Detoxification of drugs and poisons (mainly in liver cells)**
3. **Storage of calcium ions (mainly in muscle cells)**
   Smooth ER membrane pumps calcium ions from the cytosol into the ER lumen. When a muscle cell is stimulated by a nerve impulse, calcium ions rush back across the ER membrane into the cytosol and trigger contraction of the muscle cell. In other cell types, release of calcium ions from the smooth ER triggers different responses, such as secretion of vesicles carrying newly synthesized proteins.
4. **MeTabolism of carbohydrates.**

The rough ER has ribosomes on its outer surface (appears rough). Ribosomes are also attached to the cytoplasmic side of the nuclear envelope's outer membrane which is continuous with the rough ER.

Functions of Rough ER **(**Remember Secret Memories)

1. **Synthesis of Secretory proteins (e.g. pancreatic cells synthesize the protein insulin in the ER and secrete it into the bloodstream)**

➲ As a polypeptide chain grows from a **bound** ribosome, the chain is internalized into the ER lumen through a pore formed by a protein complex in the ER membrane. The new polypeptide folds into its functional shape as it enters the ER lumen. There, carbohydrates are added to the proteins by enzymes built into the ER membrane [most secretory proteins are glycoproteins; proteins with carbohydrates covalently bonded to them]. After secretory proteins are formed, the ER membrane keeps them separate from proteins in the cytosol, which are produced by **free ribosomes.** Secretory proteins depart from the ER wrapped in the membranes of **transport vesicles** that bud like bubbles from a specialized region called transitional ER.

2. **Membrane factory of the cell.**

➲ Rough ER grows by **synthesizing and adding** membrane proteins and phospholipids to its own membrane. Polypeptides are inserted by their hydrophobic portions, and phospholipids are assembled from precursors in the cytosol.

The Golgi apparatus (shipping and receiving center); it's where products of the ER, such as proteins, are modified and stored and then sent to other destinations (it's extensive in cells specialized for secretion). It consists of a group of associated, flattened membranous sacs (cisternae).

Two sides of Golgi apparatus; **(1) Cis face** which is the receiving department, usually located near the ER, and **(2) Trans face**, which is the shipping department.

Golgi apparatus **modifies proteins, alters membrane phospholipids,** and **manufactures some macromolecules** (e.g. polysaccharides such as pectin and other non-cellulose molecules are made in Golgi of plant cells and incorporated along with cellulose into their cell walls).

How does it modify proteins?

➲ Products of the ER (in transport vesicles) are usually modified during their transit from the **Cis region to the Trans region** of the Golgi apparatus *(e.g. glycoproteins formed in the ER have their carbohydrates modified, first in the ER itself, and then as they pass through the Golgi).* Golgi products are then secreted from the Trans face of the Golgi inside **transport vesicles**.

✓ Before budding vesicles from the Trans face, Golgi sorts these products and targets them for various parts of the cell. *How?* By molecular identification tags, such as phosphate groups added to the products (sorting).

✓ Transport vesicles budded from the Golgi may have external molecules on their membranes that recognize "docking sites" on the surface of specific organelles or on the plasma membrane, thus targeting the vesicles appropriately.

➲ Transport vesicles (Golgi products) destinations:

1. Other locations or to the plasma membrane for secretion.
2. Backward to less mature Golgi cisternae, where they function.
3. Back to the ER, where they function.

Cisternal maturation model: the cisternae of the Golgi progress forward from the cis to the Trans face, carrying and modifying their cargo as they move. (a dynamic structure)

A lysosome is a membranous sac of **hydrolytic enzymes** that many eukaryotic cells use to **digest** (hydrolyze) macromolecules.

1. Lysosomal enzymes work best in the acidic environment found in lysosomes (not very active in the cytosol which has a near neutral pH). Lysosomal enzymes and membrane are made by rough ER and then transferred to the Golgi apparatus for further processing.
2. There are two ways of intracellular digestion by enzymes; (1) phagocytosis (e.g. amoebas eating and human's macrophages), and (2) autophagy, in which hydrolytic enzymes recycle the cell's own material; a damaged organelle or small amount of cytosol becomes surrounded by a double membrane of unknown origin, a lysosome then fuses with the this vesicle, the lysosomal enzymes digest the material, and the resulting small compounds are released to the cytosol for reuse (e.g. human liver).
3. The cells of people with inherited lysosomal storage diseases (rare) lack a functioning hydrolytic enzyme normally present in lysosomes. The lysosomes become engorged with indigestible material, which begins to interfere with other cellular activities. (e.g. Tay-Sachs disease, a lipid-digesting enzyme is missing or inactive which damages brain cells).

Vacuoles (diverse maintenance compartments) are large vesicles derived from the ER and Golgi apparatus.

Vacuolar membrane is selective in transporting solutes.

- **Food vacuole:** formed by phagocytosis.
- **Contractile vacuole** pumps excess water out of the cell (in unicellular eukaryotes).
- **Hydrolytic vacuoles** are found in plants and fungi; they carry out enzymatic hydrolysis (shared function with lysosomes).
- **Central vacuoles** are found in mature plant cells which develop by the coalescence of smaller vacuoles; it contains cell sap (main repository of inorganic ions, including potassium and chloride), and helps in cellular growth; the cell enlarges as the vacuole absorbs water.
- **In plants**, small vacuoles can hold reserves of important organic compounds, such as the proteins in seeds. They may also protect the plant from herbivores by storing poisons. Additionally, some plant vacuoles contain pigments, such as the red and blue pigments of petals that help attract pollinating insects to flowers.

Concept 7.5: Mitochondria and chloroplasts change energy from one form to another

Mitochondria are the sites of cellular respiration, which uses oxygen to drive the generation of ATP by extracting energy from sugars, fats, and other fuels. They're found in nearly all eukaryotic cells. Some cells have a single large mitochondrion, but more often a cell has hundreds or even thousands of mitochondria; the number correlates with the cell's level of metabolic activity (cells that move have more mitochondria per volume than less active cells).

- ✓ Each of the **two membranes** enclosing the mitochondrion is a phospholipid bilayer with a unique collection of embedded proteins; the outer membrane is smooth, but the inner membrane is convoluted, and has many foldings that are called cristae; they increase the surface area and enhance the productivity of cellular respiration.
- ✓ The inner membrane divides the mitochondrion into two internal compartments; (1) the intermembrane space (between the two membranes), and (2) the mitochondrial matrix which is enclosed by the inner membrane and contains enzymes + DNA + ribosomes.
- ✓ The enzymes found in the matrix catalyze some of the steps of cellular respiration. Other proteins that function in respiration, including the enzyme that makes ATP, are built into the inner membrane.
- ✓ Mitochondria are moving around, changing their shapes, and fusing or dividing into two.

Chloroplasts are the sites of **photosynthesis;** they convert solar energy to chemical energy by absorbing sunlight and using it to drive the synthesis of organic compounds, such as sugars from carbon dioxide and water. They contain the green pigment chlorophyll, along with enzymes for the photosynthetic production of sugar. These lens-shaped organelles are found in leaves and other green organs of plants and in algae. They are surrounded by an envelope consisting of two membranes separated by a very narrow intermembrane space.

Inside the chloroplast is a membranous system in the form of flattened, inter connected sacs called thylakoids. In some regions, thylakoids are stacked; each stack is called a granum. The fluid outside the thylakoids is the stroma, which contains DNA + ribosomes + many enzymes.
The membranes of the chloroplast divide the it into three spaces; (1) the intermembrane space, (2) the stroma, and (3) the thylakoid space.
Its shape is changeable; it grows and occasionally pinches into two, reproducing itself. Also, it's a mobile organelle.
Plastids are divided into (1) chloroplasts, (2) amyloplast (colorless organelle that stores starch, and (3) **chromo**plasts **(which have pigments that give fruits and flowers their orange and yellow hues).**

The **peroxisomes** are bounded by **single** membranes. They contain enzymes that **remove hydrogen** atoms from various substrates and transfer them to oxygen (O_2), producing hydrogen peroxide (H_2O_2) as a by-product **(oxidation).**
The H_2O_2 formed by peroxisomes is toxic, but the organelle also contains an enzyme that converts H_2O_2 to water.

- Some peroxisomes use **oxygen** to break fatty acids down into smaller molecules that are transported to mitochondria and used as fuel for cellular respiration.
- Peroxisomes in the liver detoxify alcohol and other harmful compounds by transferring hydrogen from the poisonous compounds to oxygen.
- Specialized peroxisomes called glyoxysomes are found in the **fat-storing tissues** of plant **seeds**. These organelles contain enzymes that initiate the conversion of fatty acids to sugar, which the emerging seedling uses as a source of energy and carbon until it can produce its own sugar by photosynthesis.
- Peroxisomes increase in size by incorporating proteins (made in the cytosol and ER), as well as lipids (made in the ER and within the peroxisome itself).
- Peroxisomes increase in number by splitting when they reach a certain size.

Concept 7.6: The cytoskeleton is a network of fibers that organizes structures and activities

The cytoskeleton is a network of fibers extending throughout the cytoplasm (bacteria also have fibers that form a cytoskeleton).
Molecular structures in the cytoskeleton are (1) **microtubules**, (2) **microfilaments**, and **intermediate filaments. The cytoskeleton gives support and motility to the cell.** *How?*

SUPPORT: It gives mechanical support to cell, maintains its shape, and provides anchorage for many organelles and even cytosolic enzyme molecules.

MOTILITY: This includes both changes in **cell location** and movements of cell **parts**. It requires interaction of the cytoskeleton with motor proteins *(i.e. cytoskeletal elements and motor proteins work together with plasma membrane molecules to allow whole cells to move along fibers **outside the cell. Also,** inside the cell, vesicles and other organelles often use motor protein "feet" to "walk" to their destinations along a track provided by the cytoskeleton)*.

The cytoskeleton can be quickly dismantled in one part of the cell and re-assembled in a new location, changing the shape of the cell.

Microtubules are hollow rods built from globular proteins called **tubulins**. Each tubulin is a dimer that consists of **two** slightly different polypeptides; **alpha** tubulin and **beta** tubulin. They grow in length by **adding** tubulin dimers, and they can also be disassembled. The structural role of microtubules is compression-resisting.
Plus end: the end that can **accumulate or release tubulin dimers** at a much higher rate than the other.
Functions of microtubules:

1. Provide shape and support the cell.
2. Serve as tracks on which organelles equipped with motor proteins can move; these tracks guide vesicles from the ER to Golgi apparatus and from Golgi to the plasma membrane.
3. Involved in the separation of chromosomes during cell division.

➲ **Centrosomes and Centrioles;** in animal cells, microtubules grow out from a centrosome (a region near the nucleus). A centromere is a pair of centrioles, and is located in the centrosome; each centriole is composed of **nine sets of triplet** microtubules arranged in a ring. Many eukaryotic cells lack centrioles and instead organize microtubules by other means.

STRUCTURE|| Each motile cilium or flagellum has a group of microtubules sheathed (covered) in an extension of the plasma membrane. **Nine doublets** of microtubules are arranged in a ring with **two single** microtubules in the center; this arrangement, referred to as the "9 + 2" pattern, is found in nearly all eukaryotic flagella and motile cilia. They're anchored in the cell by a basal body, which is structurally very similar to a centriole, with microtubule triplets **in a "9 + 0" pattern.** The bacterial flagella have a different structure.

➲ **Flagella and Cilia** are microtubule-containing extensions that project from some cells (eukaryotes) and act as locomotors appendages.

1. Motile cilia usually occur in large numbers on the cell surface. Flagella are usually limited to just one or a few per cell, and they are longer than cilia.

2. Flagella and cilia differ in their beating patterns; a flagellum has an undulating motion. In contrast, cilia have alternating power and recovery strokes.

Bending of these structures involves large motor proteins called dynein that are attached along **each outer microtubule doublet**. A typical dynein protein has **two** "feet" that "walk" along the microtubule of the adjacent **doublet**, using ATP for energy. The outer doublets and two central microtubules are held together by **flexible cross-linking proteins**.

The primary cilium is a non-motile **single** cilium (one for each cell) which functions as a signal-receiver. Membrane proteins on this kind of cilium transmit molecular signals from the cell's environment to its interior, triggering signaling pathways that may lead to changes in the cell's activities. It is crucial to brain function and to embryonic development. It has a **"9 + 0" pattern**, lacking the central pair of microtubules.

Microfilaments (aka. actin filaments) are thin solid rods which are built from actin, a globular protein. Each is a twisted double chain of actin subunits.

Microfilaments are found in the form of **linear filaments** and **structural networks**.

Functions of microtubules include:

-Bearing tension (pulling).

-Forming a 3-D network inside the plasma membrane **(cortical microfilaments)** which supports the cell's shape.

-Making up the core of **microvilli**.

-Supporting cell motility, muscle contraction, and amoeboid movement (seen in the unicellular eukaryote Amoeba and our white blood cells).

-Cytoplasmic streaming (circular flow of cytoplasm within large plant cells).

Intermediate filaments are named for their diameter, which is larger than the diameter of microfilaments but smaller than that of microtubules. They are only found in some animal cells, including vertebral cells. Each type is constructed from a particular molecular subunit belonging to a family of proteins whose members include the **keratins**.
Intermediate filaments are more permanent fixtures of cells than other filaments. Intermediate filaments retains the cell's shape after the removal of other filaments by chemical agents, and even after cells die, intermediate filament networks often persist (e.g. the outer layer of our skin consists of dead skin cells full of **keratin filaments).
Functions of intermediate filaments include bearing tension, reinforcing the shape of a cell and fixing the position of certain organelles (such as the nucleus), making up the nuclear lamina, and anchoring actin filaments in the intestinal **microvilli**.

Concept 7.7: Extracellular components and connections

- **The cell wall** is an extracellular structure of plant cells. It distinguishes plant cells from animal cells. It protects the plant cell, maintains its shape, prevents excessive uptake of water, and holds the plant up against the force of gravity.
- Prokaryotes, fungi, and some unicellular eukaryotes also have cell walls.
- Plant cell walls are thicker than the plasma membrane and the exact chemical composition of the wall varies from one cell type to another, but the basic design of the wall is consistent.
- Cellulose **microfibrils** *(discussed before)* are synthesized cellulose synthase and secreted to the extracellular space, where they become embedded in a matrix of other polysaccharides and proteins. This matrix is called "ground substance".
  - ➲ A young plant cell first secretes a relatively thin and flexible wall called the primary cell wall. Between the primary walls of adjacent cells is the middle lamella, a thin layer rich in sticky polysaccharides called **pectin**. The middle lamella glues adjacent cells together. When the cell matures and stops growing, it strengthens its wall, by (1) secreting hardening substances and (2) adding **secondary cell walls** between the plasma membrane and the primary wall. The secondary wall has several laminated layers and a strong matrix that protects and supports the cell (e.g. wood consists mainly of secondary walls). Plant cell walls are usually perforated by channels between adjacent cells called plasmodesmata.

- The main ingredients of the **ECM of animal cells** are **glycoproteins** and other **carbohydrate-containing** molecules secreted by the cells. The most abundant glycoprotein is collagen which is embedded in a network woven out of **proteoglycans** secreted by cells.
- A proteoglycan molecule consists of a small core **protein** plus many carbohydrate chains (covalently attached). **Large proteoglycan complexes** can form when hundreds of proteoglycan molecules become non-covalently attached to a single long polysaccharide molecule.
- Some cells are attached to the ECM by **ECM glycoproteins** such as fibronectin.
  Fibronectin and other ECM proteins bind to **cell-surface receptor** proteins called **integrins** that are built into the plasma membrane.
  Integrins span the membrane and bind on their cytoplasmic side to associated proteins attached to **microfilaments** of the cytoskeleton.
- Functions of the ECM include:
  1. Regulating the cell's behavior by communicating with a cell through integrins (e.g. cells in a developing embryo migrate along specific pathways by matching the orientation of their **microfilaments** to the "grain" of fibers in the ECM).
  2. Influencing the activity of genes in the nucleus.

Cell junctions in animal cells include:

1. Gap junctions (communicating junctions) provide channels between cells (similar to plasmodesmata in plants but gap junctions aren't surrounded by a membrane). They consist of membrane proteins that surround a pore. (e.g. heart cells and embryonic cells).

2. Tight junctions tighten the plasma membranes of neighboring cells; they form continuous seals around the cells and prevent leakage of ECF across a layer of epithelial cells (e.g. tight junctions between skin cells make us watertight).

3. Desmosomes (anchoring junctions) function like rivets, fastening cells together into strong sheets. Intermediate filaments -made of **keratin-** anchor desmosomes in the cytoplasm *(e.g. desmosomes attach muscle cells to each other in a muscle, and some "muscle tears" involve desmosomes' rupture).*

**All three types of cell junctions are especially common in epithelial tissue.

Walls of plant cells have plasmodesmata channels; cytosol passing through these channels joins the internal chemical environments *(water, solutes, certain proteins and RNA molecules)* of adjacent cells. The plasma membranes of adjacent cells line these channels and thus are continuous.

➲ ***Test your understanding***

1. The cellular junction that blocks the flow of fluid between adjacent epithelial cells is_____

A. None of the options is correct.
B. Gap junctions.←
C. All the options are correct.
D. Desmosomes.
E. Tight junctions.

2. Which of the following contains nine doublets of microtubules surrounding a pair of single microtubules?

A. Both flagella and motile cilia.←
B. Centrioles only.
A. Both motile cilia and microvilli.
C. Both centrioles and basal bodies.
D. Both basal bodies and microvilli.

3. Which of the following structures is found in eukaryotic but NOT prokaryotic cells?

A. Ribosomes.
B. Cytosol.
C. Mitochondria. ←
D. DNA.
E. Plasma membrane.

4. Elements of cytoskeleton in plant cells are_____

A. Chitin, microtubules, and intermediate filaments.
B. Microtubules, microfilaments, and intermediate filaments.
C. Cellulose, chitin, and microtubules.
D. Only microtubules and microfilaments. ←
E. Cellulose, microfilaments, and microtubules.

5. Compression-resisting girders that maintain cell shape are_____

A. Intermediate filaments.
B. All the options are correct.
C. Microtubules.←
D. Kertins.
E. Microfilaments.

6. Which of the following represents similarities between mitochondria and chloroplast?

A. Each organelle synthesizes some of its own protein.
B. Each contains a small amount of DNA.
C. Both are capable of semi-autonomous growth and reproduction.
D. Neither are components of the endomembrane system.
E. All the options are correct. ←

7. Which organelle or structure is absent in plant cells?

A. Centrosomes.←
B. Peroxisomes.
C. Golgi vesicles.
D. Microtubules.
E. Mitochondria.

8. Unlike a eukaryotic cell, a prokaryotic cell does not have a _____

a. DNA.
b. Cell membrane.
c. Cytoplasm.
d. Nucleus.←

9. Which plant cell organelle contains its own DNA and ribosomes?

A. Vacuole.
B. Golgi apparatus.
C. Peroxisome.
D. Glyoxysome.
E. Chloroplast.←

10. Steroid hormones are made by the_____

A. Ribosomes.
B. Rough ER.
C. Microsomes.
D. Lysosomes.
E. Smooth ER.←

11. Cytoplasmic connection(s) between adjacent eukaryotic cells occur(s) through_____

A. Plasmodesmata.
B. Desmosomes.
C. Tight junctions.
D. Either plasmodesmata or gap junctions.←
E. Gap junctions.

12. Which is common for both mitochondria and chloroplast

A. Both have DNA and ribosomes.
B. Both transform energy.
C. ATP is produced.
D. All the options are correct.←
E. Both are surrounded by two membranes.

13. Which of the following is mismatched?

A. Lysosome …… phagocytosis.
B. Central vacuole ……. Tonoplast.
C. Peroxisomes …… H_2O_2 breakdown.
D. Chloroplast ……. Thylakoid.
E. Microtubules ……. Muscle contraction.←

14. The extracellular matrix is_____

A. Composed mainly from cellulose.
B. Composed only from carbohydrate.
C. Found in animal cells. ←
D. All the options are correct.
E. Part of the cell membrane.

15. Which of the following pairs would be separated by differential centrifugation?

A. Ribosomes and microsomes.←
B. Na^+, K^+
C. $Cl^-, H_2PO_4^-$
D. Amino acid and glucose.
E. None of the above could be separated by this.

16. Which of the following is not part of the endomembrane system?

A. Nuclear envelope.
B. Golgi Apparatus.
C. Mitochondria.←
D. Endoplasmic reticulum.
E. Food Vacuole.

17. The structure -in the figure- functions in all the following except_____

A. Carbohydrate metabolism.
B. Steroid synthesis.
C. Calcium storage.
D. Drug detoxification.
E. Protein sorting and packaging.←

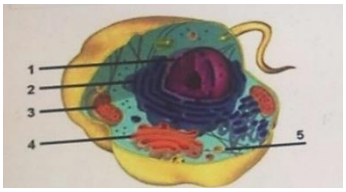
18. Intermediate filaments are involved in_____

A. Pseudopodia.
B. Spindle fibers.
C. Anchorage of the nucleus.
D. Nuclear lamina in animal cells.
E. C and D are correct.←

19. Which of the following is a function of the rER?

A. Synthesis of secretory proteins. ←
B. Synthesis of lipids.
C. Synthesis of cytoplasmic proteins.
D. Detoxification of drugs.
E. Stores calcium ions.

20. Which organelle is responsible for production of membrane proteins?



A. 1
B. 2 ←
C. 3
D. 4
E. 5

21. Microtubules are not involved in which of the following?

A. Cilia.
B. Flagella.
C. Spindle fiber.
D. Basel body.
E. Pseudopodia.←

22. In addition to nucleus, DNA is found also in the ____

A. Mitochondria.←
B. Cytoplasm.
C. Ribosome.
D. Golgi apparatus.
E. Nucleus.

23. Which of the following maintains the shape of the nucleus?

A. Nuclear lamina.←
B. Nuclear envelope.
C. Nucleolus.
D. Chromosomes.
E. Pore complex.

24. Materials in one animal cell might be able to enter an adjacent cell through_____

A. Tight junctions.
B. Gap junctions.←
C. Microtubules.
D. Plasmodesmata.
E. Desmosomes.

25. Ribosomes are_____

A. Made of chromatin.
B. Made of ribosomal RNA + protein.←
C. Typed into free or bound.
D. A and C.
E. B and C.

26. The enzymes responsible for synthesis of new membrane phospholipids are located in_____

A. Endoplasmic reticulum. ←
B. Nucleus.
C. Lysosomes.
D. Golgi apparatus.
E. Plasma membrane.

27. What is true about contractile vacuoles?

A. They digest organic macromolecules.
B. They remove excess fluids.←
C. They normally store internal compounds.
D. They have acidic environment.
E. They produce ATP.

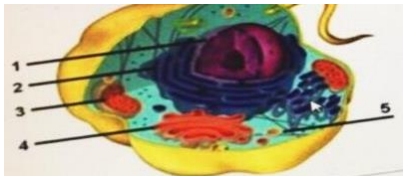
28. In what part of the nucleus does ribosome production occur?

A. Nuclear lamina.
B. Nuclear envelop.
C. Nucleolus.←
D. Pore Complex.

29. All the followings are associated with the extracellular matrix of animal cells except_____

A. Cholesterol.←
B. Carbohydrates.
C. Fibronectin.
D. Integrins.
E. Proteoglycans.

30. Which organelle has hydrolytic enzymes and acidic pH?



A. 1
B. 2
C. 3
D. 4
E. 5 ←

31. Which of the following contains hydrolytic enzymes?

A. Lysosome.←
B. Smooth endoplasmic reticulum.
C. Mitochondrion.
D. Golgi apparatus.
E. Peroxisome.

32. Intermediate filaments are involved in_____

A. Pseudopodia.
B. Spindle fibers.
C. Anchorage of the nucleus.
D. Nuclear lamina in animal cells.
E. C and D are correct.←

33. All the following cell components are found in prokaryotic cells except_____

A. DNA.
B. Ribosomes.
C. Cell membrane.
D. Nuclear envelope.←
E. Enzymes.

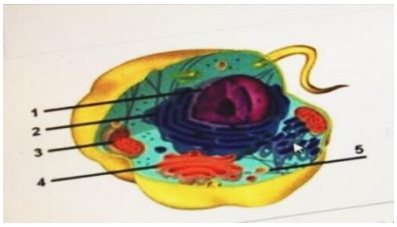
34. Which of the following is <u>not</u> an extracellular matrix component?

A. Collagen.
B. Proteoglycans.
C. Fibronectin.
D. Cellulose.←
E. B and C.

35. Which of the following organelles is directly involved in intracellular digestion of macromolecules?

A. Golgi apparatus.
B. Contractile vacuole.
C. Lysosomes.←
D. Central vacuole.
E. Food vacuole.

36. Which organelle controls the process of protein synthesis by production of mRNA?



A. 1 ←
B. 2
C. 3
D. 4
E. 5

37. Which of these pairs of organelles is responsible for energy conversion?

A. Mitochondrion and chloroplast.←
B. Vacuole and ribosome.
C. Centriole and lysosome.
D. Golgi apparatus and smooth ER.
E. All are correct.

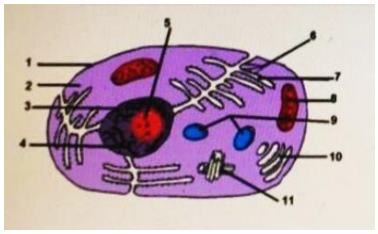
38. Which of the following structures contain enzymes for oxidizing small organic molecules with the formation of hydrogen peroxide?

A. Transport vesicles.
B. Ribosomes.
C. Vacuoles.
D. Peroxisomes.←
E. Lysosomes.

39. Viruses can be seen by:

A. Compound microscope.
B. Dissecting microscope.
C. Electron microscope.←
D. Unaided eye.
E. A, B and C.

40. Which part of the cell, indicated by a number, produces rRNA?



A. 10
B. 8
C. 5 ←
D. 11
E. 9

41. In which organelle does photosynthesis occur?

A. Chloroplast.←
B. Mitochondrion.
C. Nucleus.
D. Smooth endoplasmic reticulum.
E. Peroxisomes.

42. The middle lamella that joins plant cells is_____

A. Produced by the endoplasmic reticulum.
B. Produced by the Golgi apparatus.
C. Rich in sticky polysaccharides called pectin.←
D. Made of cellulose.
E. All are correct.

43. Which of the following organelles are interconnected and made of membranous tubules and sacs known as cisternae?

A. Golgi apparatus.
B. Smooth endoplasmic reticulum.
C. Rough endoplasmic reticulum.
D. B and C.
E. All the above. ←

44. Larger organisms don't have larger cells than smaller organisms, but have more cells because_____

A. Small cells have greater surface area to volume ratios.←
B. Small cells have smaller surface area to volume ratios.
C. Diffusion cannot occur in large cells.
D. Large cells have fewer metabolic reactions.
E. Small cells move faster than big cells.

45. The resolution of a microscope is a measure of the_____ of the image:

A. Contract.
B. Clarity.←
C. Magnification.
D. Wavelength.
E. B and C.

46. Which structure is the site of the synthesis of proteins that may be exported from the cell?

A. Free cytoplasmic ribosomes.
B. Lysosomes.
C. Rough ER.←
D. Plasmodesmata.
E. Golgi vesicles.

47. The liver is involved in detoxification of many poisons and drugs. Which of the following structures is primarily involved in this process and therefore abundant in liver cells?

A. Nuclear envelope.
B. Transport vesicles.
C. Golgi apparatus.
D. Rough ER.
E. Smooth ER.←

Chapter 8

Cell Membranes

Concept 8.1: Cellular membranes are fluid mosaic of lipids and proteins

- ✓ **Cell membranes** consist of lipids (mostly phospholipids), proteins and carbohydrate.
- ✓ Membrane lipids are an amphipathic molecule; each has both a hydrophilic and a hydrophobic region.
- ✓ Most membrane proteins are amphipathic (in the phospholipid bilayer with their hydrophilic regions protruding). This molecular orientation maximizes contact of hydrophilic regions of proteins and lipids with water in the **cytosol** and **extracellular fluid**, while providing their hydrophobic parts with a non-aqueous environment.
- ✓ The fluid mosaic model: the membrane is a mosaic of protein molecules bobbing in a fluid bilayer of phospholipids.
- ✓ Phospholipids form the main fabric, but proteins determine most of the cellular functions.

- ✓ Integral proteins are proteins that are **embedded** in the phospholipid bilayer (penetrate the hydrophobic interior), and most of them are **transmembrane proteins** (span the entire membrane). Their hydrophobic regions consist of one or more stretches of nonpolar amino acids, typically 20–30 amino acids in length, usually coiled into α helices. The **hydrophilic parts** of the molecule are exposed to the aqueous solutions on (1) **either side of the membrane**, and some also (2) **hydrophilic channels** that allow passage through the membrane of hydrophilic substances.
- ✓ Other proteins are attached to the **periphery** or to **integral proteins**, these are called peripheral proteins (not embedded in the lipid bilayer at all); they are **loosely** bound to the surface of membrane, often to exposed parts of integral proteins.
- ✓ On the cytoplasmic side of the membrane, some membrane proteins are attached to the cytoskeleton. On the extracellular side, some are attached to fibers of the ECM.
- ✓ In animal cells, the membrane also consists of **cholesterol** which acts as fluidity buffer. **Carbohydrates** are attached to membrane proteins forming glycoproteins or to lipids forming glycolipids.

A membrane remains fluid as temperature decreases **until the phospholipids settle into a closely packed arrangement and the membrane solidifies**.As the temperature decreases, the membrane remains fluid to a very **low** temperature if it is rich in phospholipids with **un**saturated hydrocarbon tails, because of kinks in the tail; unsaturated hydrocarbon tail cannot pack together as closely as saturated hydrocarbon tails making the membrane more fluid.

The steroid cholesterol has different effects on membrane fluidity at different temperatures; at moderate-high temperatures (e.g. at 37°C) cholesterol makes the membrane **less fluid by restraining phospholipid movement, however,** at lower temperatures, it hinders the close packing of phospholipids, so it lowers the temperature required for the membrane to solidify; thus, it resists changes in membrane fluidity that can be caused by

A membrane is held together mainly by **hydrophobic interactions** (weak).

Membrane lipids have a (1) **sideways movement** which is rapid, and (2) **a flip-flop movement** from layer to another (rare movement).

Proteins are larger than lipids and move more slowly; some membrane proteins do **drift,** and others are held **immobile.**

The membrane is a structural and functional mosaic

- Membrane proteins carry out several different functions, such as (1) **transport** through the cell membrane - like hydrophilic selective channels and carriers- , (2) **enzymatic activity**, (3) **signal transduction** – by acting as surface receptors with binding sites for chemical messengers like hormones-, (4) **cell-cell recognition** which provides short term connection between cells, (5) **intercellular joining** -by gap junctions or tight junctions that provide long lasting connection-, and (6) **attachment to the cytoskeleton and ECM** (cytoskeletal elements may be non-covalently bond to membrane proteins).

Sidedness of membranes; membranes have distinct inside and outside faces. The asymmetrical arrangement of proteins, lipids, and their associated carbohydrates in the plasma membrane is determined as the membrane is being built by the ER and Golgi apparatus.

Clinically!

A protein called CD4 on the surface of immune cells helps the human immunodeficiency virus (HIV) infect these cells, leading to acquired immune deficiency syndrome (AIDS).
CD4 is the **main** HIV receptor, and HIV must also bind to **CCR5** as a **"co-receptor"** to infect most cells. An absence of CCR5 prevents the virus from entering the cells.

➲ Interfering with CD4 causes dangerous side effects because of its many important functions in cells, so, CCR5 co-receptor is a safer target for drugs that mask this protein and block HIV entry (e.g. maraviroc (*Selzentry*)).

- **Cell-cell recognition** is important for (1) sorting of cells into tissues and organs in an animal embryo, and (2) the rejection of foreign cells by the immune system.
- Cells recognize other cells by binding to molecules, often containing **carbohydrates**, on the extracellular surface of the plasma membrane. Membrane carbohydrates are short and branched, and their binding to a protein or a lipid by **a covalent bond** forms a **glycoprotein** or a **glycolipid**, respectively. (glycoproteins **>>>** glycolipids)
- The four human blood types (A, B, AB, and O) reflect variation in the carbohydrate part of glycoproteins on the surface of red blood cells.

Concept 8.2: Membrane structure results in selective permeability

Cell membranes are selectively permeable and substances do not cross the barrier indiscriminately. The cell is able to take up some small molecules and ions and exclude others.

TRANSPORT PROTEINS

Hydrophilic substances (sugar, water, ions…etc.) can avoid contact with the lipid bilayer by passing through **transport proteins** that span the membrane.

A transport protein (channels and carriers) is **specific** for the substance it translocates (or a small group of related substances). For example, the glucose transporter is so selective that it even rejects fructose, a structural isomer of glucose.

THE LIPID BILAYER

Nonpolar molecules (C-H molecules), CO_2, and O_2, are **hydrophobic,** as are lipids. They can all dissolve in the lipid bilayer of the membrane and cross it easily, without the aid of membrane proteins, however, the hydrophobic interior of the membrane impedes direct passage through the membrane of ions and polar molecules (hydrophilic); polar molecules (e.g. glucose and water) *pass slowly* through the lipid bilayer and charged molecules are even less likely to penetrate the membrane.

Concept 8.3: Passive transport is diffusion of a substance across a membrane with no energy investment

Diffusion is the movement of particles into the available space (e.g. oxygen uptake in cellular respiration occurs by diffusion).

- ➲ Each substance diffuses down its own concentration gradient, unaffected by the concentration gradients of other substances.
- ➲ After a substance has diffused completely, removing its concentration gradient (no concentration difference), *molecules will still move,* but there will be no net movement of the number of molecules from one area to another (**dynamic equilibrium**).
- ➲ No work must be done to make this happen; diffusion is a spontaneous process, needing no input of energy.
- ➲ The concentration gradient itself represents potential energy, and membranes are selectively permeable, therefore, they have different effects on the rates of diffusion of various molecules.

Passive transport is the diffusion of molecules down their concentration gradient; from where they're more concentrated to where they're less concentrated without the consumption of energy. If the substance transported is hydrophobic, there's no need for transport proteins (simple diffusion). If the substance transported is hydrophilic, a transport protein is needed (facilitated diffusion).

Osmosis is the **diffusion** of **free water** across a selectively permeable membrane.
Water diffuses across membranes from the region of higher free water concentration (lower solute concentration) to that of lower free water concentration (higher solute concentration) until the solute concentrations on both sides of the membrane is more nearly equal.

Tonicity: the ability of a surrounding solution to cause a cell to gain or lose water. It's affected by (1) membrane permeability and (2) concentration of non-penetrating solutes (cannot cross the membrane relative to the inside the cell.

If an animal cell (NO CELL WALL) is immersed in an environment that is **isotonic** to the cell there will be no net movement of water across the plasma membrane (dynamic equilibrium state), and the cellular volume is stable. If an animal cell is immersed in a hypertonic environment (higher concentration of non-penetrating solutes) to the cell, water will leave the cell and the cell will shrivel, and probably die. If an animal cell is immersed in a hypotonic environment (lower concentration of non-penetrating solutes) to the cell, water will enter the cell faster than it leaves, and the cell will swell and lyse (burst).

WITH CELL WALL

The cells of plants, prokaryotes, fungi, and some unicellular eukaryotes are surrounded by cell walls. When a plant cell is immersed in a **hypotonic** solution, the cell wall helps maintain the cell's water balance; the cell swells as water enters by osmosis, however, the relatively inelastic cell wall will expand only so much before it exerts a back pressure on the cell, called turgor pressure, that opposes further water uptake. At this point, the cell is turgid (very firm), and this's the healthy state for most plant cells. If a plant's cells and surroundings are **isotonic**, there is no net tendency for water to enter and the cells become flaccid (limp); the plant wilts. A cell wall is of no advantage if the cell is immersed in a **hypertonic** environment. In this case, a plant cell will lose water to its surroundings and shrink. As the plant cell shrivels, its plasma membrane pulls away from the cell wall at multiple places. This phenomenon, called plasmolysis, causes the plant to **wilt** and can lead to plant death. [The walled cells of bacteria and fungi also plasmolyze in hypertonic environments]

Organisms that lack rigid cell walls must have adaptations for osmoregulation (the control of solute concentrations and water balance). *Examples:*

1. The unicellular Paramecium lives in pond water, which is hypotonic to the cell, since it has a plasma membrane that is much less permeable to water than the membranes of most other cells. Also, it has a contractile vacuole that pumps water out of the cell as fast as it enters by osmosis.
2. The bacteria and archaea that live in hyper-saline (excessively salty) environments have cellular mechanisms that ensure that water does not move out of the cell.

Concept 8.4: Active transport uses energy to move solutes against their gradients

To pump a solute across a membrane against its gradient requires work; the cell must expend energy. Therefore, this type of membrane traffic is called active transport. The **transport proteins** that move solutes against their concentration gradients are all carrier proteins rather than channel proteins. Active transport enables a cell to maintain internal concentrations of small solutes that differ from concentrations in its environment (e.g. the Na+_K+ pump pumps 3 Na^+ out and 2 K^+ inside). ATP powers active transport **(its terminal phosphate group is transferred to the transport protein changing its shape in a manner that translocates a solute bound to the protein across the membrane).**

Facilitated diffusion is the **passive diffusion** of hydrophilic molecules with the help of **transport proteins** that span the membrane. (1) Channels and (2) carriers are involved in facilitated diffusion (transport substances down their concentration gradient)

Facilitated diffusion **speeds** transport of a solute by providing efficient passage through the membrane, but it does not alter the direction of transport.

I) Channel proteins provide corridors (tunnels) that allow specific molecules or ions to cross the membrane. ***Examples:***

1. **Aquaporins** which allow water molecules or small ions to diffuse very **quickly** from one side of the membrane to the other (important in red blood cells and kidney cells).
2. Ion channels (transport ions) which are -usually -gated channels; they open and close in response to stimuli (e.g. electrical stimulus, and binding of a specific substance other than the one to be transported to the channel).

II) Carrier proteins, such as glucose transporters, seem to undergo a **change in shape** that somehow translocates the solute-binding site across the membrane. The change is triggered by the binding and release of the molecule.

The cytoplasmic side of the membrane is negative in charge relative to the extracellular side because of an unequal distribution of anions and cations on the two sides. This **voltage** is called a membrane potential (≈-50 to -200 mV). It acts as an energy source that affects the traffic of all charged substances across the membrane; it favors the **passive** transport of cations (+) **into** the cell and anions (-) **out** of the cell.
Two forces drive the diffusion of ions across a membrane; (1) chemical force (the ion's concentration gradient) and (2) electrical force (the effect of the membrane potential on the ion's movement). The combination is called the electrochemical gradient.

Na+ in the waste is reabsorbed in the colon and diarrhea expels waste so rapidly that reabsorption is not possible. To treat this, patients are given a solution to drink containing high concentrations of salt (NaCl) and glucose. The solutes are taken up by sodium-glucose co-transporters on the surface of intestinal cells into the blood.

Co-transport: a transport protein (called a co-transporter) couple the "downhill" passive diffusion of a solute to the “uphill” active transport of a second substance against its own concentration gradient. In other words, cotransport allows an ATP-powered pump to indirectly drive the active transport of a solute *(e.g. plant cell uses H+ gradient to drive the active transport of nutrients into the cell, also, H+/sucrose co-transporter couples the transport of sucrose into the cell only if the sucrose molecule travels in the company of an H+).*

Electro-genic pump: a transport protein that generates voltage across a membrane (e.g. Na+/K+ pump in animal cells, and H+ pump in plant cells, fungi, and bacteria).
A solute that exists in different concentrations across a membrane can do work as it moves across that membrane by diffusion down its concentration gradient (e.g. H+ gradient is used for ATP synthesis during respiration).

Concept 8.5: Bulk transport across the plasma membrane occurs by exocytosis and endocytosis

Large molecules (proteins and polysaccharides & larger particles) cross the membrane in bulk; packaged in vesicles (these processes require energy).

Exocytosis: secretion of certain molecules by the fusion of vesicles with the plasma membrane.
When the transport vesicle and plasma membrane come into contact, specific proteins rearrange the lipid molecules of the two bilayers so that the two membranes fuse. The contents of the vesicle spill out of the cell, and the vesicle membrane becomes part of the plasma membrane (e.g. pancreatic cells’ secretion of insulin, and neurons’ release of neurotransmitters, and plant cells’ secretion in making cell walls).

Endocytosis: the cell takes in molecules by forming new vesicles from the plasma membrane.
Although the proteins involved in the processes are different, the events of endocytosis look like the **reverse of exocytosis**; a small area of the plasma membrane sinks inward to form a pocket. As the pocket deepens, it pinches **in**, forming a vesicle containing material that had been outside the cell.

Types of endocytosis

In **phagocytosis**, a cell engulfs a particle by extending pseudopodia around it and packaging it within a food vacuole, and eventually, the particle will be digested after it fuses with a lysosome.
In **pinocytosis**, a cell "gulps" droplets of **extracellular fluid** into tiny vesicles. In some cases, the parts of the membrane that form vesicles are lined on their cytoplasmic side by a fuzzy layer of coat protein; the “pits” and resulting vesicles are said to be "coated."
Receptor-mediated endocytosis is a specialized type of **pinocytosis** that enables the cell to acquire bulk quantities of specific substances that may not be very concentrated in the extracellular fluid (e.g. cholesterol uptake; it travels in the blood in particles called low-density lipoproteins (LDLs) which bind to LDL receptors on plasma membranes and then enter the cells).
In the inherited disease familial hypercholesterolemia (high level of cholesterol in the blood), LDLs cannot enter cells because the LDL receptor proteins are defective or missing. Consequently, cholesterol accumulates in the blood, where it contributes to early atherosclerosis which narrows the space in the vessels and impedes blood flow, potentially resulting in heart damage and stroke.

➲ ***Test your understanding***:

1. Which of the following is a characteristic feature of a carrier protein in a plasma membrane?

A. It requires the expenditure of cellular energy to function.
B. It works against diffusion.
C. It has few, if any, hydrophobic amino acids.
D. It exhibits a specificity for a particular type of molecule.←
E. It is a peripheral membrane protein.

2. Which of the following is true of integral membrane proteins?

A. They serve only a structural role in membranes.
B. They are tightly bound to the bilayer. ←
C. They are not mobile within the bilayer.
D. They lack tertiary structure.
E. They are loosely bound to the surface of the bilayer.

3. Ions diffuse across membranes through specific ion channels_____

A. Down their concentration gradients.
B. Down their electrochemical gradients. ←
C. Down their chemical gradients.
D. Down the osmotic potential gradients.
E. Down the electrical gradients.

4. According to the fluid mosaic model of cell membranes, which type of molecule spans the membrane, from its inner to outer surface?

A. Cholesterol.
B. Fatty acids.
C. Proteins. ←
D. All of the options are correct.
E. Carbohydrates.

5. What is the difference between active transport (AT) and facilitated diffusion (FD)?

A. AT requires protein carriers; FD does not.
B. AT requires energy; FD does not. ←
C. AT requires a membrane; FD does not.
D. AT transport materials down the concentration gradient; FD does not.
E. All of the options are correct.

6. Which of the following statements correctly describes the normal tonicity conditions for typical plant and animal cells?

A. The animal cell is in a hypertonic solution, and the plant cell is in an isotonic solution.
B. The animal cell is in an isotonic solution, and the plant cell is in a hypotonic solution. ←
C. The animal cell is in an isotonic solution, and the plant cell is in a hypertonic solution.
D. The animal cell is in a hypertonic solution, and the plant cell is in a hypotonic solution.
E. The animal cell is in a hypotonic solution, and the plant cell is in an isotonic solution.

7. In animal cell membranes, cholesterol molecules act to_____

A. Help hold a membrane together.
B. Transport ions across membranes.
C. None of the options is correct.←
D. Increase the fluidity of the membrane.
E. Attach to some proteins.

8. Which of the following statements about co-transport across a membrane is correct?

A. Cotransport proteins allow an ATP-powered pump to indirectly drive the active transport of a solute.←
B. The sodium-potassium pump is an example of a cotransport protein.
C. In cotransport, both solutes that are being transported are moving down their chemical gradients.
D. A cotransport protein is most commonly an ion channel.
E. Cotransport involves the hydrolysis of ATP by the transporting protein.

9. Which of the following types of molecules are the major structural components of the cell membrane?

A. Nucleic acids and proteins.
B. Proteins and cellulose.
C. Phospholipids and proteins. ←
D. Phospholipids and cellulose.
E. Glycoproteins and cholesterol.

10. Pinocytosis is one type of_____

A. Facilitated transport.
B. Active transport.
C. Diffusion.
D. Endocytosis. ←
E. Exocytosis.

11. Which of the following processes include all others?

A. Osmosis.
B. Passive transport. ←
C. Transport of an ion down its electrochemical gradient.
D. Facilitated diffusion.
E. Diffusion of a solute across membrane.

12. According to the fluid mosaic model of membrane structure, proteins of the membrane are mostly____

A. Fluid in nature.
B. Non-functional.
C. Confined to the hydrophobic core of the membrane.
D. Embedded in a phospholipid bilayer.←
E. Spread as a continuous layer over the inner and outer surfaces of the membrane.

13. _____is biological process for ATP production in cellular respiration and photosynthesis.

A. Coupling.←
B. Electron.
C. Pyruvate oxidation.
D. Chemiosmosis.
E. Glycolysis.

14. What is likely to happen to a plant cell that is placed in pure water?

A. It becomes flaccid.
B. None of the options are correct.
C. It bursts.
D. It becomes turgid. ←
E. It undergoes plasmolysis.

15. Which of the following processes in the cell uses transport proteins?

A. All of the options.
B. Cotransport. ←
C. Exocytosis.
D. Simple diffusion.
E. Pinocytosis.

16. Singer and Nicolson's fluid mosaic model of the membrane proposed that_____

A. Membranes consist of protein molecules embedded in a fluid bilayer of phospholipids.←
B. Membranes are a phospholipid bilayer.
C. Membranes are a single layer of phospholipids and proteins.
D. Membranes consist of a mosaic of polysaccharides and proteins.
E. Membranes are a phospholipid bilayer between two layers of hydrophilic proteins.

17. What kinds of molecules pass through a cell membrane most easily?

A. Large polar.
B. Small and hydrophobic.←
C. Large and hydrophobic.
D. Ionic.
E. Monosaccharides such as glucose.

18. In order for a protein to be an integral membrane protein it would have to be_____

A. Completely covered with phospholipids.
B. Amphipathic, with at least one hydrophobic region.←
C. Exposed on only one surface of the membrane.
D. Hydrophilic.
E. Hydrophobic.

19. When a plant cell, such as one from a peony stem, is submerged in a very hypotonic solution, what is likely to occur?

A. The cell will burst.
B. The cell will become turgid.←
C. Plasmolysis will shrink the interior.
D. The cell will become flaccid.
E. The cell membrane will lyse.

20. Molecules that can diffuse across a membrane include_____

A. Lipoproteins.
B. Proteins.
C. Small nonpolar molecules.←
D. Ions.
E. Small polar molecules.

21. According to the fluid mosaic model, peripheral membrane proteins_____

A. Can be loosely attached to phospholipids.
B. Can be loosely attached to integral proteins.
C. Are transmembrane proteins.
D. A and B are correct.←
E. A, B and C are correct.

22. Which of the following is involved in the Na+ passive transport across plasma membrane?

A. ATP.
B. Electrical membrane potential (electrical force).
C. Gated channel proteins.
D. Na+ concentration gradient (chemical force).
E. B and D are correct.←

23. Nonpolar small hydrocarbons, CO2, and O2 cross the membrane by_____

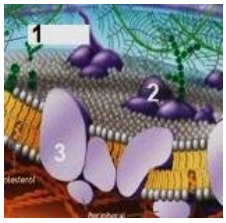
A. Simple diffusion.←
B. Active transport.
C. Facilitated diffusion.
D. Bulk transport.
E. Co-transport.

24. Water passes quickly through cell membranes because_____

A. It is a small polar molecule.
B. Its movement is driven by ATP hydrolysis.
C. It moves through aquaporins.←
D. The membrane bilayer is hydrophilic.
E. The membrane bilayer is hydrophobic.

25. **Which structure can be an ABO blood group marker?**

A. 1←
B. 3
C. 4
D. 5
E. 6



26. What would happen if a plant cell is placed in a hypotonic environment?

A. The cell becomes plasmolyzed.
B. The cell becomes turgid.←
C. The cell loses H2O to its environment.
D. H2O flows at the same rate in both directions across the plasma membrane.
E. None of the above.

27. Which of the following functions of membrane proteins involves surface carbohydrates?

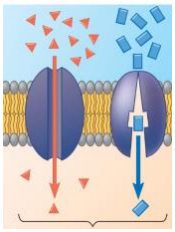
A. Cell-cell recognition.←
B. Enzymatic activity.
C. Transport.
D. Intercellular joining.
E. None of the above.

28. Which one of the following is hydrophobic?

A. NaCl
B. Glycerol.
C. Triacylglycerol.←
D. Starch.
E. Cellulose.

29. The figure shows a _____

A. Co-transport.
B. Osmosis.
C. Ion pumping.
D. Facilitated diffusion.←
E. Phagocytosis.

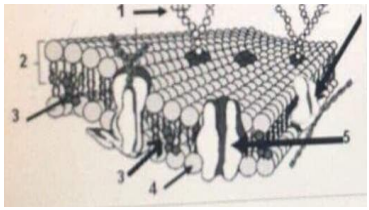


30. Carrier proteins and ATP are required for_____

A. Osmosis.
B. Facilitated diffusion.
C. Active transport.←
D. Phagocytosis.
E. A, B and C.

31. Which structure can function as aquaporin?

A. 1
B. 2
C. 3
D. 4
E. 5 ←



32. Which of the following molecules act as a fluidity buffer in animal's cell membrane?

A. Saturated fatty acids.
B. Unsaturated fatty acids.
C. Cholesterol.←
D. Integral proteins.
E. Glycolipids.

Chapter 10

Cellular respiration

Concept 10.1: Catabolic pathways yield energy by oxidizing organic fuels

Anabolic pathways: metabolic pathways that require energy to synthesize larger molecules.
Catabolic pathways: metabolic pathways that release energy by breaking down molecules.
Organic compounds possess **potential energy** as a result of the arrangement of electrons in the bonds between their atoms. Compounds that can participate in exergonic reactions can act as fuels.
Examples on catabolic pathways:
(1) Fermentation; which is partial degradation of organic fuel without the use of oxygen.
(2) Aerobic respiration which is the most effective and in which oxygen is used.
(3) Anaerobic respiration which is similar to aerobic but with the use of substances other than oxygen.
Cellular respiration includes both aerobic and anaerobic processes. However, it originated as a synonym for aerobic respiration because of the relationship of that process to organismal respiration, in which an animal breathes in oxygen.
The breakdown of glucose is exergonic, having a free-energy change of -686 kcal (2,870 kJ) per mole of glucose decomposed (ΔG = -686 kcal/mol).
Catabolism is linked to work **indirectly** by a chemical drive shaft (**ATP**). To keep working, the cell must regenerate its supply of ATP from ADP and ~P.

Oxidation-Reduction reaction: transfer of one or more electrons (e) from one reactant to another (e.g. cellular respiration).
Oxidation involves the **loss** of electrons while reduction involves the **addition** of electrons **(reduce the positive charge).**
Reducing agent is the substance that has been oxidized (electron donor), and **oxidizing agent** is the substance that has been reduced (electron acceptor). Oxidation and reduction always go hand in hand.

When methane CH3 reacts with oxygen, forming carbon dioxide, electrons end up shared **less equally between the carbon atom and oxygen atoms** which are very electronegative. The carbon atom has partially "lost" its shared electrons; thus, methane has been oxidized and each oxygen atom has partially "gained" electrons, so the oxygen molecule has been reduced.
Energy must be added to pull an electron away from an atom. **The more electronegative the atom (the stronger its pull on electrons), the more energy is required to take an electron away from it.** Thus, an electron **loses** potential energy when it shifts from a less electronegative atom toward a more electronegative one.

The hydrogen atoms are passed first to an electron carrier, a co-enzyme called nicotinamide adenine dinucleotide, a derivative of the vitamin niacin. *This coenzyme is an electron carrier because it can cycle easily between **its oxidized form NAD+ (electron acceptor)** and its **reduced form NADH (electron donor).***

Enzymes called dehydrogenases **remove a pair of hydrogen** atoms (2 electrons and 2 H+) from the substrate, thereby **oxidizing it**. The enzyme delivers the 2 electrons along with 1 H+ to its coenzyme, NAD+, forming NADH. The other H+ is released.

Electrons **lose** very little of their potential energy when they are transferred from glucose to NAD+. This stored energy can be used to make ATP when the electrons complete their "fall" down an energy gradient from NADH to oxygen. O2 captures these electrons along with hydrogen nuclei (H+), forming water. Electron transfer from NADH to oxygen is an exergonic reaction with a free-energy change of -53 kcal/mol (-222 kJ/mol).

Organic molecules that have an abundance of hydrogen are excellent fuels because their bonds are a source of electrons; hydrogen is transferred from glucose to oxygen and the energy state of the **electron** changes as hydrogen (with its electron) is transferred to oxygen. In general, fuels with multiple C—H bonds oxidized into products with multiple C—O bonds. In respiration, glucose is broken down in a series of steps, each one catalyzed by an enzyme; electrons are stripped from the glucose; each with a proton.
[Proton + electron = hydrogen atom]

- An electron transport chain consists of a number of molecules, mostly proteins, built into the inner membrane of the mitochondria of eukaryotic cells (and the plasma membrane of respiring prokaryotes).
- Electrons cascade down the chain from one carrier molecule to the next in a series of redox energy-releasing reactions in the electron transport chain, losing a small amount of energy with each step until they finally reach oxygen, the terminal electron acceptor, which has a very great affinity for electrons.
- Anaerobically respiring prokaryotes have an electron acceptor that is different from O2.

Concept 10.2: Glycolysis harvests chemical energy by oxidizing glucose

In glycolysis, glucose is split into two three-carbon sugars (**two molecules of pyruvate)** with no release of CO2. It is divided into two phases; (1) the energy investment phase (spends 2 ATP), and (2) the energy payoff phase (produces 4 ATP **by substrate level phosphorylation,** 2 NADH, 2 H2O, and 2 pyruvate). The net energy yield from glycolysis, per glucose molecule, is 2 ATP plus 2 NADH. It occurs whether or not O2 is present, but if O2 is present, the chemical energy stored in pyruvate and NADH can be extracted by pyruvate oxidation, the citric acid cycle, and oxidative phosphorylation.

Substrate-level phosphorylation ➡ transfer a phosphate group **from a substrate** to ADP, rather than adding an inorganic phosphate to ADP as in oxidative phosphorylation.

Glycolysis occurs in **10 steps** (each phase has 5 steps).

1. Hexokinase transfers a phosphate group from ATP to glucose,making it more chemically reactive. The charge on the phosphate also traps the sugar in the cell.
2. Phosphoglucoisomerase converts glucose 6-phosphate to fructose 6-phosphate.
3. Phosphofructokinase transfers a phosphate group from ATP to the opposite end of the sugar, investing a second molecule of ATP. This is a key step for regulation of glycolysis.
4. Aldolase cleaves the sugar molecule into two different three-carbon sugars.
5. Isomerase converts Dihydroxyacetone phosphate (DHAP) to Glyceraldehyde 3-phosphate (G3P) and (G3P) to (DHAP); this reaction never reaches equilibrium because G3P is used in the next step as fast as it forms.
6. Two sequential reactions by triose phosphate dehydrogenase: (1) G3P is oxidized by the transfer of electrons to NAD+, forming NADH. (2) energy from this exergonic redox reaction is used in the attachment of a phosphate group to the oxidized substrate, making a high-energy product.
7. The phosphate group is transferred to ADP (by phosphoglycerokinase) in an exergonic reaction. The carbonyl group of G3P has been oxidized to the carboxyl group (—COO–) of an organic acid (3-phosphoglycerate).
8. Phosphoglyceromutase relocates the remaining phosphate group.
9. Enolase causes a double bond to form in the substrate by extracting a water molecule, yielding phosphoenolpyruvate (PEP), a compound with a very high potential energy.
10. Pyruvate kinase transfer a phosphate group from PEP to ADP forming pyruvate.

Concept 10.3: After pyruvate is oxidized, the citric acid cycle completes the energy-yielding oxidation of organic molecules

When O2 is present; the pyruvate in eukaryotic cells enters a mitochondrion, where the oxidation of glucose is **completed**. In aerobically respiring prokaryotic cells, this process occurs in the **cytosol**. Pyruvate is a charged molecule, so it must enter the mitochondrion via active transport, with the help of a transport protein. This oxidation is carried out by a multi-enzyme complex (pyruvate dehydrogenase complex) that catalyzes three reactions:
1) Pyruvate's carboxyl group-COO is released and given off as a molecule of CO2.

2) The remaining two-carbon fragments get oxidized and the electrons are transferred to NAD+, storing energy in the form of NADH.

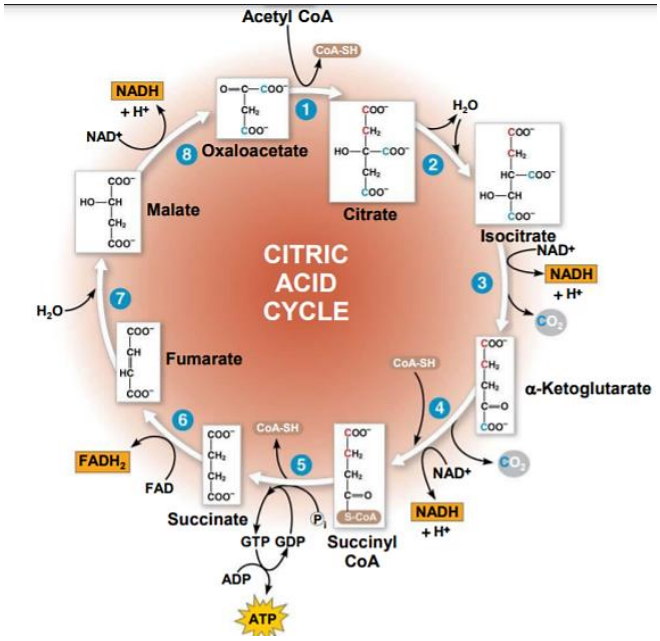
3) Coenzyme A (CoA), **a sulfur-containing** compound derived from a B vitamin, is attached via its sulfur atom to the two-carbon intermediate, forming acetyl CoA.

The Citric Acid Cycle (Krebs cycle – Tricarboxylic acid cycle)

Each acetyl CoA that enters the cycles produces: 1 ATP (substrate level phosphorylation), 3 NADH, 1 FADH2 and 2 CO2 **(for each glucose, double the products since each glucose gives 2 pyruvates ➡2 acetyl CoA).**

The citric acid cycle consists of 8 steps → In eukaryotic cells, all the citric acid cycle enzymes are located in the mitochondrial matrix except for the enzyme that catalyzes **step 6**, which resides in the inner mitochondrial membrane.

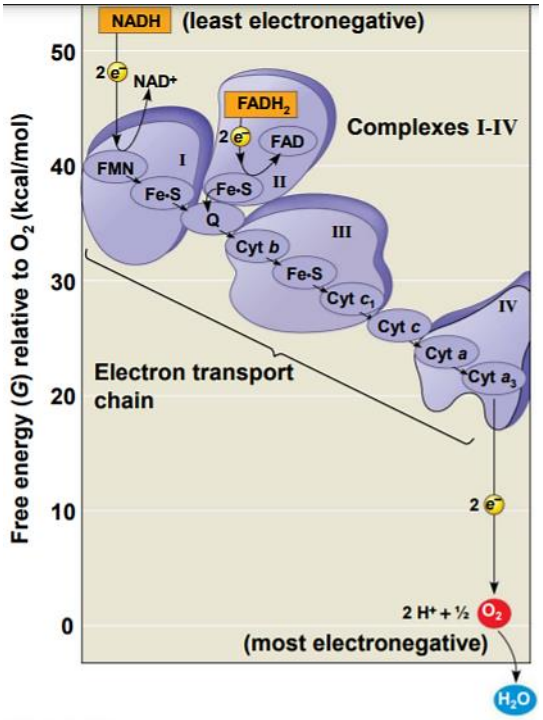
➲ FAD (flavin adenine dinucleotide) is derived from riboflavin (a B vitamin).



Concept10.4: During oxidative phosphorylation, chemiosmosis couples electron transport to ATP synthesis

Electron transport chain

1. Oxidative phosphrylation = electron transport chain + chemiosmosis.
2. NADH and FADH2 account for most of the energy extracted from each glucose molecule.
3. The electron transport chain consists of molecules embedded in the inner membrane of the mitochondrion in eukaryotic cells. In prokaryotes, these molecules reside in the plasma membrane.
4. The folding of the inner membrane to form cristae increases its surface area, providing space for thousands of copies of each component. Most of these components are proteins, which exist in multi-protein complexes numbered through IV (1 to 4).Tightly bound to these proteins are prosthetic groups, non-protein components such as **cofactors** and **coenzymes** essential for the catalysis.
5. Complex (I) is **a flavoprotein** since it has a prosthetic group called flavin mononucleotide (FMN).
6. **Q (ubiquinone) electron carrier is a small hydrophobic molecule, the only member of the electron transport chain that is not a protein. Ubiquinone is individually mobile within the membrane rather than residing in a particular complex.** It's also called coenzyme Q. Most of the remaining electron carriers between ubiquinone and oxygen are proteins called **cytochromes.** Their prosthetic group, called **a heme group**, has an iron atom that accepts and donates electrons.
7. Each oxygen atom also picks up a pair of hydrogen ions (protons) from the aqueous solution, neutralizing the -2 charge of the added electrons and forming water.
8. $FADH_2$ adds its electrons from within complex II, at a **lower energy level than NADH does.** Although NADH and FADH2 each donate two electrons for oxygen reduction, the electron transport chain provides about **one-third less energy for ATP synthesis when the electron donor is $FADH_2$ rather than NADH**.



Chemiosmosis (energy-coupling) is the process in which energy stored in the form of a hydrogen ion gradient across a membrane is used to drive cellular work such as the synthesis of ATP. The electron transport chain uses the exergonic flow of electrons from NADH and FADH2 to pump H+ across the membrane, from the mitochondrial matrix into the intermembrane space. ATP synthase uses the exergonic flow of H+ (from the intermembrane space back to the matrix) to drive the phosphorylation of ADP. Thus, the energy stored in an H+ gradient across a membrane couples the redox reactions of the electron transport chain to ATP synthesis. Proton-motive force is the H+ gradient across the inner mitochondrial membrane.

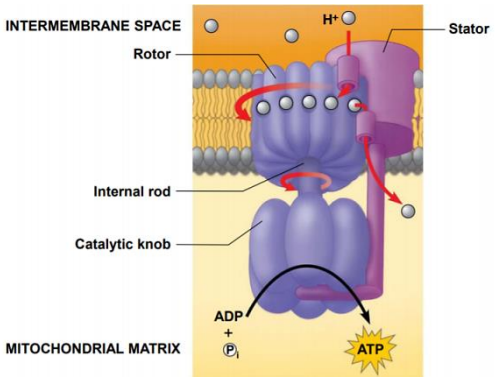
Plants (chloroplasts) and prokaryotes

Chloroplasts use chemiosmosis to generate ATP during photosynthesis; light (rather than chemical energy) drives both electron flow down an electron transport chain and H+ gradient formation. **Prokaryotes** generate H+ gradients (proton-motive force) to make ATP inside the cell, to rotate their flagella, and to pump nutrients and waste products.

- Brown fat is made up of cells packed full of mitochondria, it helps in heating the body.
- The inner mitochondrial membrane contains a channel protein called the uncoupling protein that allows protons to flow back down their concentration gradient **without generating ATP.** Activation of these proteins in hibernating mammals results in **ongoing oxidation** of stored fuel (fats), generating heat without ATP.

ATP synthase

Populating the inner membrane of the mitochondrion or the prokaryotic plasma membrane are many copies of a protein complex called ATP synthase (makes ATP from ADP and inorganic phosphate). It works like an ion pump running in reverse; rather than hydrolyzing ATP to pump protons against their concentration gradient, under the conditions of cellular respiration ATP synthase uses the energy of an existing ion gradient to power ATP synthesis. The power source for ATP synthase is a difference in the concentration of H+ on opposite sides of the inner mitochondrial membrane. It is a multi-subunit complex with four main parts, each made up of multiple polypeptides. Protons move one by one into binding sites on one of the parts (the rotor), causing it to spin in a way that catalyzes ATP production from ADP and inorganic phosphate.



Concept 10.5: Fermentation and anaerobic respiration enable cells to produce ATP without O2

Cells can oxidize organic fuel and generate ATP without the use of oxygen by:

(1) Anaerobic respiration (an electron transport chain is used).

(2) Fermentation (no electron transport chain).

Anaerobic respiration:

Organisms have an electron transport chain but do not use oxygen as a final electron acceptor at the end of the chain. Oxygen is extremely electronegative, although other substances are less electronegative, they also serve as final electron acceptors. Some "sulfate-reducing" marine bacteria, for instance, use the sulfate ion (SO_4^{2-}) at the end of their respiratory chain. Its produces ATP, but H2S (hydrogen sulfide) is made as a by-product rather than water.

Fermentation: (1+2)

Fermentation is an extension of glycolysis that allows continuous generation of ATP by the substrate-level phosphorylation of glycolysis **(without O2 or ETC).**

For this to occur there must be a sufficient supply of NAD+ to accept electrons during the oxidation step of glycolysis. Without some mechanism to recycle NAD+ from NADH, glycolysis would soon deplete the cell's pool of NAD+ by reducing it all to NADH and would shut itself down for lack of an oxidizing agent; that's why electrons are transferred from NADH to pyruvate (the end product of glycolysis).

The NAD+ can then be reused to oxidize sugar by glycolysis, which nets two molecules of ATP by substrate-level phosphorylation (fermentation includes glycolysis plus reactions that regenerate NAD+ by transferring electrons from NADH to pyruvate or derivatives of pyruvate).

1. Lactic acid fermentation (fungi and bacteria; in cheese and yogurt)

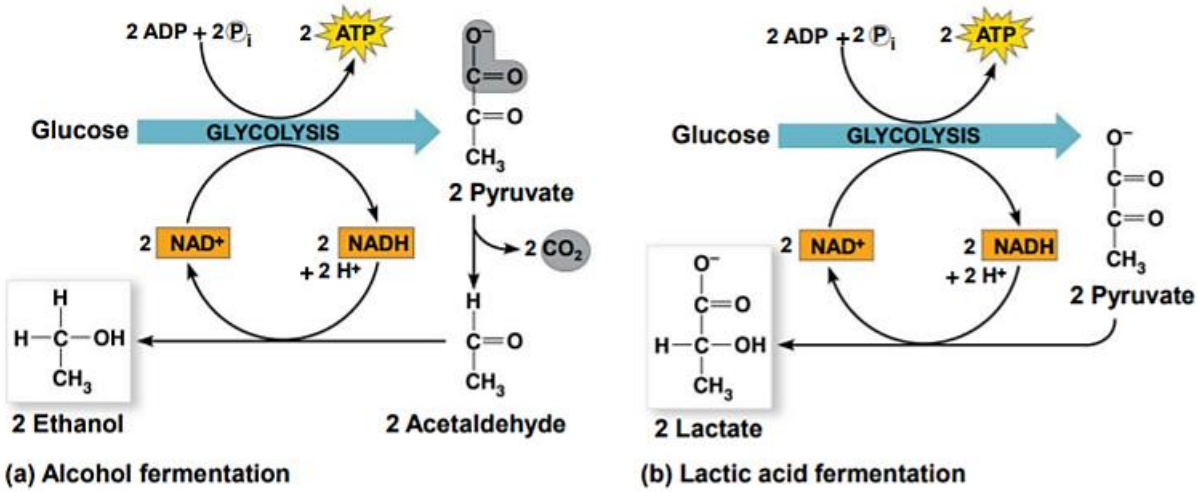
1) Pyruvate is reduced directly by NADH to form lactate as an end product (NO CO2 release).
2) Lactate is the ionized form of lactic acid.

Human muscle cells make ATP by lactic acid fermentation when oxygen is scarce. This occurs during strenuous exercise, when sugar catabolism for ATP production outpaces the muscle's supply of oxygen from the blood (lactate accumulation causes the muscle fatigue and pain).

Blood carries the excess lactate from the muscles to the liver, where it is converted back to pyruvate by liver cells and this pyruvate can then enter the mitochondria in liver cells and complete cellular respiration (since O2 is available now).

2. Alcohol fermentation (bacteria and yeast; in baking and brewing)

1) Pyruvate is converted to ***acetaldehyde*** by releasing CO2.
2) ***Acetaldehyde*** is reduced by NADH to ethanol.



ATP calculations (for cellular respiration)

The total number of ATP produced is inexact (either 30 or 32). *Why?*

1. Phosphorylation and the redox reactions are not **directly** coupled to each other, so the ratio of the number of NADH molecules to the number of ATP molecules is not a whole number.
   1 NADH results in 10 H+ being transported out across the inner mitochondrial membrane. The number of H+ that must reenter the mitochondrial matrix via ATP synthase to synthesize 1 ATP is 4 (1 NADH ➡2.5 ATP). And a single molecule of FADH2 generates enough proton motive force for the synthesis of 1.5 ATP.
2. The ATP yield varies slightly depending on the type of shuttle used to **transport electrons from the cytosol into the mitochondrion;** *the 2 electrons of NADH captured in glycolysis must be conveyed into the mitochondrion by one of **several electron shuttle systems**; If the electrons are passed to FAD, as in brain cells, only about 1.5 ATP can result from each NADH that was originally generated in the cytosol. If they're passed to mitochondrial NAD+, as in liver cells and heart cells, the yield is about 2.5 ATP per NADH.*
3. The use of the proton-motive force generated by the redox reactions of respiration to drive other kinds of work (e.g. uptake of pyruvate from the cytosol).

- If all the proton-motive force were used to drive ATP synthesis, one glucose could generate a maximum of 28 ATP produced by oxidative phosphorylation + 4 ATP from substrate-level phosphorylation to give a total yield of about 32 ATP (or 30 ATP if the less efficient shuttle were functioning).
- Glucose oxidation releases 686 kcal of energy under standard conditions (G = -686 kcal/mol), and phosphorylation of ADP to form ATP stores at least 7.3 kcal per mole of ATP. Thus, the total amount of energy consumed to produce 32 ATP➡ 7.3*32= 233.6 Kcal. Divide this number by the total amount of energy produced 233.6/686 = 34% of the potential chemical energy in glucose has been transferred to ATP. The rest of the energy stored in glucose is lost as **heat.**

Comparing Fermentation with Anaerobic and Aerobic Respiration

- ✓ All three use glycolysis to oxidize glucose and other organic fuels to pyruvate, with a net production of 2 ATP by substrate - level phosphorylation, with the use of NAD+ as the oxidizing agent.
- ✓ They differ in the mechanisms that oxidize NADH back to NAD+, which is required to sustain glycolysis. In fermentation, the final electron acceptor is an organic molecule such as pyruvate (lactic acid fermentation) or acetaldehyde (alcohol fermentation), whereas in cellular respiration, electrons carried by NADH are transferred to an electron transport chain, which regenerates the NAD+ required for glycolysis. Also, fermentation yields 2 ATP, cellular respiration yields 32 ATP.
- ✓ **Obligate anaerobes** carry out only fermentation or anaerobic respiration (they cannot survive in the presence of oxygen). Brain cells carry out only aerobic oxidation of pyruvate, not fermentation.
- ✓ **Facultative anaerobes** make enough ATP to survive using either fermentation or respiration (e.g. yeast and bacteria). Our muscle cells behave as facultative anaerobes; pyruvate leads to two alternative catabolic routes; under aerobic conditions, pyruvate can be converted to acetyl CoA, and oxidation continues in the citric acid cycle via aerobic respiration, however, under anaerobic conditions, lactic acid fermentation occurs, and to make the same amount of ATP**, a facultative anaerobe has to consume sugar at a much faster rate when fermenting than when respiring.**

Concept 10.6: Glycolysis and the citric acid cycle connect to many other metabolic pathways

Glycolysis and Krebs cycle in anabolism

Compounds formed as intermediates of glycolysis and the citric acid cycle can be diverted into anabolic pathways as precursors from which the cell can synthesize the **molecules it requires.** For example:

1) Humans can make about half of the 20 amino acids in proteins by modifying compounds siphoned away from the citric acid cycle; the rest are "essential amino acids" that must be obtained in the **diet.**
2) Glucose can be made from **pyruvate**, and **fatty acids** can be synthesized from **acetyl CoA.**

Glycolysis and the citric acid cycle function as metabolic interchanges that enable our cells to convert some kinds of molecules to others as we need them (e.g. DHAP can be converted to one of the major precursors of fats).

Glycolysis and Krebs cycle in catabolism

Starch is hydrolyzed to glucose, which can then be broken down in the cells by glycolysis and the citric acid cycle. Glycogen can be hydrolyzed to glucose between meals as fuel for respiration. Disaccharides (e.g. sucrose) provide glucose and other monosaccharides as fuel for respiration.

Proteins must be digested to amino acids which are used to build new proteins. Amino acids present in excess are converted by enzymes **to intermediates of glycolysis** and **the citric acid cycle** (e.g. pyruvate and acetyl CoA).
Before amino acids can feed into glycolysis or the citric acid cycle, their amino groups must be removed, a process called **deamination**.
The nitrogenous waste is excreted from the animal in the form of ammonia (NH3), urea, or other waste products.
After fats are digested to **glycerol and fatty acids,** the **glycerol** is converted to **glyceraldehyde 3-phosphate** (an intermediate of glycolysis), however, most of the energy of a fat is stored in the fatty acids; **beta oxidation** breaks the fatty acids down to two-carbon fragments, which enter the **citric acid cycle as acetyl CoA**. NADH and FADH2 are also generated during beta oxidation; they can enter the electron transport chain, leading to further ATP production.
Fats are excellent fuels, in large part due to their chemical structure and the high energy level of their electrons (present in many C-H bonds, equally shared between carbon and hydrogen) compared to those of carbohydrates. *A gram of fat oxidized by respiration produces more than twice as much ATP as a gram of carbohydrate.*

Regulation of Cellular Respiration via Feedback Mechanisms

Feedback inhibition happens when the end product of the anabolic pathway inhibits the enzyme that catalyzes an early step of the pathway.
The cell controls its catabolism; if the cell is working hard and its ATP concentration begins to drop, respiration speeds up. When there is plenty of ATP to meet demand, respiration slows down, sparing valuable organic molecules for other functions.
Phosphofructokinase step is the first step that commits the substrate irreversibly to the glycolytic pathway. By controlling the rate of this step, the cell can speed up or slow down the entire catabolic process. Phosphofructokinase can thus be considered the pacemaker of respiration.

➲ ***Test you understanding***

1. Which of the following processes does not produce carbon dioxide?

A. Krebs cycle.
B. Alcohol fermentation.
C. Oxidation of pyruvate.
D. Lactic acid fermentation. ←

2. The overall yield of ATP in glycolysis is_____

A. 6
B. 1
C. 4
D. 2 ←

3. What are the REACTANTS for cellular respiration?

A. Carbon dioxide and water.
B. Water and glucose.
C. Oxygen and carbon dioxide.
D. Glucose and oxygen.←

4. Which of the following is NOT correct regarding the electron transport chain?

A. Creates a proton gradient.
B. Makes ATP using a proton gradient.←
C. Oxidize NADH to NAD+.
D. Oxidize FADH2 to FAD+.

5. Carbon dioxide (CO_2) is released which of the following stages of cellular respiration?

A. Glycolysis and the oxidation of pyruvate to acetyl CoA.
B. The citric acid cycle and oxidative phosphorylation.
C. Oxidative phosphorylation and fermentation.
D. Fermentation and glycolysis.
E. Oxidation of pyruvate to acetyl CoA and the citric acid cycle.←

6. When glucose is broken down to carbon dioxide and water during cellular respiration, approximately 60% of its energy is released as_____

A. ATP.
B. Heat.←
C. NADH.
D. Oxygen.
E. CO_2.

7. What determines whether pyruvate enters into cellular (aerobic) respiration or a fermentation process?

A. Availability of glucose in cytosol.
B. Availability of CO2 in chloroplasts.
C. Availability of sufficient oxygen in the cell. ←
D. Availability of glucose in mitochondria.
E. Presence of lactate or alcohol.

8. Which term most precisely describes the cellular process of breaking down large molecules into smaller ones?

A. Dehydration.
B. Catalysis.
C. Anabolism.
D. Catabolism. ←
E. Metabolism.

9. Chemiosmosis is described as an energy coupling mechanism that_____

A. Lowers the pH in the mitochondrial intermembrane space.
B. Phosphorylates any substrate molecule.
C. Uses the energy of the proton gradient to drive chemical work. ←
D. Creates a proton-motive force.
E. Inhibits electron transfer along the electron transport chain.

10. Which of the following statements describes NAD+?

A. NAD+ is oxidized by the action of hydrogenases.
B. NAD+ is reduced to NADH during glycolysis, pyruvate oxidation, and the citric acid cycle.←
C. NAD+ has more chemical energy than NADH.
D. NAD+ can donate electrons for use in oxidative phosphorylation.
E. In the absence of NAD+, glycolysis can still function.

11. If oxygen is NOT present in muscle cells, glycolysis is completed____

A. By its Kerbs cycle.
B. By the electron transport chain.
C. As lactate fermentation. ←
D. None of the options is correct.
E. By chemiosmosis.

12. The ATP produced during fermentation is generated by which of the following?

A. The citric acid cycle.
B. Chemiosmosis
C. Substrate level phosphorylation.←
D. The electron transport chain.
E. The Kerbs cycle.

13. If 10 molecules of acetyl CoA enter the citric acid cycle. How many molecules of ATP will be made by substrate level phosphorylation?

A. 10 ←
B. 20
C. 18
D. 32
E. 4

14. Starting with four glucose molecules, how many CO_2 molecules are produced inside <u>one</u> citric acid cycle?

A. 12
B. 16
C. 2 ←
D. 24
E. 3

15. Which stage of cellular respiration requires ATP?

A. Glycolysis. ←
B. None of the options is correct.
C. Citric acid cycle.
D. Electron transport chain.
E. Chemiosmosis.

16. What is true of NADH in cellular respiration?

A. NADH carries and transfers electrons and H+ ions.←
B. NADH carries excess carbon dioxide out of the cell.
C. NADH carries the oxygen.
D. NADH is used to directly break apart the glucose molecules.

17. Glycolysis produces ATP, pyruvate and NADH by____

A. Oxidizing O2.

B. Reducing FADH2O.

C. Oxidizing glucose.←

D. Reducing glucose.

18. Which product of pyruvate oxidation enters the Krebs cycle?

A. CO_2.

B. Glucose.

C. Acetyl-CoA. ←

D. NADH.

19. Which of the following is NOT produced during the citric acid cycle?

A. Oxygen.←

B. NADH.

C. ATP.

D. CO2.

20. Hydrogen ions move through a process called _____ down their concentration gradient.

A. Oxidation.

B. ATP synthesis.

C. Electron transport chain (ETC).

D. Chemiosmosis. ←

21. _____is biological process for ATP production in cellular respiration and photosynthesis.

A. Photosynthesis.

B. Electron.

C. Pyruvate oxidation.

D. Chemiosmosis.←

E. Glycolysis.

22. The net products of breaking down of <u>one</u> acetyl CoA in citric acid cycle are_____

A. 6 CO2, 6 NADH, 2 FADH2 and 2 ATP.

B. 3 CO2, 3 NADH, 1FADH2 and 2 ATP.

C. 4 CO2, 6 NADH, 2FADH2 and 2 ATP.

D. 2 CO2, 6 NADH, 2 FADH2 and 1 ATP.

E. 2 CO2, 3 NADH, 1 FADH2 and 1 ATP.←

23. Which sugar is found in NAD+?

A. Ribose. ←

B. Sucrose.

C. Ribulose.

D. Glucose.

E. Fructose.

24. **Which of the following occurs in the cytosol of the cell?**

A. Fermentation and chemiosmosis.

B. Citric acid cycle.

C. Oxidation of pyruvate to acetyl CoA.

D. Glycolysis and fermentation.←

E. Regeneration of oxaloacetate.

25. In glycolysis glucose undergoes_____

A. Both oxidation and catabolism. ←

B. Polymerization.

C. Catabolism.

D. Reduction.

E. Oxidation.

26. Which of the following is true for anabolic pathways?

A. They consume energy to decrease the free energy of the molecules.

B. They release energy as they degrade polymers to monomers.

C. They consume energy to build up polymers from monomers. ←

D. They do not depend on enzymes.

E. They are usually highly spontaneous chemical reactions.

27. Carbohydrates and fats are considered high energy foods because_____

A. They have a lot of electrons associated with hydrogen. ←

B. They are easily reduced.

C. They have no nitrogen in their makeup.

D. They can have long carbon skeletons.

E. They have a lot of oxygen atoms.

28. Approximately how many molecules of ATP are produced from the complete oxidation of one molecule of glucose in aerobic cellular respiration?

A. 4

B. 2

C. 18- 24

D. 6- 12

E. 30-32 ←

29. In alcohol fermentation, NAD+ is regenerated from NADH by_____

A. Reduction of acetaldehyde to ethanol (ethyl alcohol).←

B. Oxidation of pyruvate to acetyl CoA.

C. Reduction of pyruvate to acetyl CoA.

D. Oxidation of ethanol to acetyl CoA.

E. Reduction of ethanol to pyruvate.

30. In prokaryotes, the respiratory electron transport chain is located_____

A. In the mitochondrial inner membrane.

B. In the mitochondrial outer membrane.

C. In the plasma membrane.←

D. In the cytoplasm.

E. In the bacterial outer membrane.

31. How many electrons are needed to pass the electron transport chain of the mitochondria for the formation of one molecule of water?

A. 1

B. 2 ←

C. 4

D. 6

E. 2 from NADH and 1 from $FADH_2$

32. Almost all of the oxygen consumed in breathing is converted to_____

A. Acetyl-CoA.

B. Water. ←

C. Carbon dioxide (CO2).

D. ATP and NADH.

E. Pyruvate.

33. How many protons in chemiosmosis are estimated to be enough for the production of one ATP molecule?

A. 1

B. 2

C. 4 ←

D. 6

E. 10

34. The number of NADH molecules produced from oxidation of <u>one</u> pyruvate to acetyl CoA and further oxidation in Krebs cycle is_____

A. 3 NADH.

B. 6 NADH.

C. 4 NADH. ←

D. 8 NADH.

E. None of the above.

35. In cellular respiration, the final electron accepter is_____

A. O2. ←

B. H2O.

C. NAD+.

D. CO2.

E. Glucose.

36. The molecule that directly passes electrons to oxygen in the electron transport chain in mitochondria is_____

A. Flavoprotein.

B. CoQ (Ubiquinone).

C. Cytochrome C.

D. Cytochrome a3.←

E. Iron Sulphur protein.

37. In the electron transport chain, NADH passes the electrons directly to the_____

A. Oxygen.

B. Iron sulfur protein.

C. Flavoprotein (FMN).←

D. Cytochromes.

E. NAD+.

38. Chemiosmotic ATP synthesis (oxidative phosphorylation) occurs in_____

A. All respiring cells, both prokaryotic and eukaryotic, using either oxygen or other electron acceptors.←

B. All cells, but only in the presence of oxygen.

C. Only in mitochondria, using either oxygen or other electron acceptors.

D. Only in eukaryotic cells, in the presence of oxygen.

E. Only in prokaryotic cells, in absence of oxygen.

39. What is correct about the electron transport chain anaerobic respiration?

A. Can use oxygen as a final electron acceptor.

B. Occurs in <u>aerobic</u> bacteria.

C. Occurs in some prokaryotes. ←

D. It is the fermentation of glucose.

E. B and C are correct.

40. When a molecule loses a hydrogen atom as the result of an oxidation-reduction reaction, the molecule becomes_____

A. Reduced.

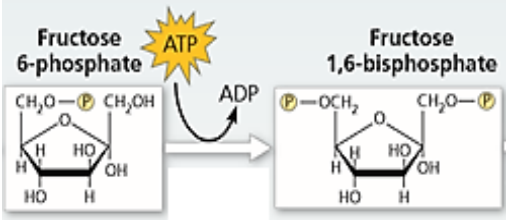
B. Hydrolyzed.

C. Hydrated.

D. An oxidizing agent.

E. Oxidized.←

41. The enzyme which is involved in this reaction is____



A. Hexokinase.

B. Phosphofructokinase.←

C. Aldolase.

D. Phosphoglycerokinase.

E. Pyruvate kinase.

42. In eukaryotic cells, which of the following normally occurs regardless of whether or not oxygen (O2) is present?

A. Fermentation.

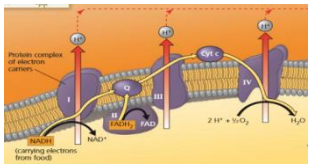
B. Oxidative phosphorylation.

C. Citric acid cycle.

D. Glycolysis.←

E. Acetyl CoA oxidation.

43. The figure shows___



A. Chemiosmosis.

B. Substrate level phosphorylation.

C. Electrochemical gradient.

D. Oxidative phosphorylation.

E. Electron transport chain creating a proton motive force.←

44. The electron transport chain_____

A. Is driven by ATP consumption.

B. Takes place in the cytoplasm of prokaryotes.

C. Is a sense of redox reactions. ←

D. Is a sense of substitution reactions.

E. Is a sense of glucose production reactions.

45. When electrons move closer to a more electronegative atom, what happens to the more electronegative atoms?

A. Oxidized, and energy is released.

B. Oxidized, and energy is consumed.

C. Reduced, and energy is released.←

D. Reduced, and energy is consumed.

E. Oxidized, and energy is not changed.

46. For each molecule of glucose oxidized by cellular respiration, how many molecules of CO2 are released in the citric acid cycle alone?

A. 2

B. 4 ←

C. 6

D. 12

E. 3

47. Energy released by the electron transport chain is used to pump H+ into which location in eukaryotic cells?

A. Mitochondrial matrix.

B. Mitochondrial outer membrane.

C. Mitochondrial intermembrane space.←

D. Mitochondrial inner membrane.

E. Mitochondrial stroma.

48. **Where are the proteins of the electron transport chain located?**

A. Cytosol.

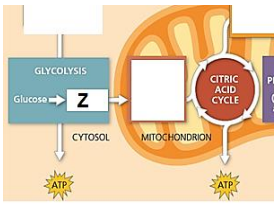
B. Mitochondrial outer membrane.

C. Mitochondrial inner membrane.←

D. Mitochondrial intermembrane space.

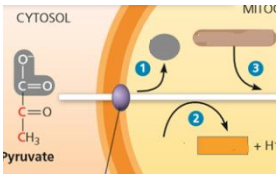
E. Mitochondrial matrix.

49. **In the figure, the product Z is_____**



A. 3 acetyl CoA molecules.
B. 2 Acetyl CoA molecules.
C. 2 Pyruvate molecules.←
D. 1 Pyruvate.
E. Ribulose bisphosphate.

50. Upon oxidation of pyruvate to acetyl CoA, the product compound no. 1 in the gray circle is___



A. NADH.
B. Coenzyme A.
C. Acetate.
D. Acetyl coenzyme A.
E. Carbon dioxide.←

51. In cellular respiration, 90 percent of ATP is produced by_____

A. Glycolysis.
B. Oxidative phosphorylation.←
C. Photophosphorylation.
D. Substrate-level phosphorylation.
E. Pyruvate oxidation.

52. In eukaryotic cells, the ATP synthase complex is located in_____

A. Plasma membrane.
B. Mitochondrial outer membrane.
C. Mitochondrial inner membrane.←
D. Mitochondrial intermembrane space
E. Mitochondrial matrix.

Chapter 11

Photosynthesis

Concept 11.1: Photosynthesis converts light energy to the chemical energy of food

- **Plants** and other **photosynthetic** organisms contain cellular organelles called ***chloroplasts***, which contain molecular complexes that capture light energy from the sun and convert it to chemical energy that is stored in sugar and other organic molecules.
- Photosynthesis: the process of conversion of light energy from sun to chemical energy stored in sugar and other organic compounds. It nourishes almost the entire living world directly or indirectly.

Types of organisms depending on the mode of nutrition:

1. Autotrophs (Self - feeders OR producers) don't eat anything derived from other living beings. They produce their organic molecules from CO2 and other inorganic raw materials obtained from the environment. They are the ultimate sources of organic compounds for all non-autotrophic organisms. Almost **all plants** are autotrophs (require water and minerals from the soil and CO2 from the air).
   Specifically, plants are **photo**autotrophs (use light as a source of energy to synthesize organic substances). Photosynthesis also occurs in algae, certain **unicellular eukaryotes**, and some **prokaryotes**.
2. Heterotrophs (Other - feeding OR consumers) are unable to make their own food; they live on compounds produced by other organisms. Some heterotrophs consume the remains of other organisms (e.g. dead organisms, feces, and fallen leaves) and these types of heterotrophs are known as **decomposers**.
   Most **fungi** and many types of **prokaryotes** get their nourishment this way. Heterotrophs depend -either directly or indirectly- on photoautotrophs for food and oxygen (a by-product of photosynthesis).

Chloroplasts: The Sites of Photosynthesis in Plants

- All green parts of a plant have chloroplasts, but the leaves are the major sites of photosynthesis in most plants.
- Chloroplasts are found mainly in the cells of the mesophyll (the tissue in the interior of the leaf).
- CO2 enters the leaf, and O2 exits, by way of microscopic pores called stomata.
- Leaves use veins for the (1) delivery of absorbed water to leaves and to (2) export sugar to roots and other non-photosynthetic parts of the plant
- A chloroplast has two membranes surrounding a dense **fluid** called the stroma.
- Suspended within the stroma is a third membrane system, made up of sacs called thylakoids, which segregates the stroma from the thylakoid space inside these sacs. In some places, thylakoid sacs are stacked in columns called grana (singular, granum).
- Chlorophyll is the green pigment that gives leaves their color; it resides in the thylakoid membranes of the chloroplast.
- What drives the synthesis of organic molecules in the chloroplast?
  It is the light energy absorbed by **chlorophyll**.

The endosymbiont theory: the original chloroplast was a photosynthetic prokaryote that lived inside an ancestor of eukaryotic cells.

The process of photosynthesis originated in a group of bacteria that had in-folded regions of the plasma membrane containing clusters of molecules and enzymes that are responsible for photosynthesis (called thylakoid membranes). In eukaryotes, these enzymes are found in internal membranes of chloroplasts.

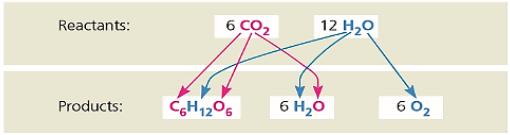
Tracking Atoms through Photosynthesis: ***VERY INTRESTING!***

- ✓ In the presence of light, the green parts of plants produce organic compounds and oxygen from carbon dioxide and water. We use glucose ($C_6H_{12}0_6$) here to simplify the relationship between photosynthesis and respiration **(photosynthesis is the reverse of cellular respiration; both occur in plant cells)**, but the direct product of photosynthesis is actually ***a three-carbon sugar that can be used to make glucose.*** Water appears on both sides of the equation because 12 molecules are consumed and 6 molecules are newly formed during photosynthesis.

- ✓ **O2 given off by plants is derived from H2O and not from CO2.** The chloroplast splits water into hydrogen and oxygen (it was thought that the O2 released during photosynthesis came from CO2). *Van Niel studied photosynthesis in bacteria that make their carbohydrate from CO2 but do not release O2. He concluded that, at least in these bacteria, CO2 is not split into carbon and oxygen.*
- ✓ **One** group of bacteria used hydrogen sulfide (H_2S) rather than water for photosynthesis, forming yellow globules of sulfur as a waste product.

  *Van Niel reasoned that the bacteria split H_2S and used the **hydrogen** atoms to make sugar. He concluded that all photosynthetic organisms require a **hydrogen source** but that the source **varies**, for example, plants split **H_2O as a source of electrons from hydrogen atoms**, releasing O2 as a by-product.*

$$\text{Sulfur bacteria: } CO_2 + 2\,H_2S \rightarrow [CH_2O] + H_2O + 2\,S$$
$$\text{Plants: } CO_2 + 2\,H_2O \rightarrow [CH_2O] + H_2O + O_2$$
$$\text{General: } CO_2 + 2\,H_2X \rightarrow [CH_2O] + H_2O + 2\,X$$



$$6\,CO_2 + 6\,H_2O + \text{Light energy} \rightarrow C_6H_{12}O_6 + 6\,O_2$$

$$CO_2 + H_2O \rightarrow [CH_2O] + O_2$$

Scientists confirmed van Niel's hypothesis by using oxygen-18 (^{18}O), a heavy isotope, as a tracer to follow the path of oxygen atoms during photosynthesis.

1. O_2 from plants was labeled with ^{18}O only if **water** was the source of the tracer.
2. If the ^{18}O was introduced to the plant in the form of CO_2, the label did not turn up in the released oxygen.

$$\text{Experiment 1: } CO_2 + 2\,H_2O \rightarrow [CH_2O] + H_2O + O_2$$
$$\text{Experiment 2: } CO_2 + 2\,H_2O \rightarrow [CH_2O] + H_2O + O_2$$

- ➲ Both photosynthesis and cellular respiration involve redox reactions.
- ➲ Photosynthesis reverses the direction of electron flow in cellular respiration; one H_2O is split, and its electrons are transferred along with hydrogen ions (H+) from the **water to carbon dioxide**, **reducing** it to sugar. Because the electrons **increase** in potential energy as they move from water to sugar, this process requires energy (endergonic process).
- ➲ This energy boost that occurs during photosynthesis is provided by light. Photosynthesis is not a single process, but two processes; (1) the light reactions (the photo part of photosynthesis), and (2) the **Calvin** cycle (the synthesis part).

The light reactions:

- ✓ Occur in **thylakoid**.
- ✓ Convert **solar** ☼ energy to chemical energy in the form **ATP and NADPH**.
- ✓ No sugar is produced.
- ✓ It uses H_2O to **produce oxygen.**
- ✓ Depends on **light directly.**

1. Water is split, providing a source of electrons and protons (hydrogen ions, H+) and giving off **O_2 as a by-product.**
2. Light absorbed by **chlorophyll** drives a transfer of the electrons and hydrogen ions from water to an acceptor called NADP+ (*nicotinamide adenine dinucleotide **phosphate***), where they are temporarily stored.

- ✓ The light reactions use solar energy to (1) **reduce** NADP+ to NADPH by adding a pair of electrons along with an H+, and to (2) generate ATP using ***chemiosmosis*** to power the addition of a phosphate group to ADP, a process called ***photophosphorylation*** **(i.e. light energy is initially converted to chemical energy in the form of (1) NADPH (reducing power) and (2) ATP (energy currency)).**

The Calvin cycle:

- ✓ Occurs in stroma.
- ✓ It uses CO_2 found in the air to produce three carbon sugar called ***G3P*** that's used to produce other sugars. Also, it uses the molecules of ATP and NADPH produced from light reaction. The metabolic steps of the Calvin cycle are referred to as the **dark reactions**, or light independent reactions, because none of the steps requires light directly.
- ✓ It occurs –mostly- during daylight; in order for the light reactions to provide the NADPH and ATP that the Calvin cycle requires.
- ✓ It has 3 stages; (1) carbon fixation, (2) reduction, and (3) regeneration of CO_2 acceptor.

Concept 11.2: The light reactions convert solar energy to the chemical energy of ATP and NADPH

Light is an energy form that's known as **electromagnetic energy**, or **electromagnetic radiation**. It travels in rhythmic waves; however, these waves are disturbances of electric and magnetic fields rather than disturbances of a material medium.

Wavelength: the distance between the crests of electromagnetic waves. It ranges from less than a nanometer (for gamma rays) to more than a kilometer (for radio waves). This entire range of radiation is known as the **electromagnetic spectrum.**

The important range to life is the narrow band from **about 380 nm to 750 nm in wavelength**. It is known as **visible light** because it can be detected as various colors by the human eye. Visible light is the radiation that drives photosynthesis.

The model of light as waves explains many of light's properties, but in certain respects light behaves as though it consists of discrete particles, called photons. Photons are not tangible objects, but they act like objects in that **each of them has a fixed quantity of energy**. This amount of energy is inversely related to the ***wavelength*** of the light (the shorter the wavelength, the greater the energy of each photon). Although the sun radiates the full spectrum of electromagnetic energy, the atmosphere acts like a ***selective window,*** allowing visible light to pass through while **screening out** a substantial fraction of other radiation.

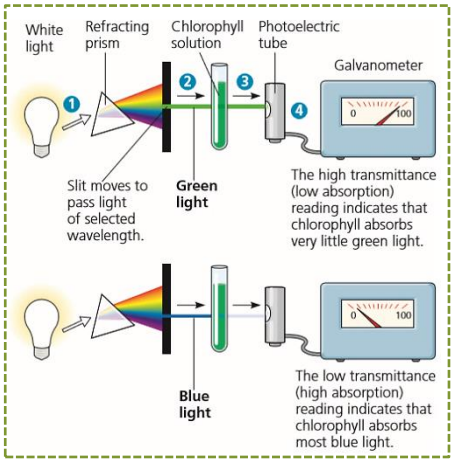
Pigment absorbs visible light; different pigments absorb light of different wavelengths, and the wavelengths that are absorbed **disappear**. If a pigment is illuminated with white light, the color we see is the color most **reflected** or **transmitted** by the pigment **(not absorbed).** If a pigment absorbs all wavelengths, it appears black. Chlorophyll absorbs violet-blue and red light while transmitting and reflecting green light.

- Spectrophotometer: instrument that used to measure the ability of a pigment to absorb various wavelengths. This machine directs beams of light of different wavelengths through a solution of the pigment and measures the fraction of the light transmitted at each wavelength.
- A graph plotting a pigment's light absorption versus wavelength is called an absorption spectrum.

What is the technique?

1. White light is separated into colors (wavelengths) by a prism. Then, one by one, the different colors of light are passed through the sample *(**chlorophyll** in this example).* Green light and blue light are passed here.
2. The transmitted light strikes a **photoelectric tube,** which converts the **light** energy to **electricity.**
3. The **electric current** is measured by a **galvanometer**. The meter indicates the fraction of light transmitted through the sample, from which we can determine the amount of light absorbed.

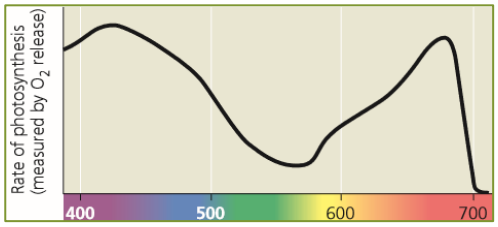
The high transmittance (low absorption) reading indicates that chlorophyll absorbs very little green light. The low transmittance (high absorption) reading indicates that chlorophyll absorbs most blue light.



There are three types of pigments in chloroplasts; (1) **chlorophyll a** is the key light-capturing pigment that participates **directly** in the light reactions, (2) **chlorophyll B** is an accessory pigment, and (3) **carotenoids** is a separate group of accessory pigments.

*Violet-blue and red light work best for photosynthesis (since they are absorbed) while green is the least effective color. This is confirmed by an **action spectrum** for photosynthesis, which profiles the relative effectiveness of different wavelengths of radiation in driving the process. An action spectrum is prepared by illuminating chloroplasts with light of different colors and then plotting wavelength against some measure of photosynthetic rate, such as CO_2 consumption or O_2 release.

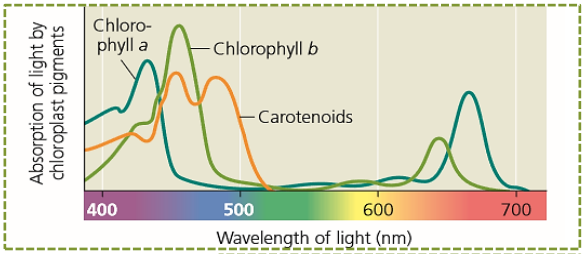
*The action spectrum for photosynthesis is much broader than the absorption spectrum of chlorophyll a. *How come?* This is partly because accessory pigments with different absorption spectra also present in chloroplasts—including chlorophyll b and carotenoids—broaden the spectrum of colors that can be used for photosynthesis.

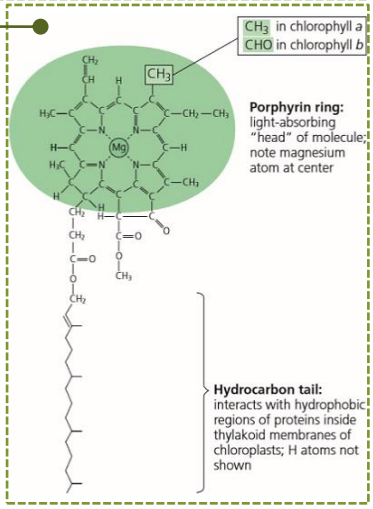


Carotenoids are accessory pigments, and their structure consists of hydrocarbons that are various shades of yellow and orange because they absorb **violet** and **blue** **green** light. **Carotenoids** may broaden the spectrum of colors that can drive photosynthesis. Their function is **photo-protection;** they absorb excessive light energy that would damage chlorophyll or interact with oxygen, forming reactive oxidative molecules that are dangerous to the cell. *Carotenoids - also- have a photo-protective role in the human eye. It's present in Carrots, many fruit & vegetables, and health food products (as "phytochemicals") for its antioxidant properties. Plants can synthesize all the antioxidants they require, but humans and animals obtain some of them from their diets.*

Structure of chlorophyll:

1. Porphyrin ring: light-absorbing "head" of molecule; there's a magnesium atom at center. **Chlorophyll a** and **chlorophyll b** differ in only one of the functional groups bonded to the **porphyrin ring** *(chlorophyll a → CH3 and chlorophyll b → CHO),* and this difference causes the two pigments to absorb at slightly different wavelengths in the red and blue parts of the spectrum. **Chlorophyll a appears blue green and chlorophyll b appears olive green under visible light.**
2. Hydrocarbon tail: interacts with hydrophobic regions of proteins inside **thylakoid** membranes of chloroplasts**.**





When pigments absorb light, the colors corresponding to the absorbed wavelengths disappear from the spectrum of the transmitted and reflected light, but **energy cannot disappear**. When a molecule absorbs a photon of light, one of the molecule's **electrons** is **elevated** to an orbital where it has **more potential energy. In other words,** absorption of a photon boosts an electron to an orbital of higher energy, and the pigment molecule is then said to be in an **excited state**, however, when the electron is in its normal orbital, the pigment molecule is said to be in **its ground state.**

The only photons absorbed are those whose energy is exactly equal to the energy difference between the ground state and an excited state, and this energy difference varies from one kind of molecule to another.

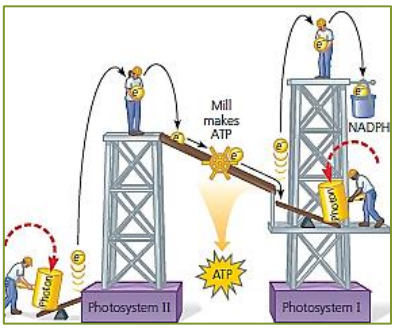
Once absorption of a photon raises an electron to an excited state, the electron cannot stay there long (excited state; unstable), so the excited electrons drop back down to the ground-state orbital in a billionth of a second, releasing their excess energy as **heat**.

Some pigments, including chlorophyll, emit **light** as well as **heat** after absorbing photons. *As excited electrons fall back to the ground state, photons are given off, an afterglow called **fluorescence**.* When electrons reach the **excited state**, there's no electron acceptor, so they fall back to their **ground state**.

A solution of chlorophyll will fluoresce **in the red part** of the spectrum and also give off **heat**. This is best seen by illuminating with ultraviolet light, which chlorophyll can also **absorb.** Viewed under visible light, the fluorescence would be difficult to see against the **green** of the solution.

In the thylakoid membrane, chlorophyll molecules are organized along with other small organic molecules and proteins into complexes called photosystems.
It's composed of a reaction-center complex surrounded by several light-harvesting complexes.
I) The reaction-center complex is an organized association of proteins holding (1) a **special pair of chlorophyll a** molecules and (2) a **primary electron acceptor**.
II) The light-harvesting complex consists of various pigment molecules *(may include chlorophyll a, chlorophyll b, and carotenoids)* bound to proteins.
The number and variety of pigment molecules enable a photosystem to harvest light over a larger surface area and a larger portion of the spectrum than could any single pigment molecule alone.
When a pigment molecule absorbs a photon, the energy is transferred from pigment molecule to pigment molecule within a **light harvesting complex** until it is passed to the **pair of chlorophyll a** molecules in the **reaction-center complex.** The pair of **chlorophyll a** (1) boosts one of the electrons to a **higher energy level**, and (2) transfers it to the **primary electron acceptor**, which is a molecule capable of accepting electrons (become reduced).
The solar-powered transfer of an electron from the reaction center chlorophyll a pair to the primary electron acceptor is the first step of the light reactions.

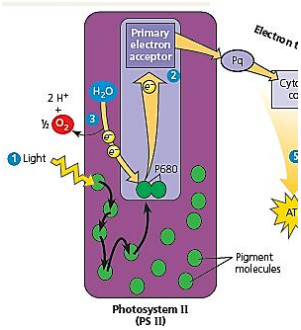
- Isolated chlorophyll **fluoresces** because there is no electron acceptor, so electrons of photo excited chlorophyll drop right back to the **ground state.**
- The function of photosystems is to convert light energy to chemical energy, which will ultimately be used for the synthesis of sugar.



The thylakoid membrane has two **types** of photosystems: (1) photosystem II (PS II) and (2) photosystem I (PS I), however, **photosystem II** functions **first** in the light reactions. Each has a characteristic reaction-center complex; the reaction-center chlorophyll a of **photosystem II is known as P680** because this pigment is best at absorbing light having a wavelength of **680 nm** (in the red part of the spectrum), and the chlorophyll a of **photosystem I** is called **P700** because it most effectively absorbs light of wavelength 700 nm (in the far-red part of the spectrum). P680 and P700 are nearly identical **chlorophyll a molecules**, but **their association with different proteins** in the thylakoid membrane affects the electron distribution accounts for the differences in their properties.

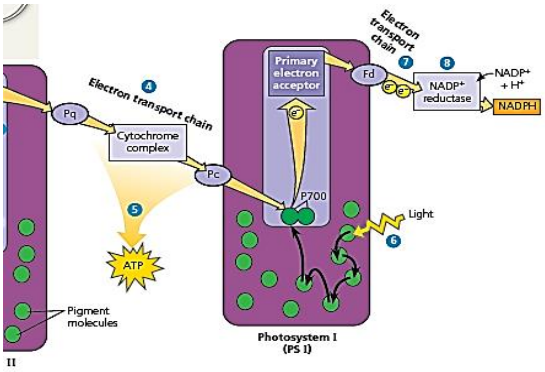
Linear electron flow: electrons flow through the photosystems and other components built into the thylakoid membrane.

1) A photon strikes one pigment molecule in a light-harvesting complex of PS II, boosting one of its electrons to a higher energy level. As this electron falls back to its ground state, an electron in a nearby pigment molecule is simultaneously raised to an excited state.
2) The process continues, with the energy being relayed to other pigment molecules until it reaches the **P680** pair of chlorophyll a molecules in the PS II reaction-center complex. This energy excites **an electron** in this pair of chlorophylls to a higher energy state, which is then transferred from the excited **P680** to the **primary electron acceptor.** The resulting form of **P680** misses an electron, and is referred as **P680+.**
3) An enzyme catalyzes the splitting of a water molecule into (1) two electrons, (2) two hydrogen ions (H+), and (3) an oxygen atom. The electrons are supplied **one by one** to the **P680+** pair (to replace the transferred ones ***(P680+ is the strongest biological oxidizing agent)***). The H+ is released to the thylakoid space, and the oxygen atom immediately combines with another oxygen atom generated by the splitting of another water molecule, **forming O2.**
4) Each electron passes from the primary electron acceptor of PS II to PS I via an electron transport chain. The electron transport chain made up of the electron carrier Plastoquinone (PQ), a cytochrome complex, and a protein called Plastocyanin (Pc).
The **exergonic** "fall" of electrons to a lower energy level provides energy for **the synthesis of ATP**.
As electrons pass through the cytochrome complex, H+ is pumped into the **thylakoid space,** contributing to the proton gradient that is subsequently used in chemiosmosis.



5) **Light energy** has been transferred via light harvesting complex pigments to the PSI reaction-center complex, exciting an electron of the **P700**.Then, the photo-excited electron (in P700) is transferred to PS I's primary electron acceptor reducing it (P700 becomes P700+). Now, P700+ can act as an electron acceptor, **accepting an electron that reaches the bottom of the electron transport chain from PS II.**

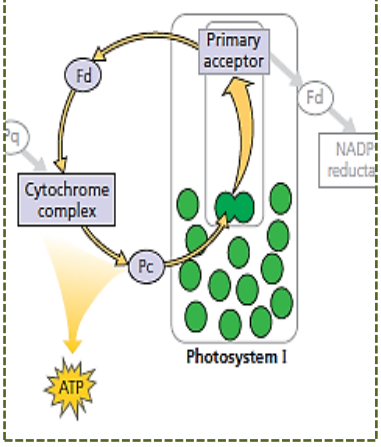
6) Photo-excited electrons are passed in a series of redox reactions from the primary electron acceptor of PS I down a second electron transport chain through the protein ferredoxin (Fd).The enzyme ***NADP+ reductase*** catalyzes the transfer of electrons from **Fd to NADP+.** Two electrons are required for its reduction to NADPH. This process also removes **an H+** from the stroma.



1. Electron transport chain proteins in the thylakoid membrane of the chloroplast pump protons **from the stroma** into the **thylakoid space** (interior of the thylakoid), which functions as the H+ reservoir.
2. When chloroplasts in an experimental setting are illuminated, the pH in the thylakoid space drops to about 5 (H+ increases), and the pH in the stroma increases to about 8 (H+ decreases). This gradient of three pH units corresponds to a thousand fold differences in H+ concentration.
3. If the lights are then turned **off**, the pH gradient is abolished, but it can quickly be restored by turning the lights back **on.**

In certain cases, photo-excited electrons can take an alternative path called **cyclic electron flow,** which uses photosystem I but not photosystem II.

- It's a short circuit; the electrons cycle back from ferredoxin (Fd) to the cytochrome complex, then via a plastocyanin molecule (Pc) to a **P700** chlorophyll in the PS I **reaction-center complex** ***(no production of NADPH and no release of oxygen; it only generates ATP).***
- Many photosynthetic bacteria *(e.g. purple sulfur bacteria and green sulfur bacteria)* are known to have a single photosystem related to either PS II or PS I. Thus, for them, cyclic electron flow is the one and only means of generating ATP during the process of photosynthesis.
- Cyclic electron flow can also occur in photosynthetic species that possess **both** photosystems; this includes some prokaryotes (e.g. cyanobacteria), and eukaryotic photosynthetic species.
- Plants with mutations that render them unable to carry out cyclic electron flow are capable of growing well in low light, but do not grow well where light is intense (**since cyclic electron flow may be photo protective).**



A Comparison of Chemiosmosis in Chloroplasts and Mitochondria

1. Some of the electron carriers, including the iron-containing cytochromes, are very similar in chloroplasts and mitochondria. The ATP synthase complexes of the two organelles are also quite similar.

2. The synthesis of ATP in chloroplasts occurs via photophosphorylation, while the synthesis of ATP in the mitochondria occurs via oxidative phosphorylation.

3. In chloroplasts, the high-energy electrons dropped down the transport chain come from water, however, in mitochondria, they are extracted from organic molecules.

4. Chloroplasts do not need molecules from food to make ATP; their photosystems capture light energy and use it to drive the electrons from water to the top of the transport chain.

5. Mitochondria use chemiosmosis to transfer chemical energy from food molecules to ATP, whereas chloroplasts use it to transform light energy into chemical energy in ATP.

Concept 11.3: The Calvin cycle uses the chemical energy of ATP and NADPH to reduce CO2 to sugar

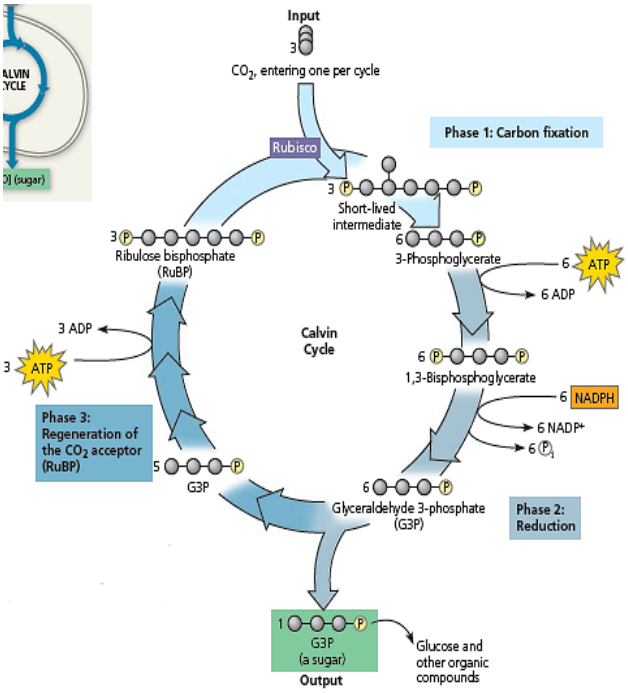
The Calvin Cycle

Carbon enters the cycle in the form of CO_2 and leaves in the form of sugar. It spends ATP as an energy source and consumes NADPH as reducing power for adding high-energy electrons to make the sugar. The carbohydrate produced **directly** is not glucose. It is actually a three carbon sugar called glyceraldehydes 3-phosphate (G3P). For the net synthesis of one molecule of G3P, the cycle must take place **three times**. It consumes one CO_2 per turn, total = 3 CO2 molecules. It is divided into three phases:

Phase 1: Carbon fixation

The Calvin cycle incorporates CO2 by attaching it to a five-carbon sugar named ribulose bisphosphate (RuBP). The enzyme that catalyzes this first step is RuBP carboxylase-oxygenase, or rubisco.

The product is **a six-carbon intermediate** that is short-lived because it is so **energetically unstable** that it immediately splits in half, forming two molecules of 3-phosphoglycerate.



Phase 2: Reduction

Each molecule of 3-phosphoglycerate receives an additional ↑**phosphate** group from **ATP**, becoming 1, 3 – bis-phosphoglycerate. Also, a pair of **electrons** donated from NADPH reduces 1,3-bisphosphoglycerate, which also loses a ↓**phosphate** group in the process, becoming glyceraldehyde 3-phosphate (G3P).

- *The electrons from NADPH reduce a carboxyl group on 1,3-bisphosphoglycerate to the aldehyde group of G3P, which stores **more potential energy.***
- *For every **three** molecules of CO2 that enter the cycle, there are **six** molecules of G3P formed.* ***But only one can be counted as a net gain of carbohydrate because the rest are required to complete the cycle.***

Phase 3: Regeneration of the CO2 acceptor (RuBP)

Five molecules **of G3P** are rearranged into **three** molecules **of RuBP (in the expense of 3 ATP)**, then, The RuBP is now prepared to receive CO2 again, and the cycle continues.

*For the net synthesis of **one G3P molecule,** the Calvin cycle consumes a total of **nine molecules of ATP** and **six molecules of NADPH.***

The G3P spun off from the Calvin cycle becomes the starting material for the synthesis of glucose (from two molecules of G3P), the disaccharide sucrose, and other carbohydrates.

➲ ***Test you understanding***

1. **Which of the following is INCORRECT for P680 and P700?**
   A. They are modified **chlorophyll a** pigment.
   B. Participate in linear electron flow.
   C. They are found in thylakoid membrane.
   D. They are oxidized following excitation.
   E. Directly involved in chemiosmosis.←

2. **Rubisco_____**
   A. Is found in the stroma of the chloroplast.
   B. Catalyzes carbon fixation in chloroplast.
   C. Is a Calvin cycle enzyme.
   D. CO_2 and RuBP are its substrates.
   E. All of the options are correct.←

3. **The product of Calvin cycle is_____**
   A. Starch.
   B. Carbon dioxide.
   C. Glucose.
   D. Oxaloacetate.
   E. Glyceraldehyde 3 phosphate.←

4. **Which of the following is a heterotroph?**
   A. Algae.
   B. Cyanobacteria.
   C. Purple sulfur bacteria.
   D. Fungi. ←
   E. Plants.

5. **Which of the following activities occurs in the stroma?**
   A. Linear electron flow.
   B. Photophosphorylation.
   C. Regeneration of RuBP. ←
   D. Cyclic electron flow.
   E. Chemiosmosis.

6. **Splitting water molecules in photosynthesis occurs in_____**
   A. Dark reactions.
   B. Stroma.
   C. Calvin cycle.
   D. Linear electron flow.←
   E. Cyclic electron flow.

7. **In plant leaves, gas exchange occurs through**
   A. Stomata.←
   B. Lower epidermis.
   C. Upper epidermis.
   D. Guard cells.

8. **It's the strongest known biological oxidizing agent.**
   A. P680
   B. P680++
   C. P700+
   D. P700
   E. P680+ ←

9. **A biological coupling process for ATP production in cellular respiration and photosynthesis.**
   A. More than one of the below.
   B. Electron transport chain.
   C. Pyruvate oxidation.
   D. Chemiosmosis.←
   E. Glycolysis.

10. **Linear electron flow produce _____while cyclic electron flow produce_____**
    A. ATP and NADPH, ATP. ←
    B. ATP and NADH, ATP.
    C. NADH, NADH and ATP.
    D. ATP, ATP.
    E. ATP, ATP and NADPH.

11. **Which is not required by the Calvin cycle?**
    A. NADPH.
    B. All of the options are correct.
    A. O2 ←
    C. ATP.
    D. CO2

12. **At the end of the electron transport chain found in the thylakoid membrane, the electrons are transferred to a molecule of**
    A. ATP
    B. O2
    C. Glucose
    D. NADP+ ←
    E. H2O

13. **The multiple stacks of the thylakoid system are called _____**
    A. Grana.
    B. Glyoxysomes.
    C. A granum.←
    D. Cristae.
    E. Cisternae.

14. **In non-cyclic electron flow which of the following supplies the electrons to photosystem ll?**
    A. NADPH.
    B. Water. ←
    C. Electron transport from photosystem.
    D. Oxygen.
    E. ATP.

15. **The Calvin cycle involves all of the following except_____**
    A. Regeneration of RuBP.
    B. Oxidation of NADPH.
    C. Consumption of ATP.
    D. Carbon fixation.
    E. Reduction of G3P.←

16. **The Calvin cycle forms sugar from CO_2, using ATP and NADPH in the stroma.**
    A. True.←
    B. False

17. **Wavelength is the distance between crests of waves.**
    A. True. ←
    B. False.

18. **Heterotrophs sustain themselves without eating anything derived from other organisms.**
    A. True.
    B. False.←

19. **The light harvesting complexes in PSII____**
    A. Absorb electrons.
    B. All of the options are correct.
    C. Donate protons.
    D. Break down H2O.
    E. Pass energy to the reaction center.←

20. **Where is PSI found in a plant cell?**
    A. Thylakoid membrane.←
    B. Thylakoid space.
    C. Cristae.
    D. Stroma.
    E. Chloroplast envelops.

21. **Which of the following is not involved in the transfer of electrons from P680 to P700?**
    A. Plastoquinone.
    B. Plastocyanin.
    C. Primary electron acceptor of PSII.
    D. Cytochrome complex.
    E. Ferredoxin.←

22. **In photosynthesis, the chemiosmotic production of ATP_____**
    A. Requires oxygen.
    B. Is basically similar to the production at ATP in mitochondria.←
    C. Requires the input of NADPH.
    D. Is done by the Calvin cycle.
    E. All of the above are correct.

23. **Which molecule is the CO2 acceptor in the first step of the Calvin cycle?**
    A. ATP.
    B. Glucose.
    C. Citrate.
    D. Rubisco.←
    E. Acetyl-coA.

24. **In the figure, synthesis of one molecule of the output needs_____**

    A. 9 NADPH molecules.
    B. 9 NADPH and 6 ATP molecules.
    C. 6 NADPH and 9 ATP molecules.
    D. Fixation of three CO2 molecules, 9 NADPH and 6 ATP molecules.
    E. Fixation of three CO2 molecules, 8 NADPH, and 9 ATP molecules.←

25. **The electrons lost from the reaction center pigment of photosystem II, are replaced by electrons from_____**
    A. ATP.
    B. CO2.
    C. H2O.←
    D. NADPH.
    E. P700.

26. **An overall result of photosynthesis in plants is the use of electrons from water to reduce___**
    A. Glucose.
    B. Carbon dioxide. ←
    C. Oxygen.
    D. Chlorophyll.
    E. NADPH.

27. **In the light reactions in photosynthesis, the final acceptor of both electrons and protons is____**
    A. NAD+
    B. NADP+ ←
    C. The primary electron acceptor.
    D. B and C.
    E. Either A or B.

Chapter 16

Nucleic acids and Inheritance

Concept 16.1: DNA is the genetic material

- Genes exist as parts of chromosomes and each chromosome is composed of a long DNA molecule and proteins.
- In the past, biochemists identified proteins as a class of macromolecules with great heterogeneity and specificity of function, essential requirements for the hereditary material.
- Evidences that DNA is the genetic material are numbered from 1 to 3.→

(1) In 1928, Frederick Griffith was studying *Streptococcus pneumonia*; he had two strains; **S (smooth)** ☺ strain that causes pneumonia in mice (it is pathogenic (disease causing) because the cells have an outer capsule that protects them from an animal's immune system), and **R (rough)** strain which lacks a capsule and is non-pathogenic. Griffith injected 4 mice; each with a different strain.

He was surprised to find that when he killed the pathogenic bacteria with heat and then mixed the cell remains with living bacteria of the nonpathogenic strain, some of the living cells cause disease, so some chemical component of the dead pathogenic cells caused this heritable change, although the identity of the substance was not known.
Griffith called the phenomenon **transformation**; a change in genotype and phenotype due to the assimilation of external DNA by a cell. Later work identified the transforming substance as DNA.

(2) Erwin Chargaff analyzed the base composition of DNA from a number of different organisms. He concluded the following rules (Chargaff's rules):

1. The base composition of DNA varies from one species to another
2. He noticed a peculiar regularity in the ratios of nucleotide bases; *the number of adenines approximately equaled the number of thymines, and the number of guanines approximately equaled the number of cytosines. In another words, the percentage of purines is equal to the percentage of pyrimidines.*

(3) The virus T2 infects *E.coli* bacterium (*E.coli* lives normally in our intestines), it is composed of DNA and proteins, and can quickly turn an E. coli cell into a T2-producing factory by infecting it and taking over its metabolic machinery to release many copies of new phages, *but which viral component (protein or DNA) is responsible for that?*

1. Alfred Hershey and Martha Chase used radioactive sulfur ^{35}S to tag the proteins of T2.
2. T2 infected the bacterial cells.
3. A mixture of infected bacterial cells was put in a blender to free phage parts outside the bacteria from the cells.
4. A centrifuge was then used to separate the contents of the mixture based on density and size.
5. After the mixture was centrifuged, the bacteria formed a pellet at the bottom of the test tube. Free phages and phage parts, which are lighter, remained suspended in the liquid (supernatant).
6. **The labeled material (proteins) appeared in the supernatant which means that it wasn't transmitted to infected bacterial cells**.
7. The scientists did the same experiment again but this time they used radioactive phosphorus isotope ^{32}P to tag DNA. **The labeled material (DNA) appeared in the pellet which means that it was transmitted from T2 to infected bacterial cells**.

- *They concluded that the DNA injected by the phage must be the molecule carrying the genetic information that enters the cells and makes them produce new viral DNA and proteins!*
- *The Hershey-Chase experiment provided evidence that nucleic acids, rather than proteins, are the hereditary material, at least for certain viruses.*

Watson and Crick's Discovery of the Double Helix

A 23-year-old American named James D. Watson journeyed to Cambridge University, where Englishman Francis Crick was studying protein structure with a technique called X-ray crystallography. While visiting the laboratory of Maurice Wilkins at King's College in London, Watson saw an X-ray crystallographic photograph of DNA, produced by Wilkins's colleague Rosalind Franklin.

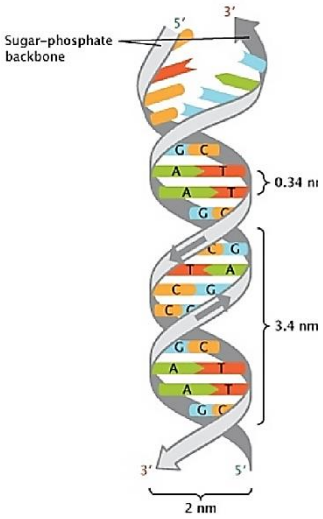
On the basis of Watson's later analysis of the photo, he and Crick deduced that *the diameter of the helix was uniform*. *The thickness* of the helix suggested that it was made up of two polynucleotide strands—in other words, a spiral **double helix.**

They failed to make a model that placed the sugar-phosphate backbones inside the double helix, so, Watson tried putting the backbones on the outside and *forcing the nitrogenous bases in the interior of the molecule* (Rosalind suggested *that* before).

At first, Watson imagined that the bases paired like with like—for example, A with A, C with C. But that kind of pairing did not fit with the fact that the DNA molecule has a uniform diameter. An AA pair (made of two double-ringed bases) would be almost twice as wide as a CC pair (made of two single-ringed bases), causing bulges in the molecule. It soon became apparent that a double-ringed base on one strand must always be paired with a single-ringed base on the opposite strand.

Moreover, Watson and Crick realized that the individual structures of the bases dedicated the pairings even more specifically. Each base has chemical side groups that can best form hydrogen bonds with one appropriate partner (Adenine can best form hydrogen bonds with thymine, and guanine with cytosine).

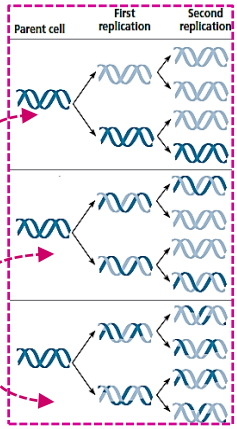
- In the biologist's shorthand, A pairs with T, and G pairs with C. A is also said to be "complementary" to T, and G to C.
- DNA is a pair of templates, each of which is complementary to the other.



Concept 16.2: Many proteins work together in DNA replication

Models for DNA replication:

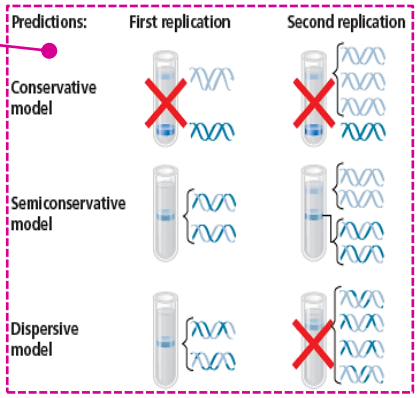
1. The conservative model→ the two parental strands come back together after the process *(the parental **molecule** is conserved).* (INCORRECT)
2. Semi-conservative model→ each of the two daughter molecules will have one old strand, from the parental molecule, and one newly made strand. (CORRECT)
3. Dispersive model→ all four strands of DNA following replication have a mixture of old and new DNA. (INCORRECT)



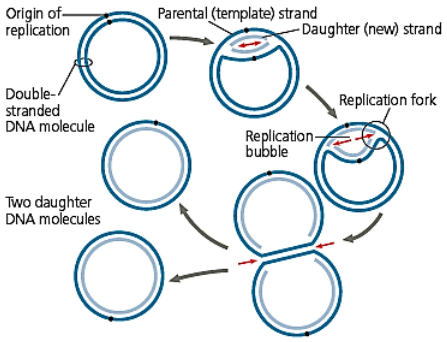
Matthew Meselson & Franklin Stahl cultured E. coli in a medium containing nucleotide precursor labeled with a heavy isotope of nitrogen, ^{15}N. Then, they transferred the bacteria to a medium with only ^{14}N a lighter isotope. They took one sample after the 1st DNA replication and the 2nd replication. They extracted DNA from the bacteria in the samples and then centrifuged each DNA sample **to separate DNA of different densities**.

The first replication in the ^{14}N medium produced a band of hybrid (^{15}N -^{14}N) DNA (this result eliminated the conservative model).

The second replication produced both light (^{14}N) and hybrid DNA (this result refuted the dispersive model and supported the semiconservative model).

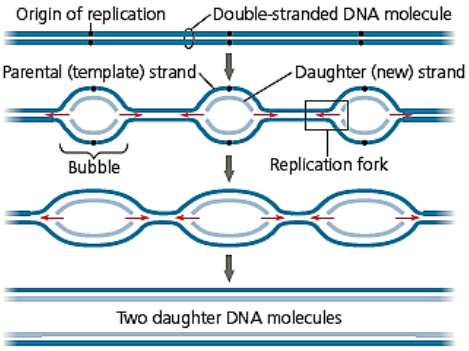


In order for DNA to replicate, its two chains (strands) must be separated by breaking the hydrogen bonds between them. After separating them, each chain will serve as a template chain (parent strand) for the formation -onto itself- of a new companion chain (daughter strand). Where there was one double-stranded DNA molecule at the beginning of the process, there are now two, each an exact replica of the "parental" molecule.



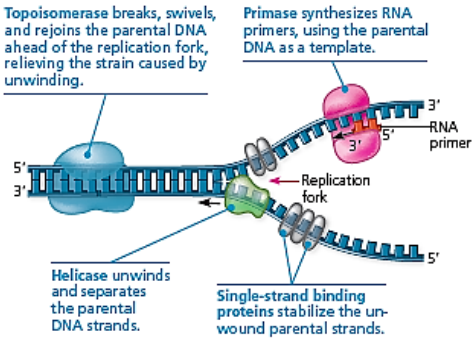
Origin of replication: short stretches of DNA that has a specific sequence of nucleotides which the replication of DNA starts from it.

a. The bacterial chromosome (e.g. *E. coli*) is circular and has a single origin. Proteins that initiate DNA replication recognize this sequence and attach to the DNA, separating the two strands and opening up a replication "bubble". Replication of DNA then proceeds in both directions until the entire molecule is copied.
b. A eukaryotic chromosome is linear and may have hundreds to a thousand replication origins. Proteins that initiate DNA replication open multiple replication bubbles which eventually **fuse**, thus speeding up the copying of the very long DNA molecules. DNA replication proceeds in both directions from each origin. At each end of a replication bubble is a replication fork (a Y-shaped region where the parental strands of DNA are being unwound).



Enzymes involved in DNA replication: [1-6]

1. Helicase→ untwists the double helix at the replication forks, separating the two parental strands and making them available as template strands.
2. Single-strand binding proteins (SSBP) → bind to the unpaired DNA strands, keeping them from re-pairing (stabilize the unwound strands).
3. Topoisomerase → helps relieve wounding **strain** by breaking, swiveling, and rejoining DNA strands ahead of replication fork.



4. Primase → synthesizes RNA primers, using the parental DNA as a template.

The enzymes that synthesize DNA cannot **initiate** the synthesis of a polynucleotide; they can only add DNA nucleotides to the 3' end of an **already existing chain** that is base-paired with the template strand. *The initial nucleotide chain that is produced during DNA synthesis is actually a short stretch of **RNA**, not DNA.* This RNA chain is called a primer and is synthesized by the enzyme **primase**. Primase starts a complementary RNA chain with a single RNA nucleotide and adds RNA nucleotides **one at a time**, using the parental DNA strand as a template (*the completed primer (5–10 nucleotides) is base-paired to the template strand)*. The new DNA strand will start from the 3' end of the RNA primer.

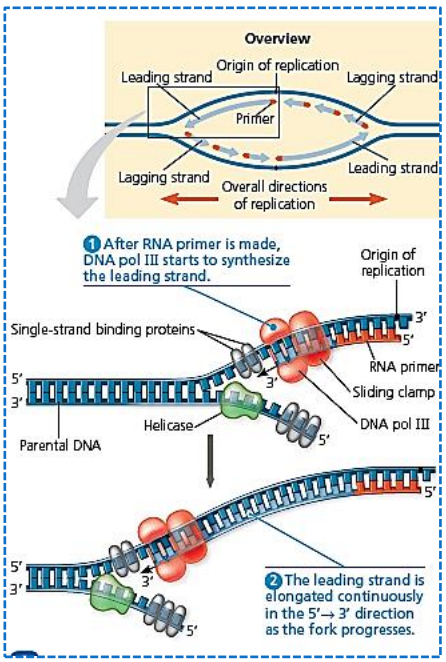
5. DNA polymerases → add nucleotides to the 3′ end of a preexisting chain.
   c. In E. coli, there are several DNA polymerases, but two appear to play the major roles in DNA replication: DNA polymerase III and DNA polymerase I. The situation in eukaryotes is more complicated, with at least 11 different DNA polymerases discovered so far.
   d. The rate of elongation = 500 nucleotides/second in bacteria and 50/second in human cells.
   e. Each nucleotide is composed of a deoxyribose, a nitrogenous base and three phosphate groups (similar to the structure of ATP except that ATP is composed of a ribose not deoxyribose).These nucleotides are reactive, partly because their triphosphate tails have an unstable cluster of negative charge.
   f. DNA polymerase adds each monomer via a dehydration reaction. As each monomer is joined to the growing end of a DNA strand, **two phosphate groups are lost** as a molecule of pyrophosphate $_2(P)_i$. Hydrolysis of the pyrophosphate into two molecules of inorganic phosphate (Pi) is a coupled **exergonic reaction** that helps drive the polymerization reaction.
   g. After **DNA polymerase III** is done, DNA pol I, removes RNA nucleotides of primer from 5′ end and replaces them with DNA nucleotides added to 3′ end of adjacent fragment.

6. DNA ligase joins the **final DNA nucleotide** of this replacement (primer → DNA) to the first DNA nucleotide of the adjacent **Okazaki fragment** by joining the **sugar-phosphate backbones,** and on the leading strand, joins 3′ end of DNA that replaces primer to rest of leading strand DNA.

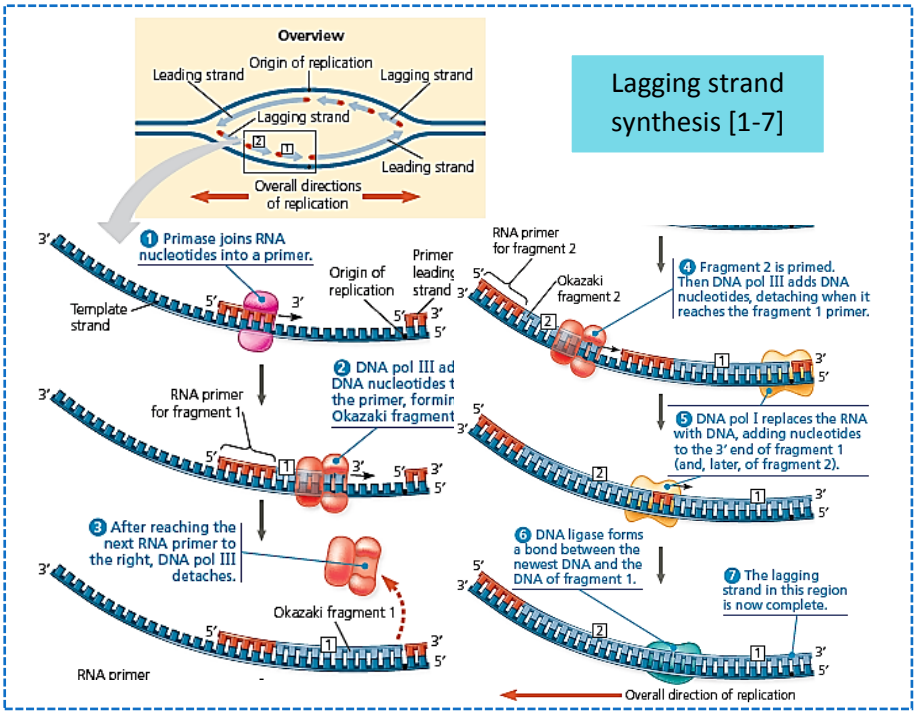
[What are the leading strand & Okazaki fragments? ↴]

- What happens is that, primase adds only one primer along one template strand. DNA polymerase III can synthesize a complementary strand **continuously** by elongating the new DNA in the 5′ → 3′ direction. DNA pol III remains in the replication fork to add nucleotides as the fork progresses.
- The daughter DNA strand made by this mechanism is called the leading strand **(one primer is required for DNA pol III to synthesize the entire leading strand continuously).** There's a sliding clamp complex which moves DNA pol III along the DNA template strand.
- Along the other template strand, primase adds **more than one** primer, and DNA pol III work in the direction away from the replication fork (since synthesis occurs in the 5′ → 3′ direction).This daughter strand is called the lagging strand. The lagging strand is synthesized discontinuously, as a series of segments; these segments are called Okazaki fragments, and **each Okazaki fragment requires a primer**.
- Synthesis of the leading strand and synthesis of the lagging strand occur concurrently and at the same rate.

Leading strand synthesis [1-2]



Lagging strand synthesis [1-7]



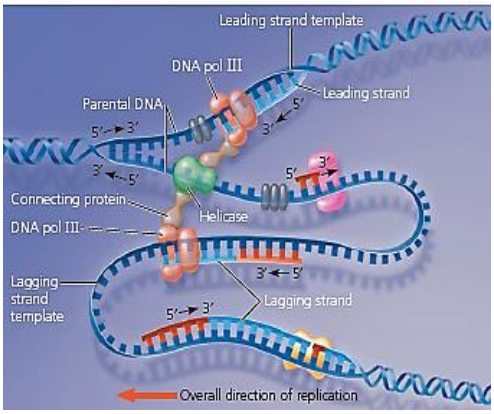
The DNA Replication Complex

(1) The various proteins that participate in DNA replication actually form a **single large complex** (called DNA replication machine). *Protein-protein interactions facilitate the efficiency of this complex; for example, by interacting with other proteins at the fork, primase acts as a brake, slowing progress of the replication fork and coordinating the placement of primers and the rates of replication on both strands.*

(2) The DNA replication complex may not move along the DNA; rather, the DNA may move through the complex during the replication process.

In eukaryotic cells, multiple copies of this complex, grouped into "factories," may be anchored to the **nuclear matrix.**

- Trombone model is a model in which two DNA polymerase molecules, one on each template strand, "reel in" the parental DNA and extrude newly made daughter DNA molecules, and the lagging strand is also looped back through the DNA. (see the figure↓)



xeroderma pigmentosum (XP) is a disorder caused by an inherited defect in a nucleotide excision repair enzyme. Individuals with XP are hypersensitive to sunlight; mutations in their skin cells caused by UV light are left uncorrected, often resulting in skin cancer. *(The effects are extreme; without sun protection, children can develop skin cancer by age 10)*

During DNA replication ,many DNA polymerases proofread each nucleotide against its template as soon as it is covalently bonded to the growing strand). In other words, upon finding an incorrectly paired nucleotide ,the polymerase removes the nucleotide and then resumes synthesis.*

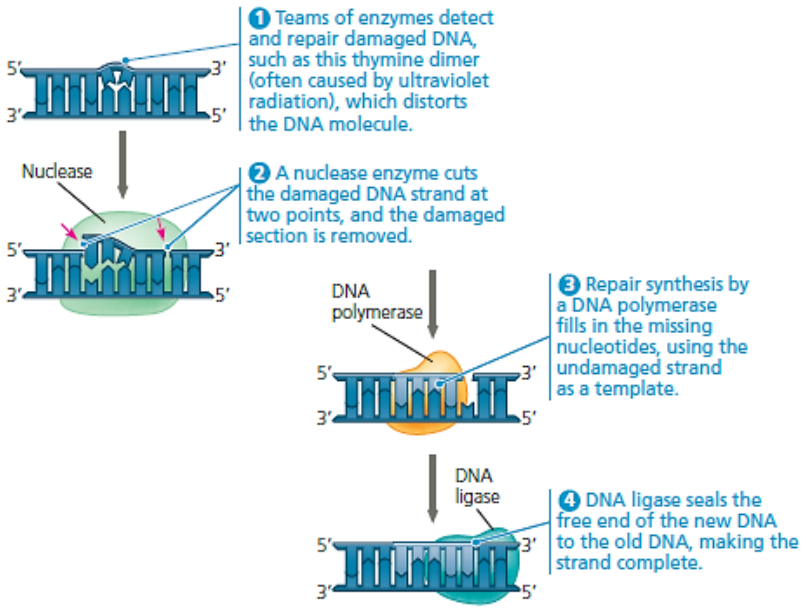
*Mismatched nucleotides sometimes evade proofreading by the DNA polymerase. In this case, (aka. mismatch repair), other enzymes remove and replace incorrectly paired nucleotides that have resulted from replication errors.

*A hereditary defect in one of those enzymes is associated with a form of **colon cancer** (since this allows cancer-causing errors to accumulate in the DNA faster than normal).

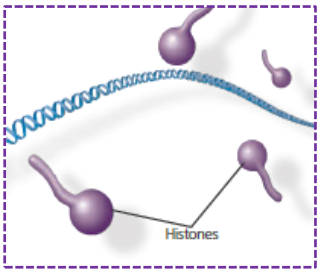
*Incorrectly paired or altered nucleotides can also arise after replication; due to the exposure to harmful chemical and physical agents (e.g. X-rays), which causes DNA bases to undergo spontaneous chemical changes under normal cellular conditions. However, these changes in DNA are usually **corrected** before they become permanent changes—mutations—perpetuated through successive replications.

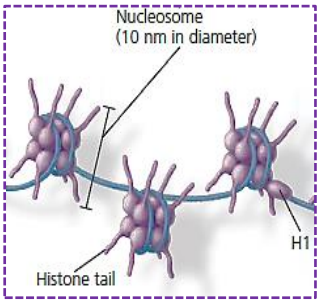
[How corrected? By DNA repair systems↴]

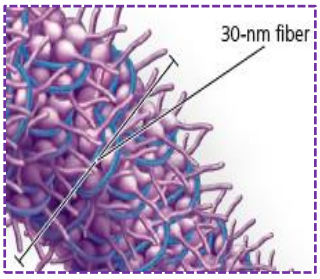
One DNA repair system is called nucleotide excision repair; it's important in our skin cells to repair genetic damage caused by the ultraviolet rays of sunlight (UV light can cause covalent linking of thymine bases that are adjacent on a DNA strand and such thymine dimers cause the DNA to buckle and interfere with DNA replication).

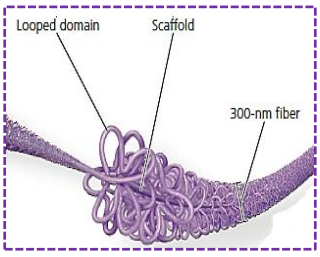


Concept 16.3: A chromosome consists of a DNA molecule packed together with proteins









Chromatin Packing in a Eukaryotic Chromosome

1. Stretched out, the circular DNA of an E. coli cell would measure about a millimeter in length, and small amount of protein causes the chromosome to coil (supercoil) densely, packing it so that it fills only part of the cell (**nucleoid**). However, each eukaryotic chromosome contains a single linear DNA double helix that, in humans, averages about 1.5 * 10^8 nucleotide pairs, and if stretched out, it would be about 4 cm long (1000X of a cell nucleus), and the double helix is about 1 nm in diameter. The eukaryotic DNA is combined with a large amount of protein to form **chromatin** which fits into the **nucleus** through an elaborate, multilevel system of packing .
2. **Histones** are small *(≈100 amino acids)* responsible for the first level of DNA packing in chromatin. Their total mass roughly **equals** the mass of DNA. More than a 1/5 of a histone's amino acids are positively charged **(lysine or arginine),** and therefore bind tightly to the negatively charged DNA. Four types of histones are most common in chromatin. Histones are very similar among eukaryotes *(e.g. in cows and pea plants, histones differ in two amino acids).*
3. Unfolded chromatin is 10 nm in diameter, and resembles beads on a string; each bead is a **nucleosome (the basic unit of DNA packing),** and the string between beads is the linker DNA. A nucleosome ***(10 nm fiber)*** consists of DNA wound **twice** around a protein core of **eight histones**, two each of the main four histone types. The amino end **(N-terminus)** of each histone **(tail)** extends outward from the nucleosome. In the cell cycle, the histones leave the DNA only briefly during DNA replication and transcription as well. Also, **tails** are involved in the **regulation** of gene expression.
4. Interactions between the **histone tails** of one **nucleosome** and the **linker DNA** and **nucleosomes** on either side cause the extended 10-nm fiber to coil or fold, forming a chromatin fiber roughly 30 nm in thickness (***30-nm fiber is prevalent in interphase nucleus).***The fifth type of histone is involved at this level (the 30 nm fiber level).
5. The 30-nm fiber forms *looped* domains attached to a chromosome scaffold composed of proteins, thus making up a *300-nm fiber*. The scaffold is rich in one type of ***topoisomerase***.
6. In a mitotic chromosome, the looped domains coil and fold, compacting all the chromatin to produce the **metaphase** chromosome. The width of one chromatid is 700 nm. Genes always end up located at the same places in metaphase chromosomes (packing is highly specific and precise).

In interphase cells, the chromatin usually appears as a diffuse mass (highly extended), and this type of chromatin is called heterochromatin. As a cell prepares for mitosis, its chromatin coils and folds up (condenses) forming short, thick metaphase chromosomes that are distinguishable from each other, and this type of chromatin is called euchromatin.

Although an interphase chromosome lacks an obvious scaffold, its looped domains (300nm fibers) appear to be attached to the nuclear lamina, on the inside of the nuclear envelope, and perhaps also to fibers of the nuclear matrix. These attachments may help organize regions of chromatin where genes are active.

- Gene activity: [histone modification also affects gene activity]
  * Heterochromatin: inactive genes
  * Euchromatin: active genes

➲ ***Test your understanding***

1. **Okazaki fragments_____**
   A. Are fragments of the discontinuously synthesized DNA strand. ←
   B. Demonstrate that DNA replication is dispersive.
   C. Are fragments of the template DNA during replication.
   D. Are fragments produced by DNA polymerase.
   E. None of the options are correct.

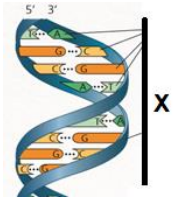
2. **Which one of the following statements about nucleosomes is INCORRECT?**
   A. They're the units of DNA packing.
   B. The nucleosome core is wrapped by the DNA double helix.
   C. Four copies of histone Hl are present in the nucleosome core.←
   D. The nucleosome core contains an octet of 8 histone proteins.
   E. There are two copies of each histone protein in the nucleosome core.

3. **Which of the following help to hold the DNA strands apart while they are being replicated?**
   A. Single-strand binding proteins.←
   B. Ligase.
   C. DNA polymerase l.
   D. Topoisomerase.
   E. Helicase.

4. **According to <u>Watson Crick</u> model, the two strands of the DNA double helix are_____**
   A. Antiparallel.←
   B. 3.4 nm apart.
   C. Semiconservative.
   D. Parallel.
   E. Identical.

5. **Which of the following is synthesized from 3' to 5'?**
   A. Primers.
   B. The leading strand.
   C. The lagging strand.
   D. Okazaki fragments.
   E. None of the options are correct.←

6. **In this figure, the distance represented by the letter (x) is_____**
   A. 0.34nm
   B. 34nm
   C. 3.4nm ←
   D. 1.5cm
   E. 2cm



7. **Which of the following can be said to be a semiconservative process?**
   A. Translation.
   B. Transcription.
   C. Translocation.
   D. DNA replication.←
   E. Transformation.

8. **In this figure representing DNA replication, which letter represents the leading strand?**
   A. A. ←
   B. B.
   C. C.
   D. D.
   E. None of the above.

9. **Cytosine makes up 38% of the nucleotide bases in a sample of DNA from an organism. Approximately, what is the percentage of the Thymine nucleotides?**
   A. 12%←
   B. 24%
   C. 31%
   D. 38%
   E. It cannot be determined from the information given.

Chapter 17

Gene Expression

Concept 17.1: Genes specify proteins via transcription and translation

- Archibald Garrod hypothesis: each gene dictates the production of a specific **enzyme** (called gene–one enzyme hypothesis).This hypothesis got rejected, *why?*
  1. Not all proteins are enzymes (e.g. Keratin, insulin…).
  2. Many proteins are made up from two or more different chains and each polypeptide is specified by its own gene (e.g. hemoglobin).
- Beadle and Tatum's idea was therefore restated as the "one gene–one polypeptide hypothesis". However, the one gene-one polypeptide hypothesis isn't accurate, *why?*
  1. A eukaryotic gene can code for a set of closely related polypeptides via a process called alternative splicing.
  2. A few genes code for RNA molecules that have important functions in cells (not translated into proteins).

Transcription is the synthesis of RNA using information in the DNA. The type of RNA molecule that can be translated into a protein is called messenger RNA (mRNA). Translation is the synthesis of a polypeptide using the information in the mRNA; the cell must translate the nucleotide sequence of an mRNA molecule into the amino acid sequence of a polypeptide.
The sites of translation are ribosomes.

Bacteria do not have nuclei; they don't have nuclear membranes to separate bacterial DNA and mRNA from ribosomes and the other protein-synthesizing equipment. This lack of compartmentalization allows translation of an mRNA to begin while its transcription is still in progress (transcription and translation occur in the cytoplasm). However, eukaryotic cells have nuclei, and the presence of a nuclear envelope separates transcription from translation in space and time. Transcription occurs in the nucleus and the mRNA is transported to the cytoplasm for translation. Before the mRNAs leave, they are modified in various ways to produce the final, functional mRNA. The transcription results in pre-mRNA, and further processing yields the finished mature mRNA.
Primary transcript: the initial RNA transcript from any gene, including those specifying RNA that is not translated into protein.

For each gene, only one of the two DNA strands is transcribed. This strand is called the template strand because it provides the pattern, or template, for the sequence of nucleotides in an RNA transcript. The other strand is called the non-template strand (aka. coding strand).

- ✓ For any given gene, **the same** strand is used as the template every time the gene is transcribed. However, farther along on the same chromosomal DNA molecule, the opposite strand may function as the template for **a different gene.**
- ✓ The strand that is used as the template is determined by the **orientation of the enzyme** that transcribes genes, which in turn depends on the **particular DNA sequences** associated with that gene.
- ✓ An mRNA molecule is **complementary** rather than identical to its DNA template. The RNA molecule is synthesized in an antiparallel direction to the template strand of DNA.

- ✓ As mentioned before, genes program protein synthesis via genetic messages in the form of mRNAs. This concept was dubbed the central dogma.
  [Some enzymes use RNA molecules as templates for DNA synthesis]
- ✓ During translation, the mRNA is read as a sequence of nucleotide triplets, called codons. Each codon specifies an amino acid to be added to the growing polypeptide chain. In other words, triplets of nucleotide bases are the smallest units of uniform length that can code for all the amino acids. Thus, the genetic instructions for a polypeptide chain are written in the DNA as a series of non-overlapping, three-nucleotide words.

-Keep in mind that Guanine is transcribed into Cytosine and Adenine is transcribed into Uracil -not Thymine-.

-mRNA is synthesized in the 5' → 3' direction.

The term codon is also used for the **DNA nucleotide triplets** along the **non-template strand**. These codons are complementary to the template strand and thus **identical in sequence to the mRNA,** except that they have a T wherever there is a U in the mRNA (codons are identical to the non-template strand). For this reason, the non-template DNA strand is often called the **coding strand** and the sequence of the coding strand is used when a gene's sequence is reported. Codons are written in the 5' → 3' direction.

61 of the 64 triplets (codons) code for amino acids; the three codons are "stop" signals, or termination codons, marking the end of translation.

There is redundancy in the genetic code, but no ambiguity

For example, codons GAA and GAG both specify glutamic acid (redundancy), however, neither of them ever specifies any other amino acid (no ambiguity).The redundancy in the code is not altogether random; codons that are synonyms for a particular amino acid differ only in the **third** nucleotide base of the triplet.

The short stretch of a polypeptide will be made correctly only if the mRNA nucleotides are read from 5' → 3' in triplets.
Although a genetic message is written with no spaces between the codons, the cell's protein synthesizing machinery reads the message as a series of non-overlapping three-letter words; this is called the reading frame.

The codon AUG (1) codes for the amino acid methionine (Met, or M) and also (2) functions as a "start" signal, or initiation codon *(it signals the protein synthesizing machinery to begin translating the mRNA at its location),* and because AUG also stands for methionine, polypeptide chains begin with methionine when they are synthesized. However, an enzyme may subsequently remove this starter amino acid from the chain.

Concept 17.2: Transcription is the DNA-directed synthesis of RNA: a closer look

Transcription overview

RNA is synthesized by an enzyme called RNA polymerase; it pries the two strands of DNA apart and adds RNA nucleotides in its 5' → 3' direction (adding to the 3' end). Unlike DNA polymerases, RNA polymerases are able to start a chain from scratch; they don't need to add the first nucleotide onto a pre-existing primer.

- The DNA sequence where **RNA polymerase** attaches and initiates transcription is known as the promoter; in bacteria, the sequence that signals the end of transcription is called the terminator.
- Molecular biologists refer to the direction of transcription as "downstream" and the other direction as "upstream." These terms are also used to describe the positions of nucleotide sequences within the DNA or RNA.
- The stretch of DNA downstream from the promoter that is transcribed into an RNA molecule is called a transcription unit.
- Bacteria have a single type of RNA polymerase that synthesizes not only mRNA but also other types of RNA that function in protein synthesis (e.g. ribosomal RNA). In contrast, eukaryotes have at least three types of RNA polymerase **in their nuclei;** the one used for **pre-mRNA synthesis** is called RNA polymerase II. The other RNA polymerases transcribe RNA molecules that are not translated into protein.

** The three stages of transcription are initiation, elongation, and termination of the RNA chain.

Stage 1: RNA polymerase Binding and Initiation of Transcription

1. The promoter of a gene includes within it the transcription start point-the nucleotide where RNA polymerase actually begins synthesis of the mRNA (upstream from the transcription unit).
2. In prokaryotic, part of the RNA polymerase **itself** specifically recognizes and binds to the promoter. In eukaryotic cells, proteins called transcription factors mediate the initiation of transcription by RNA polymerase II, and only after transcription factors are attached to the promoter, RNA polymerase II bind to it.
3. A eukaryotic promoter commonly includes a TATA box (a nucleotide sequence containing TATA) about 25 nucleotides upstream from transcriptional start point.
4. **Several transcription factors,** one recognizing the TATA box, must bind to the DNA before RNA polymerase II can bind in the correct position. Then, additional transcription factors bind to the DNA along with RNA polymerase II, forming the transcription initiation complex. RNA polymerase II then unwinds the DNA double helix, and RNA synthesis begins.

Stage 2: Elongation of the RNA Strand

As RNA polymerase moves along the DNA (5' → 3') untwisting the double helix and exposing about 10-20 DNA nucleotides at a time for pairing with RNA nucleotides, it adds nucleotides to the 3' end of the growing RNA molecule. The new RNA molecule peels away from its DNA template, and the DNA double helix re-forms.
A single gene can be transcribed simultaneously by several molecules of RNA polymerase following each other, increasing the amount of mRNA transcribed from it, which helps the cell make the encoded protein in large amounts. The length of each new RNA strand reflects how far along the template the enzyme has traveled from the start point.

Stage 3: Termination of Transcription

- Bacteria and eukaryotes differ in the way they terminate transcription; in bacteria, transcription proceeds through a terminator sequence in the DNA. The transcribed terminator (an RNA sequence) functions as the termination signal, causing the polymerase to detach from the DNA and release the transcript, which requires no further modification before translation.
- In eukaryotes, RNA polymerase II transcribes a sequence on the DNA called **the polyadenylation signal sequence,** which is transcribed to a polyadenylation signal (AAUAAA) in the **pre-mRNA.** This is called a "signal" because once this stretch of six RNA nucleotides appears, it is immediately bound by certain proteins in the nucleus.
- Then, at a point about 10–35 nucleotides downstream from the AAUAAA, these proteins cut the RNA transcript free from the polymerase, releasing the **pre-mRNA.**

Concept 17.3: Eukaryotic cells modify RNA after transcription

Enzymes in the eukaryotic nucleus modify pre-mRNA in specific ways before the genetic message is dispatched to the cytoplasm for translation.

Alteration of mRNA Ends

1) The 5' end, which is synthesized first, receives a 5' cap which is a modified form of a guanine (G) nucleotide added onto the 5' end after transcription of the first 20–40 nucleotides.
2) At the 3' end, an enzyme then adds 50–250 more Adenine (A) nucleotides, forming a poly-A tail.

This alteration (1) facilitates the export of the mature mRNA from the nucleus, (2) helps protect the mRNA from degradation by hydrolytic enzymes, and (3) helps ribosomes attach to the 5' end of the mRNA once the mRNA reaches the cytoplasm.

Ribozymes are RNA molecules that function as enzymes.
In some organisms, RNA splicing can occur **without** proteins or additional RNA molecules; the intron RNA functions as a ribozyme and catalyzes its own excision **(e.g. in the ciliate protist *Tetrahymena*, self-splicing occurs in the production of ribosomal RNA (rRNA)).**

- Three properties of RNA enable some RNA molecules to function as enzymes.
  First, because RNA is single-stranded, a region of an RNA molecule may base-pair, in an antiparallel arrangement, with a complementary region elsewhere in the **same molecule**; this gives the molecule a particular three dimensional structure, and this specific structure is essential to the catalytic function of ribozymes.
  Second, some of the bases in RNA contain functional groups that can participate in catalysis.
  Third, the ability of RNA to hydrogen bond with **other nucleic acid molecules** (RNA or DNA) adds specificity to its catalytic activity. For example, complementary base pairing between the RNA of the spliceosome and the RNA of a primary RNA transcript precisely locates the region where the ribozyme catalyzes splicing.

Many genes are known to give rise to two or more different polypeptides, depending on which segments are treated as exons (the same segment may be treated as an intron or an exon); this is called alternative RNA splicing. Because of alternative splicing, the number of different protein products an organism produces can be much greater than its number of genes.

Split Genes and RNA Splicing

- RNA splicing is the process where large portions of the RNA molecules are removed and the remaining portions are reconnected.

RNA transcripts have long noncoding stretches of nucleotides, regions that are **not translated,** and most of these noncoding sequences are interspersed between coding segments of the gene and thus between coding segments of the pre-mRNA.
In other words, the sequence of DNA nucleotides that codes for a eukaryotic polypeptide is usually **not continuous;** it is split into segments. The noncoding segments of nucleic acid that lie between coding regions are called intervening sequences, or **introns**. The other regions are called **exons**, because they are usually expressed *(or because they **ex**it the nucleus)*, usually by being translated into amino acid sequences.
Exons include un-translated regions (UTRs) at the ends of the RNA, which make up part of the mRNA but are not translated into protein. The terms ***intron*** and ***exon*** are used for both RNA sequences and the DNA sequences that specify them.
The removal of introns is accomplished by a large complex made of proteins and small RNAs called a spliceosome. This complex binds to several short nucleotide sequences along an intron, including key sequences at each end, the intron is then released (and rapidly degraded), and the spliceosome joins together the two exons that flanked the intron.
What do small RNAs in the spliceosome do?

1. Participate in spliceosome assembly and **splice site recognition.**
2. Catalyze the splicing reaction (enzymatic activity 😳)

Proteins often have an architecture consisting of discrete structural and functional regions called domains. Different exons code for the different domains of a protein.

Exon shuffling

Introns increase the probability of crossing over between the exons of alleles of a gene—simply by providing more terrain (topography) for crossovers without interrupting coding sequences. This might result in new combinations of exons ➔ proteins with altered structure and function.

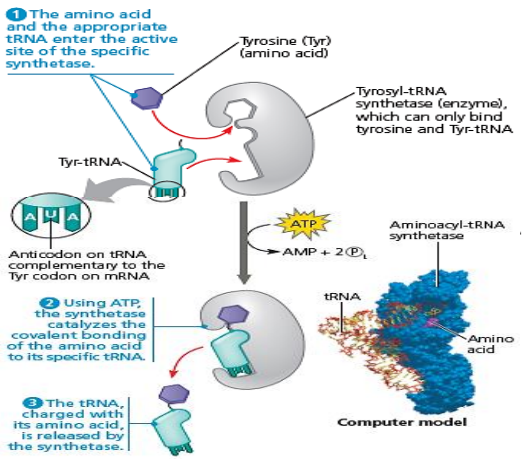
Also, mixing and matching of exons may occur between completely different (non-allelic) genes ➔ new proteins with novel combinations of functions. However, most of the shuffling would result in non-beneficial changes, and occasionally a beneficial variant might arise.

Ribosomes are composed of a small subunit and a large subunit. Each subunit is made of proteins and ribosomal RNA" rRNA".

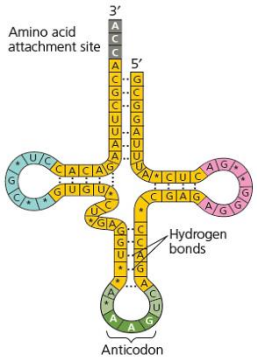
1. The number of rRNA molecules is 3 in bacteria and 4 in eukaryotes.
2. About one-third of the mass of a ribosome is made up of proteins.
3. Subunits are made in the nucleolus and then exported to cytoplasm via nuclear pores.
4. Ribosomes of eukaryotic slightly larger than of bacteria's ribosomes.
5. rRNA is primarily responsible for both the structure and the function of the ribosome.
6. Large and small subunits join to form a functional ribosome only when attached to an mRNA molecule.
7. Each ribosome has a binding site for mRNA and **three (1-3)** binding sites for tRNA.

1- The P site (peptidyl-tRNA binding site) holds the tRNA carrying the growing polypeptide chain.
2- The A site (aminoacyl-tRNA binding site) holds the tRNA carrying the next amino acid to be added to the chain.
3- Discharged tRNAs leave the ribosome from the E site (exit site).

8. As the polypeptide grow, it passes through an exit tunnel in the ribosome's large subunit. When the polypeptide is complete, it is released through the exit tunnel.



- **Transfer RNA (tRNA)** transfers an amino acid from the cytoplasmic pool of amino acids to a growing polypeptide in a ribosome. A cell keeps its cytoplasm stocked with all 20 amino acids, either by synthesizing them from other compounds or by taking them up from the surrounding solution.

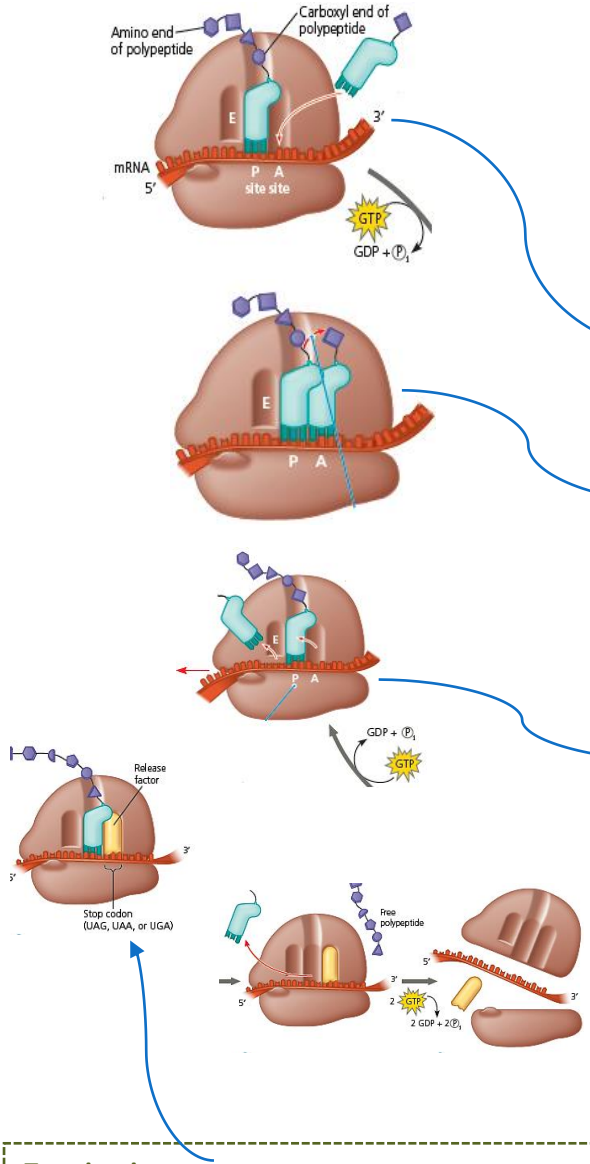


- It consists of a single RNA strand
- that is only about 80 nucleotides long. Because of the presence of complementary stretches -within the molecule- that can hydrogen bond to each other, this single strand can fold back on itself and form a molecule with a three dimensional structure that is roughly L-shaped with the 5' and 3' ends of the linear tRNA both located near one end of the structure.
- tRNA molecule looks like a cloverleaf 🍁.
- The 3' end is the amino acid attachment site. The loop extending from the 5' end includes the **anticodon**- the particular nucleotide triplet that base-pairs to a specific mRNA codon.
- Anticodons are conventionally written 3' → 5' to align properly with codons written 5' → 3'.
- Each tRNA molecule is used repeatedly, picking up its designated amino acid in the cytosol, depositing it onto a polypeptide chain at the ribosome, and then leaving the ribosome, ready to pick up another of the same amino acid.

- The correct matching up of tRNA and amino acid is carried out by a family of related enzymes that are named aminoacyl-tRNA synthetases.
- **There are 20 different synthetases, one for each amino acid**.
- Aminoacyl-tRNA = **charged** tRNA = tRNA + its appropriate amino acid (or polypeptide chain).
- In bacteria, there are only about 45 tRNAs, signifying that some tRNAs must be able to bind to more than one codon (since there are 61 codons). This's possible because base pairing between the **third** nucleotide base of a **codon** and the **corresponding base** of a tRNA **anticodon** is relaxed compared to those at other codon positions, and this flexible base pairing is called wobble; it explains why the codons for a given amino acid most often differ in their third nucleotide base.
  For example, *a tRNA with the anticodon 3'-UCU-5' can base-pair with either the mRNA codon 5'-AGA-3' or 5'-AGG-3', both of which code for arginine.*

(1) Ribosome Association and Initiation of Translation

-The start codon (AUG) signals the start of translation; it establishes the codon reading frame for the mRNA.
-In the first step, a small ribosomal subunit binds to both the mRNA and a specific initiator tRNA, which carries the amino acid methionine. *In bacteria,* the small subunit can bind the two in either order; it binds the mRNA at a specific RNA sequence, just upstream of the AUG start codon. *In eukaryotes,* the small subunit, with the initiator tRNA already bound, binds to the 5' cap of the mRNA and then moves (scans) downstream along the mRNA until it reaches the start codon; the initiator tRNA then hydrogen-bonds to the AUG start codon.
*Thus, the first components to associate with each other → (1) an mRNA molecule, (2) a tRNA bearing the first amino acid of the polypeptide and (3) the small ribosomal subunit. This is followed by the attachment of (4) a large ribosomal subunit, completing the translation initiation complex *((5) initiation factors are required to bring all these components together).* Hydrolysis of GTP provides the energy for this assembly.



Elongation of the polypeptide chain

-In the elongation stage of translation, amino acids are added one by one to onto the C-terminus of the growing chain. Each addition involves several proteins called elongation factors.
-The mRNA is moved through the ribosome in one direction only, 5' end first (i.e. the ribosome moves from 5' → 3' on the mRNA).
-This stage occurs in a three-step cycle, and energy expenditure occurs in the **first and third** ones.

1. Codon recognition: The anticodon of an incoming aminoacyl tRNA base-pairs with the complementary mRNA codon in the A site. Hydrolysis of GTP increases the accuracy and efficiency of this step.
2. Peptide bond formation: An rRNA molecule of the large ribosomal subunit catalyzes the formation of a peptide bond between the **amino** group of the new amino acid in the A site and the **carboxyl** end of the growing polypeptide in the P site *(this step removes the polypeptide from the tRNA in the P site and attaches it to the amino acid on the tRNA in the A site).*
3. Translocation: The ribosome translocates the tRNA in the A site to the P site. At the same time, the empty tRNA in the P site is moved to the E site, where it is released to the cytoplasm to be reloaded with the appropriate amino acid.
The mRNA moves along with its bound tRNAs, bringing the next codon to be translated into the **A site.**

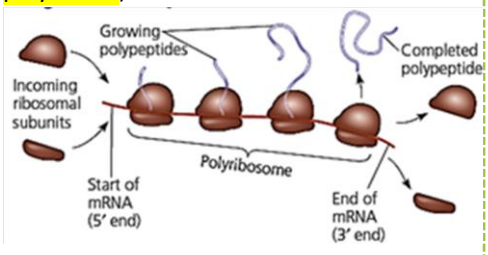
Termination:

-Elongation continues until a stop codon (UAG, UAA, and UGA) in the mRNA reaches the A site.
-A release factor, a protein shaped like an aminoacyl tRNA, binds directly to the stop codon in the A site.
-The release factor causes the addition of a water molecule instead of an amino acid to the polypeptide chain, and this addition breaks (hydrolyzes) the bond between the **completed polypeptide** and the tRNA in the P site, releasing the polypeptide through the exit tunnel of the ribosome's large subunit.
-The remainder of the translation assembly then comes apart in a multistep process, aided by other protein factors. Breakdown of the translation assembly requires the hydrolysis of two more GTP molecules.

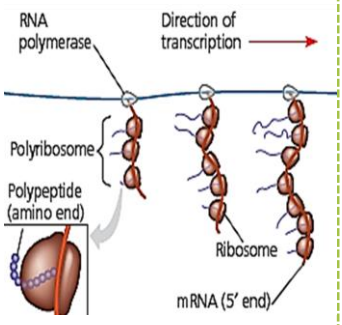
Targeting Polypeptides to Specific Locations

It is important to note that the ribosomes themselves are identical and can alternate between being free ribosomes one time they are used and being bound ribosomes the next. Polypeptide synthesis begins on a free ribosome in the cytosol, and the polypeptides of proteins destined for the endomembrane system or for secretion are marked by a signal peptide, which targets the protein to the ER. The signal peptide, a sequence of about 20 amino acids at or near the leading end (N-terminus) of the polypeptide, is recognized as it emerges from the ribosome by a **protein-RNA complex called a signal-recognition particle (SRP).** This binding halts synthesis momentarily. Then, the SRP binds to a receptor protein complex in the ER membrane (part of the pore complex (pore complex=translocation complex). After binding, the SRP leaves and the synthesis resumes, with simultaneous translocation across the ER membrane. The signal peptide is cleaved by an enzyme in the receptor protein complex, and the rest of the completed polypeptide leaves the ribosome and folds into its final shape.

In bacteria and eukaryotes, multiple ribosomes can **translate** an mRNA at the same time (i.e. a single mRNA is used to make many copies of a polypeptide)
Once a ribosome is far enough past the start codon, a second ribosome can attach to the mRNA, eventually resulting in a number of ribosomes trailing along the mRNA (called polyribosomes or polysomes).



Bacteria can simultaneously transcribe and translate the same gene, and the newly made protein can quickly diffuse to its site of function.



Post-translational modifications: additional steps may be required before the protein can begin doing its particular job in the cell.

1. *Chemical modification (e.g. attachment of sugars, lipids, and phosphate groups).*
2. *Enzymes may remove one or more amino acids from the leading (amino) end of the polypeptide chain.*
3. *A polypeptide chain may be enzymatically cleaved into two or more pieces (e.g. an enzyme cut insulin in a central part of the chain, leaving a protein made up of two chains connected by disulfide bridges).*
4. *Two or more polypeptides that are synthesized separately may come together, becoming the subunits of a protein that has a quaternary structure.*

Concept 17.5: Mutations of one or a few nucleotides can affect protein structure and function

Point mutations are small-scale mutations of one or a few nucleotide pairs, including changes in a single nucleotide pair of a gene. If it occurs in a gamete *-or in a cell that gives rise to gametes-*, it may be transmitted to offspring.

If it has an adverse effect on the phenotype, the mutant condition is referred to as a genetic disorder or hereditary disease (e.g. sickle-cell disease, and a heart condition called familial cardiomyopathy, which causes sudden death in young athletes).

SICKLE-CELL DISEASE

A mutation of a single nucleotide pair in the gene that encodes the β-globin polypeptide of hemoglobin causes sickle cell disease.

The mutant DNA (sickle-cell) template strand has an adenine where the wild-type (normal) template has a thymine. Thus, the mutant mRNA has a uracil instead of an adenine in one codon and the resulting β-globin has a valine (Val) instead of a glutamic acid (Glu).

Types of Small-Scale Mutations

1. Single nucleotide-pair substitutions (usually missense)

A nucleotide-pair substitution is the replacement of one nucleotide and its partner with another pair of nucleotides. It may result in:

(1) A silent mutation: it has no effect on the encoded protein (no effect on the phenotype), owing to the redundancy of the genetic code (e.g. CCG →CCA, the mRNA codon that used to be GGC would become GGU, but a glycine would still be inserted at the proper location).

(2) A missense mutation: it changes one amino acid to another one. It may have little effect on the protein (the new amino acid may have properties similar to those of the amino acid it replaces, or it may be in a region of the protein where the exact sequence of amino acids is not essential to the function), or it may cause a major change in a protein (e.g. sickle-cell disease). Such a mutation can lead to an improved protein with novel capabilities ☺, but much more often such mutations are neutral or detrimental. ☹

(3) A nonsense mutation: it changes a codon for an amino acid into a **stop codon**. It causes translation to be terminated **prematurely** 👶; the resulting polypeptide will be shorter than the normal one (mostly, nonfunctional).

2. Nucleotide-pair insertions or deletions (addition or loss of **one or more** nucleotide pairs)

They have a disastrous effect on the resulting protein more often than substitutions do, since they may cause a frame-shift mutation.

A frame-shift mutation occurs whenever the number of nucleotides inserted or deleted is not a multiple of three which alters the **reading frame (the triplet grouping of nucleotides) of the genetic message.

In this case, all nucleotides downstream of the deletion or insertion will be improperly grouped into codons.

The result will be **extensive missense mutations**, usually ending in a **nonsense mutation** that leads to premature termination 👶.

Insertions and deletions also occur outside of coding regions (not frame-shift mutations), but can have effects on the phenotype— for instance, they can affect ***how*** a gene is expressed.

Also, silent mutations (←) may indirectly affect the level of gene expression.

Mutations can also arise due to chemical or physical mutagens - which are mostly carcinogenic ☹-.
Examples on mutagens:

- ***Mutagenic radiation***: a physical mutagen that includes (1) UV light, which can cause disruptive thymine dimers in DNA and (2) X-rays.
- ***Nucleotide analogs***: chemical mutagens similar to normal DNA nucleotides but they pair incorrectly during DNA replication.
- Some chemical mutagens interfere with correct DNA replication by inserting themselves into the DNA and distorting the double helix.
- Mutagens that cause chemical changes in bases that change their **pairing properties.**

Spontaneous mutations: mutations that arise due to errors during DNA replication or recombination, which can lead to nucleotide-pair substitutions, insertions, or deletions, as well as to mutations affecting longer stretches of DNA.

In many cases, the error will be corrected by DNA proofreading and repair systems. Otherwise, the incorrect base will be used as a template in the next round of replication, resulting in a mutation.

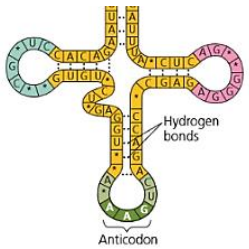
A gene is a region of DNA that can be expressed to produce a final functional product that is either a polypeptide or an RNA (e.g. rRNA, tRNA) molecule.

Promoters and other regulatory regions of DNA are not transcribed, but they can be considered part of the functional gene because they must be present for transcription to occur.

In multicellular organisms, a given type of cell expresses only a subset of its genes.

➲ *Test your understanding*

1. The figure represents tRNA that recognizes and binds the amino acid phenylalanine, which codon on the mRNA strand codes for the amino acid?



A. UGG.
B. GUG.
C. UUC.←
D. CUU.
E. CAU.

2. During protein biosynthesis, targeting polypeptides to endoplasmic reticulum does not involve_____

A. Signal peptide.
B. SRP receptor.
C. Translocation complex.
D. RNA polymerase.←
E. Signal recognition particle.

3. Which of the following components is not directly involved in translation?

A. tRNA.
B. mRNA.
C. RNA polymerases. ←
D. Ribosomes.
E. GTP.

4. Which is INCORRECT for RNA polymerase?

A. All of the options are incorrect
B. It can unwind the two strands of DNA to initiate transcription.
C. Its binding to the DNA template strand is mediated by transcription factors.
D. Several RNA polymerases can transcribe a gene Simultaneously.
E. It needs a primer. ←

5. An anticodon_____

A. Is read in 3' to 5' direction.
B. Normally base-pairs to a specific mRNA codon.
C. Is a triplet of bases found on the tRNA.
D. All of the options are correct.←
E. None of the options is correct.

6. Which of the following stages of translation require Energy?

A. Termination.
B. Elongation.
C. Formation of aminoacyl-tRNA.
D. Formation of translation initiation complex.
E. All of the options are correct. ←

7. The E site on the ribosome is_____

A. The site which holds the tRNA carrying the growing polypeptide chain.
B. The site which the empty tRNA leaves the ribosome.←
C. The site which holds aminoacyl tRNA.
D. The site from which developed polypeptide chain leaves the ribosome.
E. None of the options is correct

8. Which of the following is mis-matched?

A. DNA: double helix.
B. Splicing: eukaryotic pre-mRNA.
C. (G=C) and (A=T): Chargaff's rules.
D. Lagging strand: Okazaki fragments.
E. TATA box: DNA polymerase binding.←

9. Given the template DNA sequence 3'-TACATG-5', which of the following is its complementary mRNA strand?

A. (3')-AGTAGG-(5').
B. (5')-AUGUAC-(3'). ←
C. (5')-ATGTAC-(3').
D. (3')-AGUAGG-(5').
E. (5')-TACATG-(3').

10. A gene promotor_____

A. Contains the polyadenylation signal.
B. Is a nucleotide sequence that signals the start of translation.
A. Is a nucleotide sequence that signals the end of transcription.
B. None of the options is correct.
C. Is the binding site for RNA polymerase.←

11. The point mutation that doesn't produce a change in the amino acid sequence of protein is known as_____

A. Non-sense mutation.
B. Silent mutation.←
C. Missense mutation.
D. Chromosomal mutation.
E. Frame-shift mutation.

12. Which of the following is the translation initiation codon?

A. AUU
B. AUG ←
C. AGG
D. UAA
E. ACG

13. What are the coding segments of a stretch eukaryotic DNA called?

A. Introns.
B. Exons.←
C. Codons.
D. Replicons.
E. Transposons.

14. During a normal translocation cycle, where would you expect to find t-RNA attached to a single amino acid?

A. E site.
B. P site.
C. A site.←
D. Both E and p sites.
E. Both A and P sites.

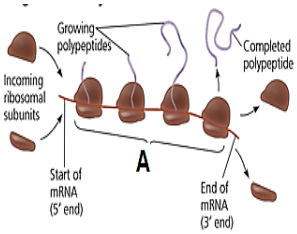
15. Aminoacyl t-RNA synthetase_____

A. Links a tRNA to the corresponding amino acid.←
B. Removes introns from the pre-mRNA transcript.
C. Splices exons in the pre-mRNA transcript.
D. Causes the RNA polymerase to attach from the DNA.
E. Joins together RNA nucleotides complementary to the template strand.

16. Transcription in eukaryotic requires which of the following in addition to RNA polymerase?

A. The protein product of the promoter.
B. Start and stop codons.
C. Ribosomes and tRNAs.
D. Several transcription factors. ←
E. Aminoacyl synthetase.

17. In the figure, the letter A illustrates a_____

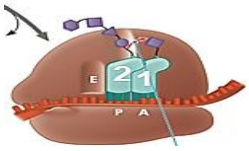


A. Nucleosome.
B. Ribosome.
C. Spliceosome.
D. Polysome.←
E. None of these.

18. What kind of molecules are the transcription factors?

A. DNA and RNA.
B. RNA and proteins.
C. Proteins. ←
D. Liquids.
E. Liquid and carbohydrates.

19. In the figure, where does the 2nd t-RNA move to after the bonding of lysine to the polypeptide?



A. A site.
B. P site.
C. E site.←
D. D site.
E. Directly to the cytosol.

20. What is the effect of a non-sense mutation in a gene?

A. It changes an amino acid in the encoded region.
B. It has no effect on the amino acid of the produced protein.
C. It introduces a stop codon into the mRNA and translation is terminated prematurely.←
D. It alters the reading frame of the mRNA.
E. It prevents introns from being cut.

21. In eukaryotes, translation occurs in the_____

A. Mitochondria.
B. Cytoplasm.←
C. Nucleolus.
D. Lysosome.
E. Centriole.

22. RNA polymerase moves in which direction along the DNA?

A. 3’ → 5’ along the template strand.←
B. 3’ → 5’ along the newly synthesized strand.
C. 5’ → 3' along the newly synthesized strand.
D. 3' → 5' along the antisense strand.
E. 5' → 3' along the double- stranded DNA.

23. Which of the following is INCORRECT about the genetic code?

A. Redundancy.
B. Read in the 5' to 3' direction.
C. Nearly universal for all species on earth.←
D. Doublets of nucleotides.
E. None of the options is incorrect.

Word	Meaning
Ability to bind another molecule	قدرة البروتين على الارتباط بجزيء آخر
Ability to moderate air temperature	قدرة الماء على تلطيف درجة حرارة الهواء
Absorb	يمتص
Absorbed	تم امتصاصه
Absorbing heat	امتصاص الحرارة
Absorption spectrum	طيف الامتصاص
Abundance	وفرة
Abundant	وفير
Accelerates	يسرع
Acceptor	مستقبل
Accumulate	يتراكم
Accumulation	تراكُم
Accuracy	دقة
Accurate	دقيقة
Acquired	مكتسبة
Activator	مفعِّل
Active	فعال و نشط
Adaptation	تكيف
Adhesion	التلاصق
Adipose tissue	النسيج الدهني
Adjacent	مجاور
Aerobic	هوائي
Affinity	انجذاب
Aggregate	تتجمع
Agitates	يثير
Aided	بمساعدة
Algae	الطحالب
Alternate	يتردد و يتبدّل
Alters	يغيّر
Ambiguity	التباس و غموض
Amoeboid movement	الحركة الأميبية
Amplifies	يكثّر و يضخّم
An asymmetric atom	ذرة بأطراف غير متماثلة
Anaerobic	لا هوائي
Analogs	نظير و شبيه
Anchorage	تثبيت
Anchored	مثبت
Antibiotics	مضادات حيوية
Antioxidants	مضادات أكسدة
Antiparallel strands	في اتجاهين متعاكسين
Appendages	زوائد
Aqueous	مائي
Aqueous solutions	محاليل مائية
Arthropods	المفصليات
Assembly	تكوين
Assimilation	استيعاب و امتصاص
Asymmetric	غير متماثل
Asymmetrical	غير متماثل

At a time	في الوقت نفسه
Atherosclerosis	تصلب الشرايين
Atoms	الذرات
Attain	الوصول إلى
Autophagy	الالتهام الذاتي
Average	معدل
Bead	خرزة
Beam	حزمة
Bearing	تحمل
Beating patterns	أنماط الحركة
Beneath	تحت
Binding	ارتباط
Blender	خلاط
Block	يغلق و يمنع
Boosts	يدفع و يثير
Branched	متفرع
Break	كسر
Bridge	الجسر
Brightness	السطوع
Broaden	يوسّع
Buckle	ينبعج
Building blocks	وحدات بنائية
Bulk	حجوم كبيرة نسبيًا
By-product	ناتج جانبي
Calcification	التكلس
Capable	قادر
Capacity	سعة و قابلية
Capture	يلتقط
Cargo	حمولة
Cascade	تسلسل
Catabolism	عمليات الهدم في الخلية
Catalyst	عامل محفّز (يسرع التفاعلات)
Cell fractionation	تجزئة الخلية
Cell membranes	الأغشية الخلوية
Cell recognition	التعرف الخلوي
Cell sap	عصارة الخلية
Cellular reproduction	التكاثر (الانقسام) الخلوي
Cellular respiration	التنفس الخلوي
Center	المركز
Centrifuge	الطرد المركزي
Centrifuged	وُضِعَت في الطرد المركزي
Chains	سلاسل
Chemical equilibrium	الاتزان الكيميائي
Cilium	هدب
Clarity	وضوح
Cleave	يقسم و يقص
Climate change	التغير المناخي
Clinging	متشبثة
Cloverleaf	ورق البرسيم
Cluster	تتجمع

Coalescence	يندمج
Coated	مغلّف
Cohesion	التماسك
Coil	يلتف
Coiled	ملفوف
Collapses	ينهدم و ينكمش
Collision	تصادم
Column of water	عامود الماء
Commit	يُلزم
Compacting	يرتص
Compartmentalization	تقسيم الخلية إلى عضيات
Competitive	تنافسي
Complementary	مكملات لبعض
Compression-resistance	مقاومة الضغط
Concentration	تركيز المذاب
Concluded	استنتج
Concurrently	في نفس الوقت
Condense	يتكاثف
Confocal	البؤري
Conservative	محافظ
Consume	يستهلك
Consumed	يفنى و يتم استهلاكه
Contact	يتواصل
Contents	محتويات
Contorting	ثني و طعج
Contract	يتقلص
Contraction	انقباض
Convert	يحول
Convoluted	ملفوف و معقد
Coordination	تنسيق
Core	لب و مركز
Co-receptor	مستقبل مصاحب
Correlates	يدل على
Co-transport	النقل المصاحب
Couple	يجمع و يصاحِب
Covalent	تساهمية
Crests	قمم الأمواج
Cross	يعبر
Crucial	مهم و أساسي
Crystalline lattice	شبكة بلورية
Cytology	علم تركيب الخلية
Cytoplasmic streaming	التدفق السيتوبلازمي
Cytoskeleton	الهيكل الخلوي
Dangerous	خطير
Dark areas	المناطق المعتمة
Decomposers	كائنات محللة
Deepen	يتعمق
Deforming	يشوه
Degradation	تحلل و تفكك
Dehydration	إزالة جزيء ماء
Delivery	توصيل

Denaturation	تمسخ و تخريب
Densely stained granules	حبيبات غامقة الصبغة
Denser	أكثر كثافة
Density	كثافة
Deplete	ينفذ
Derivatives	مشتقات
Derived	مشتق من
Destination	المكان المقصود
Destroyed	مدمَّر
Detach	ينفصل
Detected	تم التقاطه
Detoxification	إزالة السموم
Detrimental	ضار
Diameter	قطر
Dictate	يحدد
Different responses	استجابات مختلفة
Diffraction	انحراف
Diffuse mass	كتلة متناثرة غير واضحة
Diffusion	الانتشار
Digest	يهضم
Digested	مهضوم
Direct physical continuity	اتصال فيزيائي مباشر
Discrete	منفصل
Dismantled	يتفكك
Dispersive	مشتت
Disrupt	يخرب
Dissolve	يذوب
Distinct	مختلف و مميز
Distinguish	يميز
Distinguished	يمكن تمييزه
Distorting	تشويه
Distribution	توزيع
Disturbances	اضطرابات
Diversity	التنوع
Diverted	ينحرف عن
Do not have a distinct 3D structure	ليس لها بناء أو شكل محدد
Docking sites	أماكن رسوها (غاياتها)
Donor	متبرع
Double-layered	ثنائية الطبقات
Drift	يتحرك جانبيًا
Drop back	يعود
Droplets	قطرات
Dynamic	حركي
Dynamic equilibrium	اتزان حركي
Efficiency	كفاءة
Elaborate	دقيق
Electron transport chain	سلسلة نقل الالكترون
Electronegative	كهر وسلبي
Electronegativity	كهر وسلبية
Elongation	إطالة

Embryo	الجنين
Embryonic	جنيني
Embryonic development	التطور الجنيني
Emit	يشع
Enable	يسمح
Endergonic	ماص للطاقة
Energy	طاقة
Energy coupling	مصاحبة التفاعلات الطاردة بالتفاعلات الماصة للطاقة
Engorged	مكتظ و ممتلئ
Engulf	يبتلع
Enhance	يحسن
Ensure	يضمن
Entering	دخول
Environment	البيئة المحيطة
Epithelial tissue	النسيج الطلائي
Establishes	ينشئ
Eukaryotic	حقيقية النوى
Evade	يهرب
Evaporate	يتبخر
Evaporative cooling	التبريد بتبخر الماء
Excessive	زائد عن اللازم
Excessive heat	الحرارة العالية
Excited state	حالة نشطة و مثارة
Exclude	يبعِد
Excluded by water	تبعدها جزيئات الماء عنها
Exclusion	إبعاد
Exergonic	طارد للطاقة
Exert	يؤثر بـ
Existing	موجود
Exocytosis	الطرد الخلوي
Exoskeleton	الهيكل الخارجي
Expansion upon freezing	تمدد الماء بعد تجمده
Expel	يتخلص
Expenditure	باستهلاك
Expense	على حساب (باستهلاكه)
Export	تصدير
Exposed	معرض
Extend	يمتد
Extension	امتداد
Extensive	واسع
Extracted	مستخلص
Extrude	يبرز
Facilitated	مسهل
Facultative	اختياري
Fastening	يربط و يشد
Fatigue	تعب
Fatty acids	حموض دهنية
Feedback	التغذية الراجعة
Fermentation	التخمر
Fibers	خيوط

Final state	الحالة النهائية
Five-membered ring	حلقة خماسية
Fixing	تثبيت
Flaccid	رخو
Flagella	أسواط
Flanked	محاط
Flexible	مرن
Flip-flop movement	تقفز من طبقة لأخرى
Flow	تدفق
Fluidity	سيولة
Fluidity buffer	مقاوم للتغير في السيولة
Flush from the body	يندفع خارج الجسم
Focuses	يسلط
Fold	ينطوي
Folded and coiled	ملتف و منطوي
Foreign	غريب
Fossil fuels	الوقود الأحفوري
Fragile	هشة
Frame-shift mutation	طفرة الإزاحة
Fuel	وقود
Fungi	الفطريات
Further	زيادة
Fuses	يندمج
Fusion	اندماج
Gain	كسب
Gated	له بوابة
Generates	يولد
Generation	توليد
Glass lenses	عدسات زجاجية
Global warming	الاحتباس الحراري
Globular	كروي
Gradient	ممال أو فرق
Groove	حفرة
Gulp	ترتشف
Halted	متوقف
Heart diseases	أمراض القلب
Held	مثبت
Helical	حلزوني و لولبي
Helper	مساعد
Herbivore	آكل العشب
Hereditary	وراثي
Heterogeneity	اختلاف و عدم تجانس
Hibernating mammals	الثدييات في سباتها الشتوي
High	عالي
Hinder	يعيق
Hollow rods	عصيات مجوفة
Homogenized	تم تحويله إلى خليط متجانس
Hydration shell	غلاف أو قشرة مائية
Hydrocarbon regions	مناطق هيدروكربونية
Hydrocarbon tails	الأذيال الهيدروكربونية

Hydrogenated vegetable oils	الزيوت النباتية المهدرجة
Hydrolysis	التحلل المائي
Hydrolyze	تحلل
Hydrophilic substances	مواد محبة للمياه
Hydrophobic	كارهة الماء
Hydrophobic substances	مواد كارهة للمياه
Hypercholesterolemia	ارتفاع الكوليسترول في الدم
Identical	متماثل أو متطابق
Identification tags	علامات تعريف
Illuminated	تمت اضاءتها
Illuminating	اضاءة
Imaginary axis	محور وهمي
Immediately bound	مرتبط مباشرة
Immersed	مغمور
Immobile	غير متحرك
Immune	المناعة
Immune deficiency syndrome	متلازمة نقص المناعة
Immune system	جهاز المناعة
Immunodeficiency	نقص المناعة
Impeding	معيق
Imperceptible	ضئيل جدًا
Improperly	بشكل غير صحيح
Inactive	غير فعال
Incoming	القادم أو التالي
Incorporated	ينضم أو يندمج
Increasing speeds	بسرعات متزايدة
Indiscriminately	عشوائيًا
Infecting	إصابة
Ingredients	المكونات
Inhibitor	مثبط
Initial state	الحالة الأولية
Initiate	يبدأ
Initiation	البدء
Injected	محقون
Inorganic	غير عضوي
Inserted	يضاف
Instability	عدم استقرار (اضطراب)
Instructions	تعليمات
Insulate	يعزل
Integrate	يدمج
Intense	كثيف
Interact	يتفاعل
Intercellular joining	توصيل بين خلوي
Interface between water and air	السطح الفاصل بين الماء والهواء
Interfere	يعيق
Interior	داخل
Intermediate complex	مركب وسيط
Intermembrane space	الحيز بين الغشائين
Inter-molecular	بين الجزيئات

Internal structures	التراكيب الداخلية
Internalized	تم إدخاله
Interphase	مرحلة من مراحل الانقسام
Interrupting	مقاطعة
Interspersed	يتخلل
Intervening	يتدخّل
Intestinal	معوي
Intestines	الأمعاء
Intracellular	داخل الخلية
Introduced	تم إدخاله
Inversely	عكسيًا
Investment	استثمار (الانتفاع منه)
Ionized	متأين
Irreversible	غير رجعي
Join	يربط
Kidneys	الكليتين
Kind	نوع
Kinetic energy	الطاقة الحركية
Kinks	طعجات أو ثنيات
Lack	عدم
Lactic acid fermentation	تخمر حمض اللاكتيك
Lactose intolerance	حساسية اللاكتوز
Laminated layers	طبقات مصفّحة
Less dense	أقل كثافة
Limited	محدود
Lip	حافة
Liver	الكبد
Locked	مقيد
Long lasting	طويل الأمد
Looped	على شكل حلقات
Loosely	بشكل خفيف أو ضعيف
Lumen	تجويف أو حيز
Lyse	ينفجر
Magnification	التكبير
Magnified	تم تكبيره
Maintain	يحافظ
Manufacture	يصنع
Marine	المائية
Mask	يغطي أو يخبئ
Matrix	حشوة
Membranous	غشائي
Membranous vesicles	الحويصلات الغشائية
Metaphase	مرحلة من مراحل الانقسام
Microscopes	المجاهر
Migrate	تتحرك أو تهاجر
Mis-folded	بتركيب غير صحيح
Missense mutation	طفرة مخطئة التعبير
Mitosis	الانقسام المتساوي
Mitotic chromosome	الكروموسوم في انقسام الخلية
Modify	يعدل

Pathogenic	مسبب للمرض
Pathways	مسارات
Payoff	ربح أو تعويض
Peculiar	مميز
Peel	يقشر
Penetrate	يتخلل
Pentose	سكر خماسي
Percentage	نسبة
Perforated	مثقب
Periodic	دوري (على شكل هجمات)
Peripheral	طرفي
Periphery	الأطراف
Permanent fixtures	مثبت دائم للخلية
Permeability	نفاذية
Permeable	منفِذ
Perpetuated	دائم
Persist	بقي
Petals	بتلات
Phagocytosis	البلعمة
Phase contrast	الطور المتباين
Phenotype	الطراز الشكلي
Photosynthesis	البناء الضوئي
Pick	يلتقط
Pinch	ينقسم
Pit	تجويف
Pleated sheets	الشرائط المطوية
Pocket	جيب
Polar bonds	روابط قطبية
Polar molecule	جزيء قطبي
Polarity of water	قطبية جزيء الماء
Pollinating	التي تقوم بتلقيح الأزهار
Polymerization	بناء البوليمرات
Polypeptide	سلسلة عديد ببتيد
Pond	عذبة
Populating	يحتل
Pore	ثقب
Pore complex	مركب بروتيني حول الثقب
Portion	جزء
Position	موقع
Possess	يملك
Potential energy	طاقة وضع
Poured	مصبوب
Precursor	مكون بدائي
Pre-existing	موجود مسبقًا
Premature	مبكر
Presence	وجود
Pressure	ضغط
Prevents	يمنع
Primary	الأولي
Prism	موشور
Probability	احتمالية

Modifying	تعديل
Molecular signals	رسائل و إشارات
Momentarily	لحظيًا
Mosaic	فسيفساء
Mostly	عادة
Motility	الحركة
Motor protein	بروتين محرك
Movement	الحركة
Multi-protein	أكثر من بروتين
Multi-subunit	أكثر من وحدة
Muscle tears	تمزق عضلي
Mutagens	مسببات الطفرات
Mutations	الطفرات
Nerve impulse	نبض عصبي
Nervous system	الجهاز العصبي
Net	محصلة
Netlike array	نسق على شكل شبكة
Neurotransmitters	نواقل عصبية
Neutral	متعادل
Non-aqueous	غير مائي
Non-functional	غير فعال
Non-overlapping	غير متداخلة
Non-penetrating	غير نافذ (لا ينفذ عبر الغشاء)
Nonsense mutation	طفرة غير معبرة
Non-sense mutation	طفرة غير معبرة
Nourishment	التغذية
Nucleolus	النوية
Number	عدد
Obligate	إجباري
Ocean acidification	تحمض المحيطات
Offspring	النسل
Opposes	يعاكس أو يمانع
Optimal	المثلى
Orbital	مدار
Order	ترتيب
Organelles	عضيات
Organic	عضوي
Osmosis	الخاصية الأسموزية
Outpaces	يتجاوز في سرعته
Overcome	يتجاوز
Owing	بسبب
Oxidation	التأكسد
Oxidizing agent	عامل مؤكسد
Packaged	مرصوص و مخزن
Packed	مرصوص
Packing	الارتصاص و التقارب
Partial	جزيئي
Participate	يشارك
Particles	حبيبات أو جزيئات
Passage	مرور

Replenished	تم تجديده
Replicate	يتضاعف
Replication	تضاعفه
Repository	مخزن
Requirements	متطلبات
Resemble	يقلد أو يشابه
Resists	يقاوم
Resolution	قوة التمييز
Response	استجابة
Rest	البقية
Restraining	إعاقة و تقييد
Resume	يكمل
Reverse	معاكس
Reversible	رجعي
Rigid	صلب
Rivets	مسامير
Rotate	تحرك (تدير)
Sacs	حويصلات
Saturated fatty acids	حموض دهنية مشبعة
Saturated with hydrogen	مشبعة بالهيدروجين
Saturation	إشباع
Screening out	يغربل يصفّي أو
Seals	حزام
Secondary	الثانوي
Secretion	الإفراز
Sedative phenobarbital	المهدئات أو المسكنات
Segment	قطعة
Segregates	يفصل
Selective	انتقائي
Selective acceleration	تسريع انتقائي
Selective barrier	حاجز انتقائي
Selectively	بانتقائية
Self-assemble	تشكل ذاتي
Semi-conservative	شبه محافظ
Senile dementia.	خرف الشيخوخة
Separates	يفصل
Sequence	تسلسل
Sequential	متسلسل
Settle	يترسب
Shields	يغطي
Shipping	الشحن
Short stretches	قطع صغيرة
Shrink	ينكمش
Shrivel	تقلص وانكماش
Shuffling	خلط
Sickle-cell disease	الأنيميا المنجلية
Silent	صامتة
Similar	متشابه
Simultaneous	في نفس الوقت
Sinks	يغوص أو ينغمر
Siphoned	يتم اختلاسها

Proceed	يتقدم
Product	ناتج
Productivity	انتاجية
Progress	يتقدم
Projections	زوائد
Prokaryotic	بدائية النوى
Prominent	بارز
Proofread	يتحقق بإعادة قراءة التسلسل
Protection	حماية
Protein factories	مصانع البروتين
Protein framework	هيكل بروتيني
Pump	مضخة
Push	يدفع
Quantities	كميات
Rate	سرعة
Ratio	نسبة
Raw	خام
Reabsorption	إعادة الامتصاص
Reactants	المتفاعلات
Reactive	نشط و غير مستقر
Readily	بسهولة
Rearrange	يعيد ترتيب
Re-assemble	يعيد التكون
Receiving	الاستقبال
Recipient	المستقبل
Recognition	تعرّف
Recycle	يعيد تدوير
Reduce	يقلل
Reduced	مختزل
Reducing agent	عامل مختزل
Reduction	الاختزال
Redundancy	وفرة
Reef and shells	الأصداف و الشعاب المرجانية
Reel in	يلتف كأنه على بكرة
Reflect	يشع و يظهِر
Refract	يحرف و يثني
Regenerate	إعادة تكوين
Regulate	ينظم
Regulation	تنظيم
Reinforcing	يقوي
Reject	يرفض
Rejected	مرفوض
Rejection	رفض
Rejoining	يعيد ربط
Release	يطلق أو يترك (يفك)
Relieve	يريح
Remainder	المتبقي
Remained	بقي
Renewable resource	مصدر متجدد
Replacement	الاستبدال

Tertiary	الثالثي (من الدرجة الثالثة)
Testes and ovaries	الخصيتين و المبيضين
The alpha helix coils	اللفائف اللولبية أو الحلزونية
The binding of an oxygen molecule to one binding site increases the affinity of the remaining binding sites for oxygen.	ارتباط الأكسجين في وحدة واحدة يزيد من انجذاب جزيئات الأكسجين للوحدات الأخرى.
The emerging seedling	الشتلات أو البراعم الصغيرة
The endoplasmic reticulum	الشبكة الاندوبلازمية
The nuclear envelope	الغلاف النووي
The nuclear lamina	الصفيحة النووية
The nuclear matrix	الحشوة النووية
The pellet	ما يترسب
The specific heat	الحرارة النوعية
Thermal energy	الطاقة الحرارية
Thick	سميك
Topography	تضاريس
Total	مجموع
Tracks	مسارات
Traffic	حركة
Transcription	نسخ
Transfer	نقل
Transition state	الحالة الانتقالية
Translation	ترجمة
Translocate	ينقل أو يغير مكان
Transmitting	ينفّذ أو يسمح بنفاذ
Transport	نقل
Transport proteins	بروتينات ناقلة
Transport vesicles	حويصلات ناقلة
Transporters	نواقل
Trigger	يثير
Triggered	تمت إثارته أو تحفيزه
Tubules	أنيبيبات
Tunnel	قناة
Turn	دورة أو لفة
Twisted	ملفوف
Type	نوع
Unbranched	غير متفرع
Undulating	متموجة
Unequal	غير متساوي
Unevenly	دون تساوي
Unicellular	أحادية الخلية
Uniform	محدد وثابت
Unsaturated fatty acids	حموض دهنية غير مشبعة
Unstained specimen	عينة غير مصبوغة
Untwisting	يفكك أو يحلّ أو يفصل
Unwinds	يفصل أو يفكك
Unwound	متفكك أو منفصل
Variable	متغير
Variation	اختلاف

Six - membered	حلقة سداسية
Six-membered ring	حلقة سداسية
Slip closer	تنزلق و تتقارب
Slowly	ببطء
Solar energy	الطاقة الشمسية
Solidify	تتصلّب (تصبح صلبة)
Solvent	مذيب
Sort	يرتّب
Span	يخترق
Sparing	تاركًا (موفّرًا)
Specific	محددة
Speeds	يسرّع
Sphere	جسم كروي
Spin	يلف أو يدير
Split	انقسم
Spontaneous	تلقائي
Stabilized	تم تثبيتها
Stable	مستقر
Stacked	مرصوص
Stained specimen	عينة مصبوغة
Start from scratch	يبدأ من الصفر
Steroidal hormones	الهرمونات الستيرويدية
Sticky	لاصق
Stimulated	محفّز
Stimulus	منبه
Stocked	مُخزَّن
Storage	مَخزن
Strain	سلالة
Strain (e.g. Unwounding strain)	جهد الالتواء
Strenuous	شديد و يحتاج جهد
Stripped	تم انتزاعه
Stroke (brain stroke)	سكتة دماغية
Strokes (e.g. Power stroke)	نبضات أو ضربات
Substitution	استبدال
Successive	متتالي
Support	الدعم
Surface tension	التوتر السطحي
Suspended	معلّق
Swell	تنتفخ
Swiveling	التفاف
Synthetically	صناعيًا
Tangible	ملموس
Target	هدف
Template	يتم استخدامه كقالب
Tendency	الميل إلى
Tension	قوة الشد
Terminal	الأخيرة
Termination	إنهاء
Terrain	حيز أو فراغ
Terrestrial organisms	الكائنات البرية

Vertebral	فقاري
Vertebral sex hormones	الهرمونات الجنسية للفقاريات
Vesicles	حويصلات
Visible	مرئي
Visible light	الضوء المرئي
Voltage	فرق جهد
Volume	الحجم
Water conducting cells	خلايا موصلة للماء
Watertight	لا يسرب الماء (مشدود)
Wavelength	الطول الموجي
Whales and seals	الحيتان وكلاب البحر

Wilts	يذبل ويضعُف
Young athletes	الرياضيين