HOUSTON HIGH SCHOOL

2026-2027 Pre-Term Work

Course Name	Dual Enrollment Anatomy & Physiology I
Teacher Name and Contact Email	Miriah Smith miriah.smith@gmsdk12.org
Pre-Term Work Assignment Description	Dual Enrollment Anatomy & Physiology I Recommended Pre-term Work Students should be familiar with all concepts covered in the "study guide" attached in the folder.
Purpose of Pre-Term Assignment	Knowledge of pre-requisite material required for dual anatomy and physiology I.
Assignment Due Date	N/A
How will this assignment be submitted to the teacher?	It is not required to complete or turn in answers to any of these questions, but the "study guide" covers pre-requisite material for the dual enrollment anatomy & physiology course.
How will this assignment work be assessed (include rubric, if applicable)?	Students will be expected to have an understanding of this material for application in other topics.
Additional Resources:	See folder for pdfs and study guide questions. Khan academy, Crash Course, and Professor Dave explains are also good resources for additional understanding.

Dual Enrollment Anatomy & Physiology Recommended Summer Work

Note: It is not required to complete or turn in answers to any of these questions, but the below "study guide" is pre-requisite material for the dual enrollment anatomy & physiology course, and students will be expected to have an understanding of this material for application in other topics.

Attached to this document you will find pdfs covering most of these topics to aid in your study.

Chemistry:

1. What is the difference between bulk elements, trace elements, and ultra-trace elements? Be able to identify examples of each.
2. Describe the differences between electrons, protons, and neutrons (Location, charge, mass).
3. Differentiate between atomic number, atomic mass, isotopes, and radioactive isotopes.
4. Distinguish between a molecule and a compound.
5. What is an ion? Cation? Anion? (Understand valence shells)
6. Differentiate between ionic, covalent, and hydrogen bonds. Also, what are polar molecules?
7. Describe the four basic types of reactions: Synthesis, Decomposition, Exchange, and Reversible
8. Compare the characteristics between an acid, a base, and a salt.
9. What does the pH scale measure?
10. Differentiate between acidosis and alkalosis.
11. What is a buffer? What is a catalyst?
12. What are the general differences between organic and inorganic molecules?
13. List the basic uses for the inorganic substances found in our body: water, oxygen, carbon dioxide, inorganic salts.
14. Differentiate between hydrolysis and dehydration reactions.
15. **Distinguish between the types of carbohydrates: monosaccharides, disaccharides, and polysaccharides (starch, glycogen, and cellulose).** What are the monomers called?
16. **Distinguish between the types of lipids: triglycerides (unsaturated fats and saturated fats), steroids, and phospholipids.**
17. **Differentiate between the major types of proteins: fibrous and globular.** What are the monomers called?
18. **Describe the four levels of organization of proteins with regard to structure and how those structures are formed (think about interactions/bonds, and what it looks like).**
19. Differentiate between the types of nucleic acids (RNA & DNA). What are the monomers called?

Cells:

20. What is a differentiated cell?
21. Name the three major parts/divisions of the cell and describe their functions. (slide #4)
22. Describe the chemical structure of a cell membrane.
23. **Describe the relative sizes and functions of microfilaments, intermediate filaments, and microtubules.**
24. What is the difference between passive and active transport? List the types of substances that will readily diffuse across a cell's membrane.
25. Explain the differences between diffusion, facilitated diffusion, osmosis, and filtration (Passive transport mechanisms).
26. Distinguish among isotonic, hypertonic, and hypotonic solutions.
27. Describe and distinguish among the active transport mechanisms: simple active transport, all three types of endocytosis, exocytosis, and transcystosis.
28. Describe the stages of the cell cycle, and **then list and describe the stages of mitosis** in the order of which they occur.
29. **Distinguish between a stem cell and progenitor cell, and between totipotent and pluripotent.**
30. **What is apoptosis, and why isn't it always a bad thing? What is necrosis?**

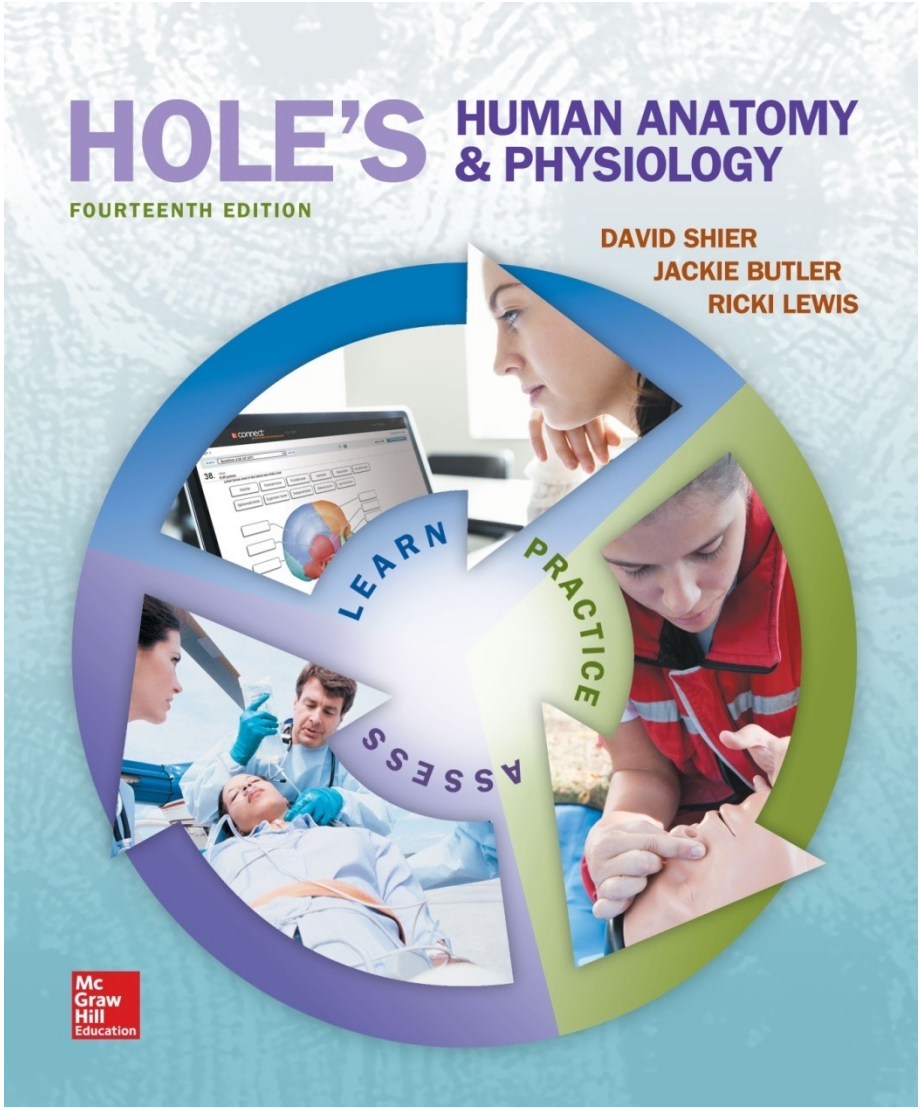
- You should also know functions of **each** cell organelle and nuclear component, as well as the differences between cilia, flagella, and microvilli. (There should be roughly 15 of these altogether including cilia, nuclear envelope, ribosomes, lysosomes, etc.)

Cellular Metabolism:

31. What are the general functions of anabolism and catabolism?
32. What type of molecule is made by anabolism of monosaccharides? of glycerol and fatty acids? of amino acids?
33. Distinguish between dehydration synthesis and hydrolysis.
34. How does an enzyme control the rate of an reaction? What factors can alter an enzyme's ability?
35. How does a rate-limiting enzyme illustrate negative feedback?
36. What is energy and which types are useable?
37. Define cellular respiration, and tell me the end (final) products.
38. What are aerobic and anaerobic reactions and which one yields more energy?
39. What are the end results of glycolysis?
40. What is the role of oxygen in cellular respiration?
41. List the products of the citric acid cycle.
42. Explain the function of the electron transport chain.
43. What is a gene?
44. List the steps of DNA replication.
45. List the steps of protein synthesis (transcription & translation).

BIOL 2010/2011
Ch 2: Chemistry (Lecture)

Miriah Smith, MS, MAT



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2.1: The Importance of Chemistry in Anatomy and Physiology

Why study chemistry in Anatomy & Physiology?

- Chemistry is concerned with composition of substances and how they change in chemical reactions
- Human body, food, and medications are all composed of chemicals
- All anatomical structures are chemicals, and all physiological processes are based on chemical reactions
- Biochemistry helps explain physiological and disease processes

2.2: Structure of Matter

- **Matter:** Anything that takes up space and has mass. Matter is composed of elements. Solids, liquids, and gases are matter.

- **Elements:** Simplest types of matter with certain chemical properties. 98 naturally occurring elements.

- **Atoms:** Smallest particles of an element that have properties of that element

Structure of Matter

Different elements are required by the body in different amounts:

- **Bulk elements:** required by the body in large amounts (C, O, H)
- **Trace elements:** required by the body in small amounts (Fe, I)
- **Ultratrace elements:** required by the body in very minute amounts (As)

Structure of Matter

Table of major and trace elements in the human body

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TABLE 2.2 Elements in the Human Body (By Weight)

Major Elements	Symbol	Approximate Percentage of the Human Body	
Oxygen	O	65.0	
Carbon	C	18.5	
Hydrogen	H	9.5	
Nitrogen	N	3.2	
Calcium	Ca	1.5	
Phosphorus	P	1.0	99.9%
Potassium	K	0.4	
Sulfur	S	0.3	
Chlorine	Cl	0.2	
Sodium	Na	0.2	
Magnesium	Mg	0.1	
Trace Elements			
Cobalt	Co		
Copper	Cu		
Fluorine	F		
Iodine	I		less than 0.1%
Iron	Fe		
Manganese	Mn		
Zinc	Zn		

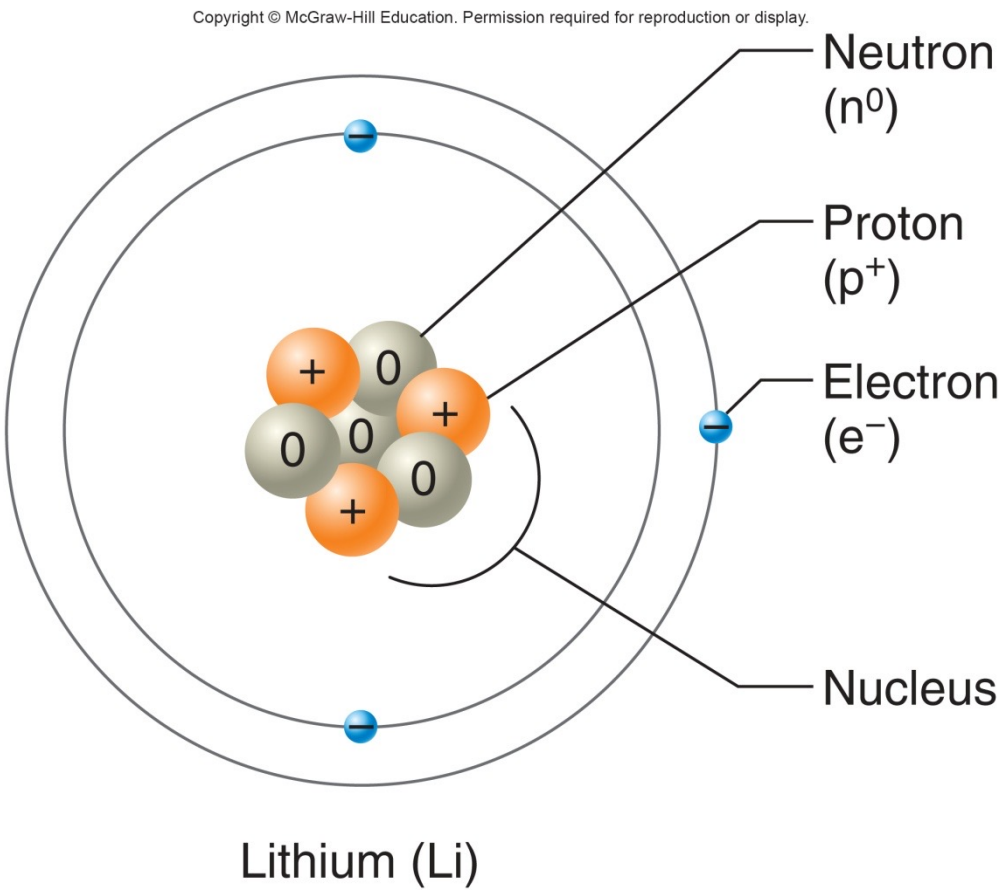
Atomic Structure

Atoms: Composed of subatomic particles:

- Proton: Carries a single positive charge
- Neutron: Carries no electrical charge
- Electron: Carries a single negative charge

Nucleus:

- Central part of atom
- Composed of protons and neutrons
- Electrons move around the nucleus



Atomic Structure

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TABLE 2.1 Some Particles of Matter

Name	Characteristic	Name	Characteristic
Atom	Smallest particle of an element that has the properties of that element	Neutron (n^0)	Relatively large particle within an atom; about the same weight as a proton; uncharged and thus electrically neutral; found within an atomic nucleus
Electron (e^-)	Extremely small particle within an atom; almost no weight; carries a negative electrical charge and is in constant motion around an atomic nucleus	Ion	Particle, formed from an atom, that is electrically charged because it has gained or lost one or more electrons
Proton (p^+)	Relatively large particle within an atom; carries a positive electrical charge and is found within an atomic nucleus	Molecule	Particle formed by the chemical union of two or more atoms

Atomic Number & Atomic Weight

- **Atomic Number:**
  - Number of protons in the nucleus of an atom of a specific element
  - Each element has a unique atomic number
  - Number of protons is equal to the number of electrons in the atom; atoms are electrically neutral
- **Atomic Weight/Mass:**
  - The number of protons plus the number of neutrons in one atom
  - Electrons do not contribute to the weight of the atom

Isotopes

Isotopes:

- All atoms of a certain element have same atomic number
- Isotopes are atoms with the same atomic numbers but with different atomic weights
- Isotopes contain different numbers of neutrons, but same number of protons & electrons
- Oxygen often forms isotopes (O^{16}, O^{17}, and O^{18}, with numbers representing atomic weights)
- ***Radioactive isotopes*** are unstable, releasing energy or atomic fragments (atomic radiation) until they gain stability; some are used to detect and treat disease.

For any element, the atomic weight is often considered the average of the atomic weights of all of its isotopes.

From Science to Technology 2.1

Radioactive Isotopes Reveal Physiology

Radioactive iodine-131 can be used to destroy cancerous thyroid gland tissue. This is very effective, because the thyroid gland is the only part of the body that actively transports and metabolizes iodine.

Radioactive isotopes have many medical uses: detecting coronary blood vessel disorders, evaluating kidney function, measuring hormone concentrations in body fluids, and assessing changes in bone density.

Molecules and Compounds

Molecule: particle formed when two or more atoms chemically combine

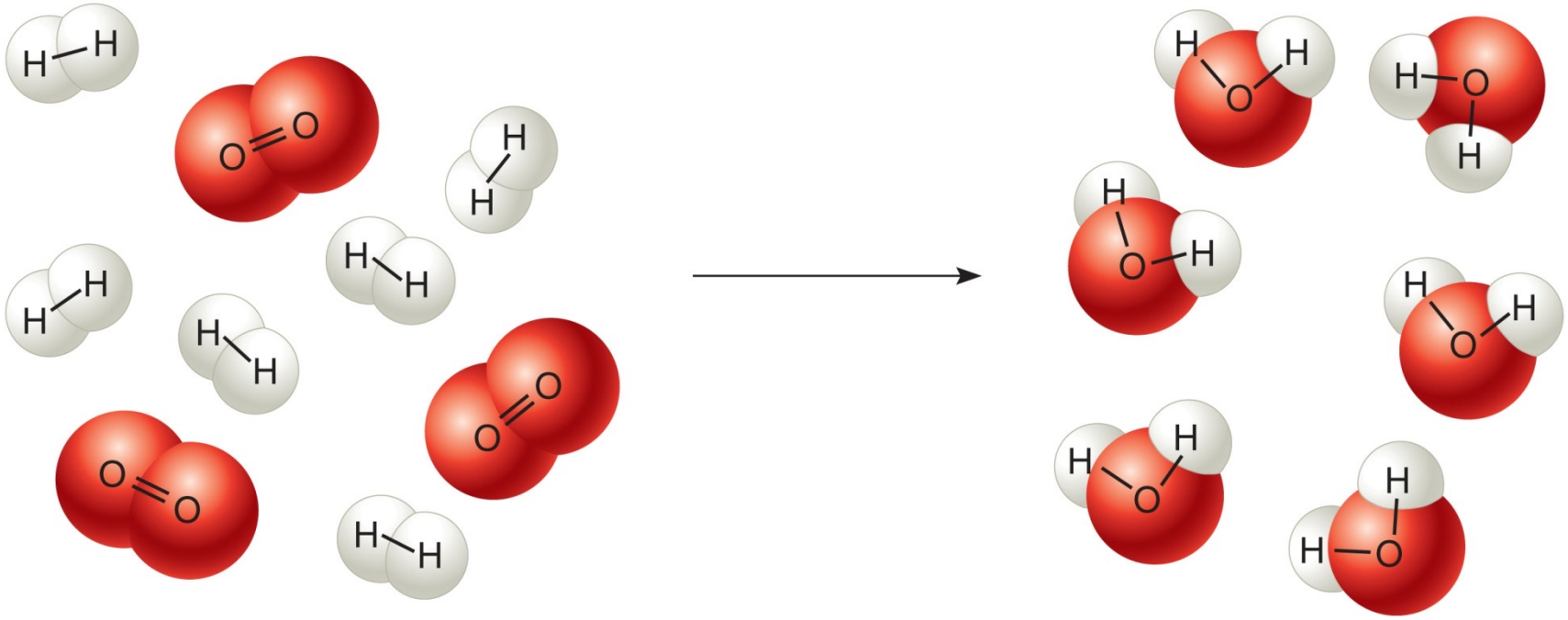
Compound: particle formed when two or more atoms of different elements chemically combine

Molecular formulas: depict the elements present and the number of each atom present in the molecule

- H_2 = a molecule of hydrogen
- $C_6H_{12}O_6$ = a molecule of glucose
- H_2O = a molecule of water

Molecules and Compounds

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Molecules of hydrogen or oxygen form when 2 identical atoms combine chemically.

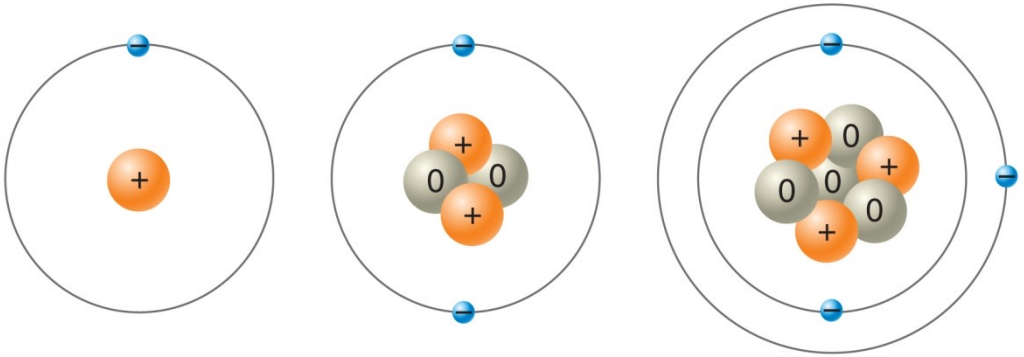
When 2 atoms of hydrogen combine with 1 atom of oxygen, the compound **water** is formed.

Bonding of Atoms

- Chemical bonds form when atoms combine with other atoms. They result from interactions between the electrons of the atoms.
- Electrons of an atom occupy regions of space called **electron shells (energy shells)**, which circle the nucleus
- For atoms with atomic numbers of 18 or less, the following rules apply:
  - The first shell can hold up to 2 electrons
  - The second shell can hold up to 8 electrons
  - The third shell can hold up to 8 electrons
- Lower energy shells / inner orbits are filled first, and are stable with a certain number of electrons in the outermost shell (2, 8 or 18—in larger atoms)

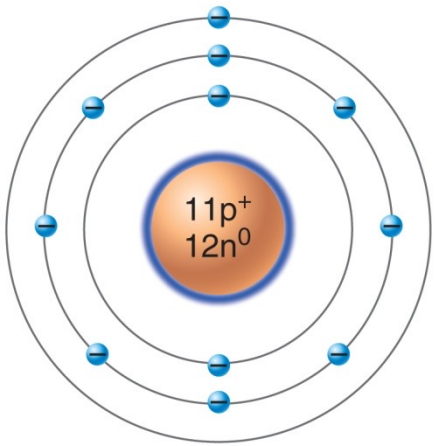
Bonding of Atoms

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Hydrogen (H) Helium (He) Lithium (Li)

(a)



Sodium atom contains
11 electrons (e^-)
11 protons (p^+)
12 neutrons (n^0)

Atomic number = 11
Atomic weight = 23

(b)

Bonding of Atoms: Ions

Ion:

- An atom that gains or loses electrons to become stable
- An electrically charged atom

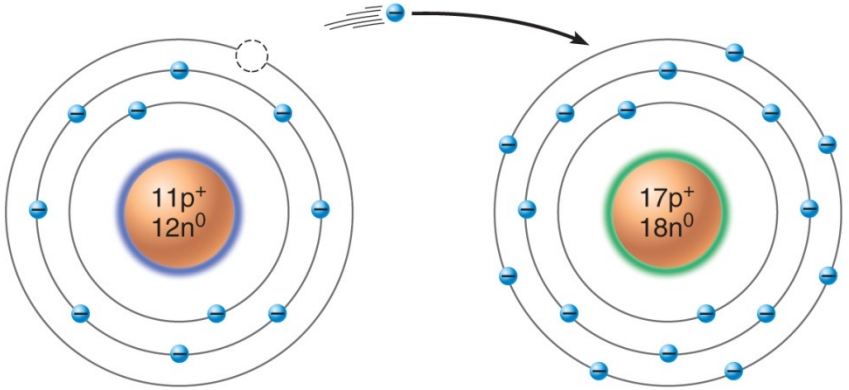
Cation:

- A positively charged ion
- Formed when an atom loses electrons

Anion:

- A negatively charged ion
- Formed when an atom gains electrons

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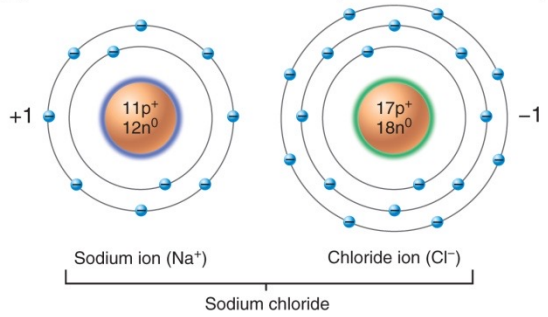
(a) Separate atoms
If a sodium atom loses an electron to a chlorine atom, the sodium atom becomes a sodium ion (Na^+), and the chlorine atom becomes a chloride ion (Cl^-).

Bonding of Atoms: Ionic Bonds

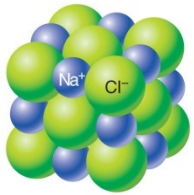
Ionic Bonds:

- Formed when electrons are transferred from one atom to another atom
- The attraction between a cation and an anion forms a very strong bond between the ions, called an ionic bond.

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(b) Bonded ions
These oppositely charged particles attract electrically and join by an ionic bond.

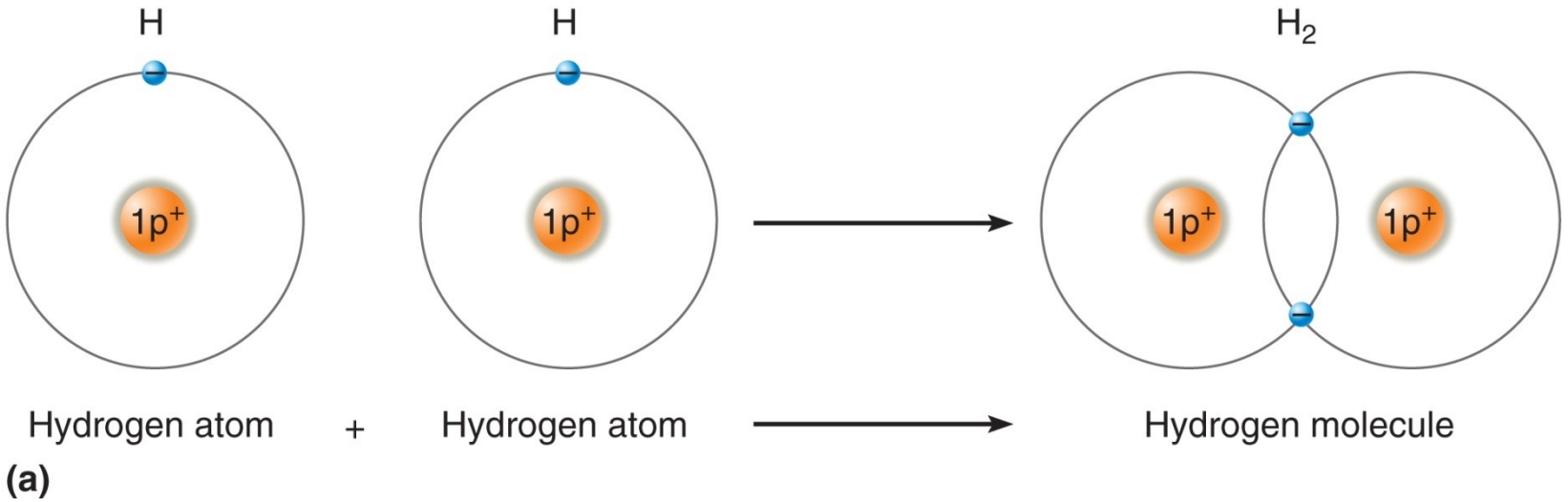


(c) Salt crystal
Ionically bonded substances form arrays such as a crystal of NaCl.

Bonding of Atoms: Covalent Bonds

Covalent Bonds: Strong chemical bonds, formed between atoms that share electrons

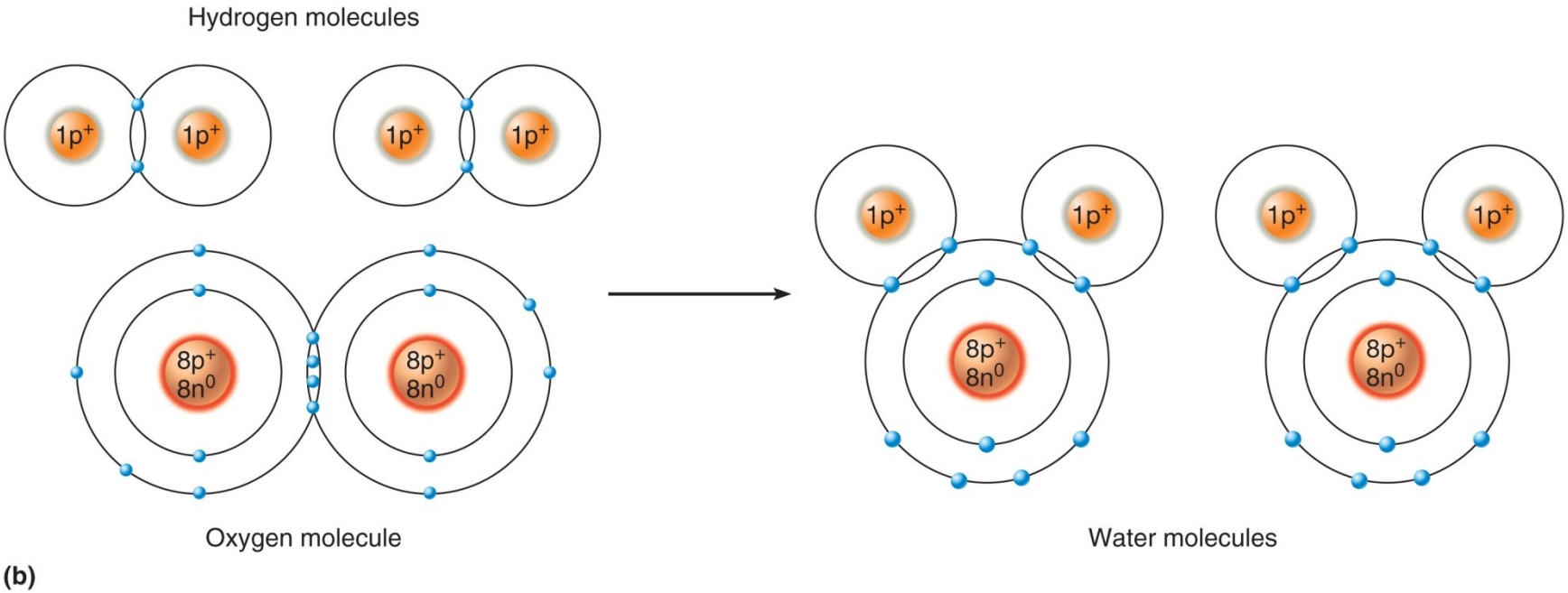
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Two atoms of hydrogen (H) have combined to form a hydrogen molecule (H_2). Both atoms in the molecule become stable.

Bonding of Atoms: Covalent Bonds

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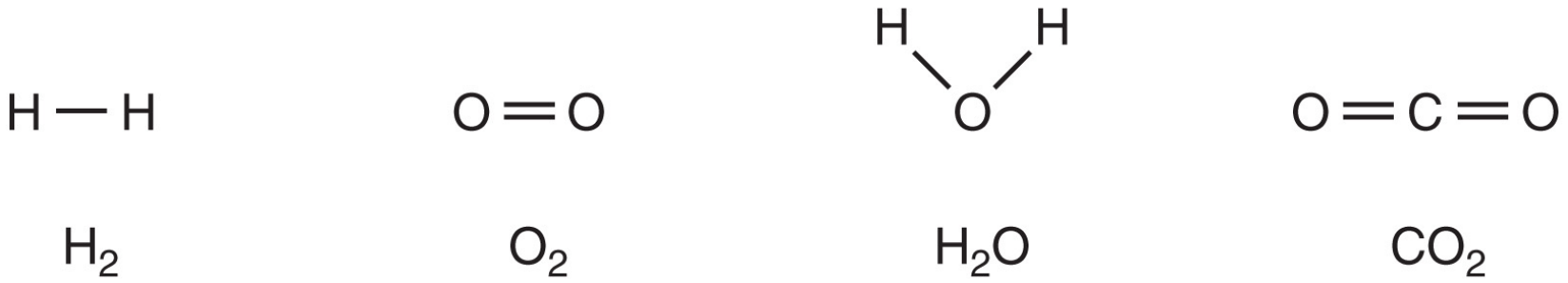


Hydrogen molecules (H_2) often combine with oxygen (O_2) molecules to form water molecules (H_2O).

Bonding of Atoms: Structural Formulas

Structural formulas show how atoms bond and are arranged in various molecules.

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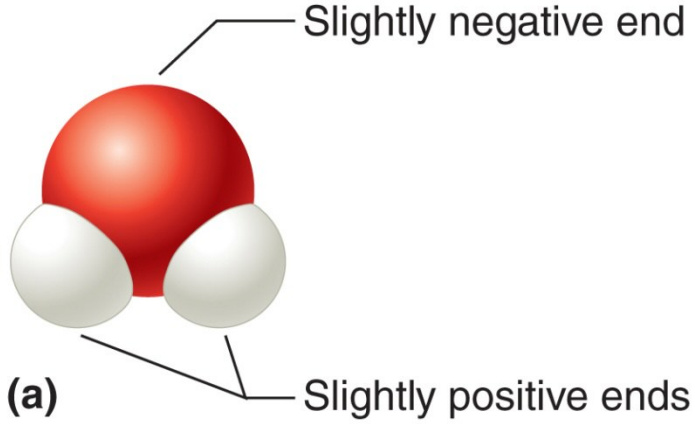
One line between atoms means that 1 pair of electrons are being shared (forming single bonds), while two lines indicate that 2 pairs are being shared (forming double bonds).

Bonding of Atoms: Polar Molecules

Polar Molecules:

- Molecules with a slightly negative end & a slightly positive end
- Results from unequal sharing of electrons in covalent bonds
- Water is an important polar molecule

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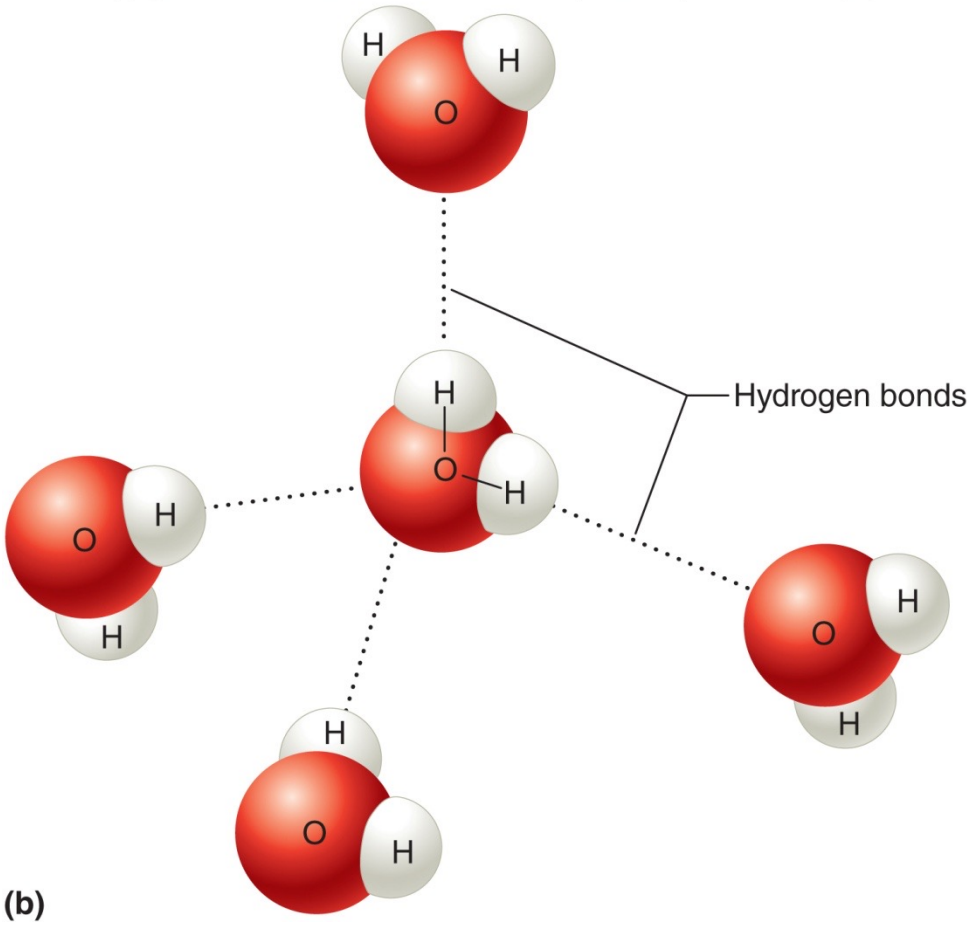
In this water molecule, the O nucleus pulls the electrons more strongly than the H nuclei, since it contains more positively charged protons.

Bonding of Atoms: Hydrogen Bonds

Hydrogen Bond:

- A weak attraction between the slightly positive (H) end of one polar molecule and the slightly negative (N or O) end of another polar molecule
- Formed between adjacent water molecules
- Important for protein and nucleic acid structure

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Chemical Reactions

Chemical reactions occur when chemical bonds form or break between atoms, ions, or molecules.

Reactants are the starting materials of a chemical reaction: the atoms, ions, or molecules.

Products are substances formed at the end of the chemical reaction.

$$\underset{\text{(Reactant)}}{\mathbf{NaCl}} \longrightarrow \underset{\text{(Products)}}{\mathbf{Na^+ + Cl^-}}$$

The above reaction involves the dissociation of NaCl in water to form Na^+ and Cl^- ions.

Types of Chemical Reactions

Synthesis Reaction: more complex chemical structure is formed

$$A + B \longrightarrow AB$$

Decomposition Reaction: chemical bonds are broken to form a simpler chemical structure

$$AB \longrightarrow A + B$$

Exchange Reaction: chemical bonds are broken and new bonds are formed

$$AB + CD \longrightarrow AD + CB$$

Reversible Reaction: the products can change back to the reactants

$$A + B \longleftrightarrow AB$$

Acids, Bases, and Salts

Electrolytes: Substances that release ions in water. The solution can conduct an electric current, so it is called an electrolyte.

$$NaCl \rightarrow Na^+ + Cl^-$$

Acids: Electrolytes that dissociate to release hydrogen ions in water

$$HCl \rightarrow H^+ + Cl^-$$

Bases: Substances that release ions that can combine with hydrogen ions

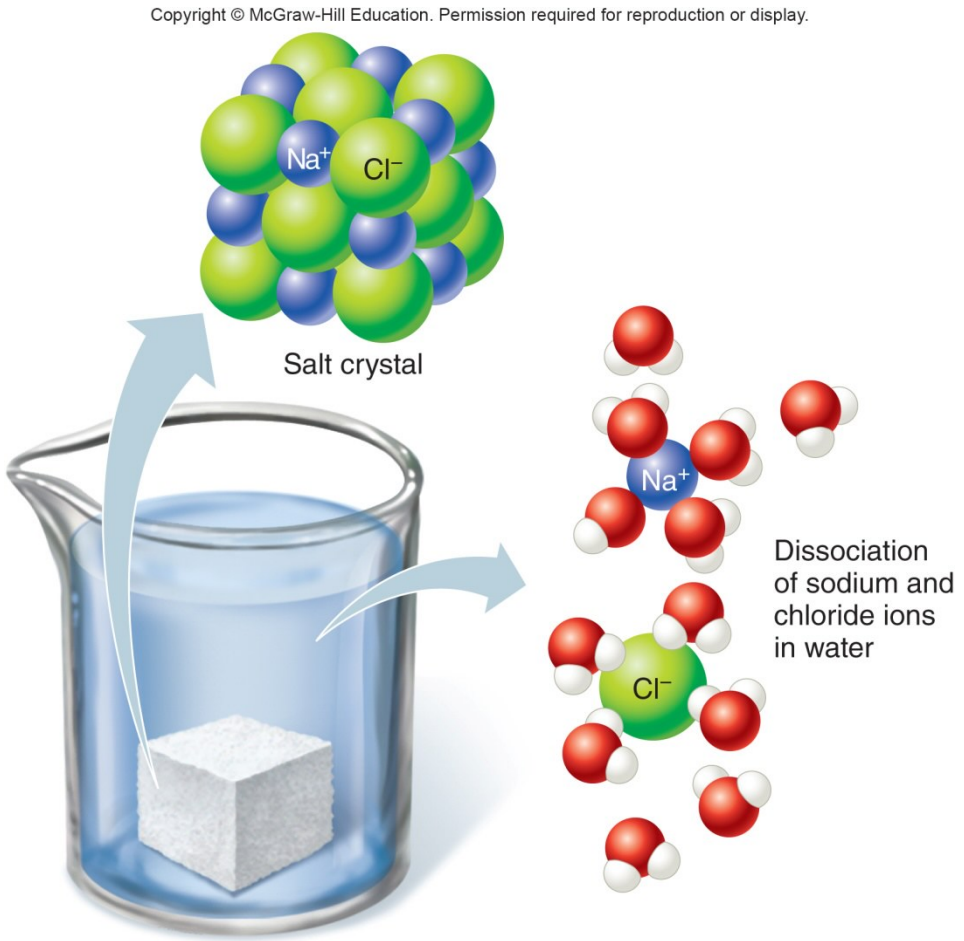
$$NaOH \rightarrow Na^+ + OH^-$$

Salts: Electrolytes formed by the reaction between an acid and a base

$$HCl + NaOH \rightarrow H_2O + NaCl$$

Acids, Bases, and Salts

When an ionically bonded substance is put into water, the charged ions are attracted to the slightly charged ends of the polar water molecules. This dissociates the substance, and the ions become surrounded by water molecules. The substance is now called an electrolyte, since it can now carry an electric current.



Acid and Base Concentrations

- Concentrations of acids and bases affect chemical reactions in living organisms.
- H^+ ion concentration is measured in g/L of body fluid
- **pH scale** is used as shorthand for H^+ ion concentration; it is based on the number of decimal places in the concentration
- If H^+ ion concentration = 0.01 g/L, the pH = 2
- If H^+ ion concentration = 0.000000001 g/L, the pH =9
- pH scale runs from 0 – 14; each number represents a tenfold difference in H^+ ion concentration
- Acids have a pH <7, and bases have a pH >7
- A pH of 7 is neutral

Acid and Base Concentrations

The higher the H^+ concentration, the lower the pH, and the higher the acidity.

The lower the H^+ concentration, the higher the pH, and the lower the acidity (which corresponds to higher alkalinity).

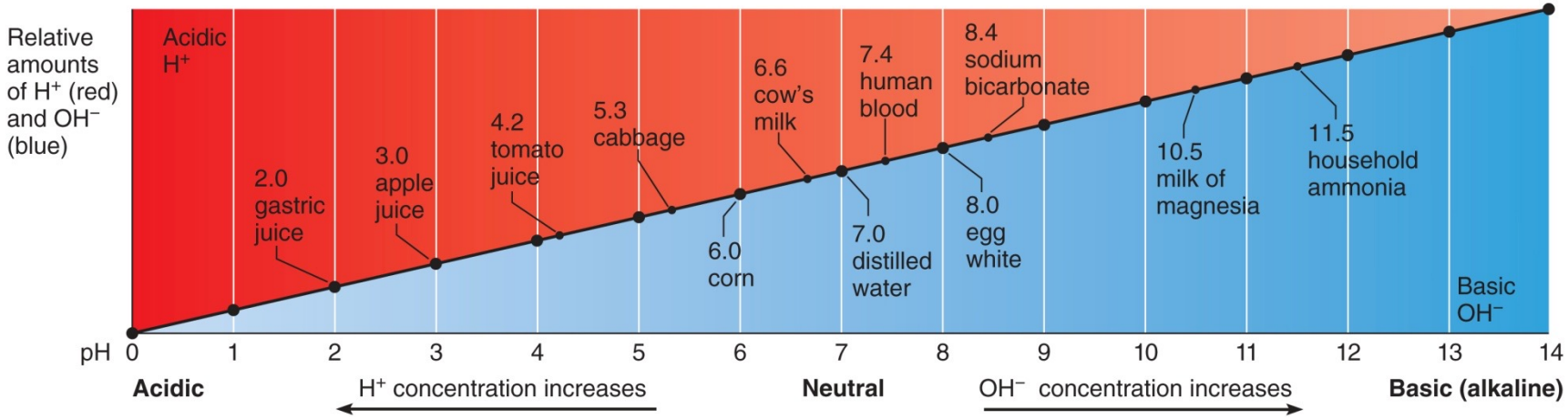
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TABLE 2.5 Hydrogen Ion Concentrations and pH

Grams of H^+ per Liter	pH	
0.00000000000001	14	
0.0000000000001	13	
0.000000000001	12	
0.00000000001	11	
0.0000000001	10	
0.000000001	9	
0.00000001	8	Increasingly basic
0.0000001	7	Neutral—neither acidic nor basic
0.000001	6	Increasingly acidic
0.00001	5	
0.0001	4	
0.001	3	
0.01	2	
0.1	1	
1.00	0	

Acid and Base Concentrations

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- pH Scale: Indicates the concentration of hydrogen ions in a solution
- Neutral: A pH of 7 indicates equal concentrations of H^+ and OH^-. This is the pH of water.
- Acidic: A pH of <7 indicates a greater concentration of H^+ than OH^-
- Basic (alkaline): A pH >7 indicates a higher concentration of OH^- than H^+

Acid and Base Concentrations

Normal range of blood pH is 7.35 – 7.45

Acidosis occurs when blood pH drops to 7.0 – 7.3

- Makes a person feel disoriented, fatigued
- Caused by vomiting of alkaline intestinal contents, diabetes, lung disease with impaired CO_2 exhalation

Alkalosis occurs when blood pH rises to 7.5 – 7.8

- Makes a person feel dizzy and agitated
- Caused by high altitude breathing, vomiting of acidic stomach contents, high fever, taking excess antacids

- Homeostatic mechanisms help regulate pH
- Buffers are chemical systems which act to resist pH changes; bind and release H^+ ions to regulate pH

2.3: Chemical Constituents of Cells

Organic vs. Inorganic Molecules

- **Organic molecules:**
  - Contain C and H
  - Dissolve in water and organic liquids
  - Water-soluble organic compounds do not release ions, and are non-electrolytes
  - Carbohydrates, proteins, lipids, and nucleic acids

- **Inorganic molecules:**
  - Generally do not contain C and H
  - Usually dissolve in water and dissociate, forming ions, and are electrolytes
  - Water, oxygen, carbon dioxide, and inorganic salts

Inorganic Substances

Water:

- Most abundant compound in living material
- Two-thirds of the weight of an adult human
- Major component of all body fluids
- Medium for most metabolic reactions
- Important role in transporting chemicals in the body
- Absorbs and transports heat
- Water balance exists when gains equal losses

Oxygen (O_2):

- Used by organelles to release energy from nutrients in order to drive cell's metabolic activities
- Necessary for survival

Inorganic Substances

Carbon dioxide (CO_2):

- Waste product released during metabolic reactions
- Must be removed from the body through exhaling

Inorganic salts:

- Abundant in body fluids
- Sources of necessary ions (Na^+, Cl^-, K^+, Ca^{+2}, etc.)
- Play important roles in metabolism
- Help control H_2O concentration, pH, blood clotting, nerve and muscle processes
- Electrolyte balance exists when gains equal losses

Organic Substances: Carbohydrates

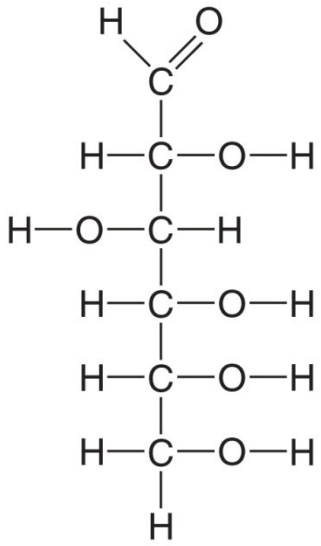
- **Main source of cellular energy**
- Supply materials to build cell structures
- Water-soluble
- Contain C, H, and O
- Ratio of H to O close to 2:1 ($C_6H_{12}O_6$ = glucose)

Size classification of carbohydrates:

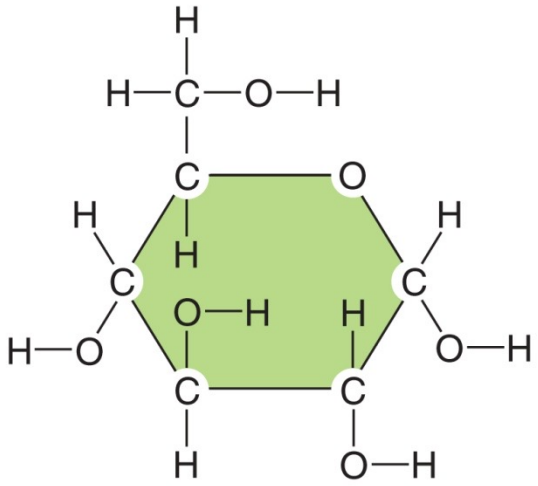
- Monosaccharides (single sugars): glucose, fructose
- Disaccharides (double sugars): sucrose, lactose
- Polysaccharides (complex carbohydrates: starch, glycogen, cellulose)

Organic Substances: Carbohydrates

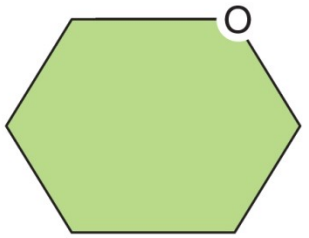
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(a) Some glucose molecules ($C_6H_{12}O_6$) have a straight chain of carbon atoms.



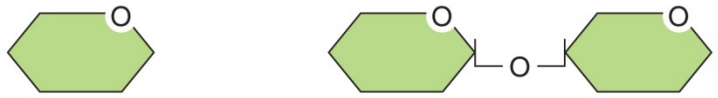
(b) More commonly, glucose molecules form a ring structure.



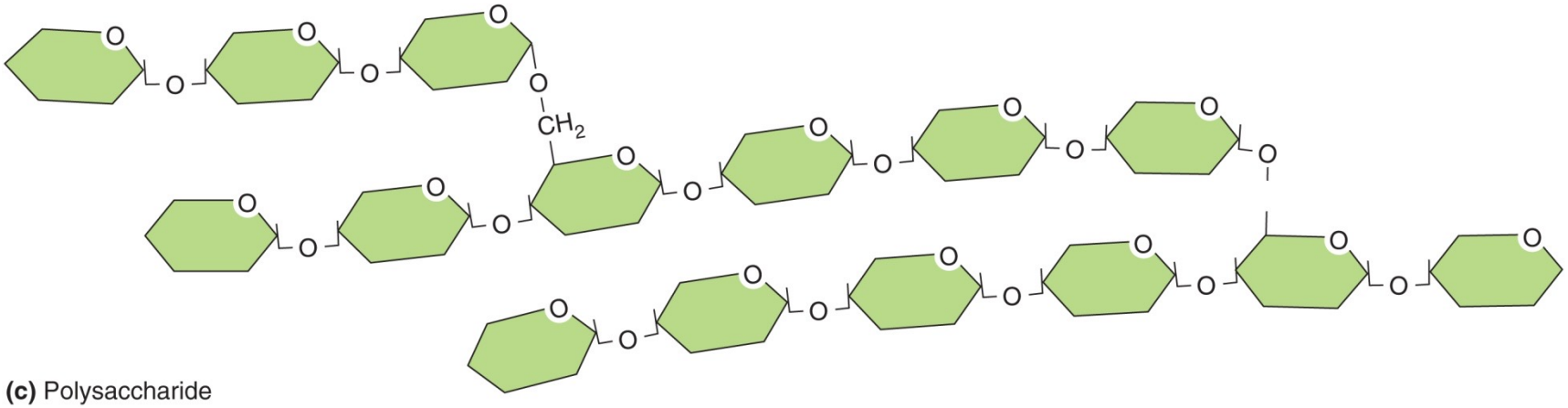
(c) This shape symbolizes the ring structure of a glucose molecule.

Organic Substances: Carbohydrates

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(a) Monosaccharide **(b)** Disaccharide



(c) Polysaccharide

Organic Substances: Lipids

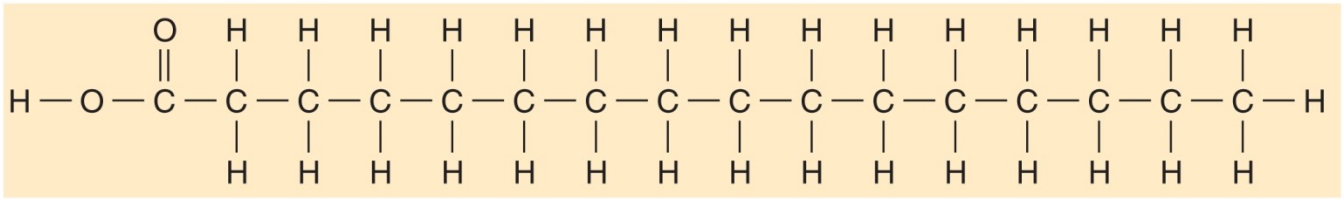
- Insoluble in water, but soluble in organic solvents
- Include triglycerides (fats), phospholipids, steroids
- Important component of cell membranes, and have several functions in cells

- Most abundant lipids are **triglycerides (fats)**:
    a. Used for cellular energy
    b. Contain more energy per gram than carbohydrates
    c. Contain C, H, and O, but less O than carbohydrates
    d. Consist of 1 molecule of glycerol and 3 fatty acids

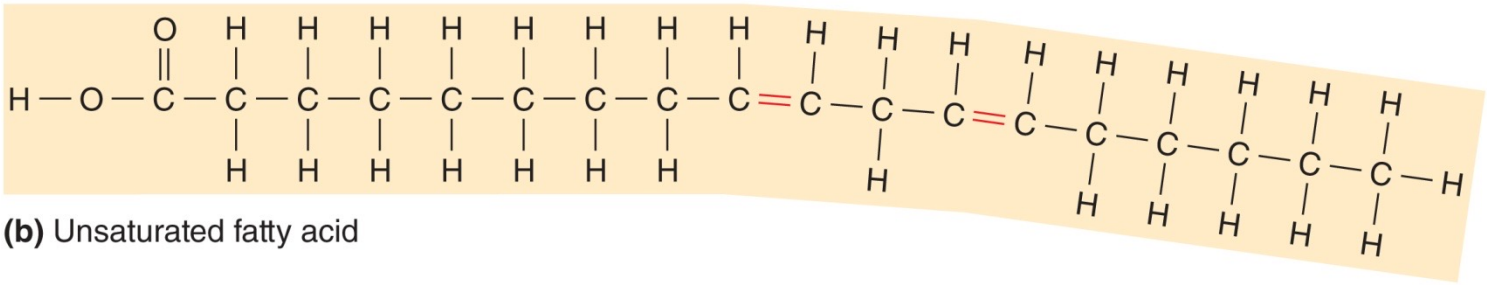
Organic Substances: Lipids

- Saturated fatty acids have only single carbon-carbon bonds. Most are solid at room temperature, and of animal origin.
- Unsaturated fatty acids have one or more carbon-carbon double bond. Most are liquid at room temperature, and are of plant origin.

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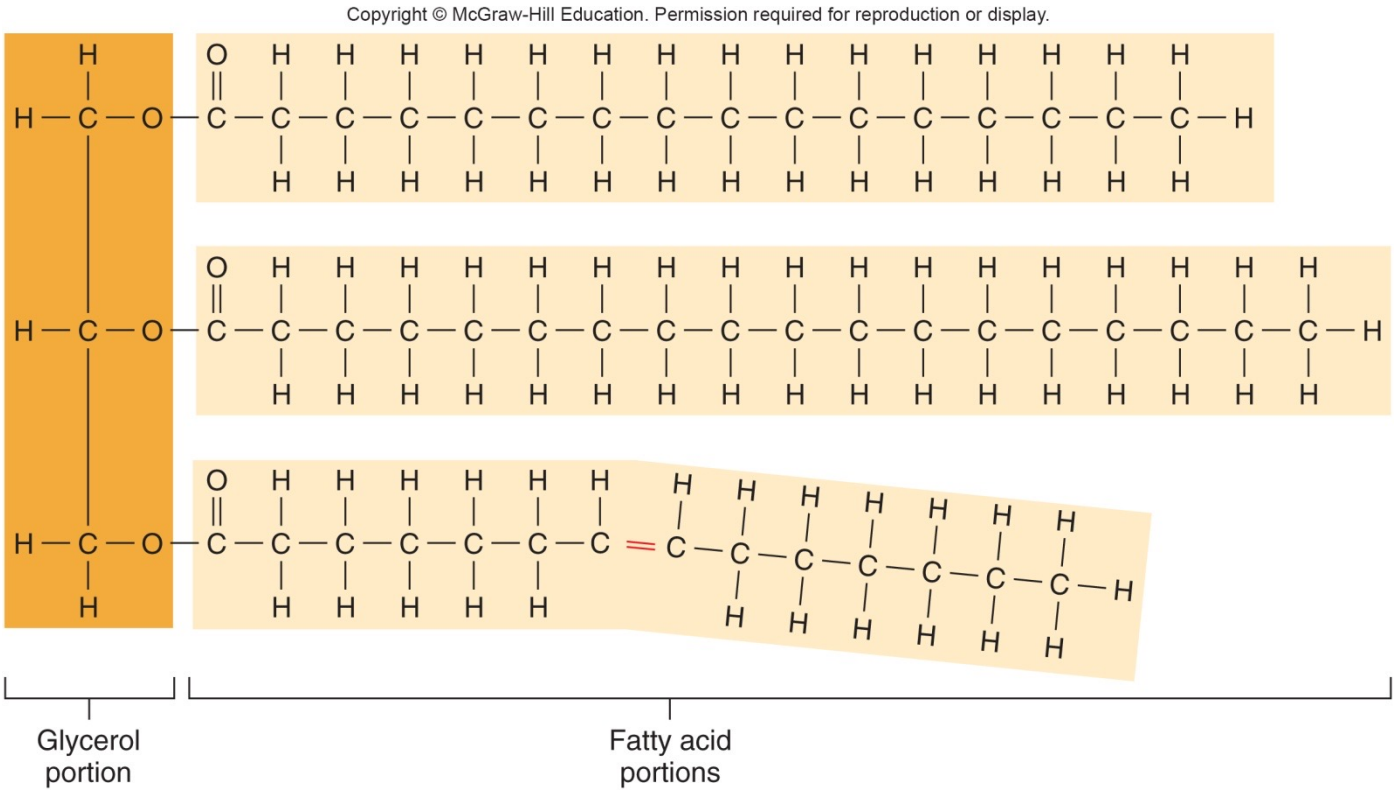


(a) Saturated fatty acid



(b) Unsaturated fatty acid

Organic Substances: Lipids

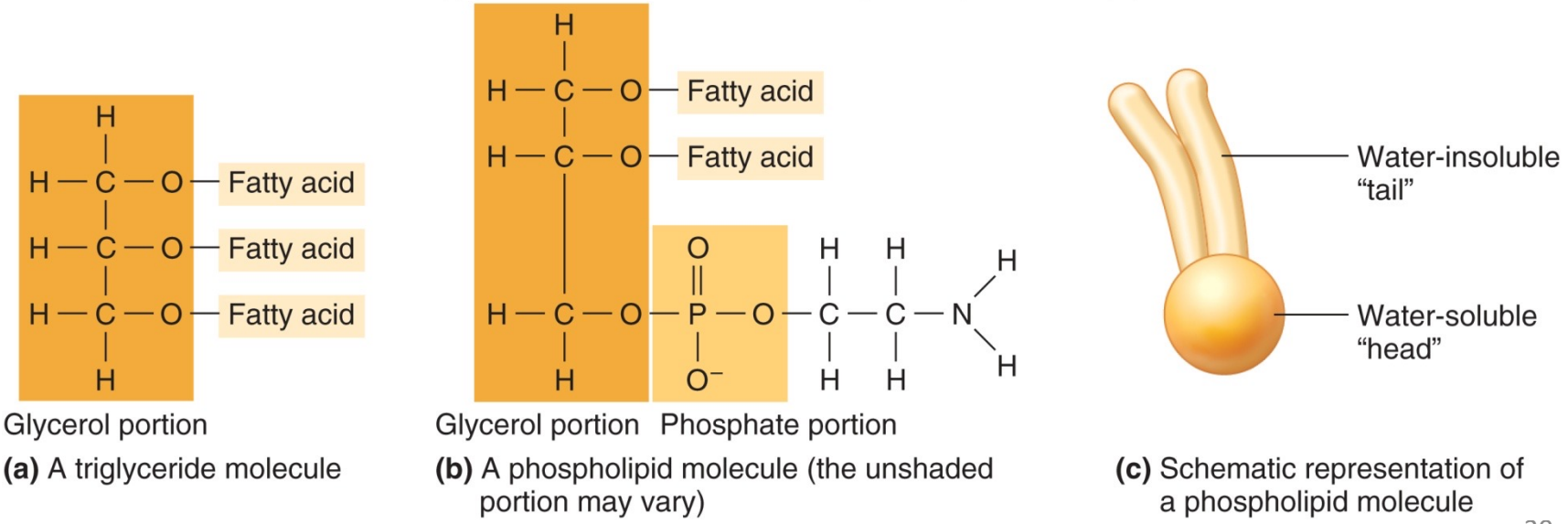


A triglyceride is composed of 1 glycerol molecule and 3 fatty acids.

Organic Substances: Lipids

- **Phospholipids:**
  - Consist of 1 glycerol, 2 fatty acids, and 1 phosphate
  - Have hydrophilic and hydrophobic ends
  - Major component of cell membranes

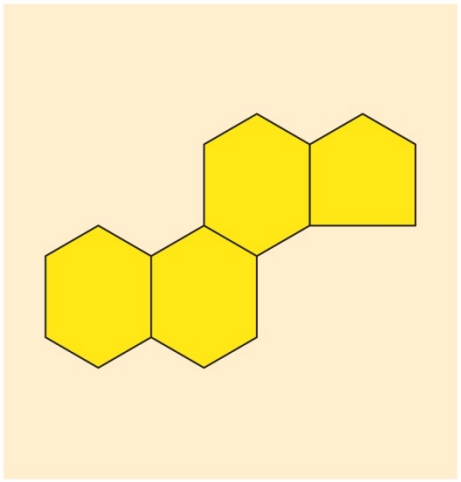
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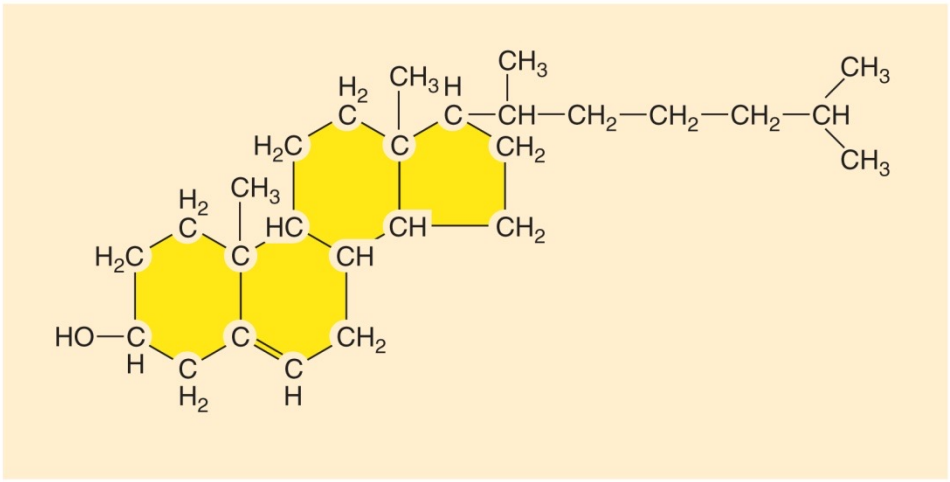
Organic Substances: Lipids

- **Steroids:**
  - 4 connected rings of carbon
  - Widely distributed in the body, various functions
  - Component of cell membranes
  - Used to synthesize adrenal and sex hormones
  - Cholesterol is the main steroid in the body

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(a) General structure of a steroid

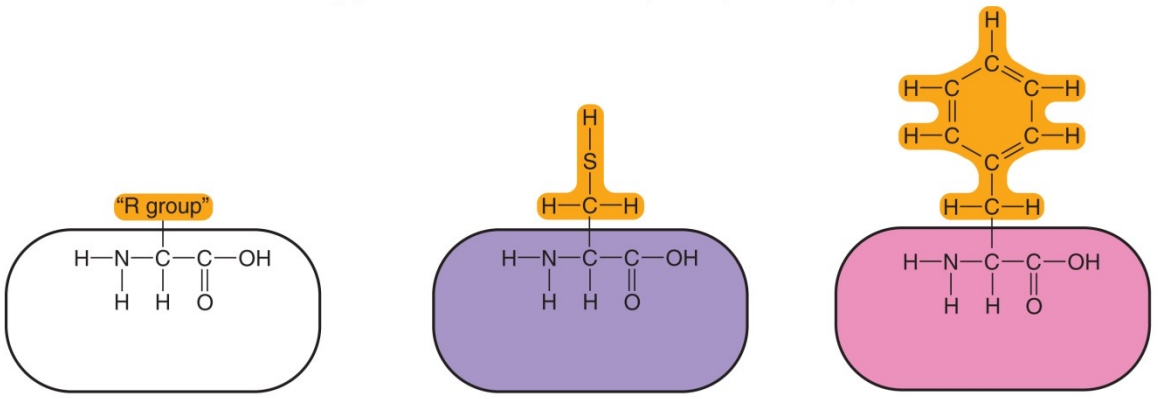


(b) Cholesterol

Organic Substances: Proteins

- Proteins are used as structural materials, energy source, hormones, receptors, enzymes, antibodies
- Consist of building blocks called amino acids
- An amino acid contains an amino (-NH_2) group, a carboxyl (COOH) group, and a unique R (side chain) group

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(a) General structure of an amino acid. The portion common to all amino acids is within the oval. It includes the amino group (—NH_2) and the carboxyl group (—COOH). The "R group", or the "rest of the molecule," varies and is what makes each type of amino acid unique.

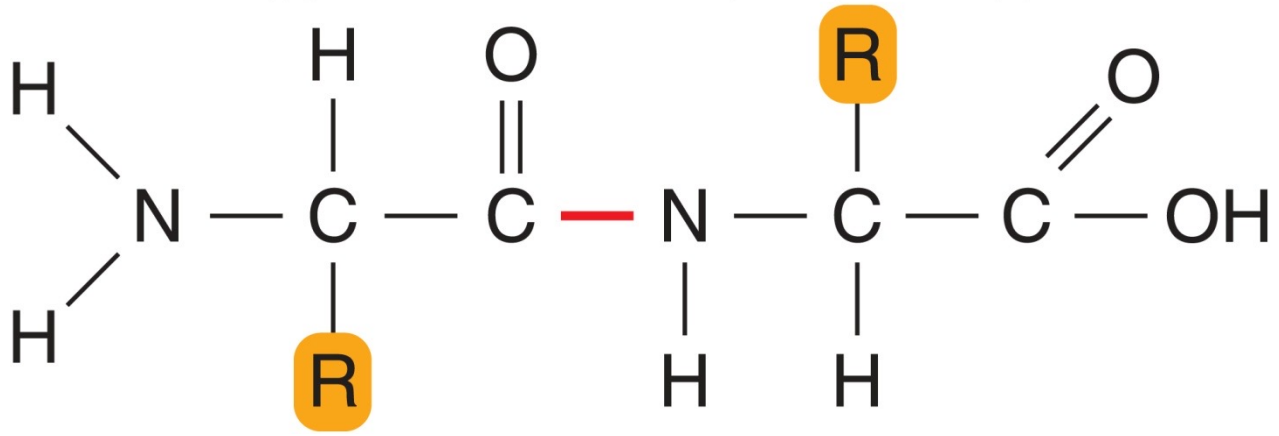
(b) Cysteine. Cysteine has an R group that contains sulfur.

(c) Phenylalanine. Phenylalanine has a complex R group.

Organic Substances: Proteins

Amino acids are bound to each other by peptide bonds:

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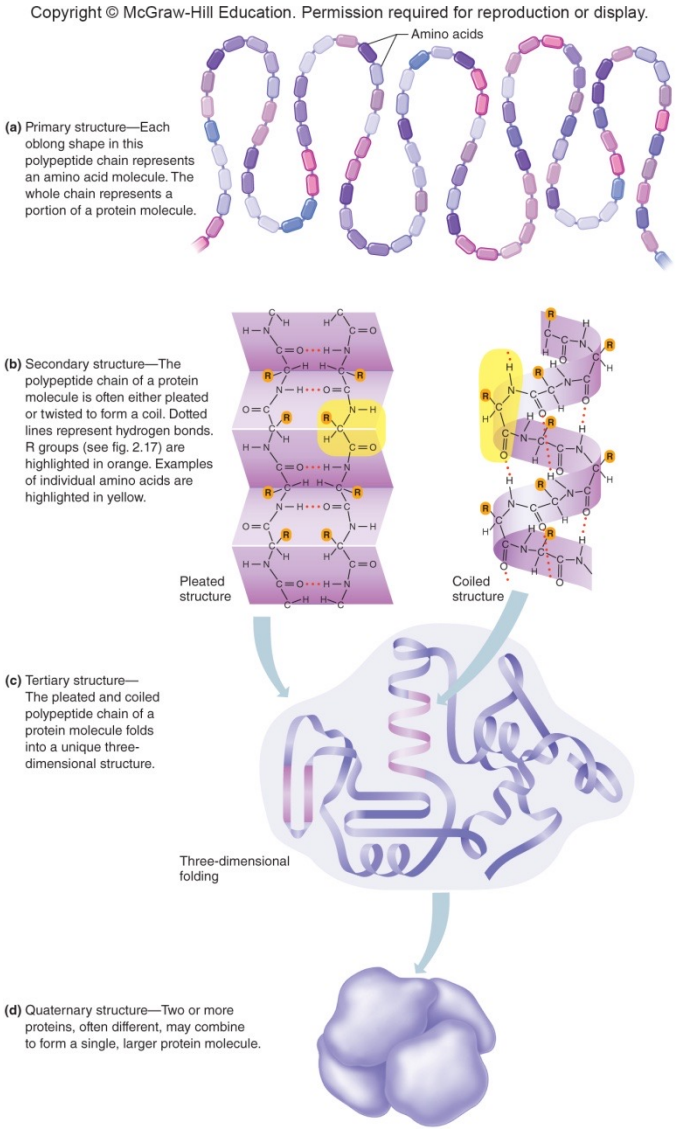


Peptide bonds form between the amino group of one amino acid, and the carboxyl group of the adjacent amino acid.

Organic Substances: Proteins

4 Levels of Protein Structure:

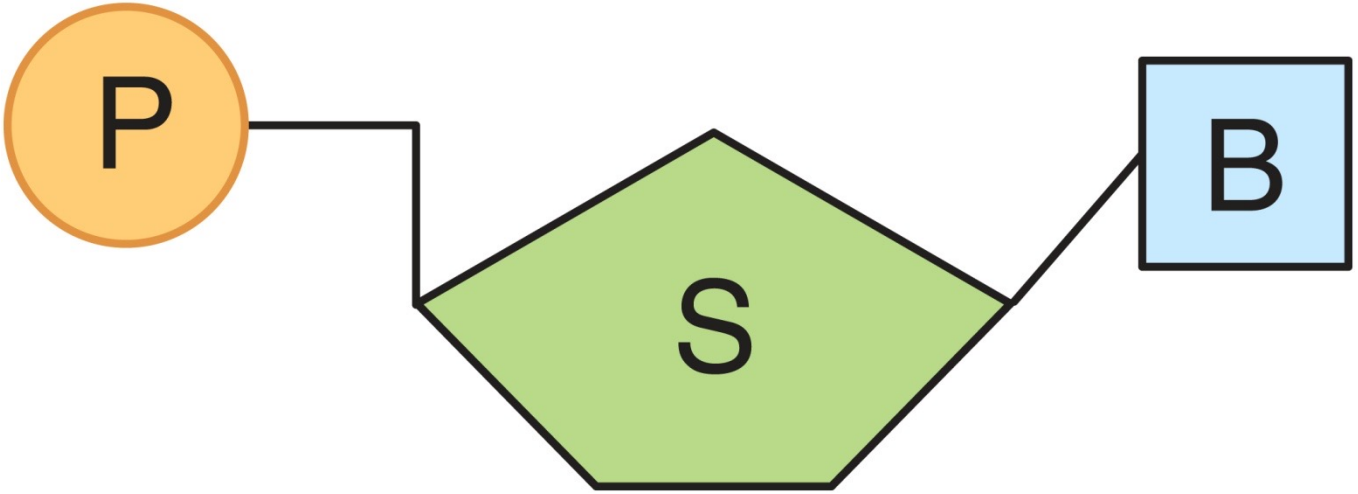
- Primary: Amino acid sequence
- Secondary: Pleated or twisted structure formed by hydrogen bonding between nonadjacent amino acids
- Tertiary: Unique 3-dimensional folded shape of the protein
- Quaternary: Structure formed by some proteins, when 2 or more polypeptide chains are connected to become 1 protein.



Organic Substances: Nucleic Acids

- Carry genetic code (DNA) or aid in protein synthesis (RNA)
- Encode amino acid sequences of proteins
- Building blocks are called nucleotides, which consist of a sugar (S), a phosphate group (P), and an organic base (B).

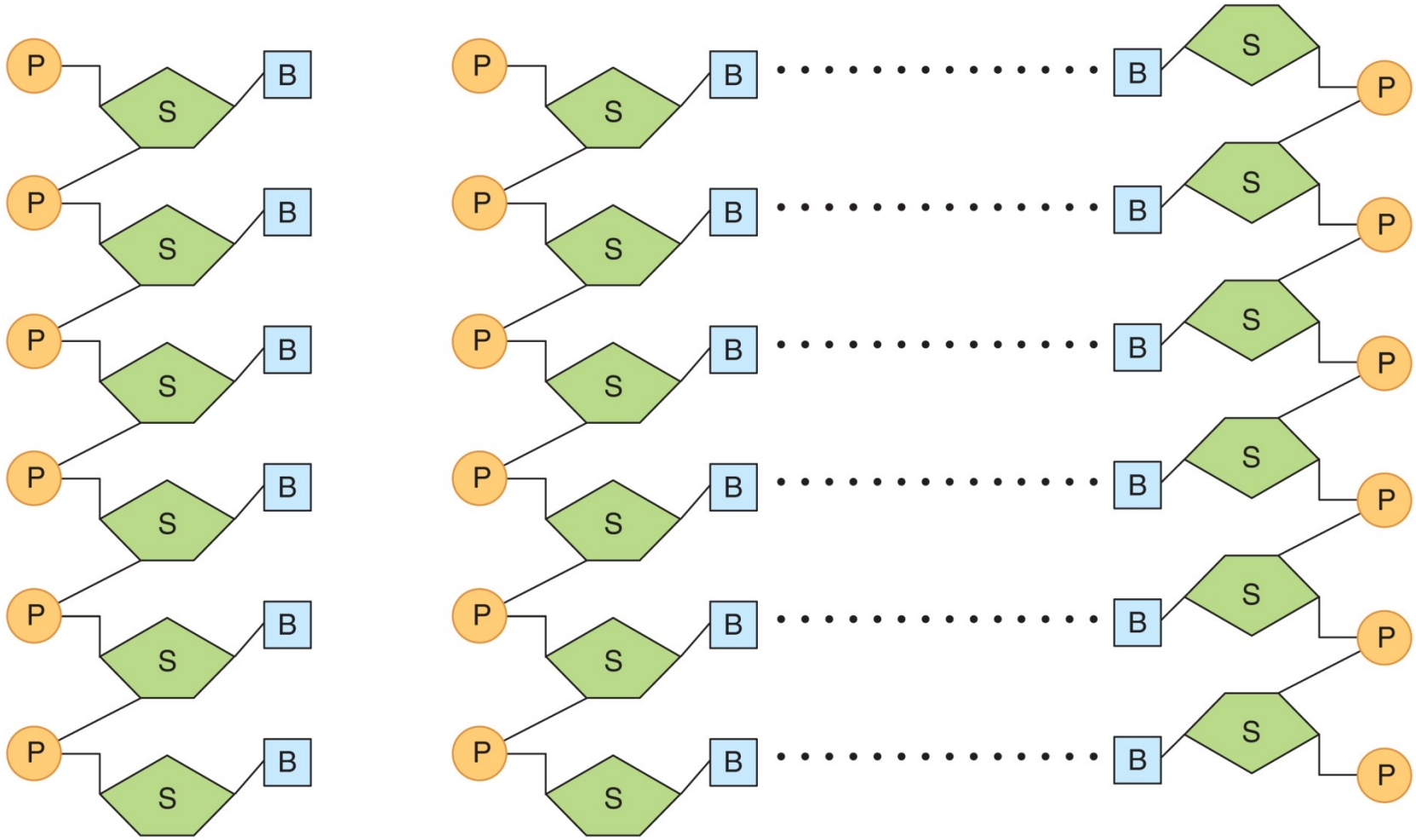
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- DNA (Deoxyribonucleic acid): a double chain of nucleotides
- RNA (Ribonucleic acid): a single chain of nucleotides

Organic Substances: Nucleic Acids

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Organic Substances: Nucleic Acids

Two major types of nucleic acids: DNA and RNA

DNA:

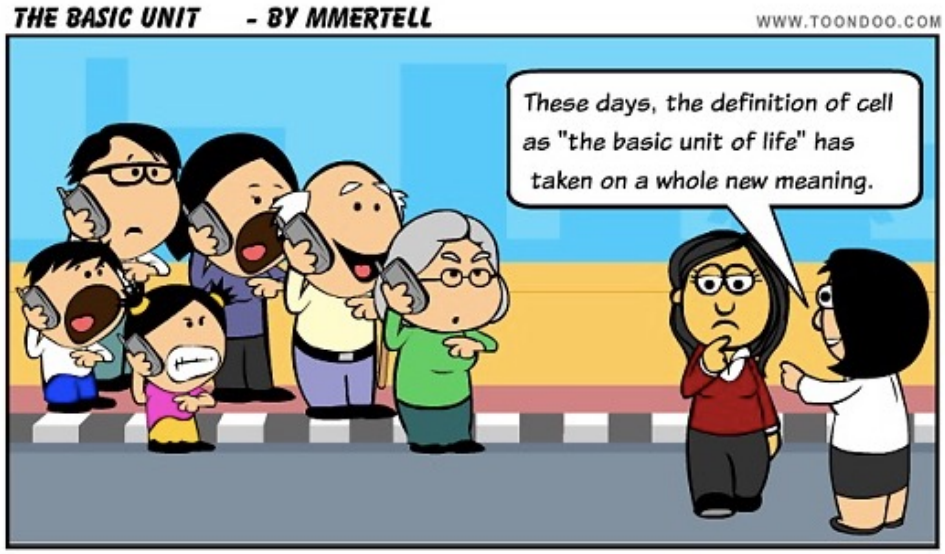
- Stores the genetic code
- Contains the sugar deoxyribose
- Structure—double helix
- Composed of nucleotides

RNA:

- Interacts with DNA to conduct protein synthesis
- Contains the sugar ribose
- Structure—single strand
- Composed of nucleotides

BIOL 2010/2011
Ch 3: Cells
(Lecture)

Miriah Smith, MS, MAT



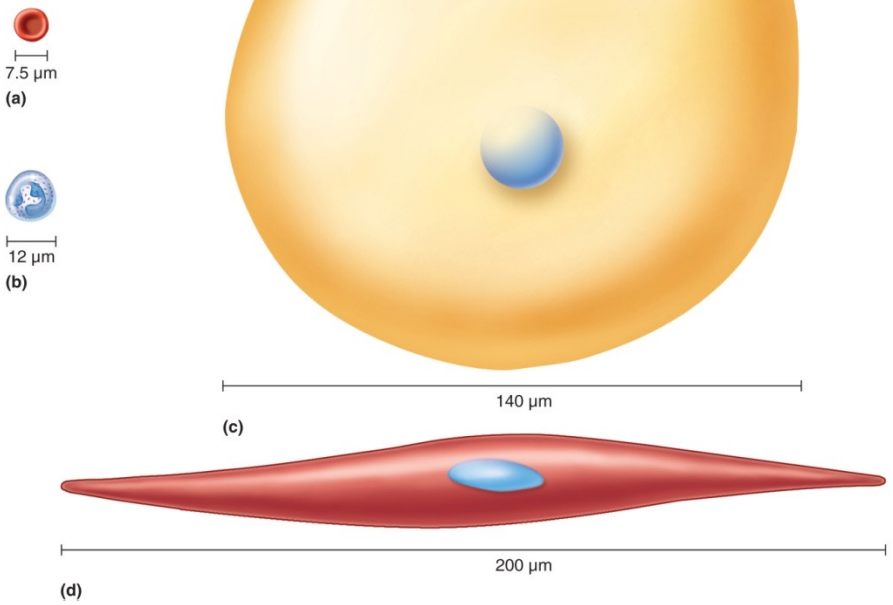
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3.1: Cells Are the Basic Units of the Body

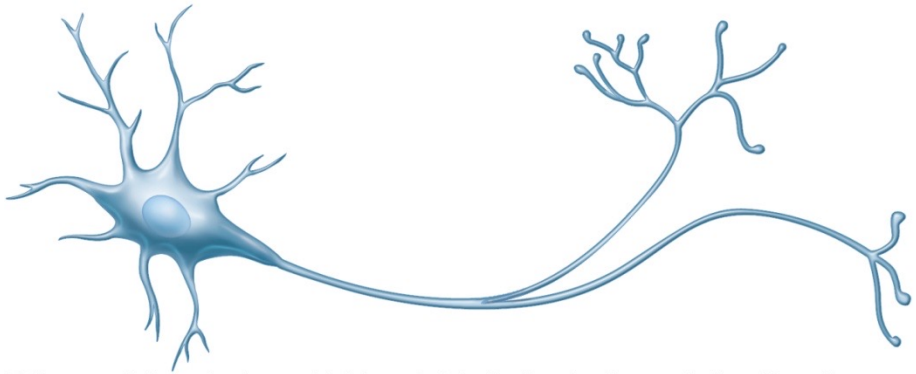
- The cell is the basic unit of structure and function in the body.
- Cells are measured in micrometers (microns, μm).
- Cells that have developed specialized characteristics are said to be differentiated.
- Cells vary in size and shape; structure and function are inter-related.

Cells are the Basic Units of the Body

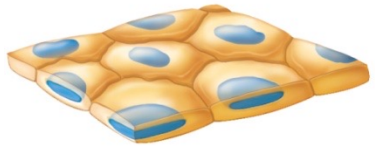
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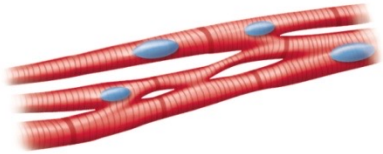
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(a) A nerve cell's long extensions enable it to conduct electrical impulses from one body part to another.



(b) The sheetlike organization of epithelial cells enables them to protect underlying cells.



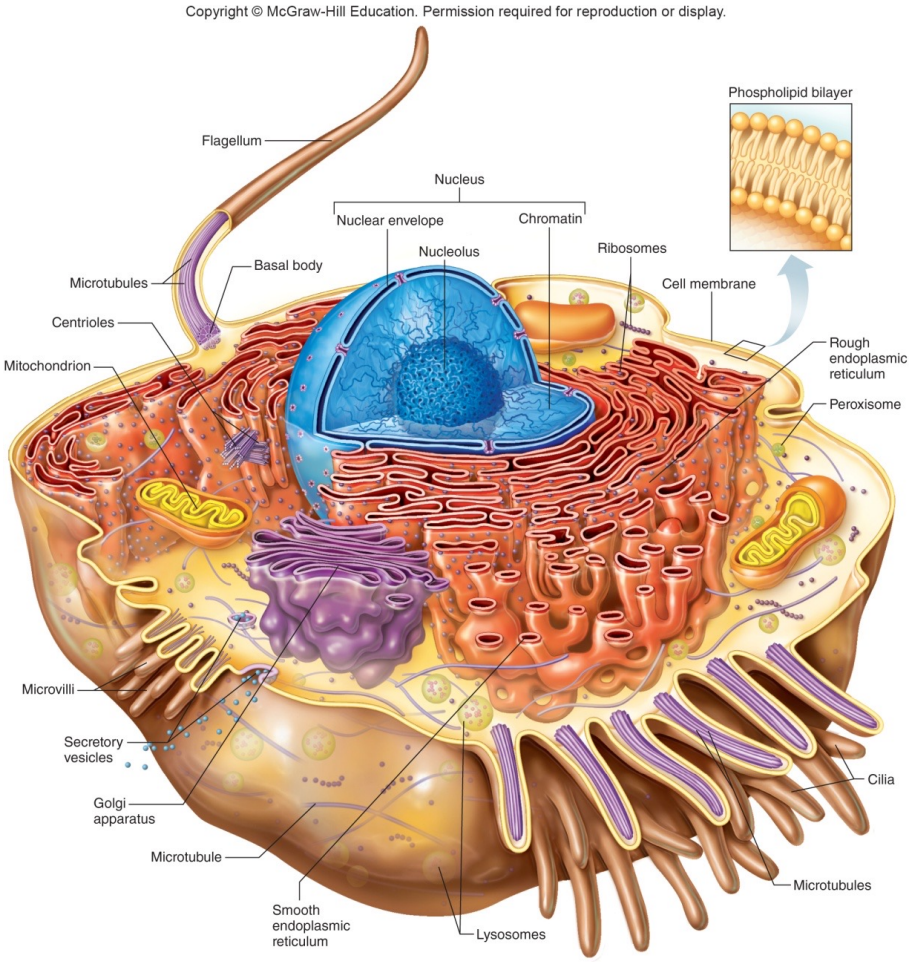
(c) The alignment of contractile proteins within muscle cells enables them to contract, pulling closer together the structures to which they attach.

3.2: A Composite Cell

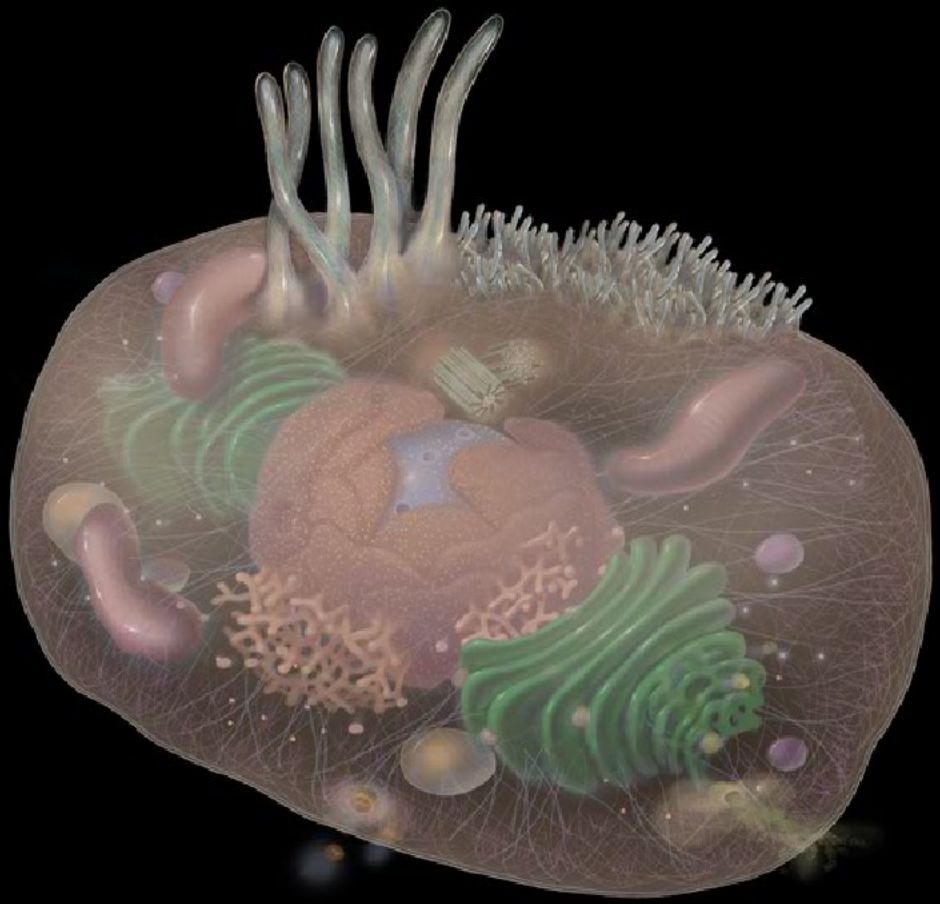
- There is no typical cell, but a composite cell shows the components found in most cells.

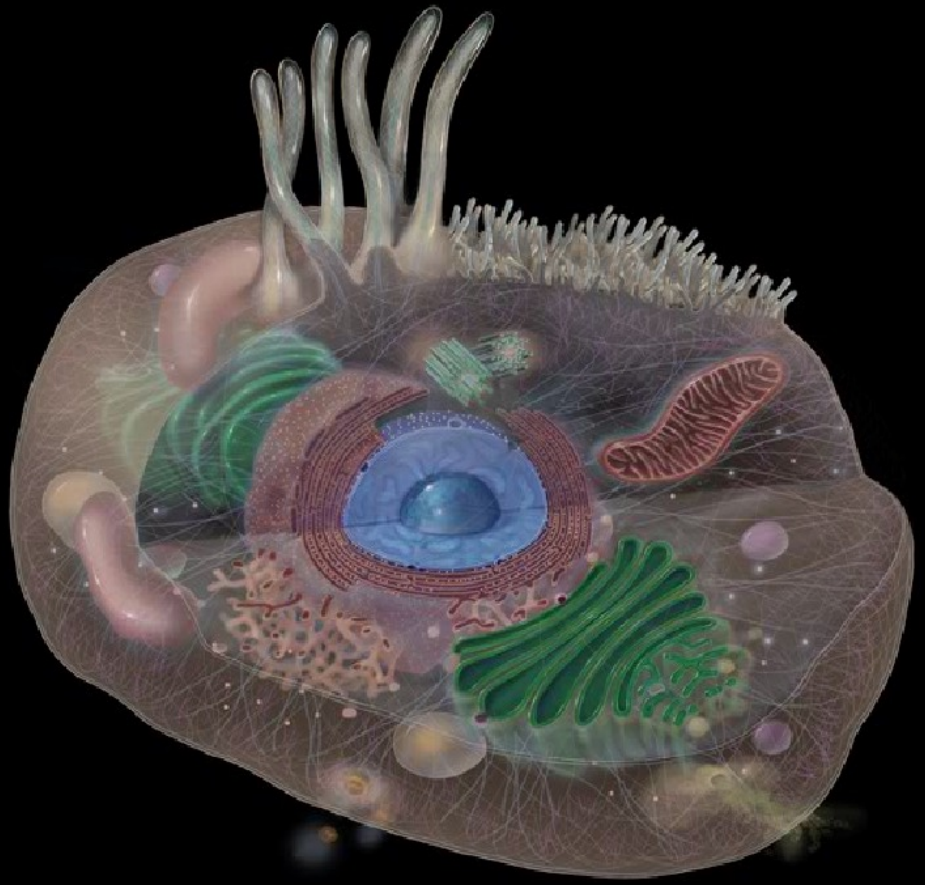
- **3 major parts of a cell:**
  - Nucleus
  - Cytoplasm
  - Cell membrane

- **Cytoplasm** consists of organelles, with specific functions, suspended in a liquid called **cytosol.**



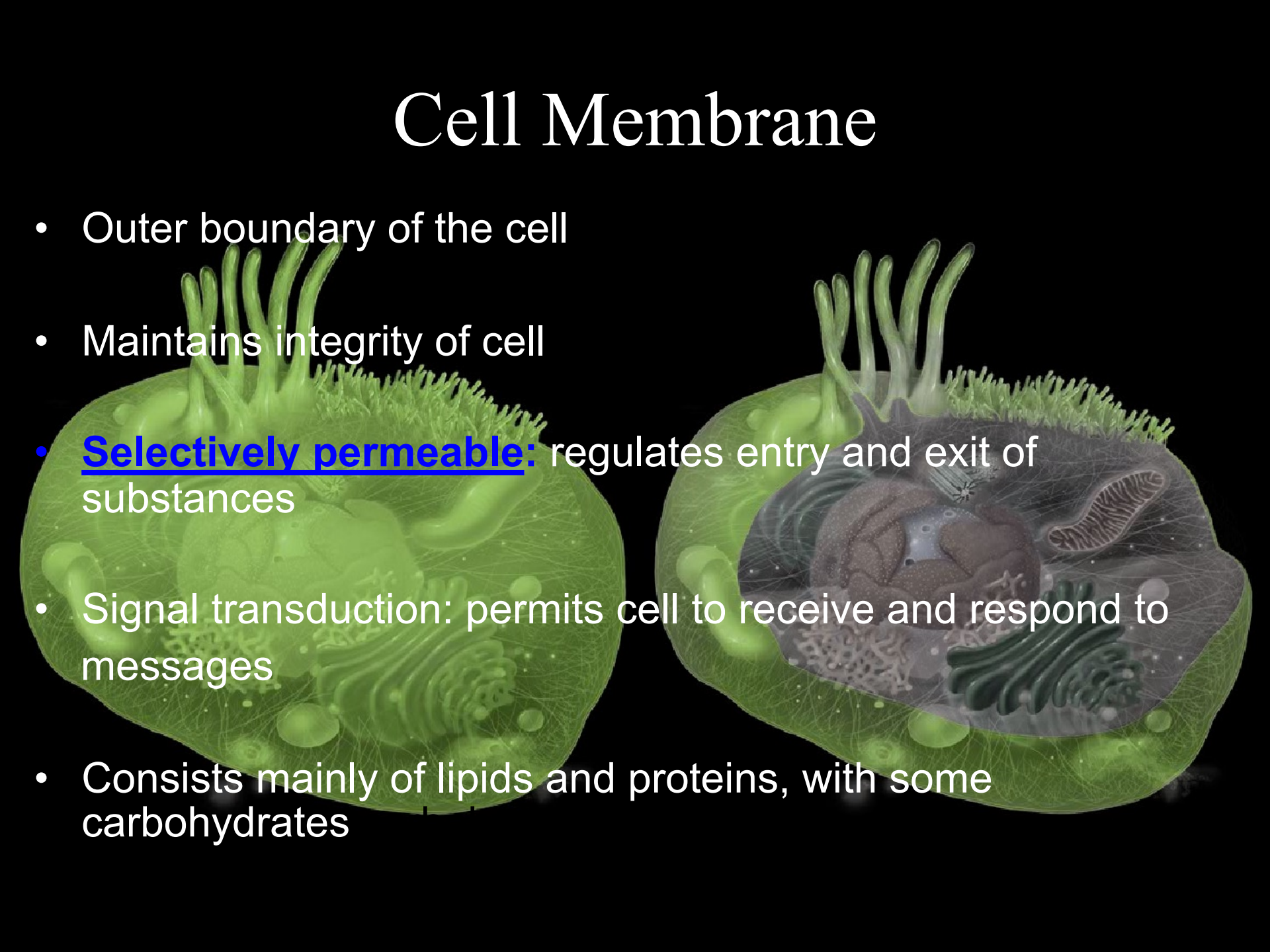
The Generalized Cell





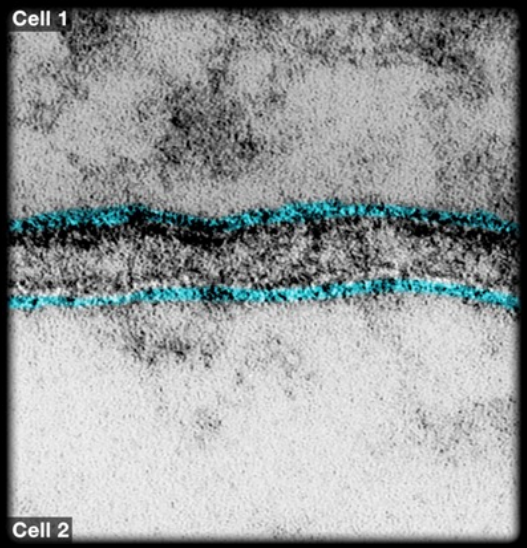
Cell Membrane

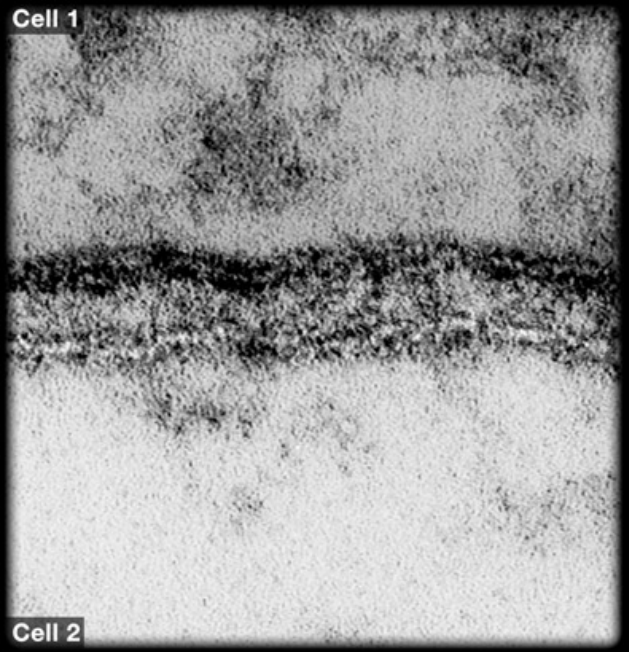
- Outer boundary of the cell
- Maintains integrity of cell
- **Selectively permeable:** regulates entry and exit of substances
- Signal transduction: permits cell to receive and respond to messages
- Consists mainly of lipids and proteins, with some carbohydrates



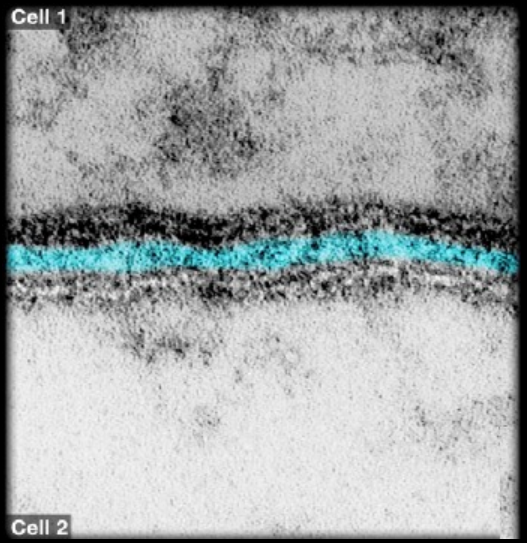
Cell Membrane

Inner leaflet

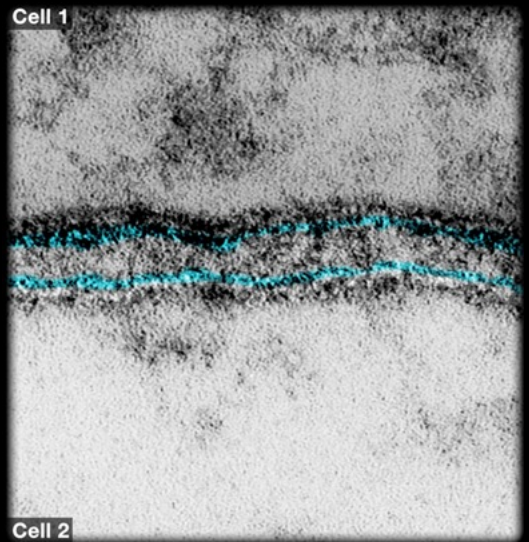




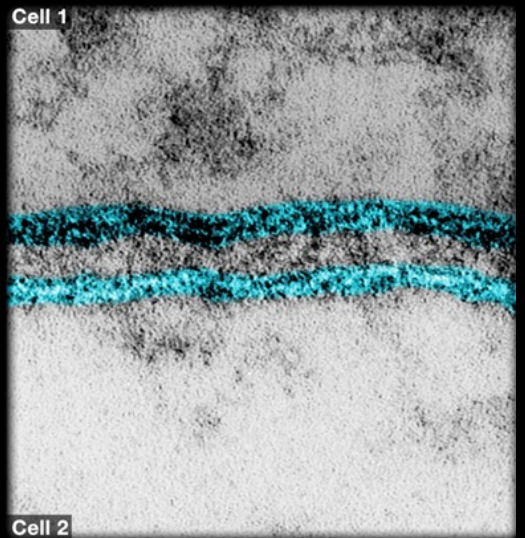
Extracellular matrix



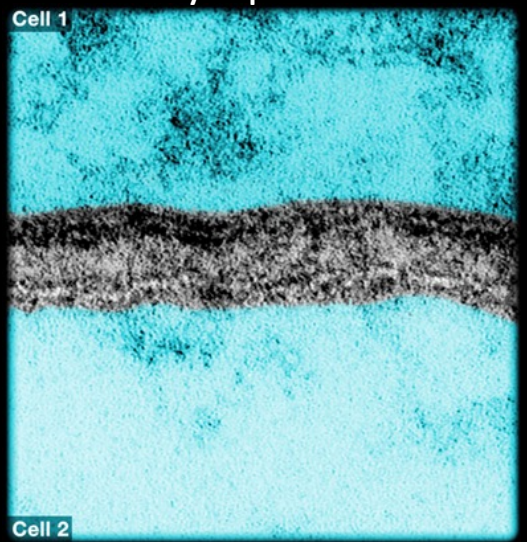
Outer leaflet



Plasma membranes



Cytoplasm

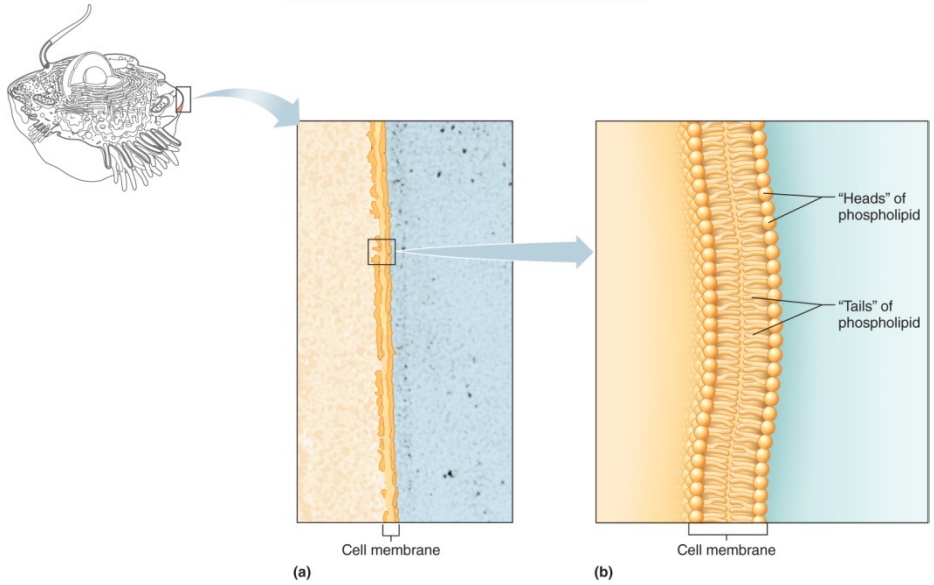


Cell Membrane Structure

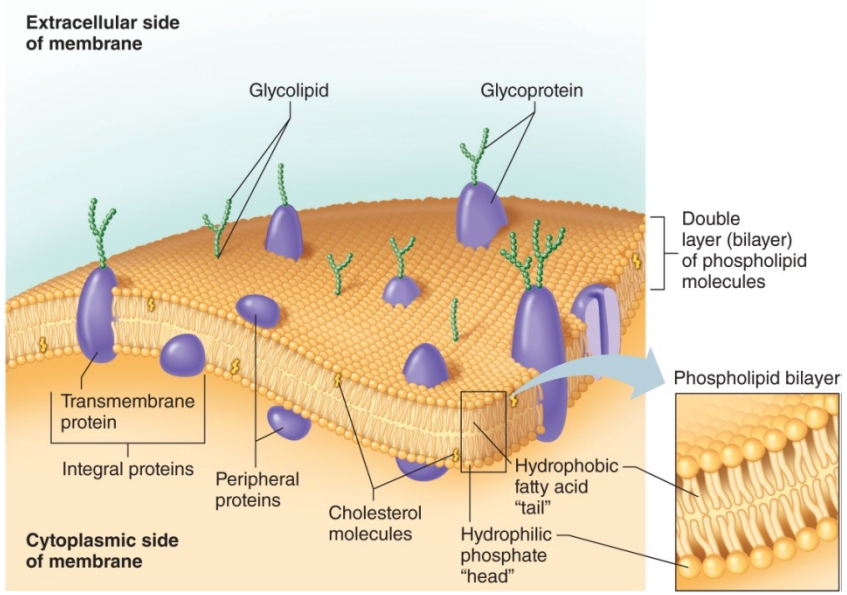
- Cell membrane framework is a **phospholipid bilayer:**
  - Water-soluble (hydrophilic) heads form surfaces
  - Water-insoluble (hydrophobic) tails form interior
- Bilayer is permeable to lipid-soluble substances, but impermeable to water-soluble substances
- Cholesterol stabilizes membrane, helps keep it impermeable to water-soluble substances
- Some lipids and proteins can move; "fluid mosaic" properties
- Membrane proteins have many functions:
  - Pores, channels, receptors, enzymes, cell contact and identification, CAMs (Cell Adhesion Molecules)
- Carbohydrates:
  - -Cell recognition and interaction, self markers

Cell Membrane Structure

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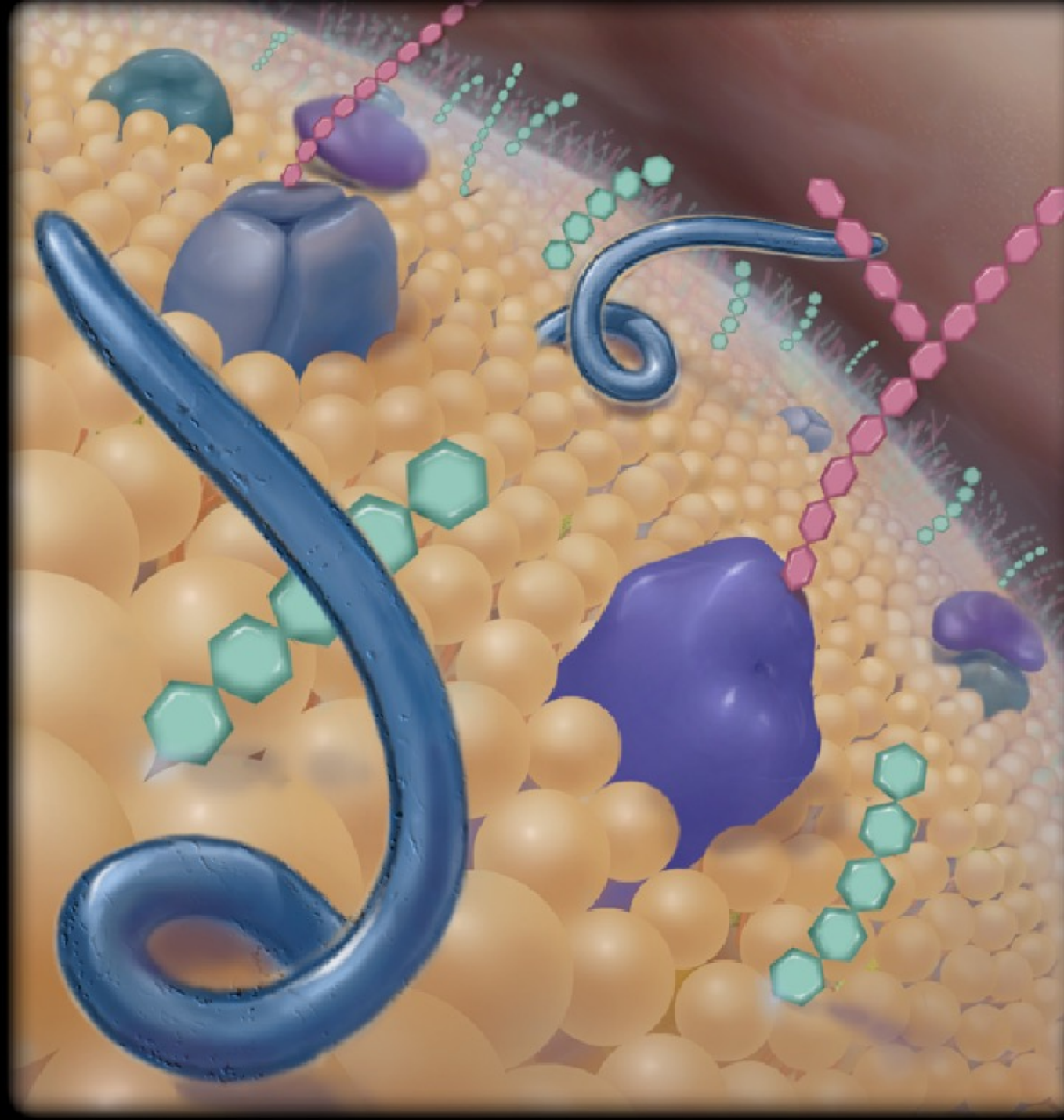
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Membrane Lipids

Membrane Proteins

Membrane Carbohydrates



Clinical Application 3.1

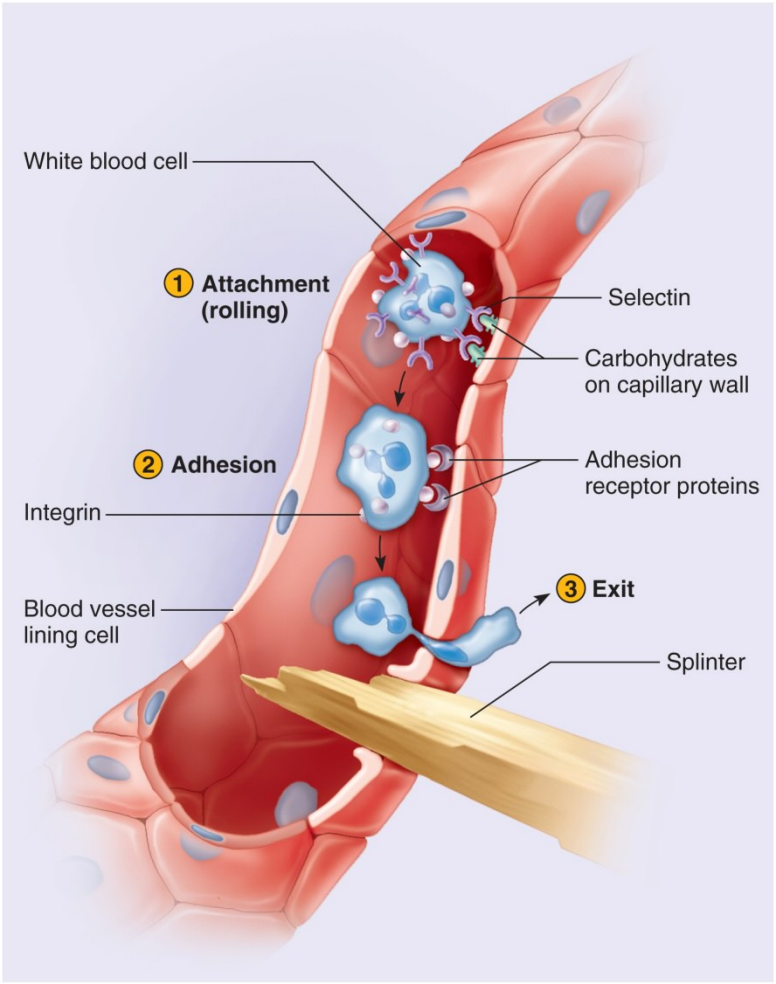
Faulty Ion Channels Cause Disease

- Mutations in Na^+ Channels can cause inability to feel pain or extreme pain conditions
- Mutations in K^+ Channels can disrupt electrical activity of the heart and disturb heart rhythm, and/or impair hearing
- Abnormal Cl^- Channels are the cause of Cystic Fibrosis: production of thick mucus causes difficulty breathing, clogged pancreas, salty sweat

Cellular Adhesion Molecules (CAMs)

- Guide cells on the move
- **Selectins** coat white blood blood cells and anchor them by providing friction
- **Integrins** direct white blood cells through capillary walls toward infection sites
- Guide embryonic cells toward maternal cells to form placenta
- Establish connections between nerve cells

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Cytoplasm

- **Cytoplasm** consists of networks of membranes and organelles suspended in cytosol

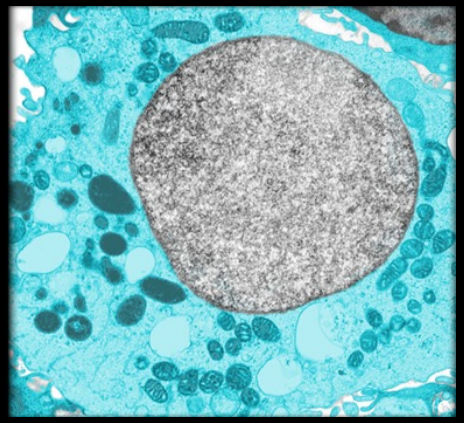
- Cytoplasm = cytosol + organelles

  Cytosol: fluid portion of the cytoplasm

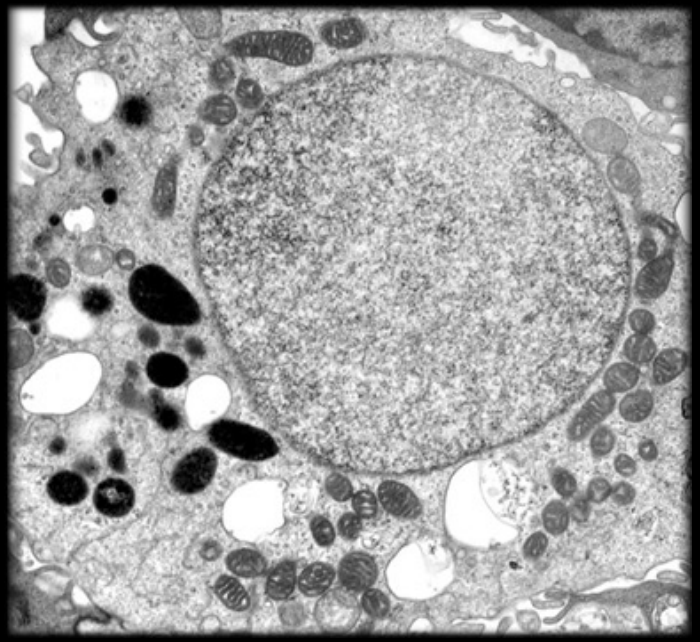
  Organelles: tiny solid structures with specific functions in the cell

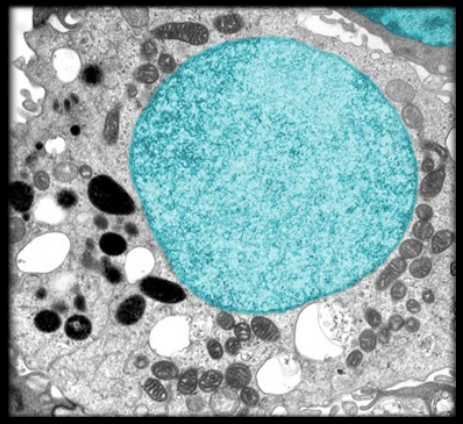
- Cytoplasm contains the **cytoskeleton**, a supporting framework of protein rods and tubules

Cytoplasm

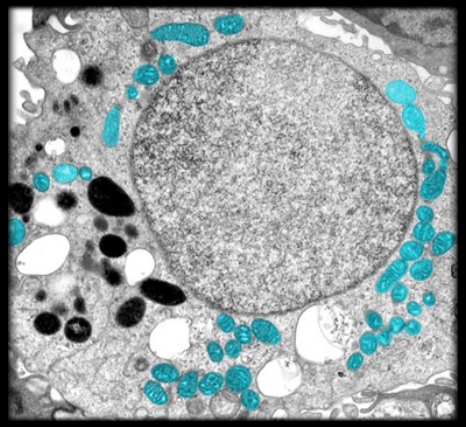


Cytoplasm

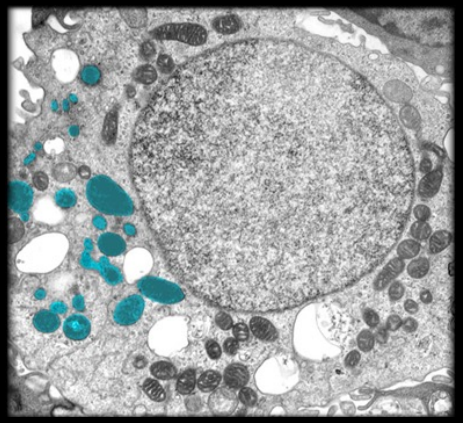




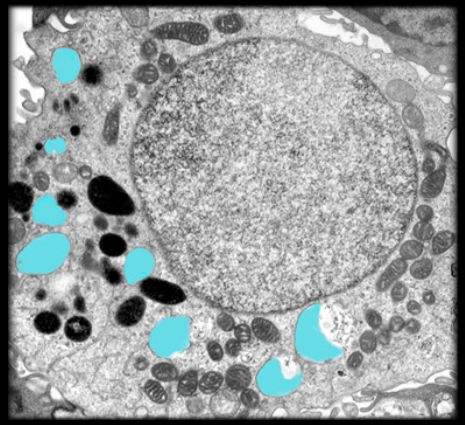
Nucleus



Mitochondria



Peroxisomes



Vesicles

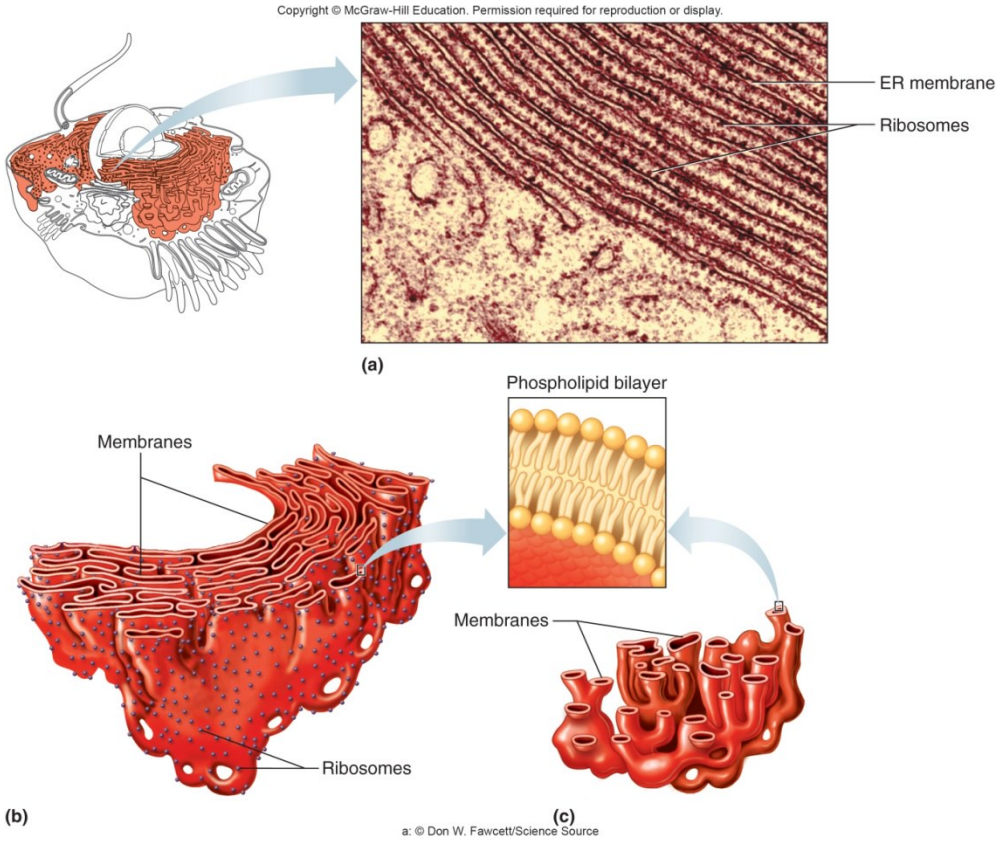
Cytoplasmic Organelles

Ribosomes:

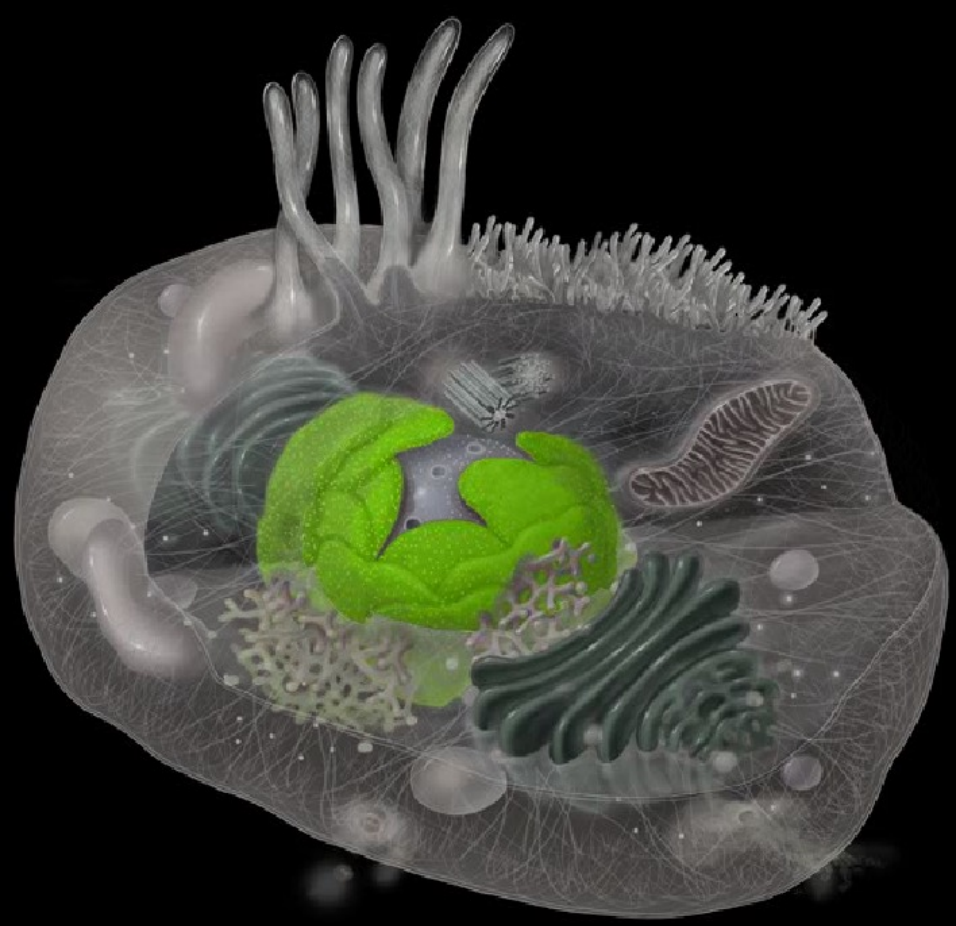
- Composed of protein and RNA
- Free in cytoplasm or on RER
  - **Free-floating** produces proteins for the cell's use
  - **Embedded** produces protein for extracellular transport
- Provide structural support and enzyme activity to link amino acids in protein synthesis

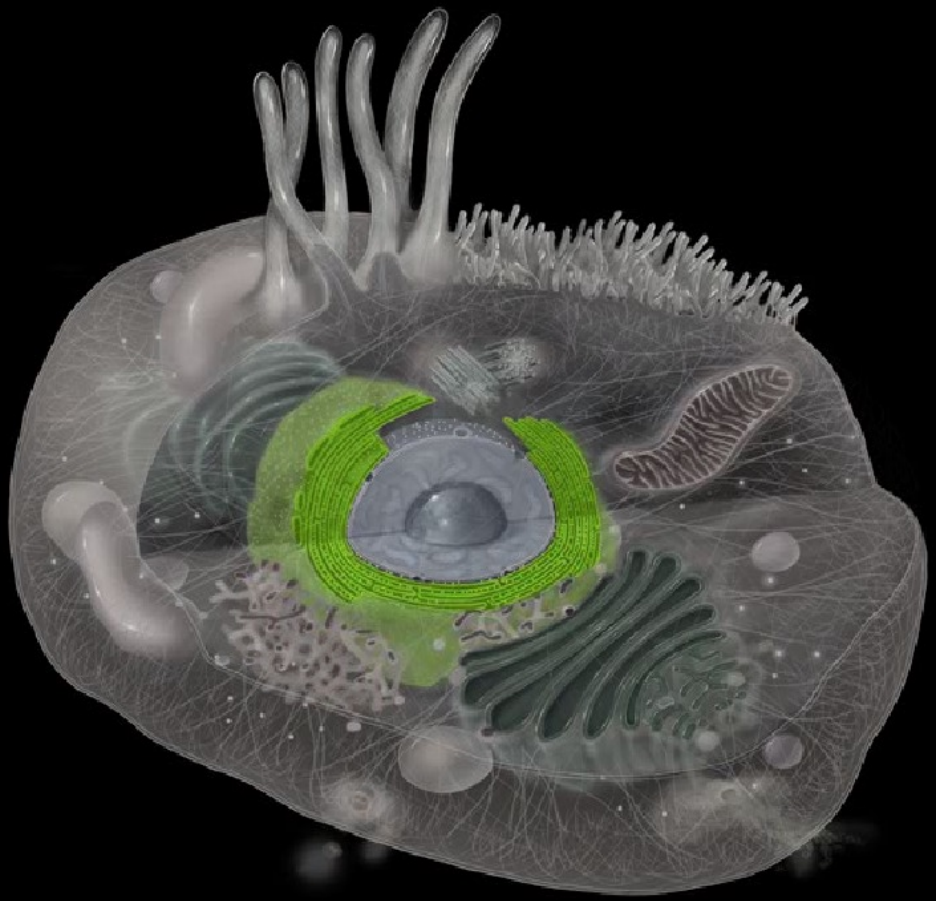
Endoplasmic Reticulum (ER):

- Membrane-bound sacs, canals, vesicles
- Tubular transport system
- **Rough ER** contains ribosomes, conducts protein synthesis
- **Smooth ER** does not have ribosomes; conducts lipid synthesis

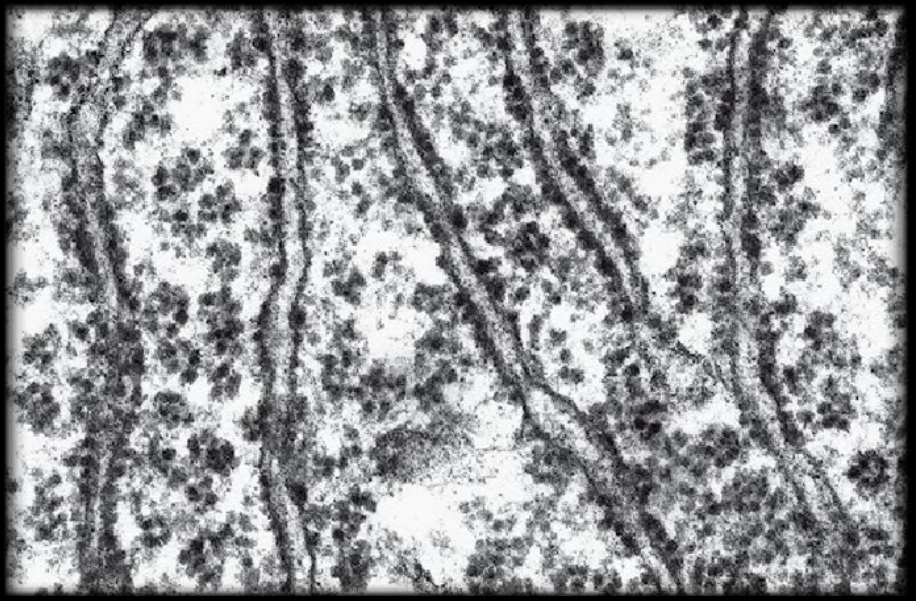


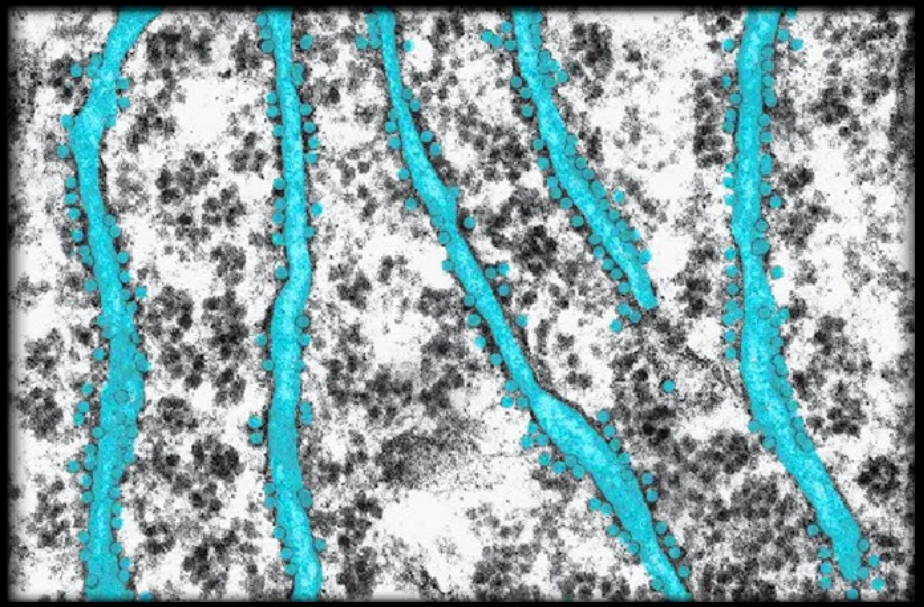
Rough Endoplasmic Reticulum



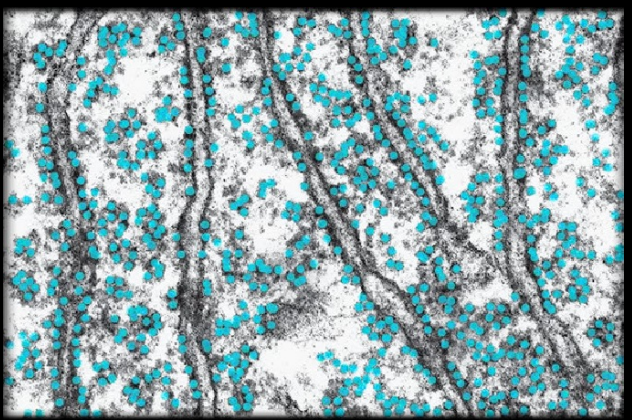


Rough Endoplasmic Reticulum

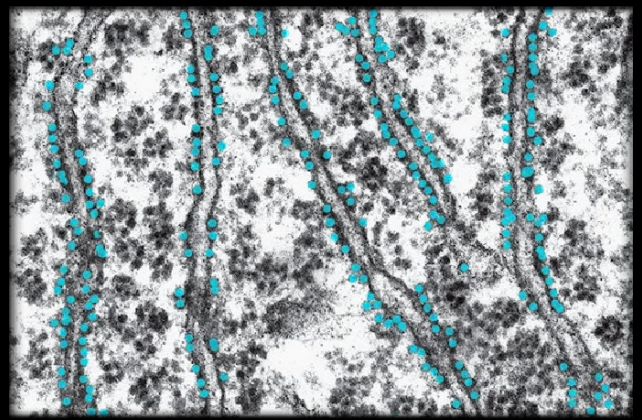




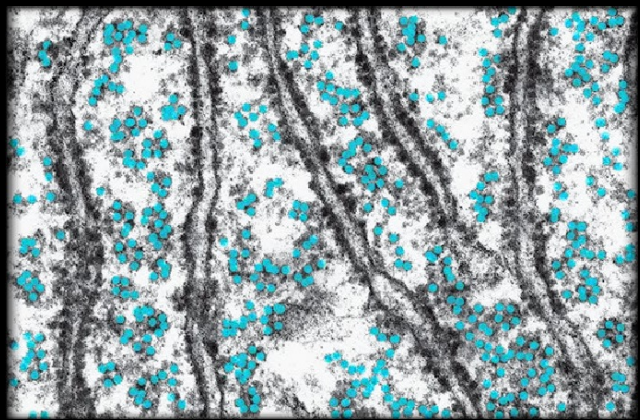
Ribosomes



Fixed ribosomes

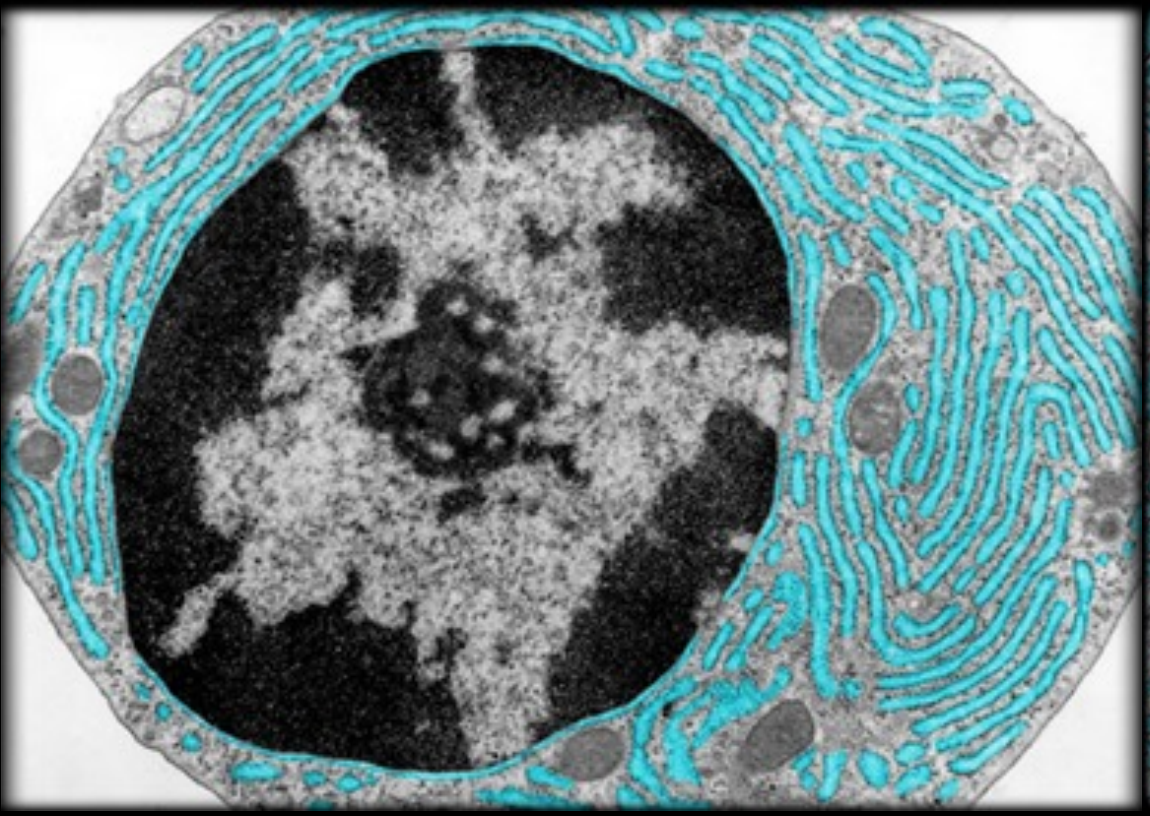


Free ribosomes

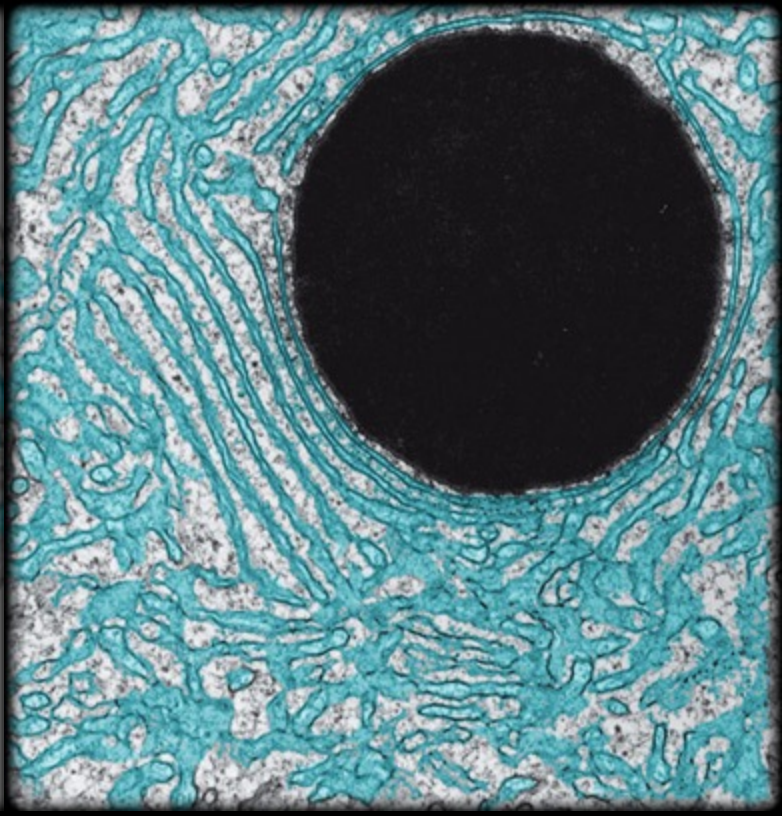


Rough & Smooth Endoplasmic Reticulum

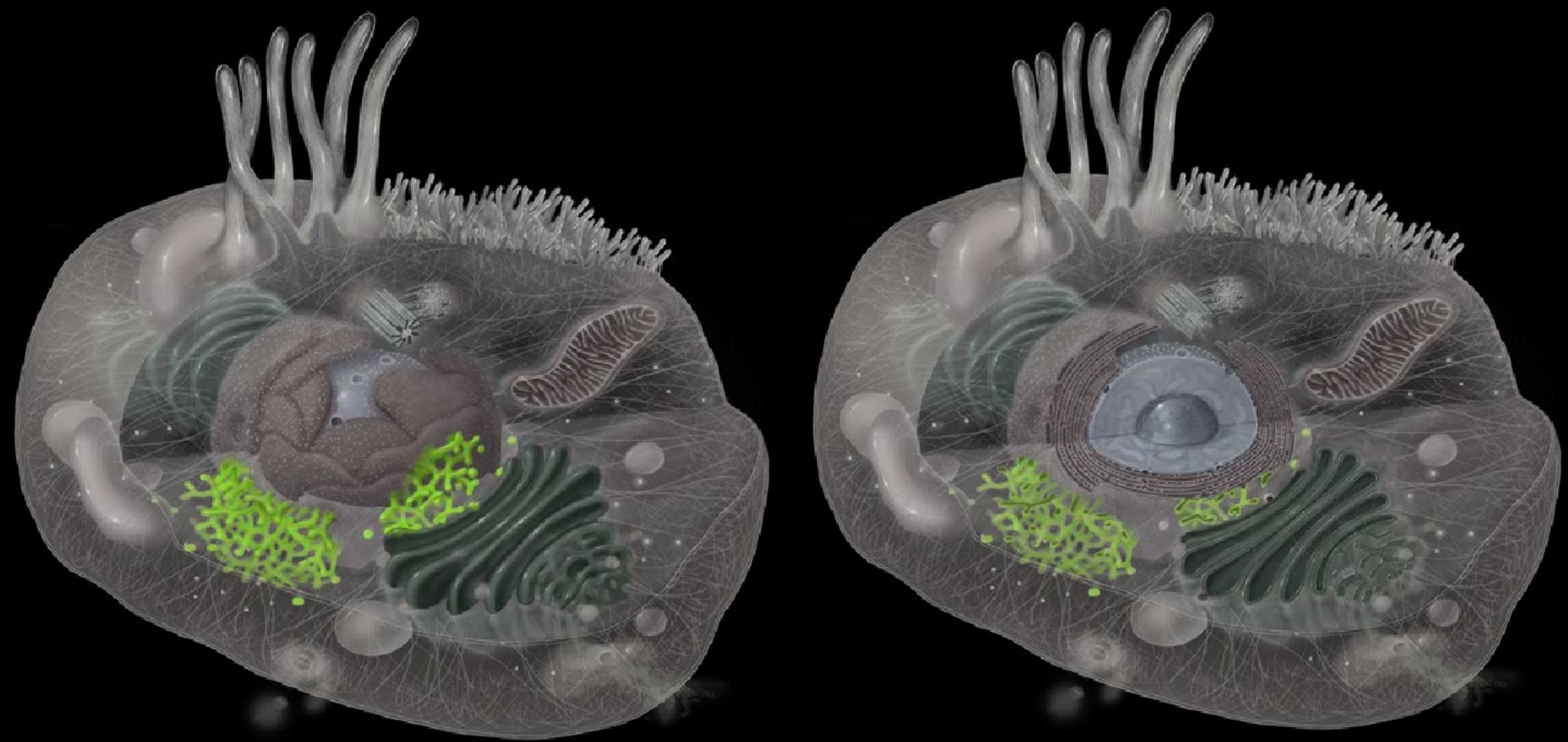
Rough



Smooth

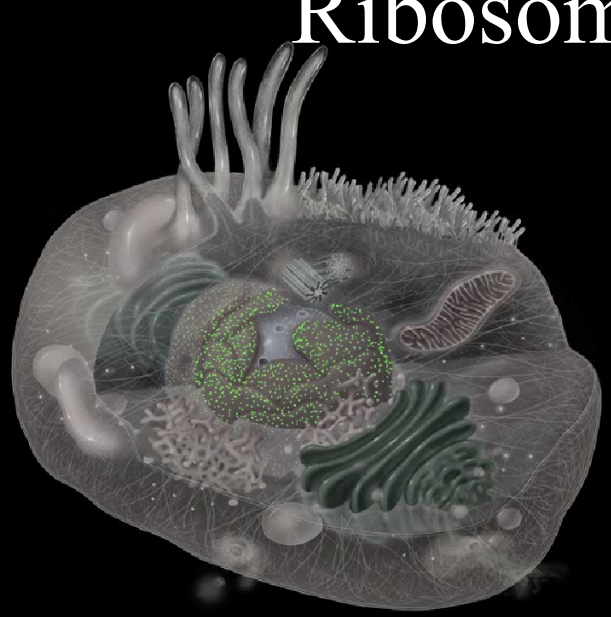


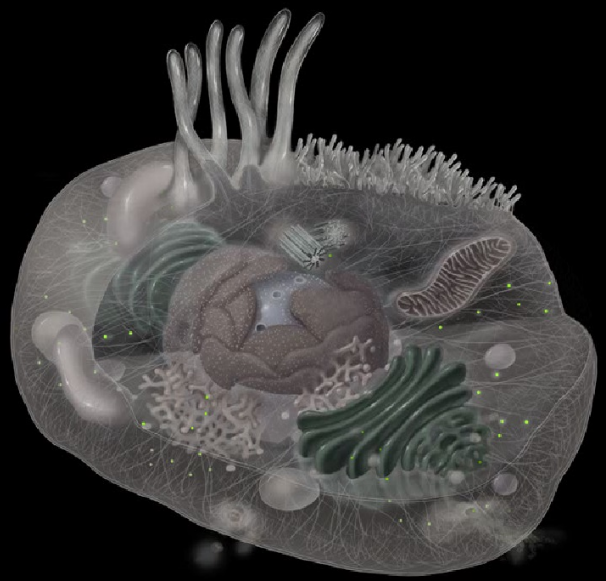
Smooth Endoplasmic Reticulum

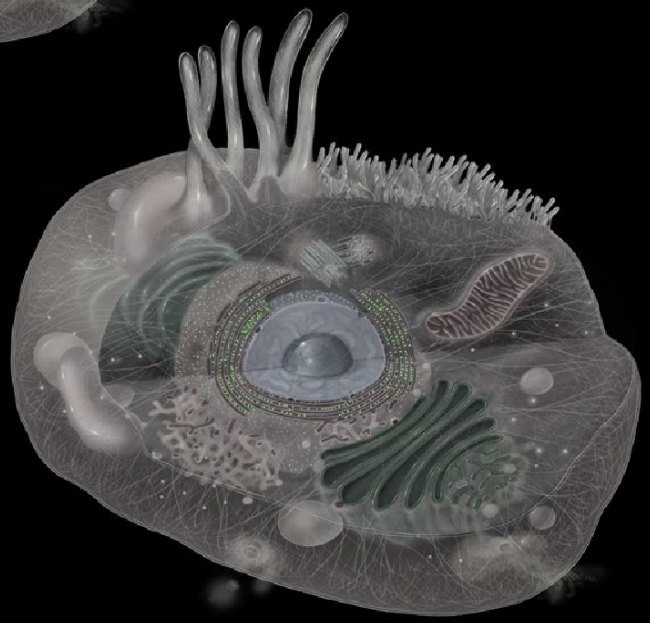


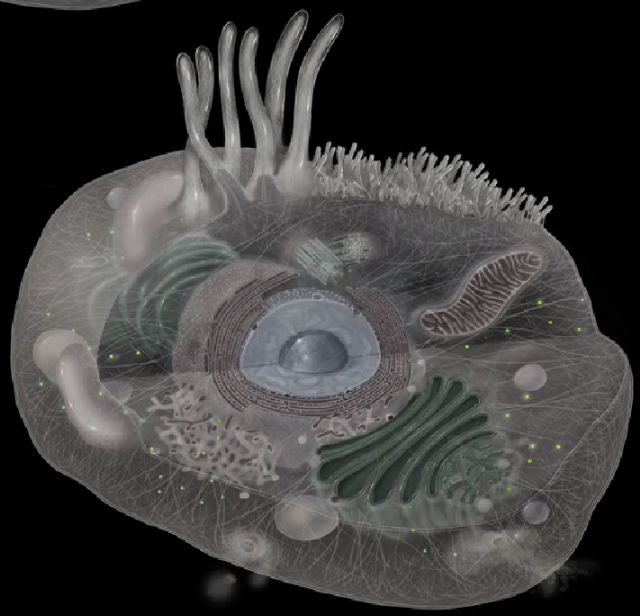
Membrane-bound Ribosomes

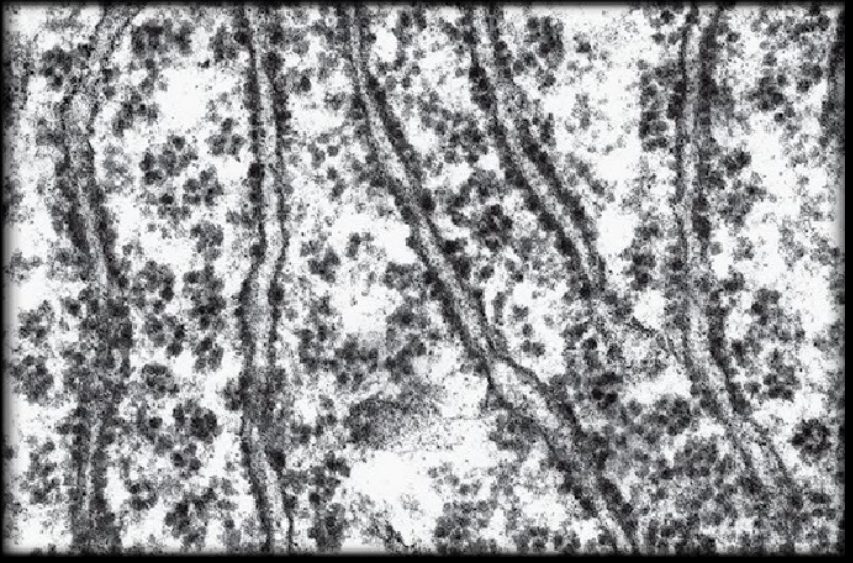
Free Ribosomes

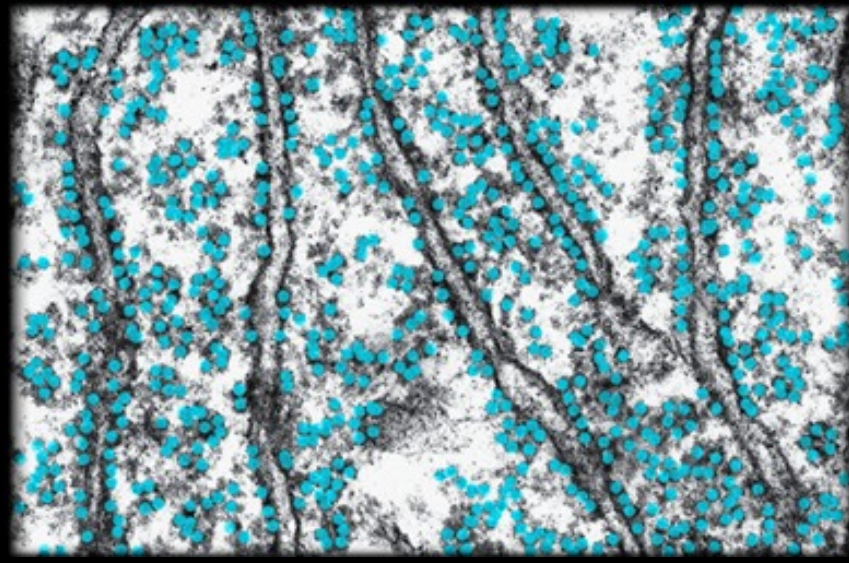






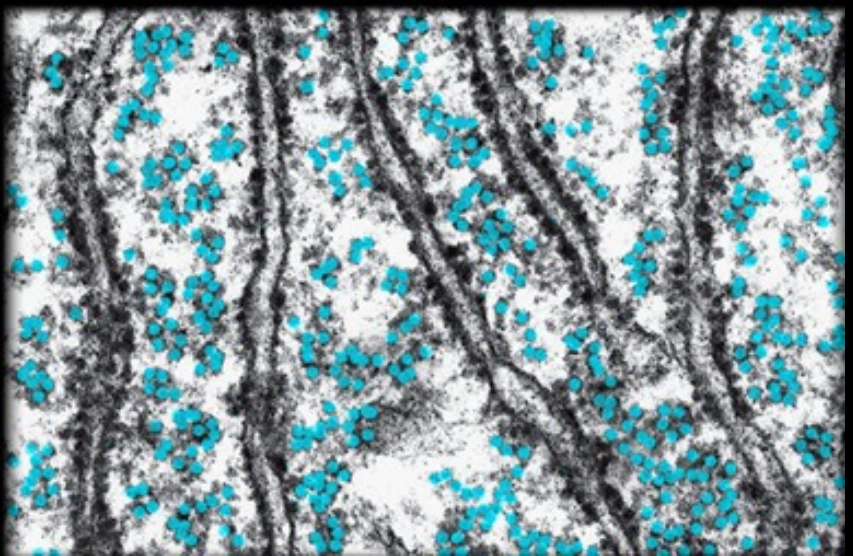




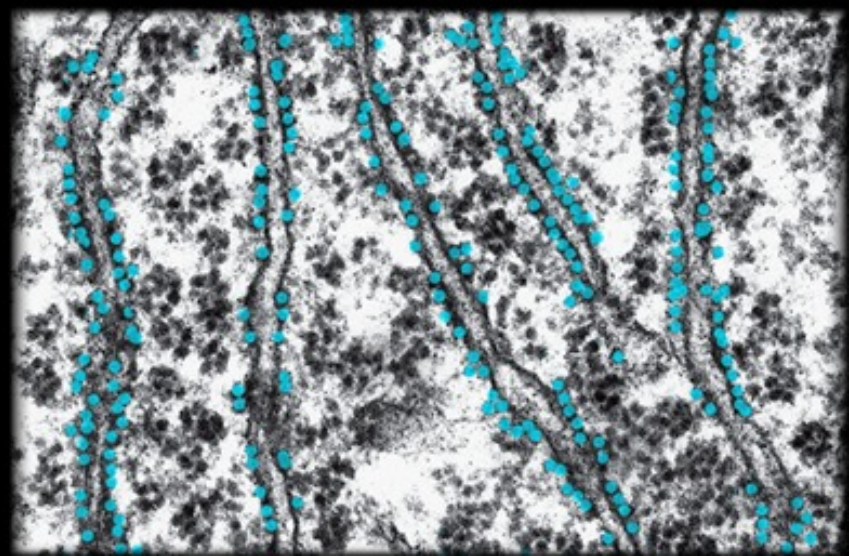


Ribosomes

Free



Membrane-bound



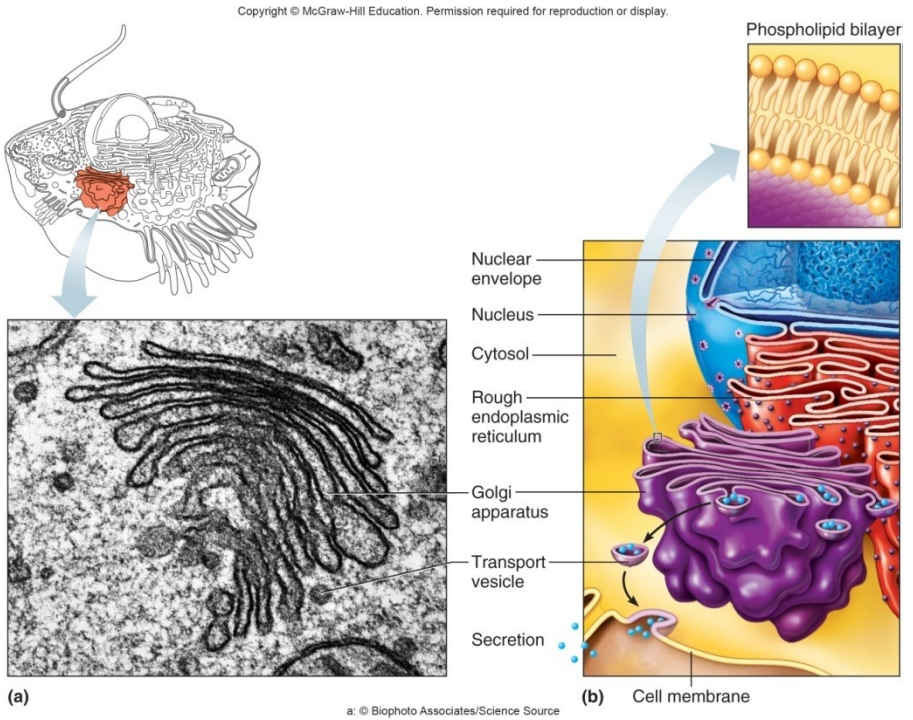
Cytoplasmic Organelles

Vesicles:

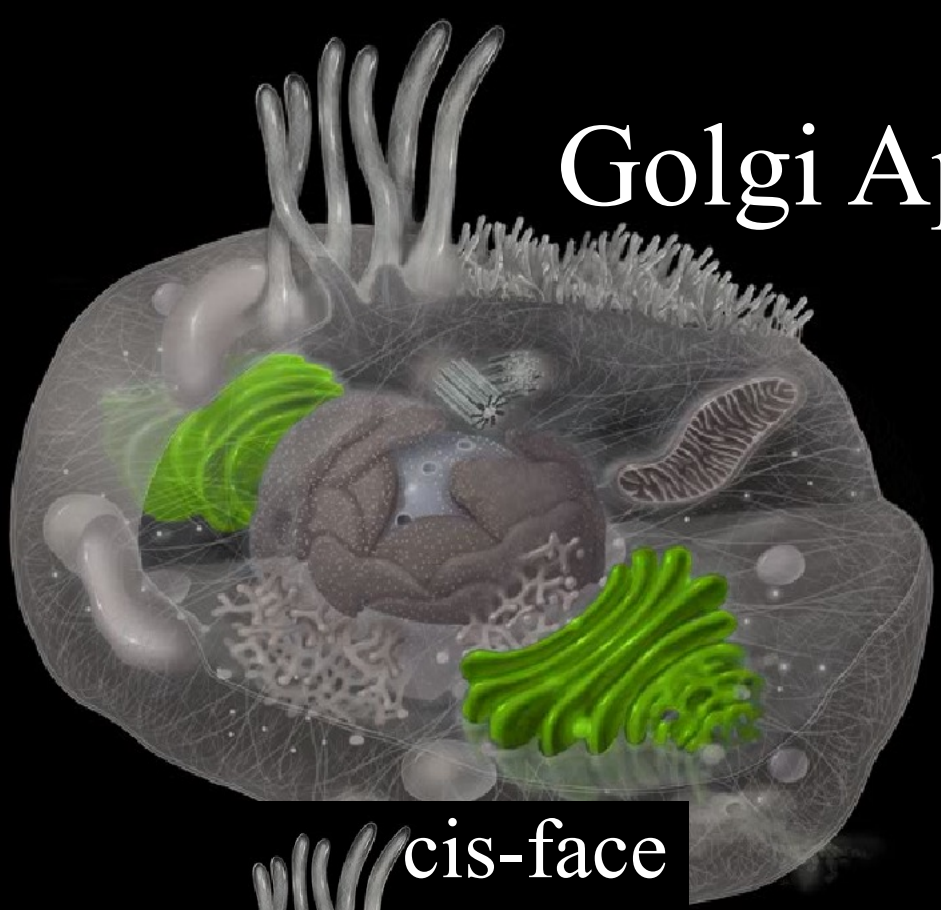
- Membranous sacs
- Store or transport substances

Golgi Apparatus:

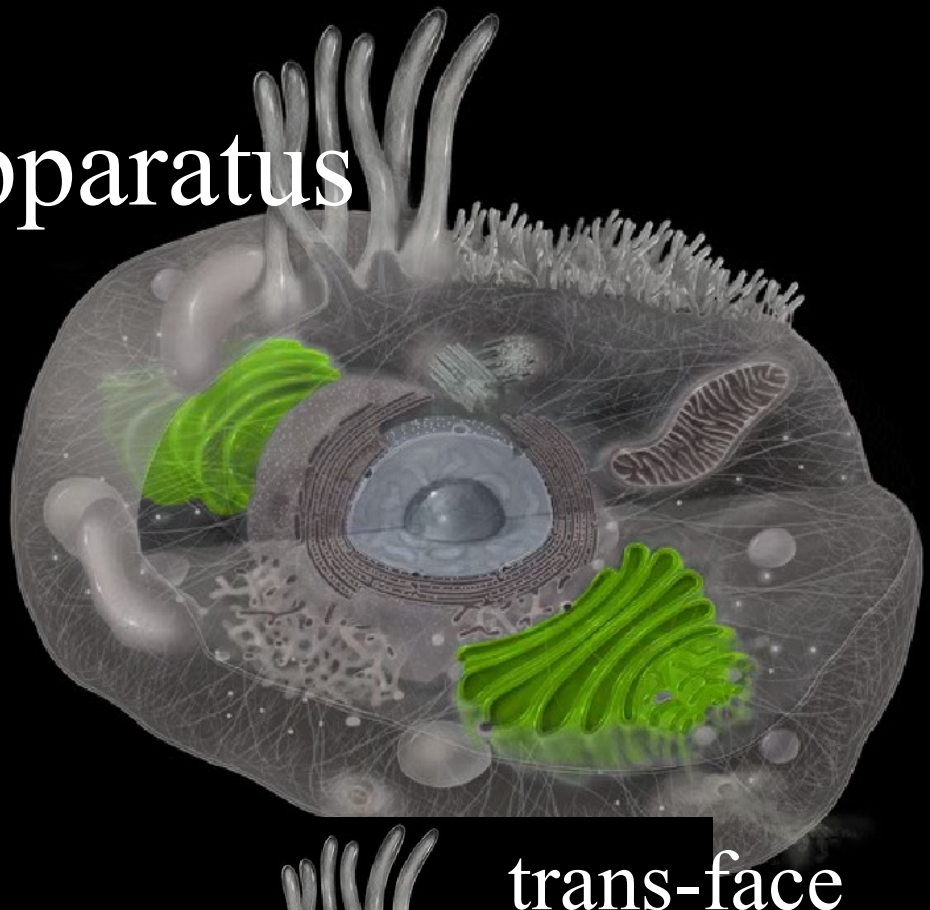
- Sacs of flattened, membranous sacs
- Refines, packages, and delivers proteins made on the RER



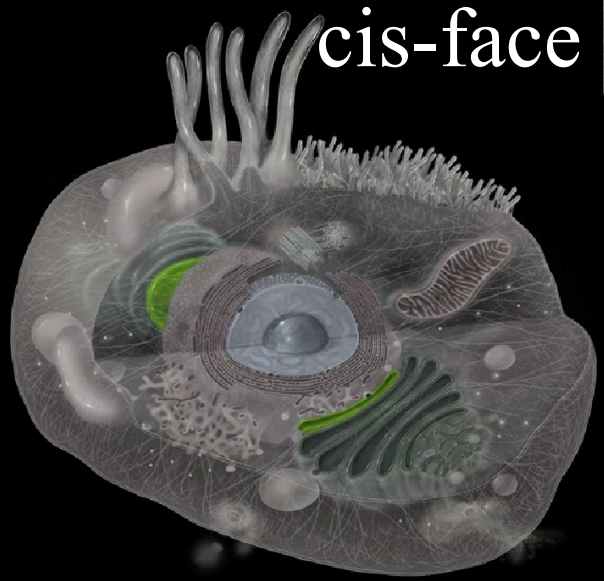
Golgi Apparatus

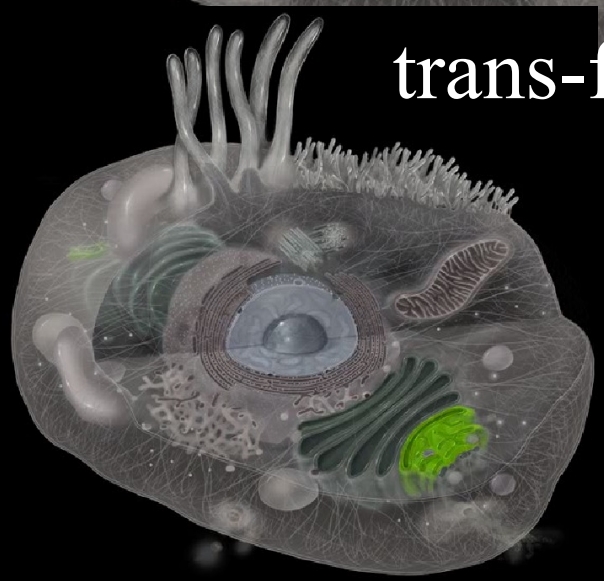


cis-face



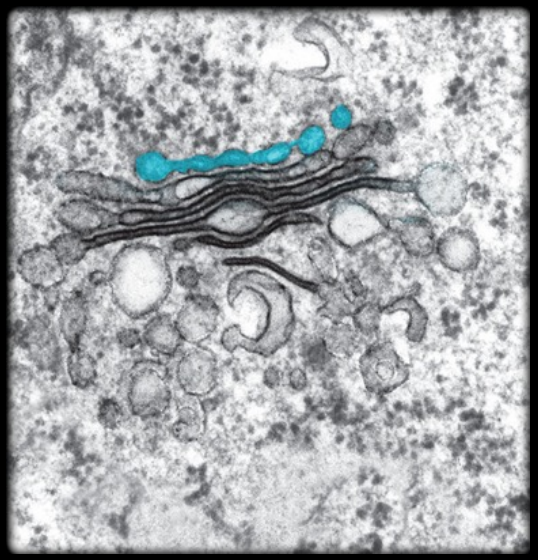
trans-face



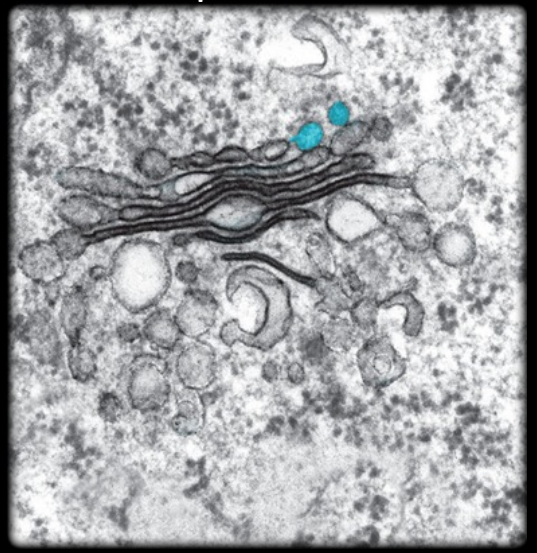


Golgi Apparatus

cis-face

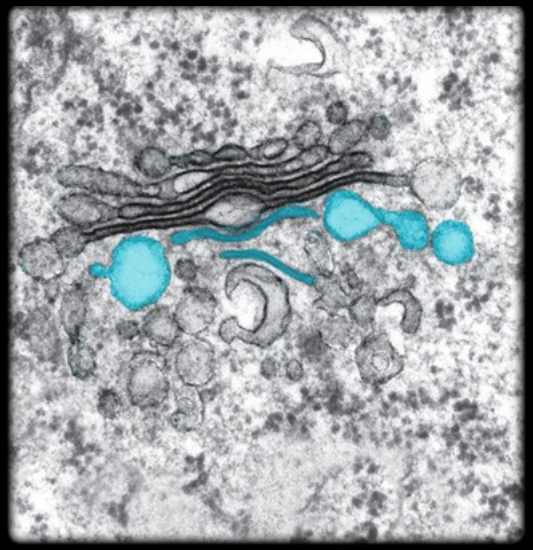


Transport vesicles

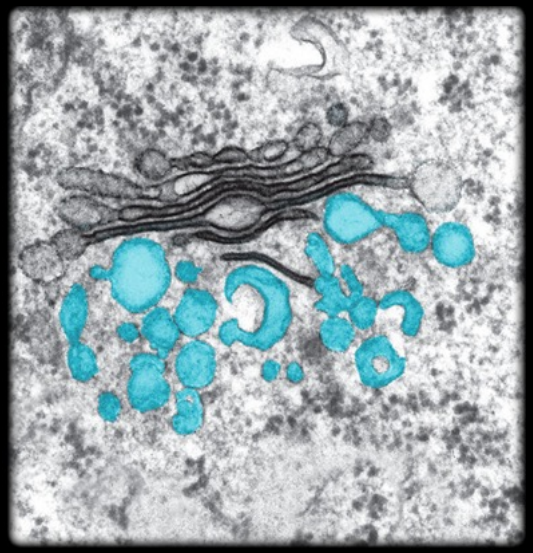


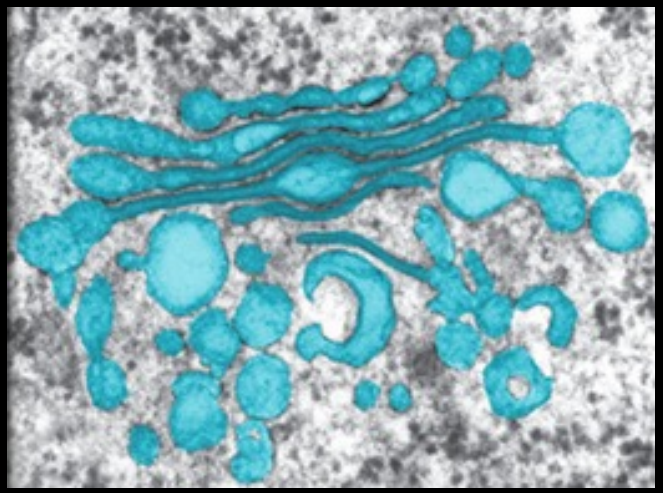


trans-face



Secretory vesicles





Cytoplasmic Organelles

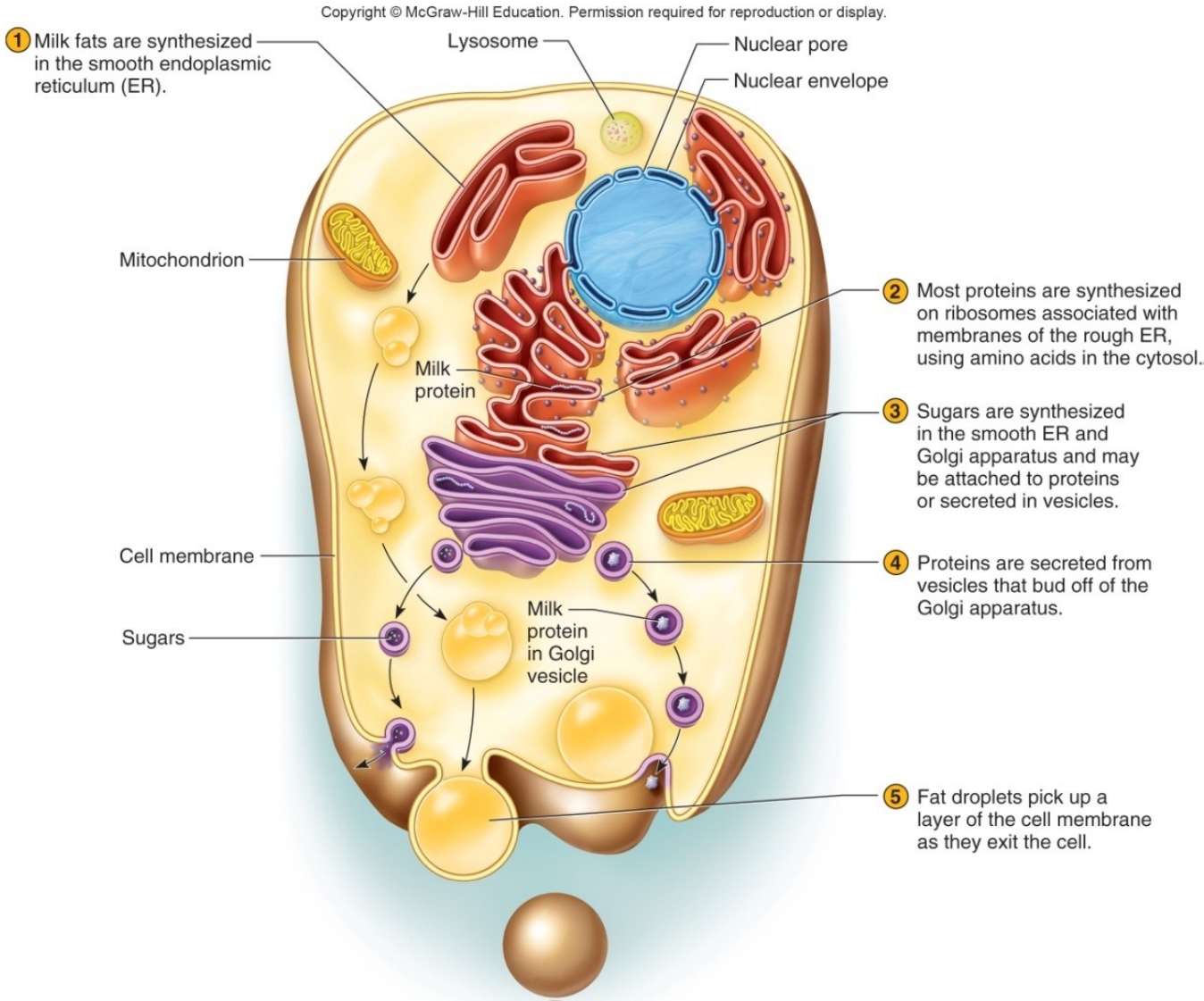
Milk secretion is an

example of organelle

interaction and the

transport of substances

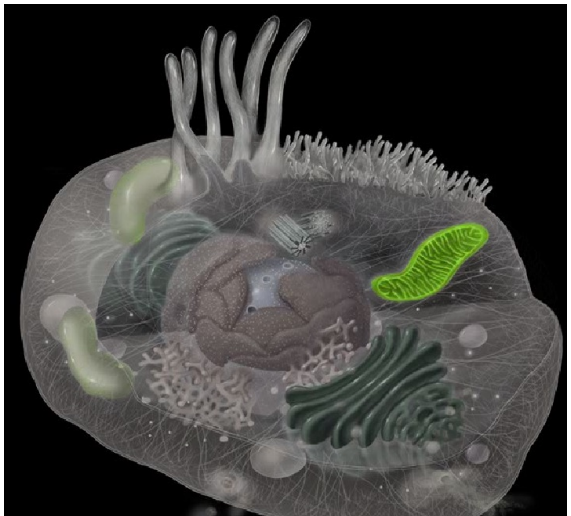
by vesicles.



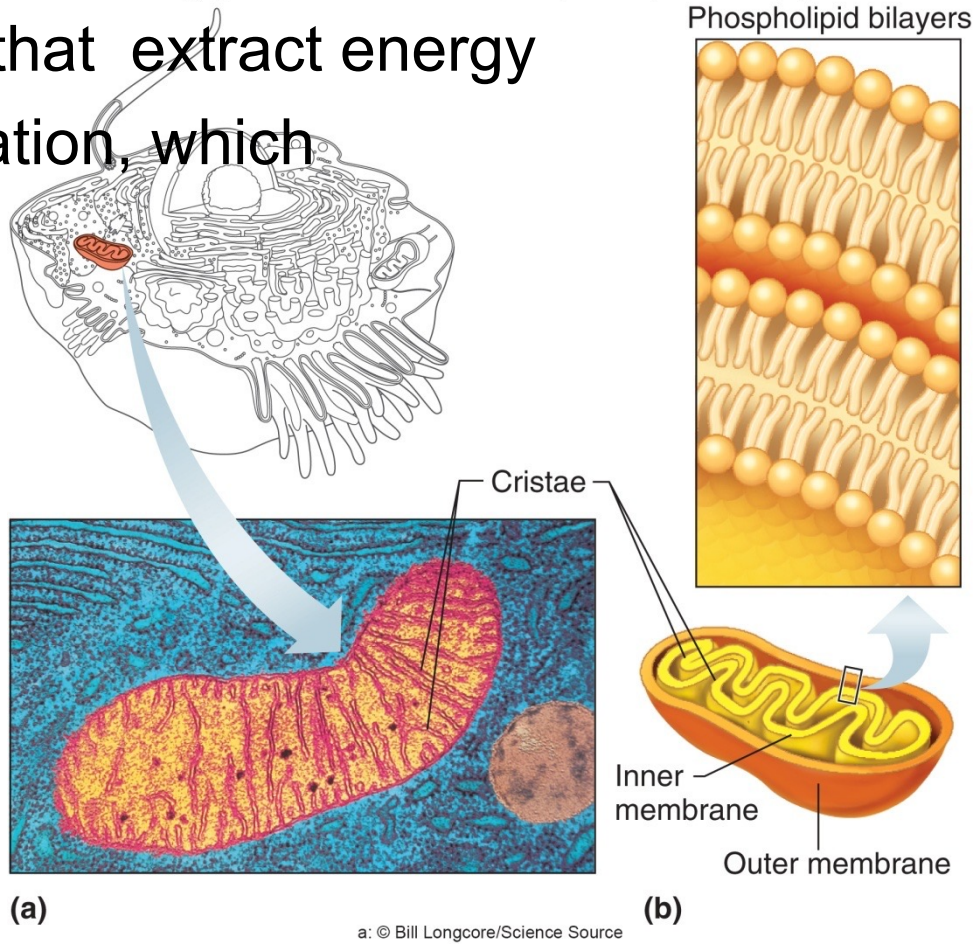
Cytoplasmic Organelles

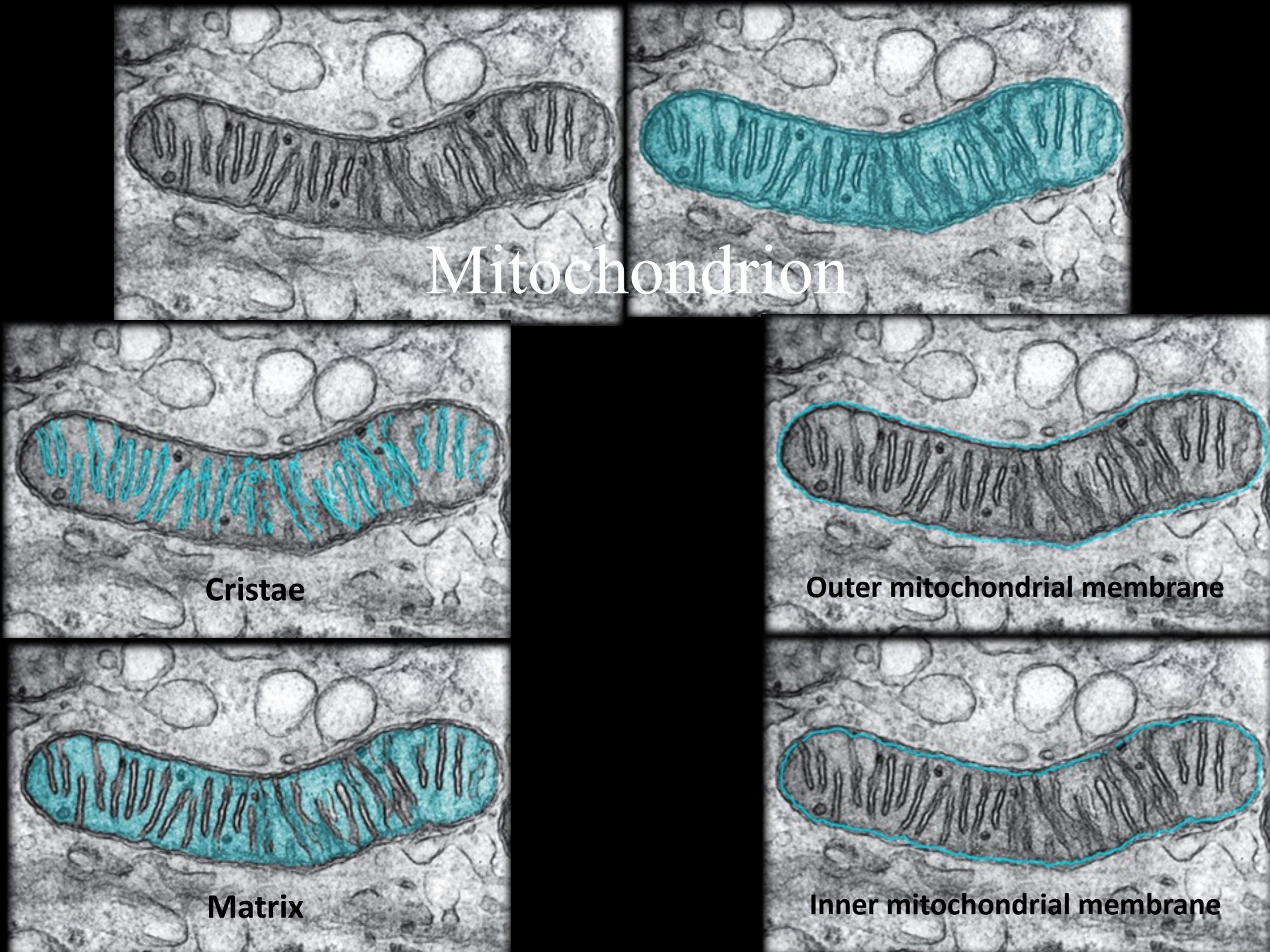
Mitochondria:

- Membrane-bound, fluid-filled sacs
- House chemical reactions that extract energy from nutrients (cellular respiration, which produces ATP)
- Called the "powerhouse of the cell"



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Mitochondrion
Cristae
Outer mitochondrial membrane
Matrix
Inner mitochondrial membrane

Cytoplasmic Organelles

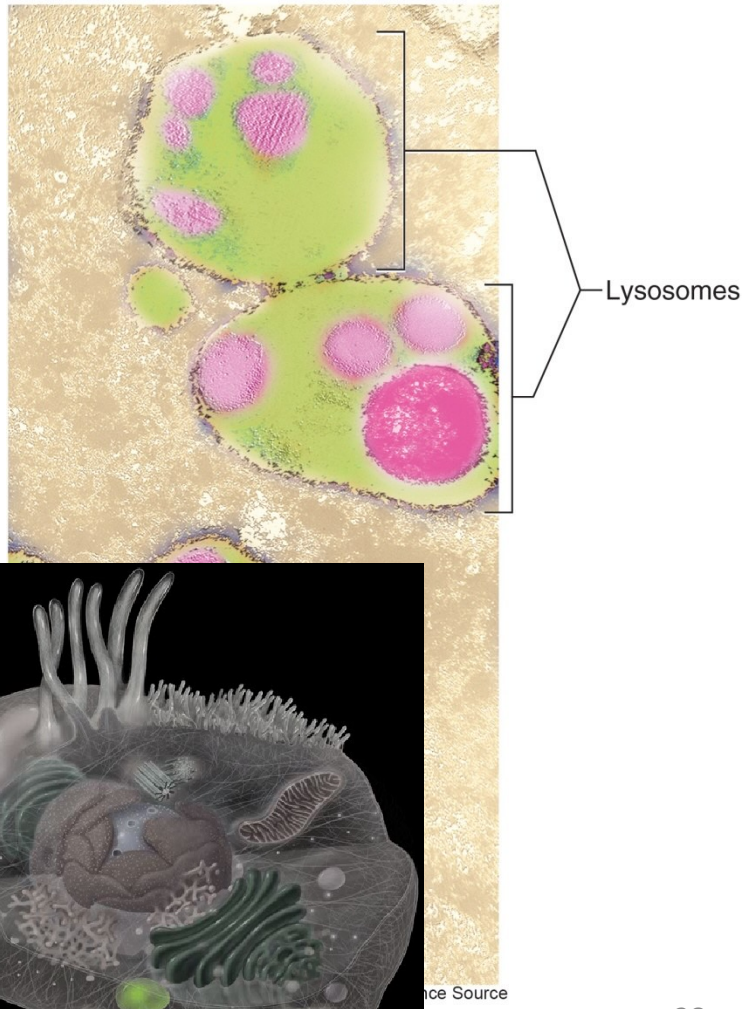
Lysosomes:

- Small membranous sacs
- Contain enzymes that digest proteins, carbohydrates, nucleic acids, bacteria, debris, worn out cell parts
- "Garbage disposals" of cell

Peroxisomes:

- Membranous sacs similar to lysosomes
- Contain enzymes that digest lipids, alcohol, hydrogen peroxide

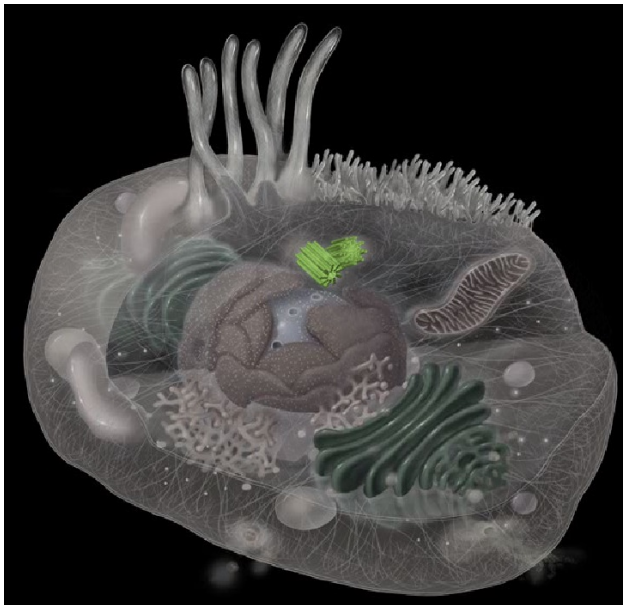
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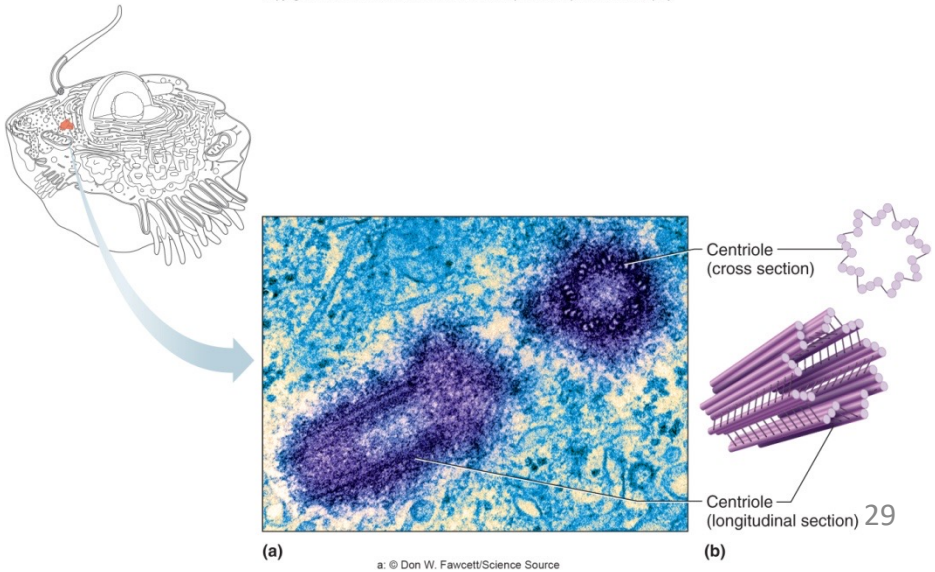
Other Cellular Structures

Centrosome:

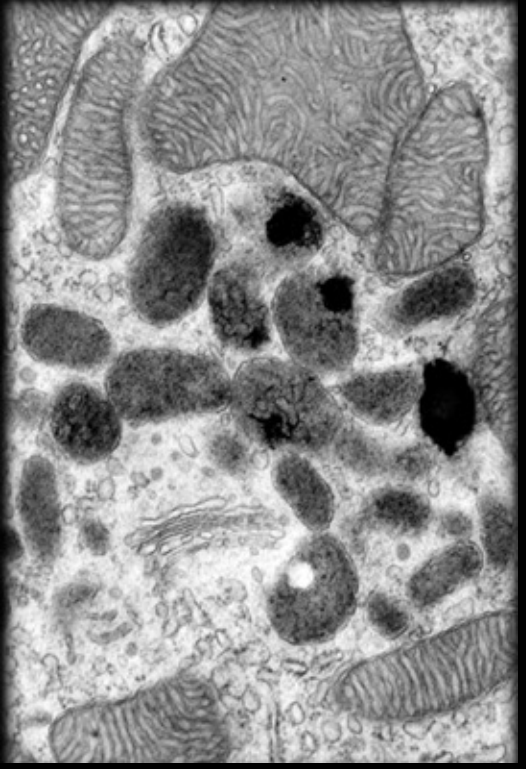
- "Central body;" consists of 2 centrioles
- In cytoplasm, near nucleus
- Centrioles are cylindrical, composed of microtubules
- Centrioles produce spindle fibers during cell division, which distribute chromosomes to forming daughter cells

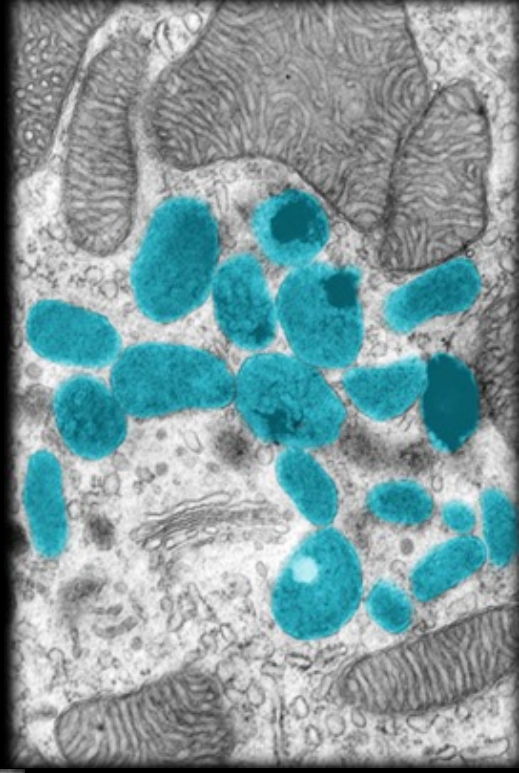


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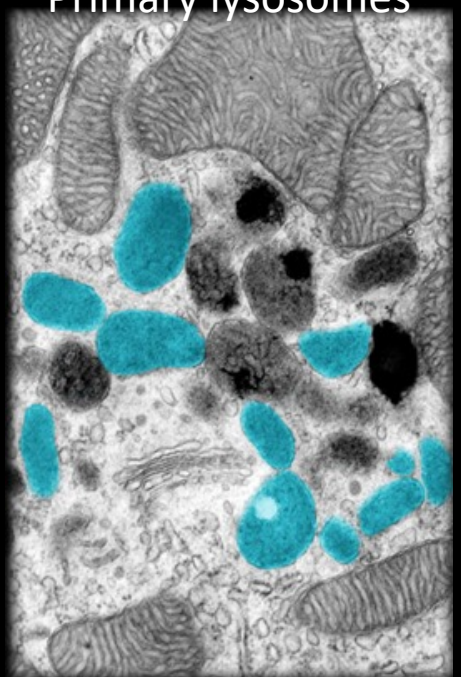


Lysosomes

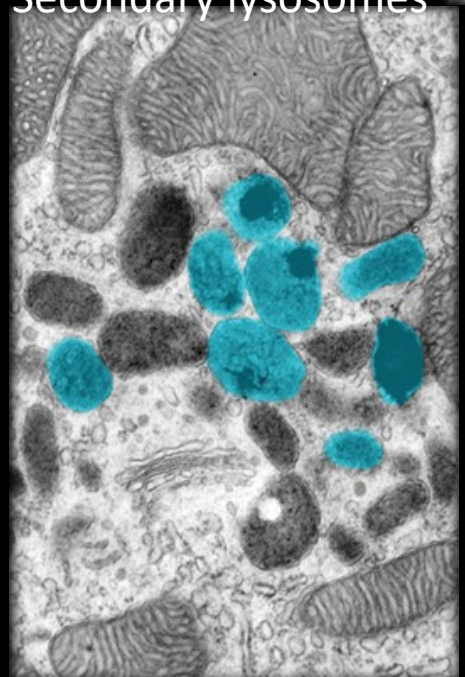




Primary lysosomes



Secondary lysosomes

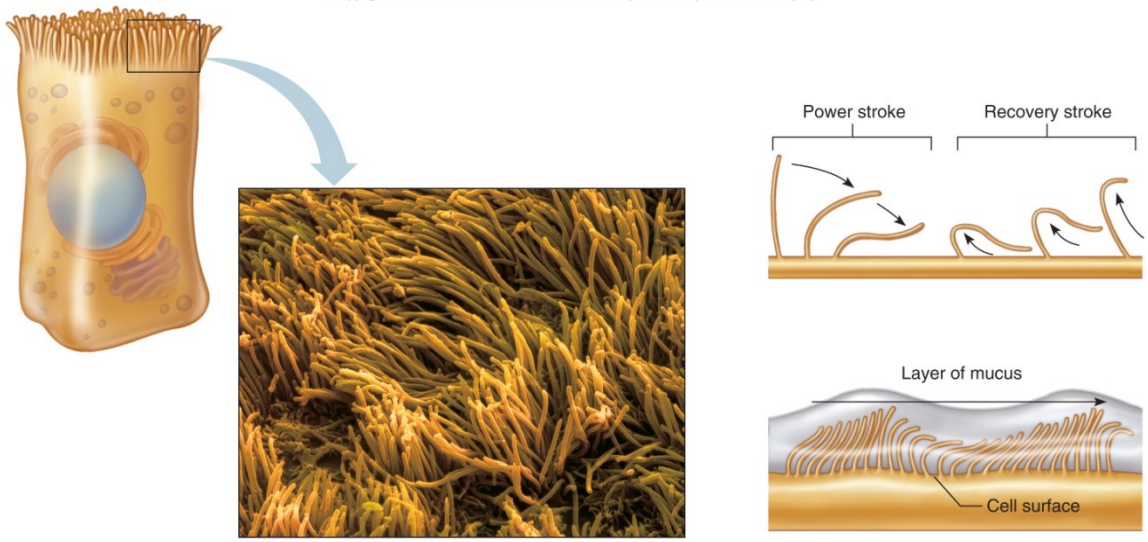


Other Cellular Structures

Cilia :

- Motile extensions of cell membrane
- Consist of microtubules in cylindrical pattern
- Form a “fringe” on surface of certain epithelial cells
- Shorten than flagella, but very abundant when present
- Beat back and forth in coordinated manner
- Propel mucus in respiratory tract, propel egg toward uterus

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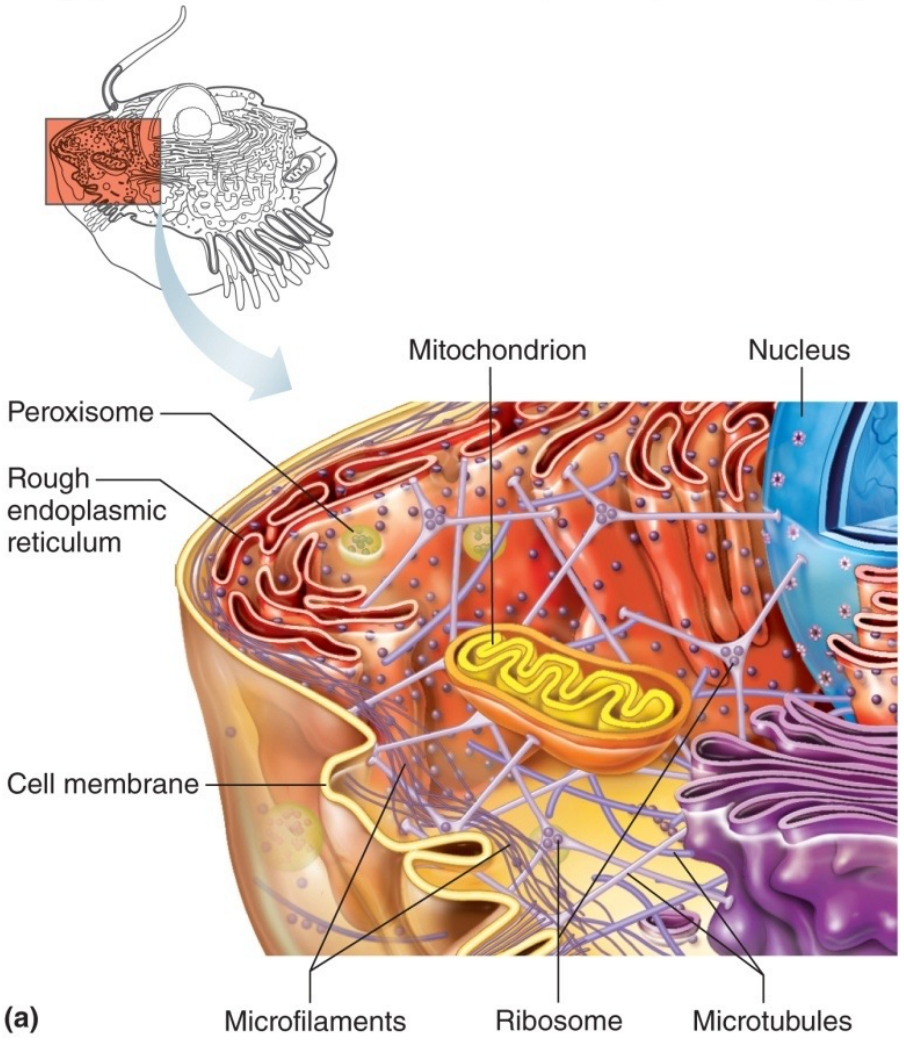


Other Cellular Structures

Microfilaments, Microtubules & Intermediate Filaments:

- Threadlike structures in cytoplasm
- Create the cytoskeleton
- In order of smallest to largest →
  - Microfilaments:
    - tiny rods of *actin;*
    - provide cellular movement,
    - such as muscle contraction
  - Intermediate filaments:
    - composed of several proteins
    - a cytoskeletal structure
    - support nuclear envelope
  - Microtubules:
    - larger tubes of *tubulin*
    - rigidity maintains cell shape
    - make up cilia, flagella, and centrioles
    - help move organelles

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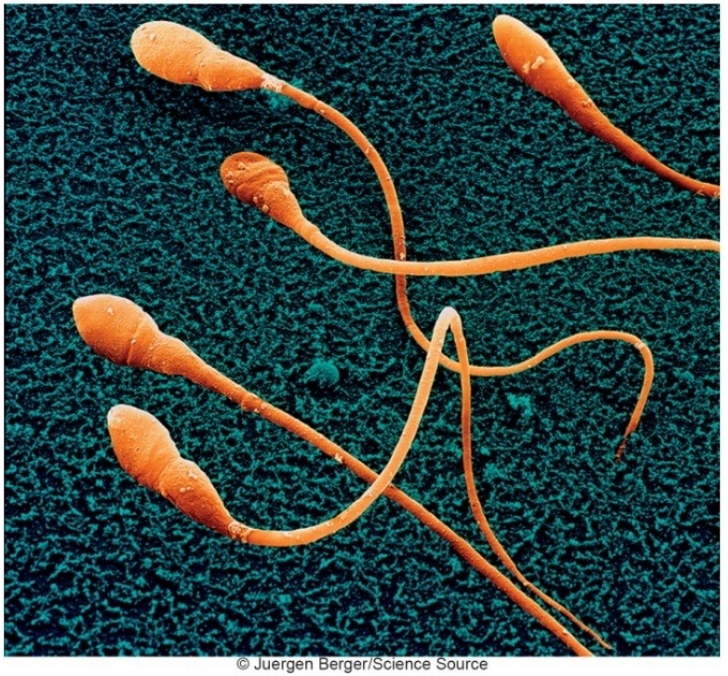


Other Cellular Structures

Flagella:

- Another type of motile extension from cell membrane
- Similar in structure to cilia, but much longer
- Flagellum causes the entire cell to move
- Tail of a sperm cell is the only flagellum in a human cell
- Each cell has only 1 flagellum

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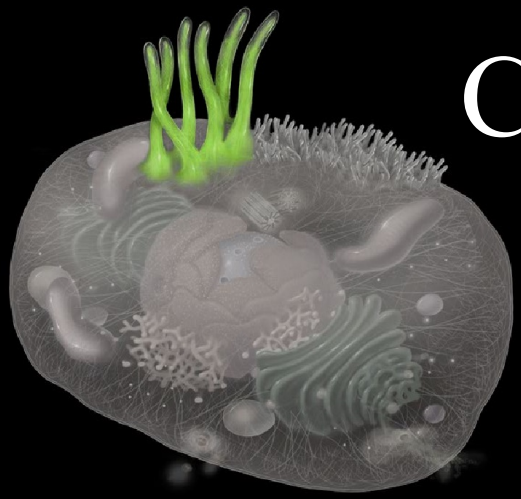


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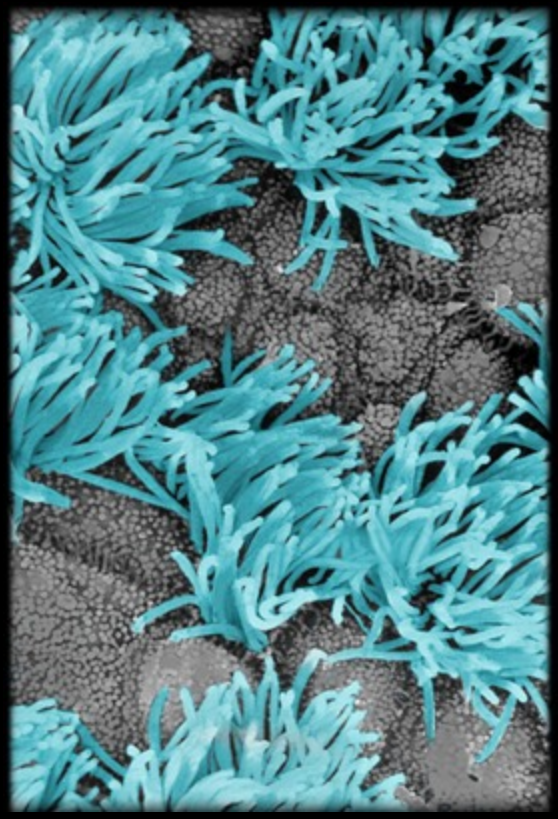
Microvilli:

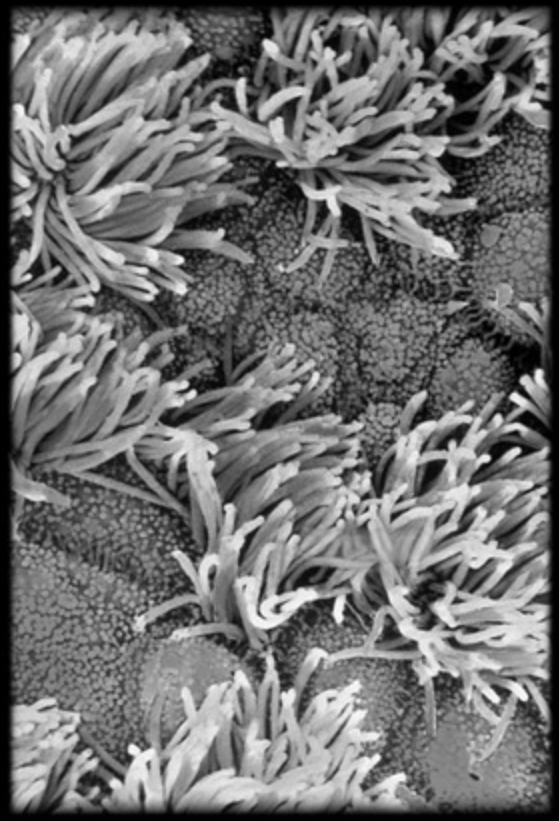
- Smallest of the extensions
- Function to increase surface area for absorption.

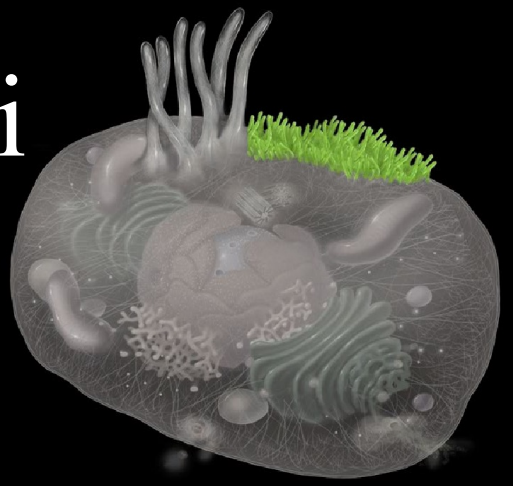
Cilia and Microvilli



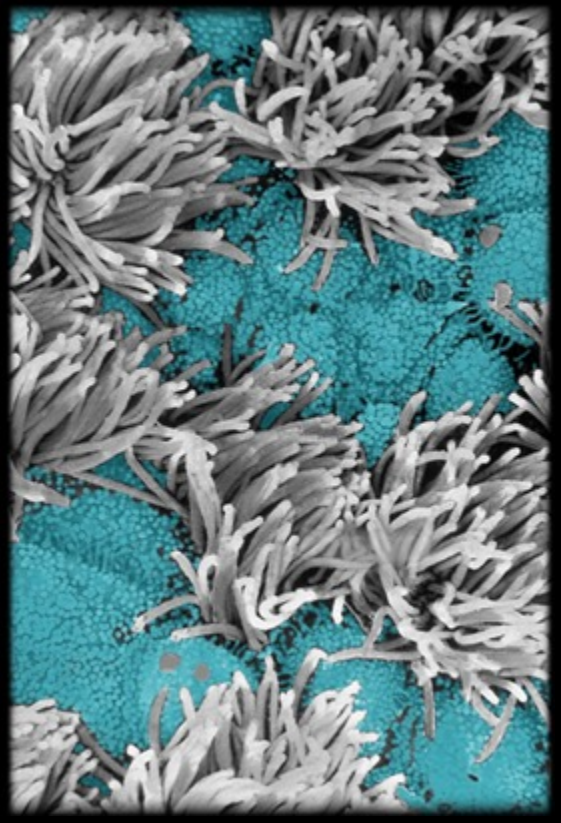
Cilia



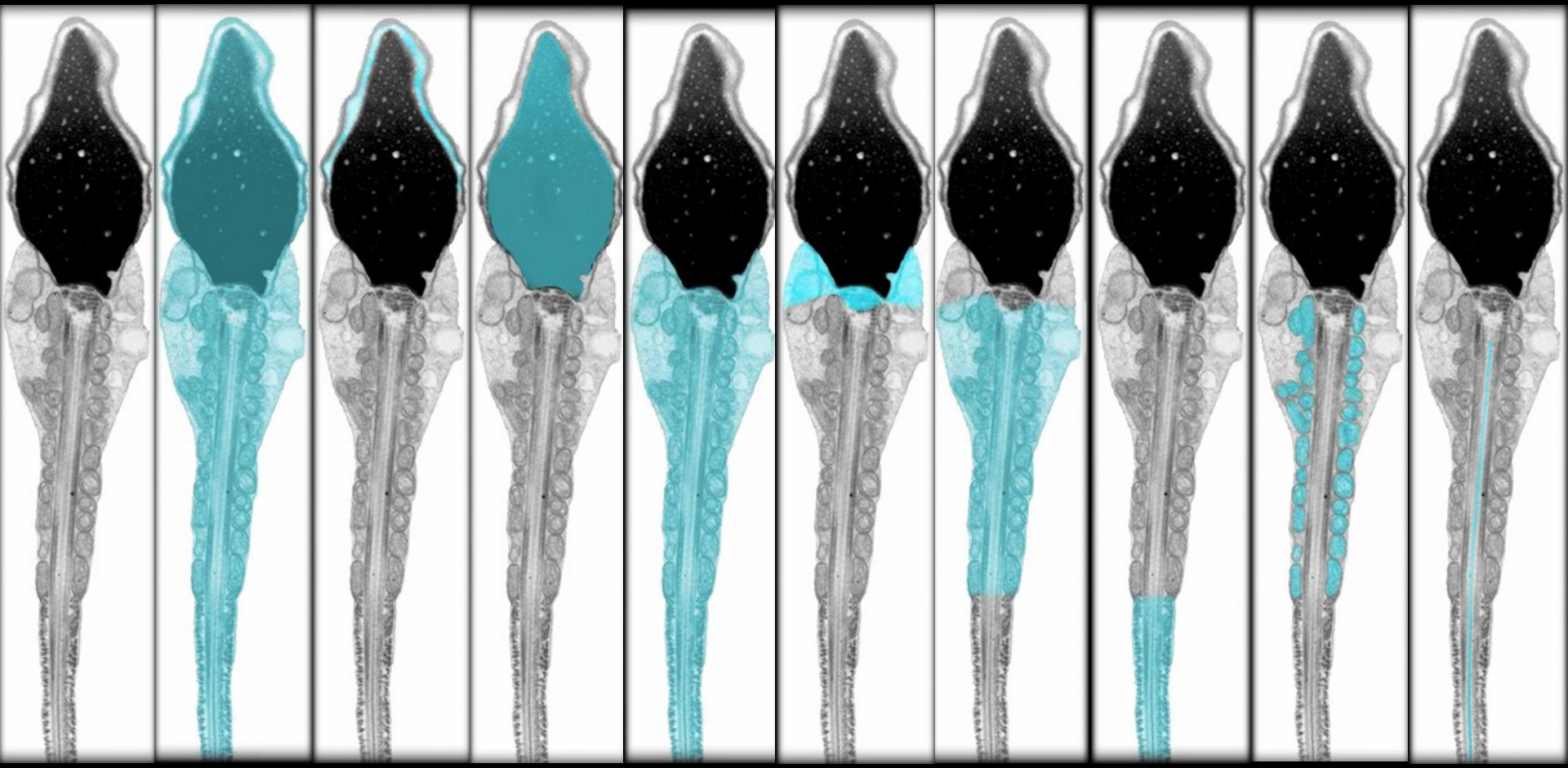




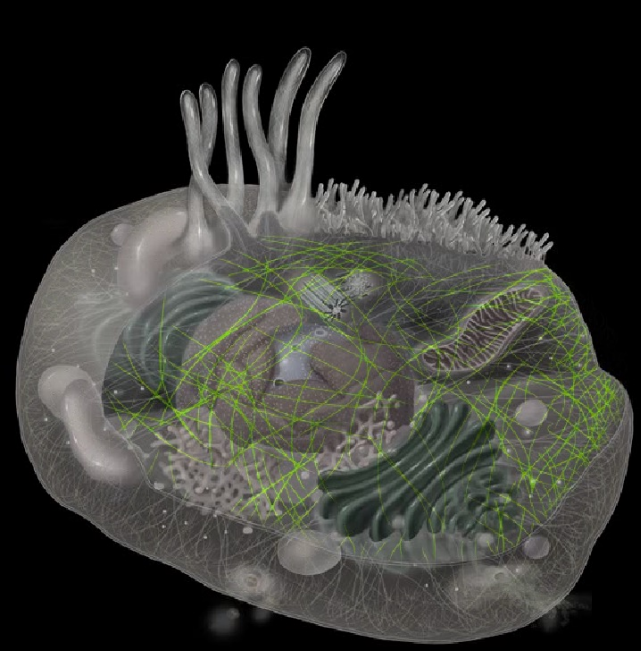
Microvilli



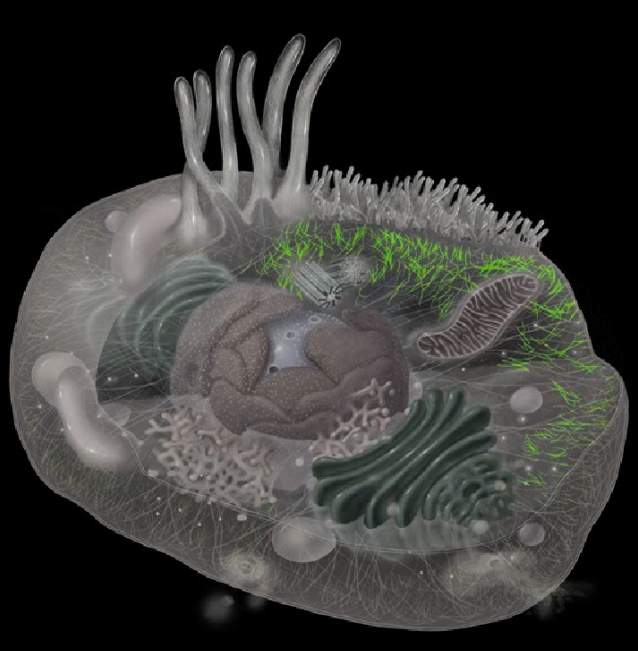
Sperm - Flagellum



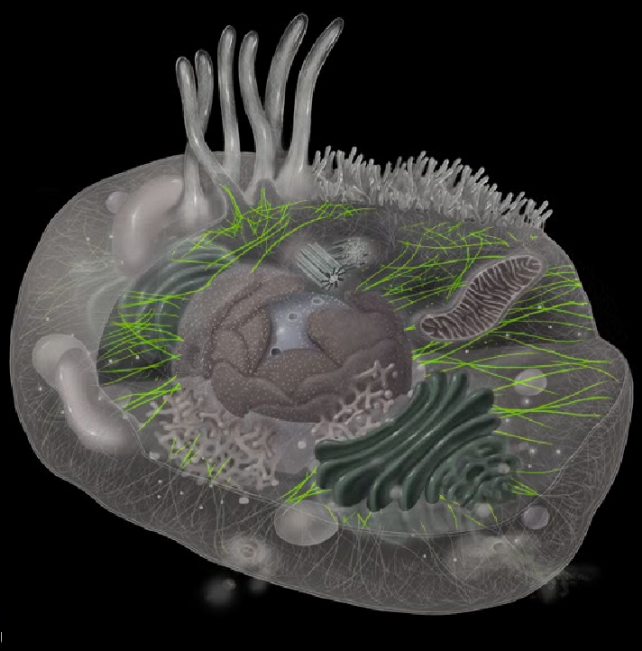
Cytoskeleton



Microfilaments

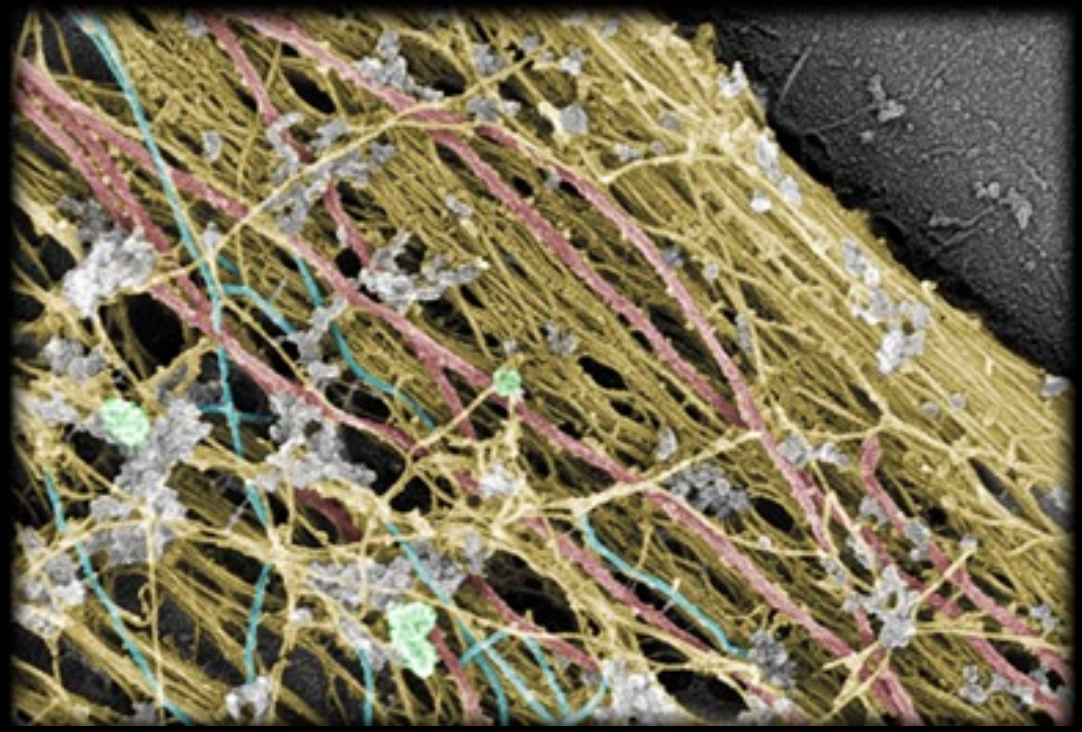


Intermediate Filaments

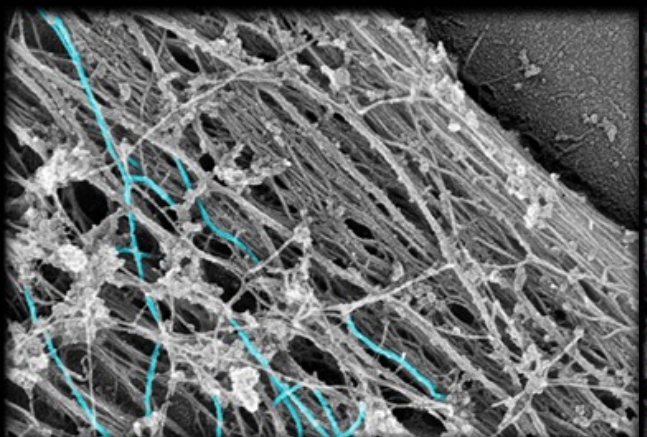


Microtubules

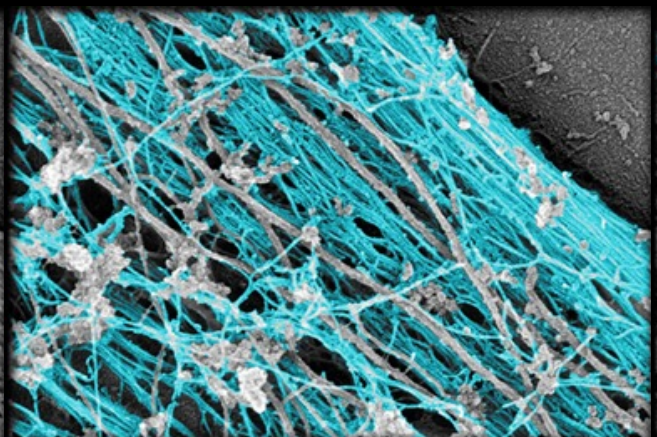
Cytoskeleton



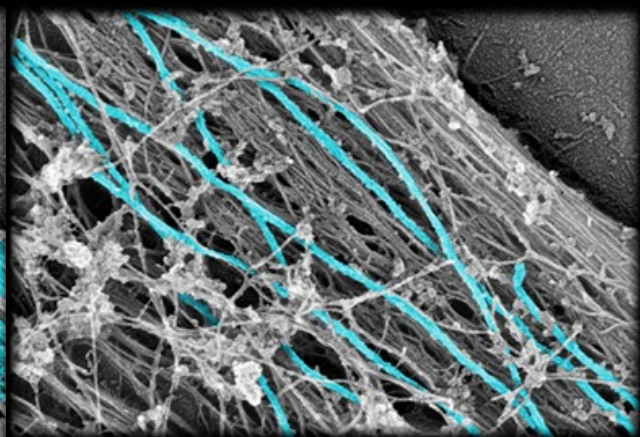
Intermediate filaments



Microfilaments



Microtubules



Cell Nucleus

Contains genetic material and controls cell activities

Nuclear envelope:

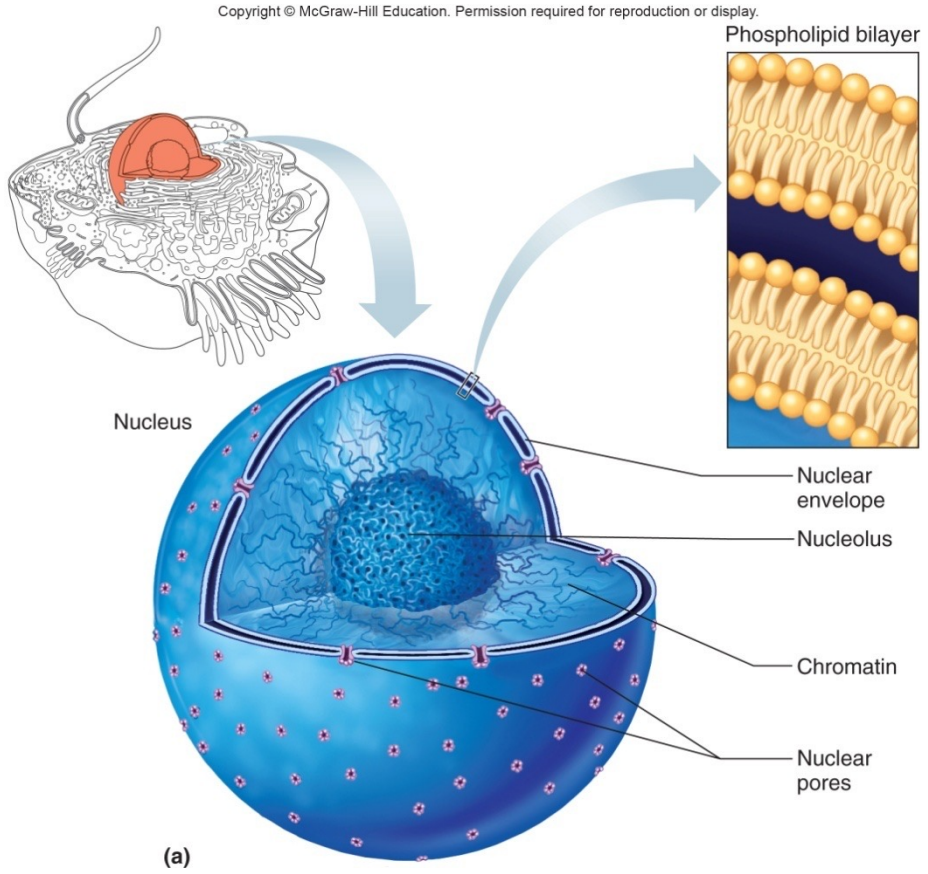
- Porous double-layered membrane
- Separates nucleoplasm from cytoplasm
- Nuclear pores allow passage of certain substances

Nucleolus:

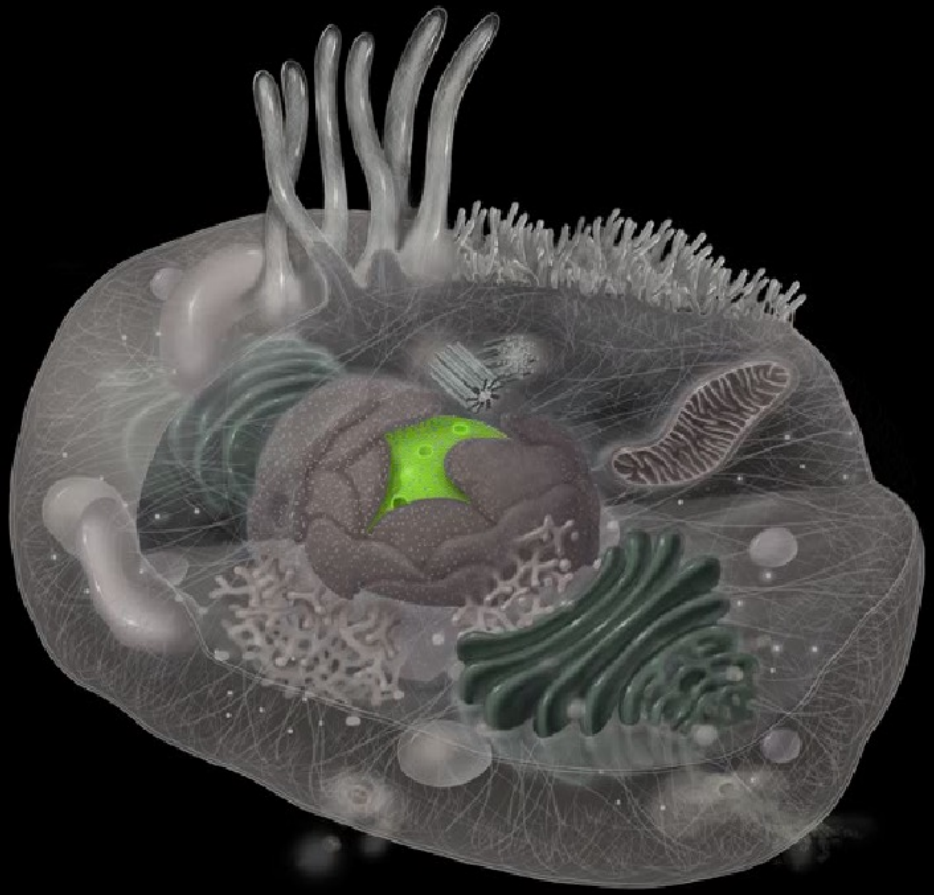
- Dense body of RNA and protein
- Site of ribosome production

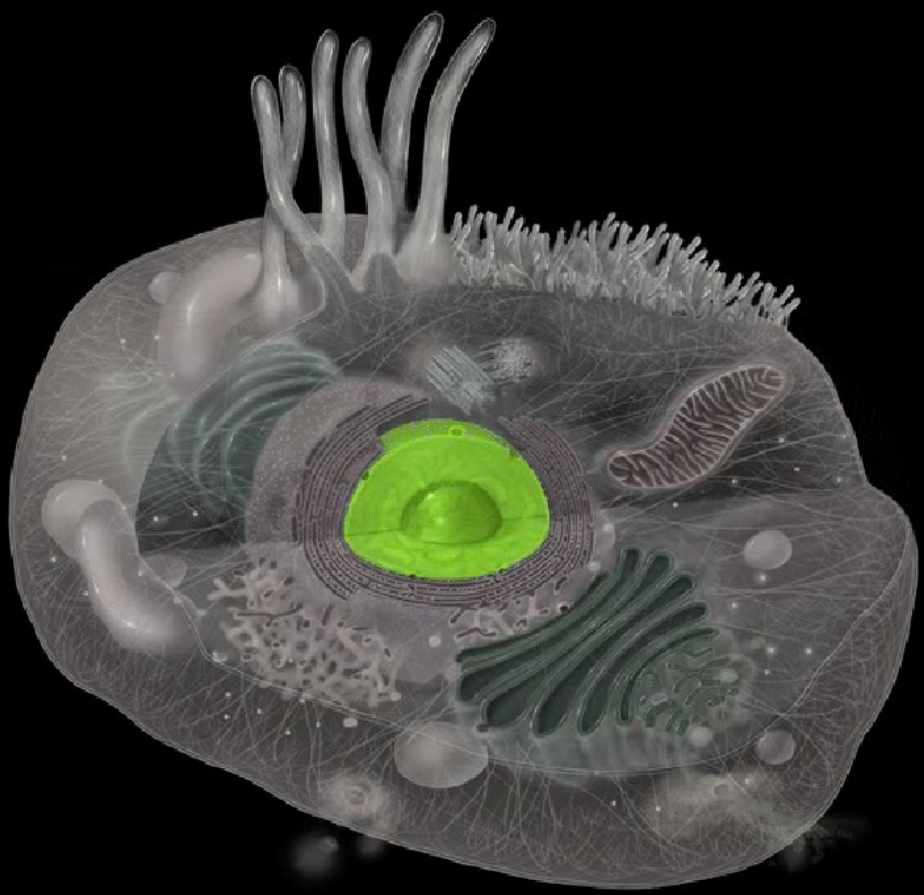
Chromatin:

- Consists of cell's chromosomes, each containing DNA wound around proteins
- Stores information for protein synthesis



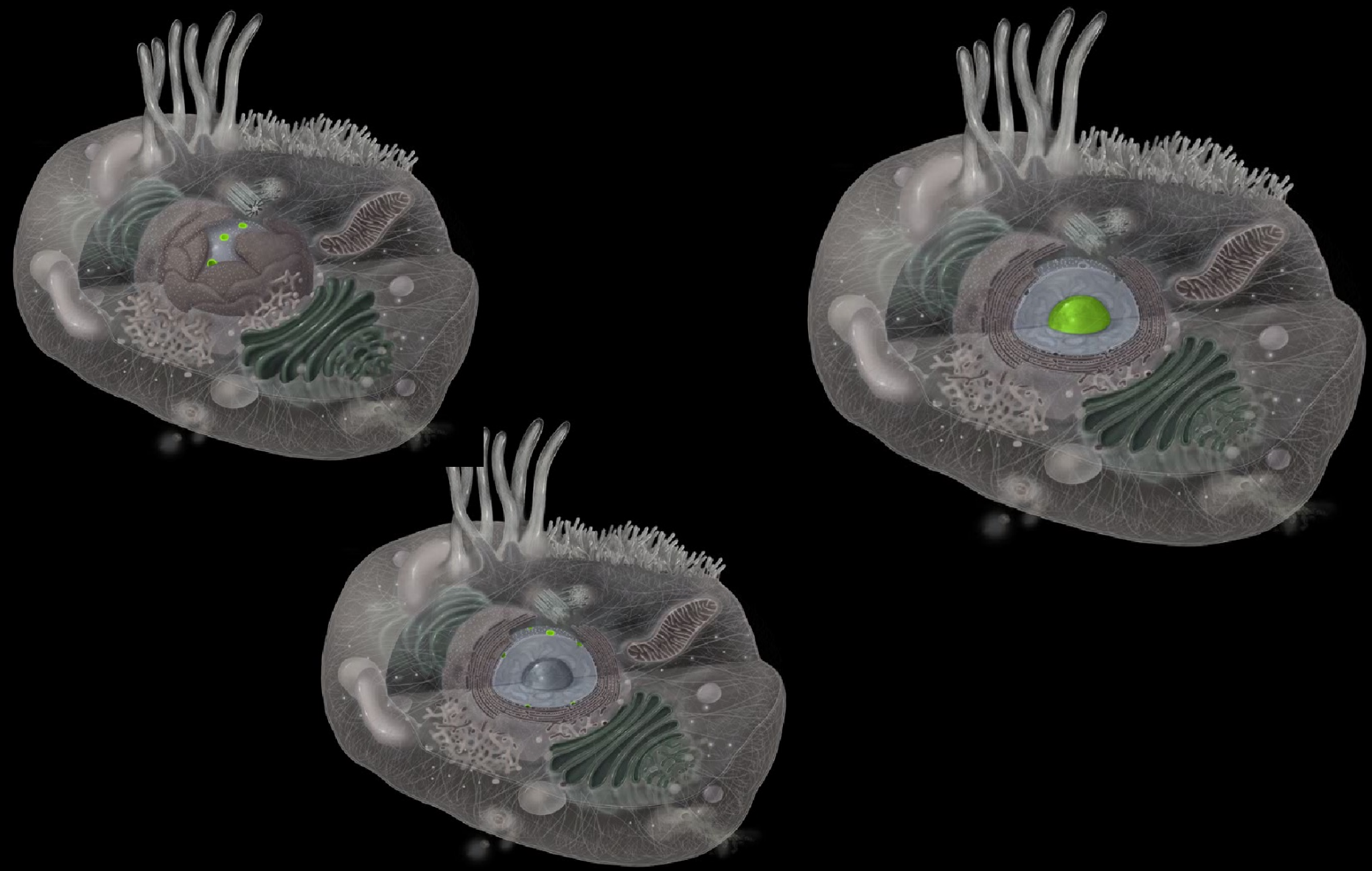
Nucleus and Nuclear Envelope





Nuclear Pores

Nucleolus



3.3: Movements Into and Out of the Cell

Physical (Passive) Processes: Do not require ATP

- Diffusion
- Osmosis
- Facilitated diffusion
- Filtration

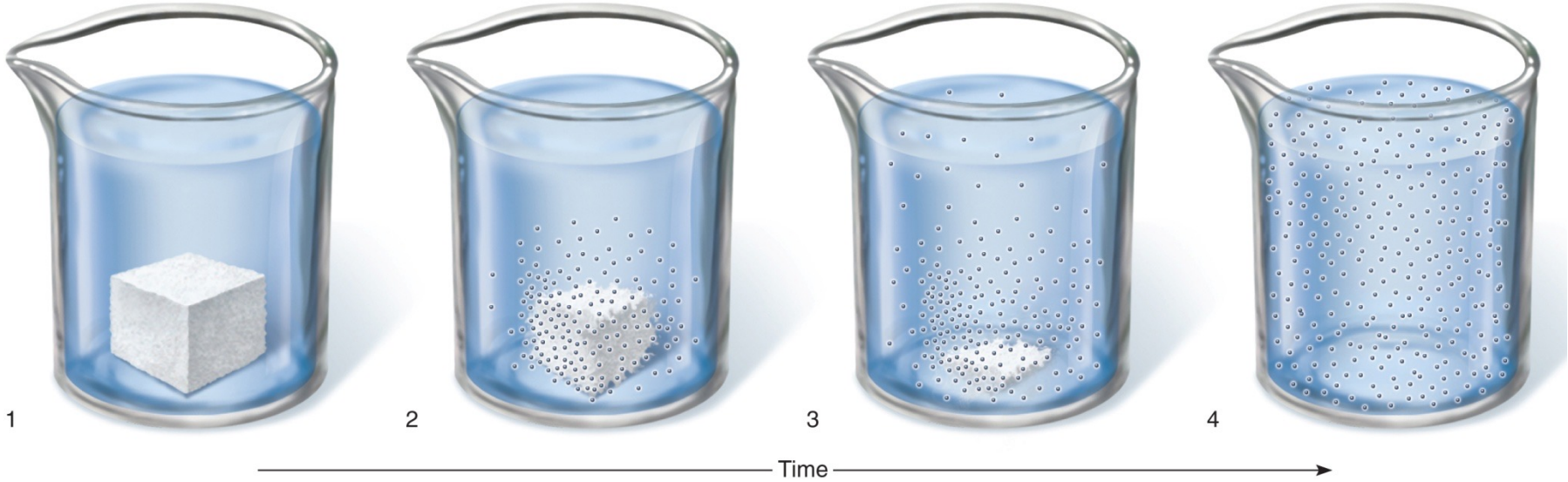
Physiological (Active) Processes: Require ATP

- Active transport
- Endocytosis
- Exocytosis
- Transcytosis

Diffusion

- Movement of atoms, molecules, or ions, from region of higher concentration to region of lower concentration
- Occurs due to constant motion of atoms, molecules, ions
- Only substances that the cell membrane is permeable to: oxygen, carbon dioxide, and other lipid-soluble substances

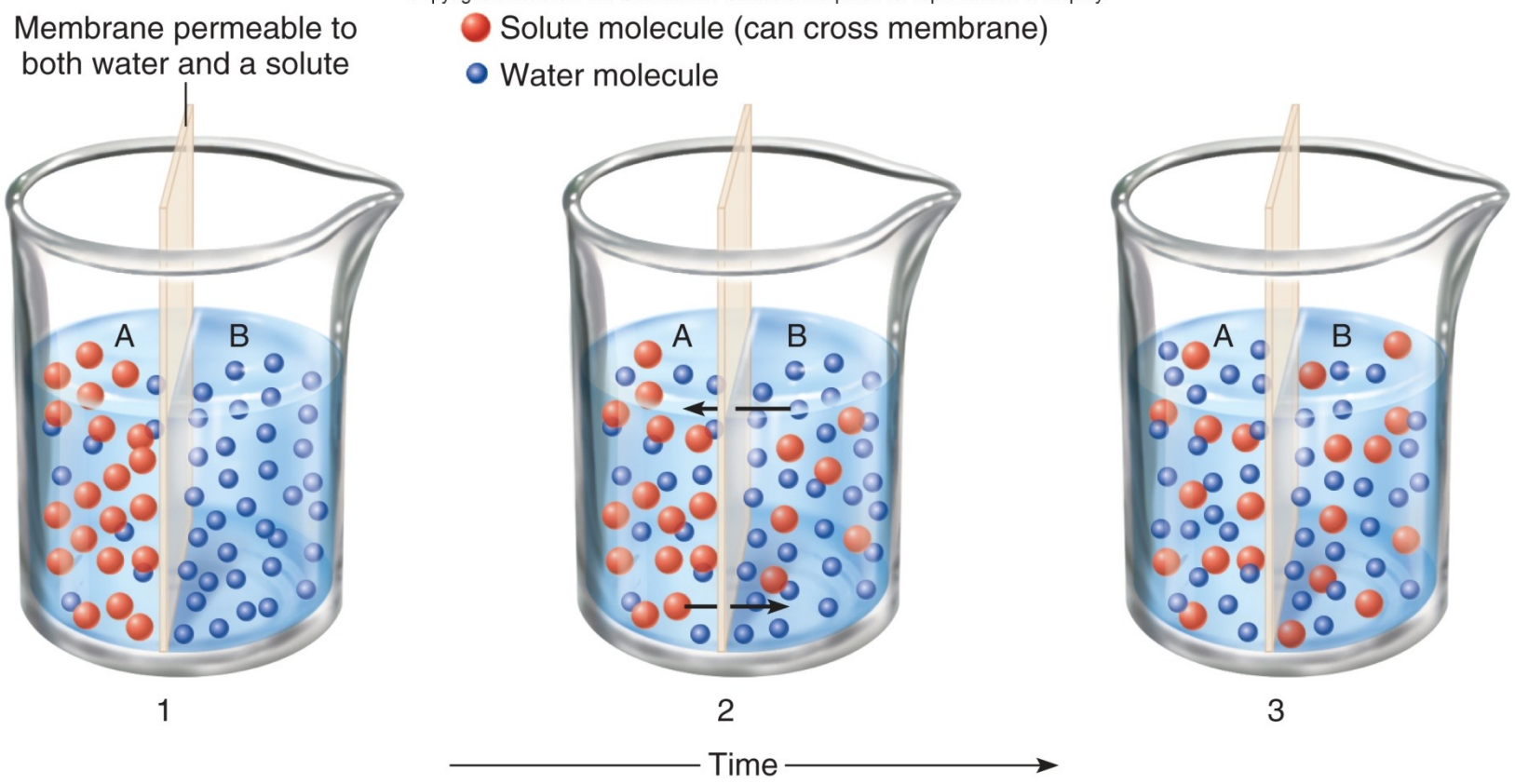
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A dissolving sugar cube is an example of diffusion.

Diffusion

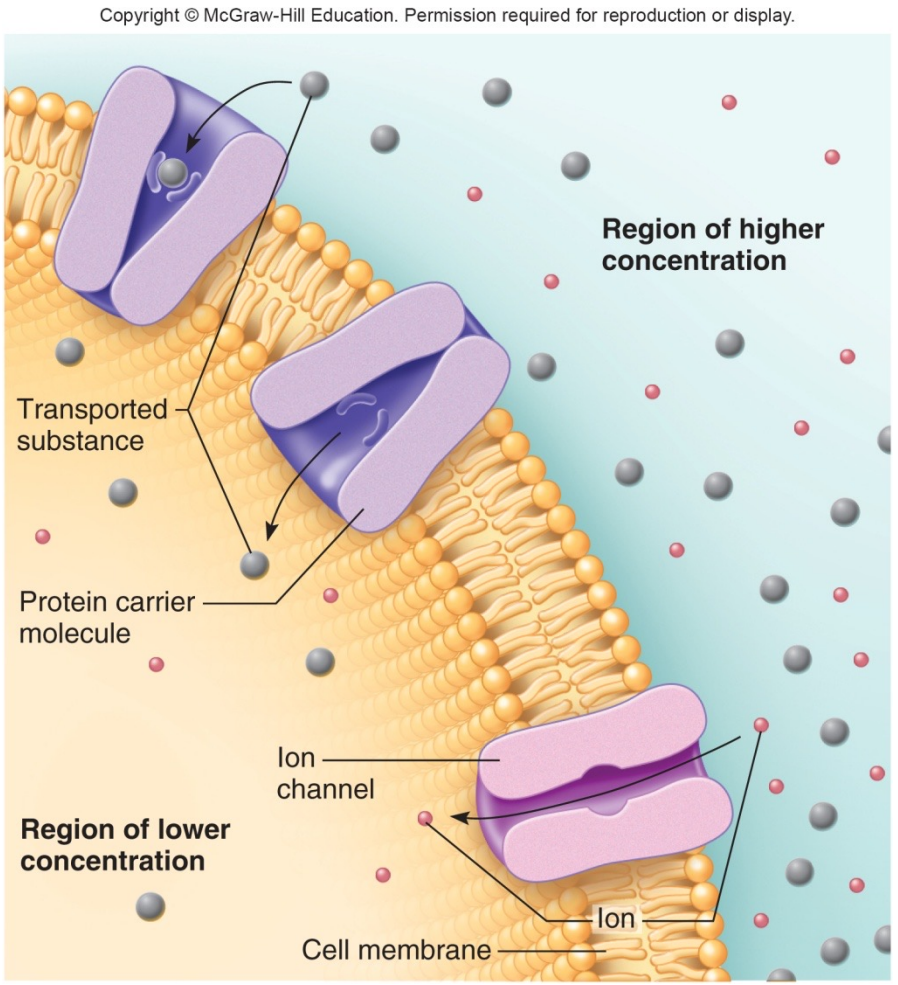
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- Membrane is permeable to both water and the solute
- Equilibrium is reached when the concentrations of water and the solute are equal in both compartments.

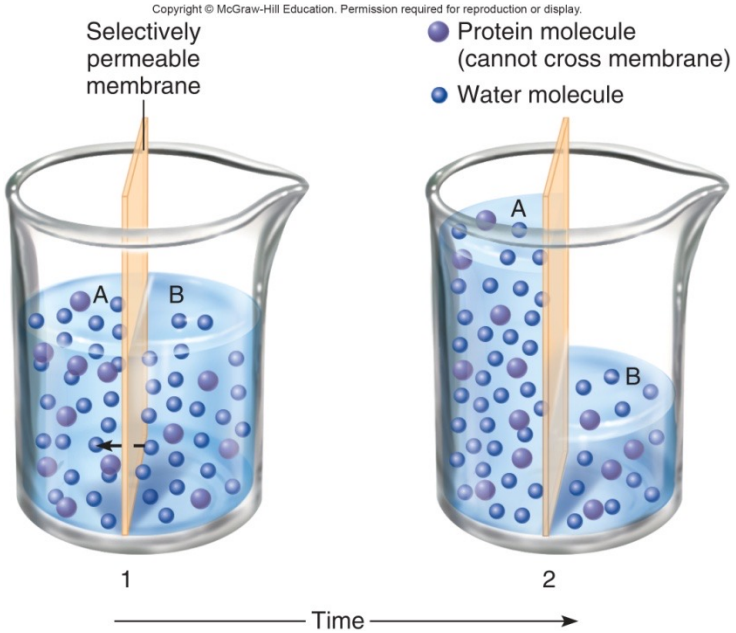
Facilitated Diffusion

- Diffusion across the cell membrane through ion channels or transporters
- Water-soluble substances (Na^+, K^+, Cl^-, glucose, amino acids)
- Passive process; no ATP required



Osmosis

- **Osmosis:** movement of water across a selectively permeable membrane from region of higher water concentration to region of lower water concentration
- Water moves into region containing higher impermeant solute concentration
- Passive process; no ATP required

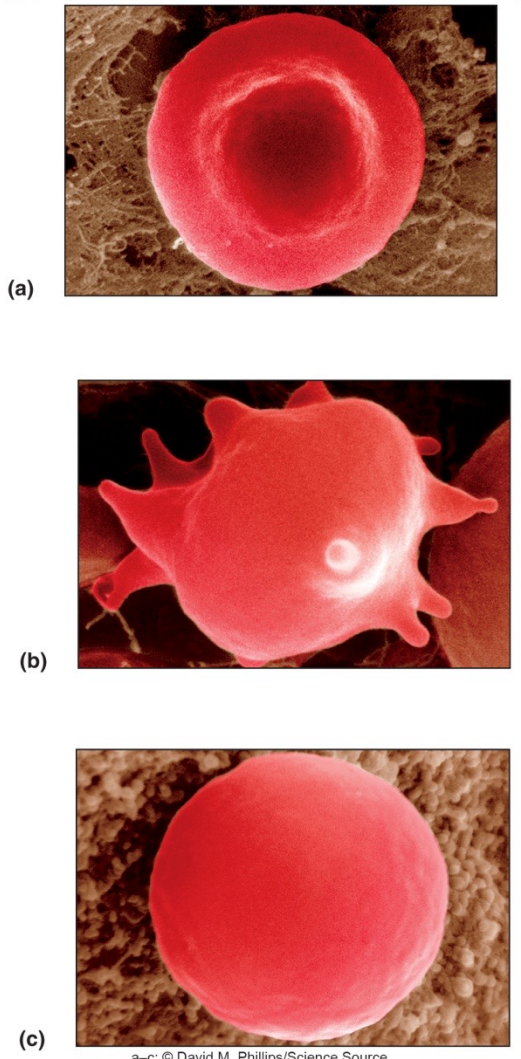


Osmotic Pressure

- **Osmotic Pressure** = ability of osmosis to generate enough pressure to lift a volume of water
- Osmotic pressure increases as the concentration of impermeant solutes increases

- **Isotonic Solution:** same osmotic pressure
  Cells in an isotonic solution have no net gain or loss of water
- **Hypertonic Solution:** higher osmotic pressure
  Cells in a hypertonic solution lose water
- **Hypotonic Solution:** lower osmotic pressure
  Cells in a hypotonic solution gain water

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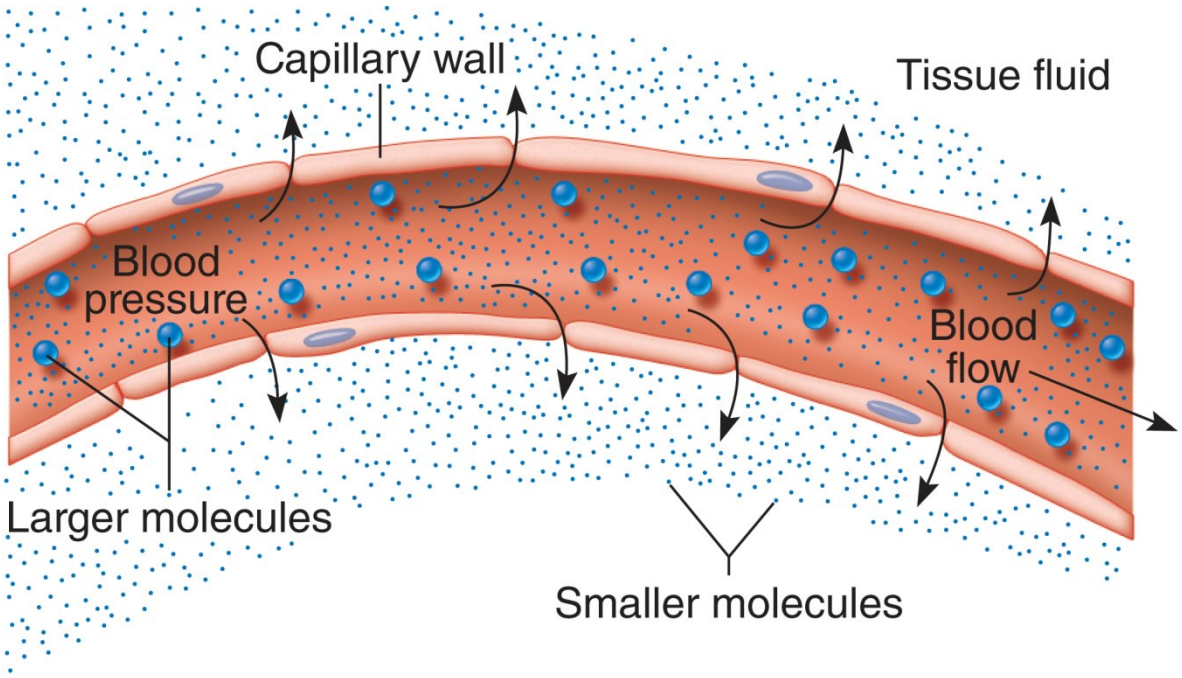


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Filtration

- **Filtration:** Process that forces molecules through membranes by exerting pressure
- Used to separate solids from water, or small particles from large ones
- Example: When blood plasma leaves capillaries, water and small solutes are filtered, but large plasma proteins are not
- Passive process; no ATP required

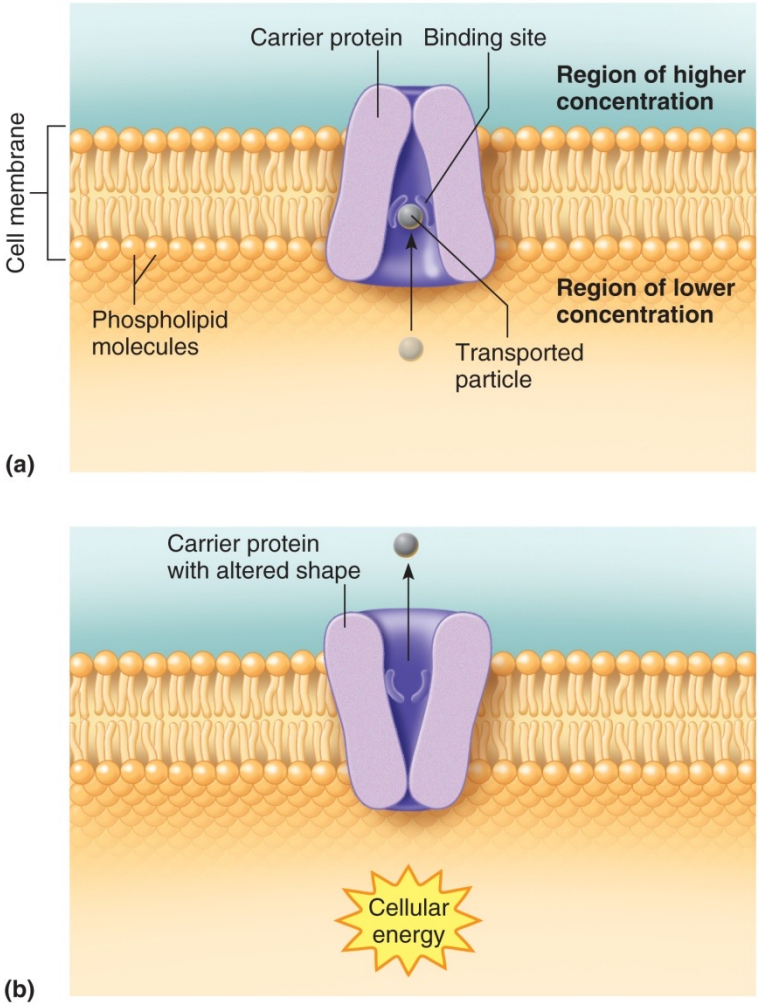
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Active Transport

- **Active Transport:** Movement of substances across a membrane from region of lower concentration to region of higher concentration (against concentration gradient)
- Uses carrier molecules in cell membrane
- Active process; requires ATP energy
- Examples: sugars, amino acids, Ca^{+2}, H^{+}, Na^{+}/K^{+} pump

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Endocytosis

- **Endocytosis:** Movement of a substance into the cell inside a vesicle
- Substances too large to enter by other methods can enter cell this way
- 3 types of endocytosis:

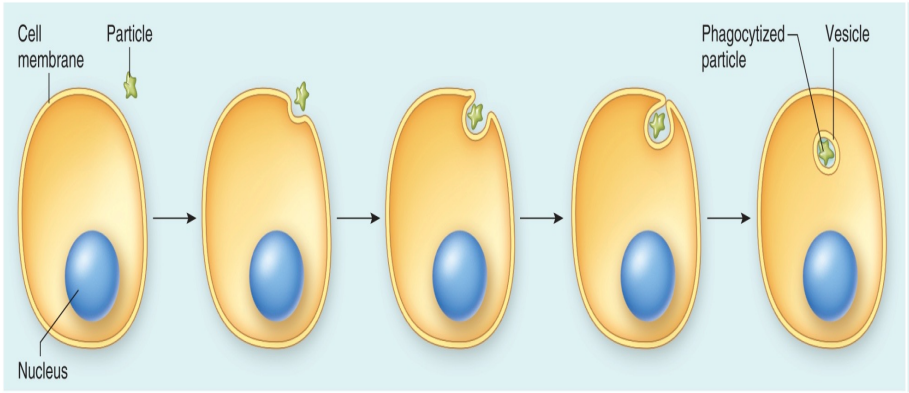
  Pinocytosis: membrane engulfs droplets of liquid

  Phagocytosis: membrane engulfs solid particles

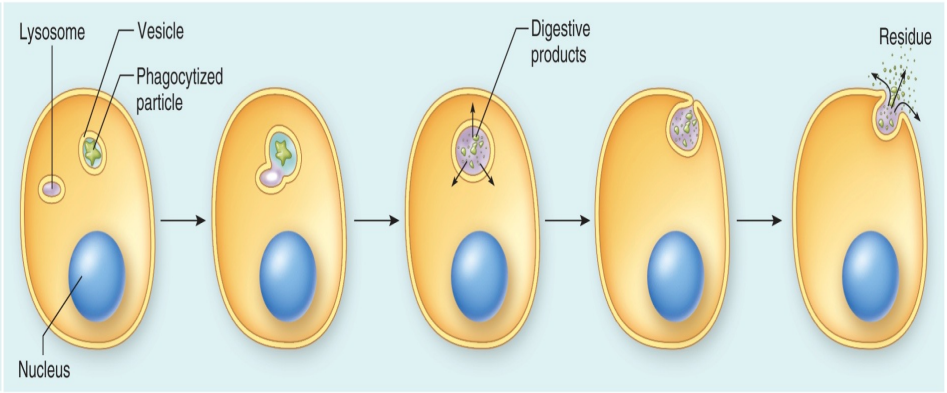
  Receptor-mediated endocytosis: membrane engulfs specific substances, which have bound to receptor proteins on the membrane

Endocytosis

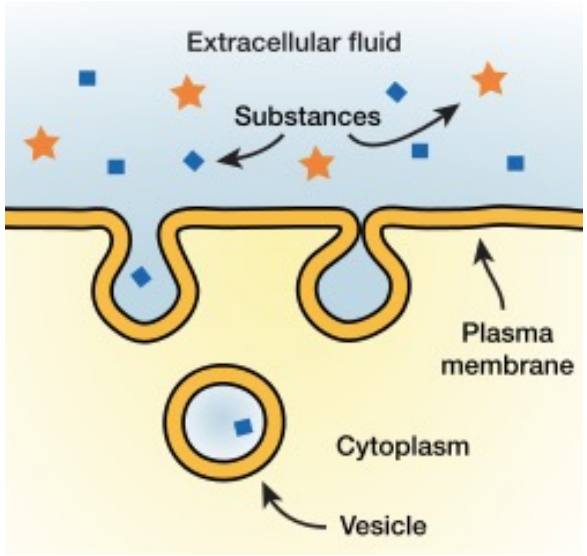
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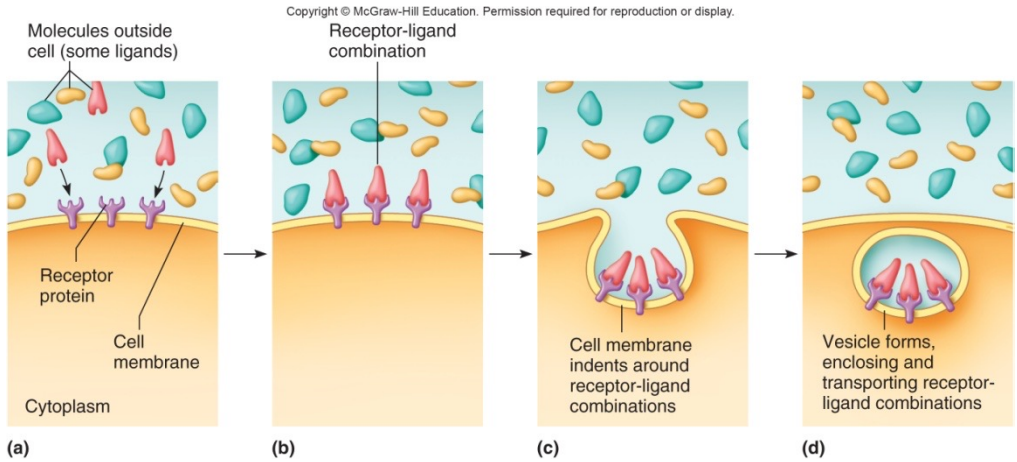


Phagocytosis & Digestion by a lysosome



Pinocytosis

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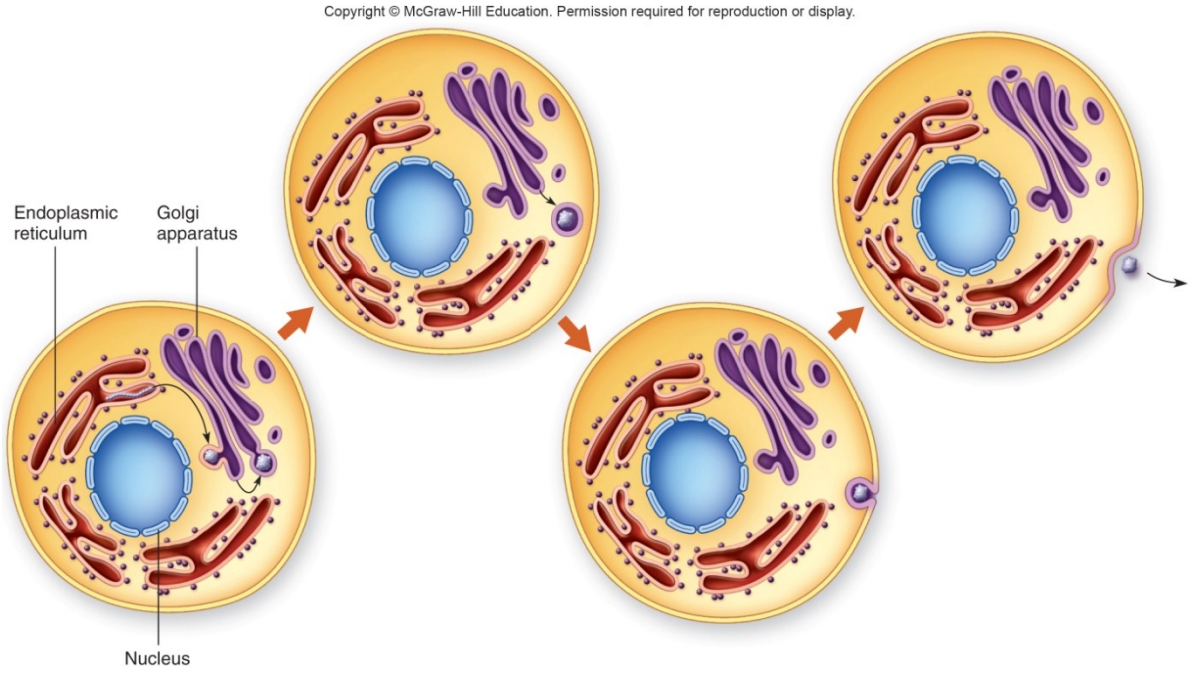


Receptor-mediated endocytosis

Exocytosis

Exocytosis:

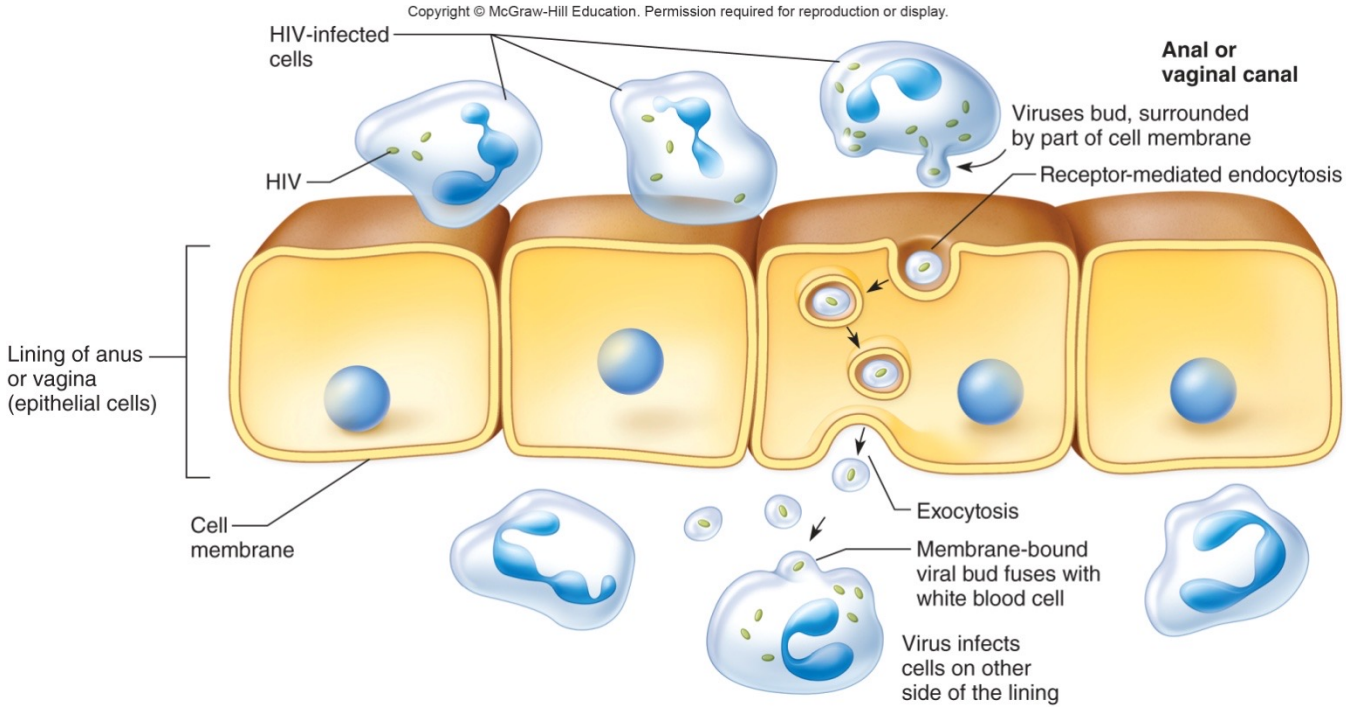
- Release of substances/particles from cell
- Vesicles containing particles fuse with cell membrane and release contents
- Example: Release of neurotransmitters from nerve cells



Transcytosis

Transcytosis:

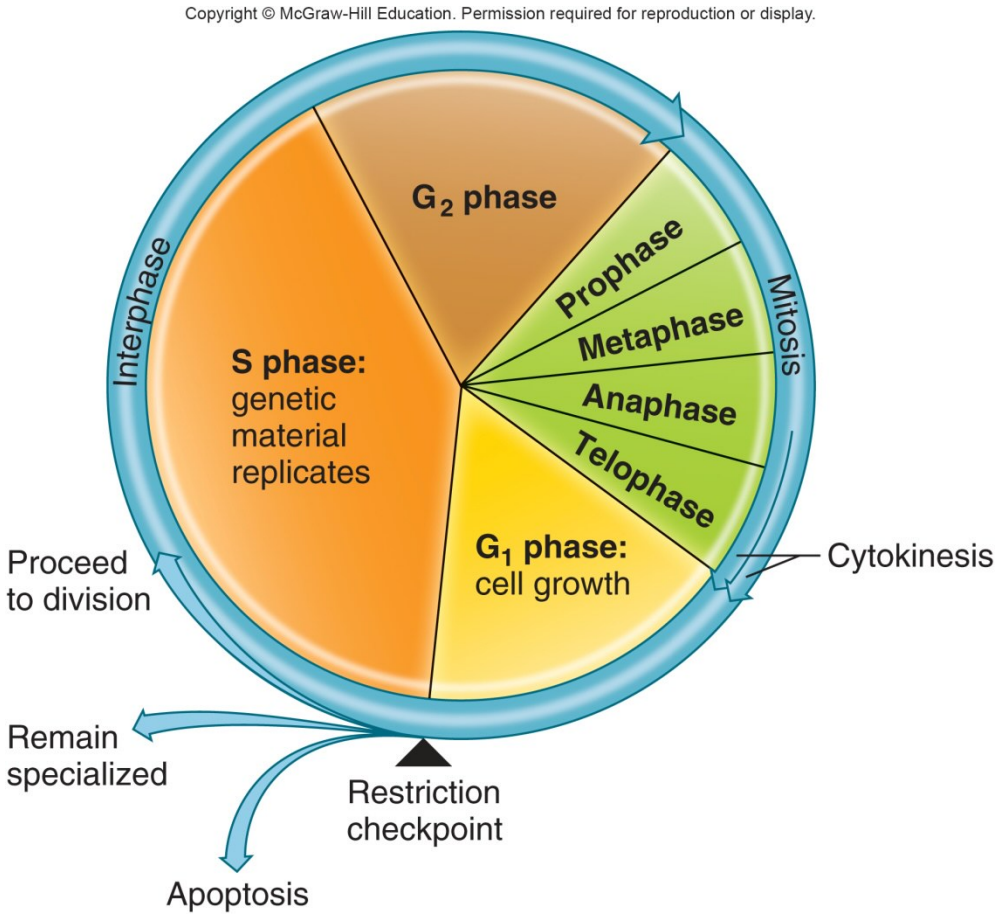
- Involves receptor-mediated endocytosis followed by exocytosis
- Quickly transports substance from one end of cell to the other
- Moves substances across barriers formed by tightly connected cells
- Example: Transport of HIV across lining of anus or vagina



3.4: The Cell Cycle

Cell Cycle:

- Series of changes a cell undergoes from the time it forms until the time it divides
- Stages:
  -Interphase
  -Mitosis
  -Cytokinesis



Interphase

Interphase:

- A very active period in cell cycle
- Cell grows
- Cell maintains normal functions
- Cell replicates genetic material (DNA) to prepare for mitosis (nuclear division)
- Cell synthesizes organelles, membranes, and biochemicals to prepare for cytokinesis (division of cytoplasm)
- Phases:

  S (synthesis) phase: DNA is replicated

  G_1 and G_2 (growth or gap) phases: structures other than DNA are replicated and cell grows

Mitotic Cell Division

- Produces two daughter cells from an original somatic cell
- **Mitosis:** Division of the nucleus
- **Cytokinesis:** Division of the cytoplasm

- Phases of mitosis:
  - Prophase: chromatin condenses to form chromosomes, nuclear envelope and nucleolus disperse
  - Metaphase: chromosomes attach to spindle fibers, and align midway between centrioles
  - Anaphase: chromosomes separate and move in opposite directions, toward centrioles
  - Telophase: chromosomes return to chromatin structure, nuclear envelope forms, nucleoli become visible

Major Events in Mitosis

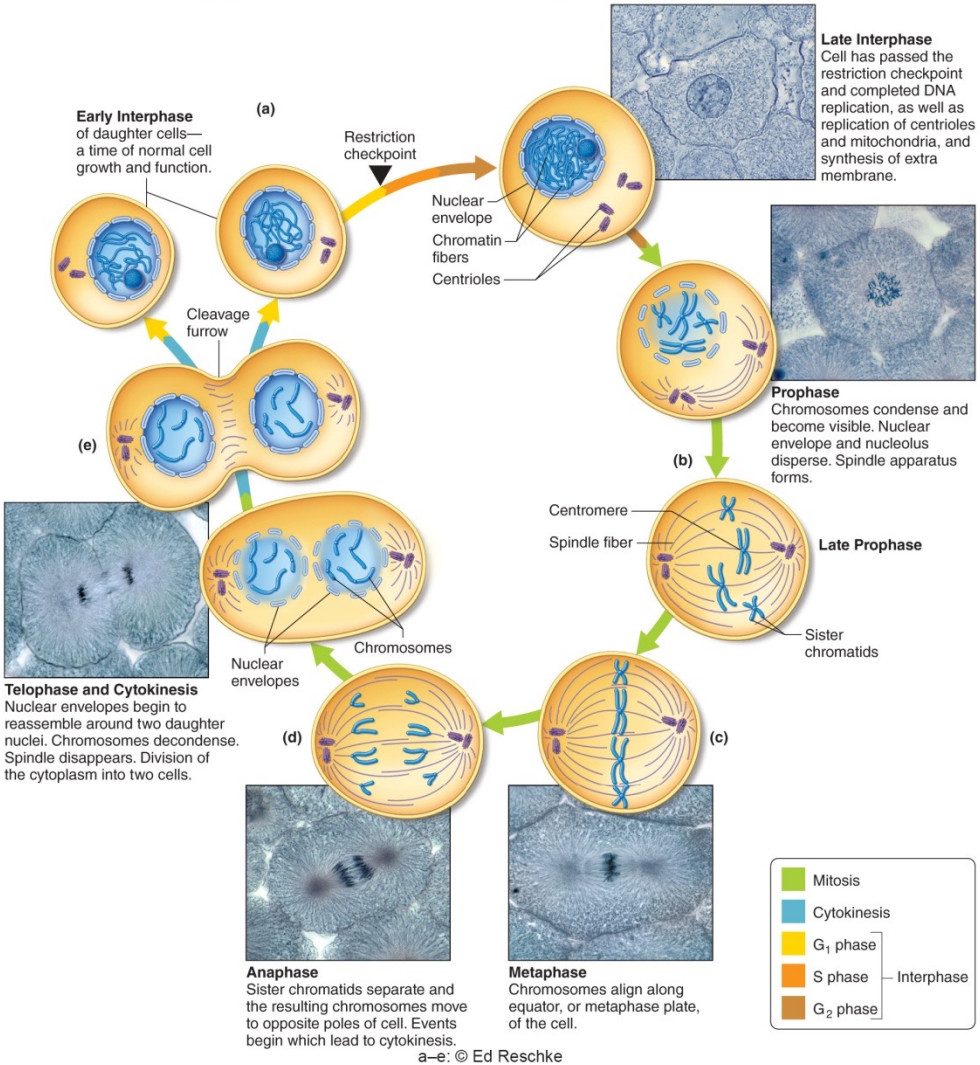
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TABLE 3.4 Major Events in Mitosis

Stage	Major Events
Prophase	Chromatin condenses into chromosomes; centrioles move to opposite sides of cytoplasm; nuclear membrane and nucleolus disperse; microtubules assemble and associate with centrioles and the two sister chromatids making up each chromosome.
Metaphase	Spindle fibers from the centrioles attach to the centromeres of the sister chromatids of each chromosome; chromosomes align midway between the centrioles.
Anaphase	Centromeres separate, and sister chromatids move apart, with each chromatid now an individual chromosome; spindle fibers shorten and pull these new individual chromosomes toward the centrioles.
Telophase	Chromosomes elongate and form chromatin threads; nuclear membranes form around each chromosome set; nucleoli form; microtubules break down.

Mitosis

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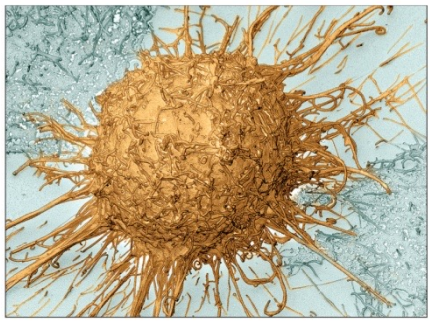


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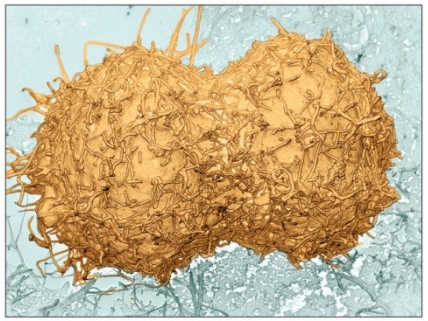
Cytoplasmic Division

- **Cytokinesis** = cytoplasmic division
- Begins during anaphase
- Continues through telophase
- Contractile ring of actin filaments pinches cytoplasm in half
- Newly formed cells will have identical DNA, may have slightly different size and number of organelles

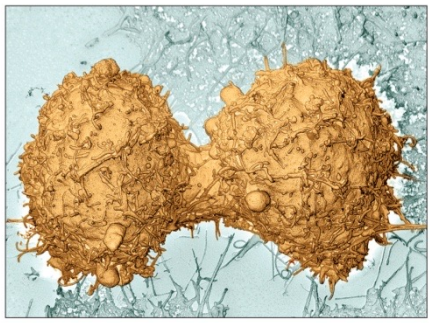
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(a)



(b)



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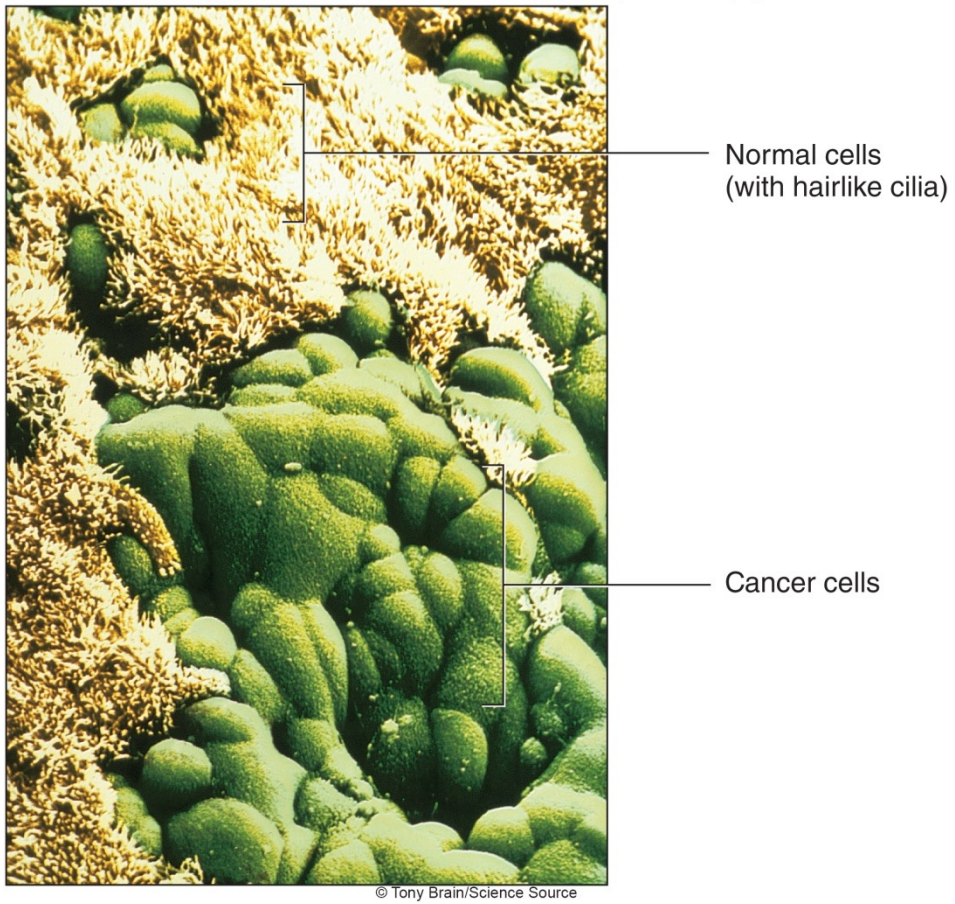
3.5: Control of Cell Division

- Frequency of cell division is strictly regulated, and varies by cell type:
  - Skin cells, intestinal cells, and blood-forming cells divide often & continually
  - Neurons divide a specific number of times, then cease
- Chromosome tips (telomeres) that shorten with each mitosis provide a mitotic clock
- Fluctuating levels of certain proteins in cell control cell cycle
- Cells divide to provide a more favorable surface area to volume relationship
- Hormones and growth factors are external controls for cell division
- Contact inhibition: Healthy cells stop dividing when they become crowded
- Tumors can result from a loss of control over frequency of mitosis

Tumors

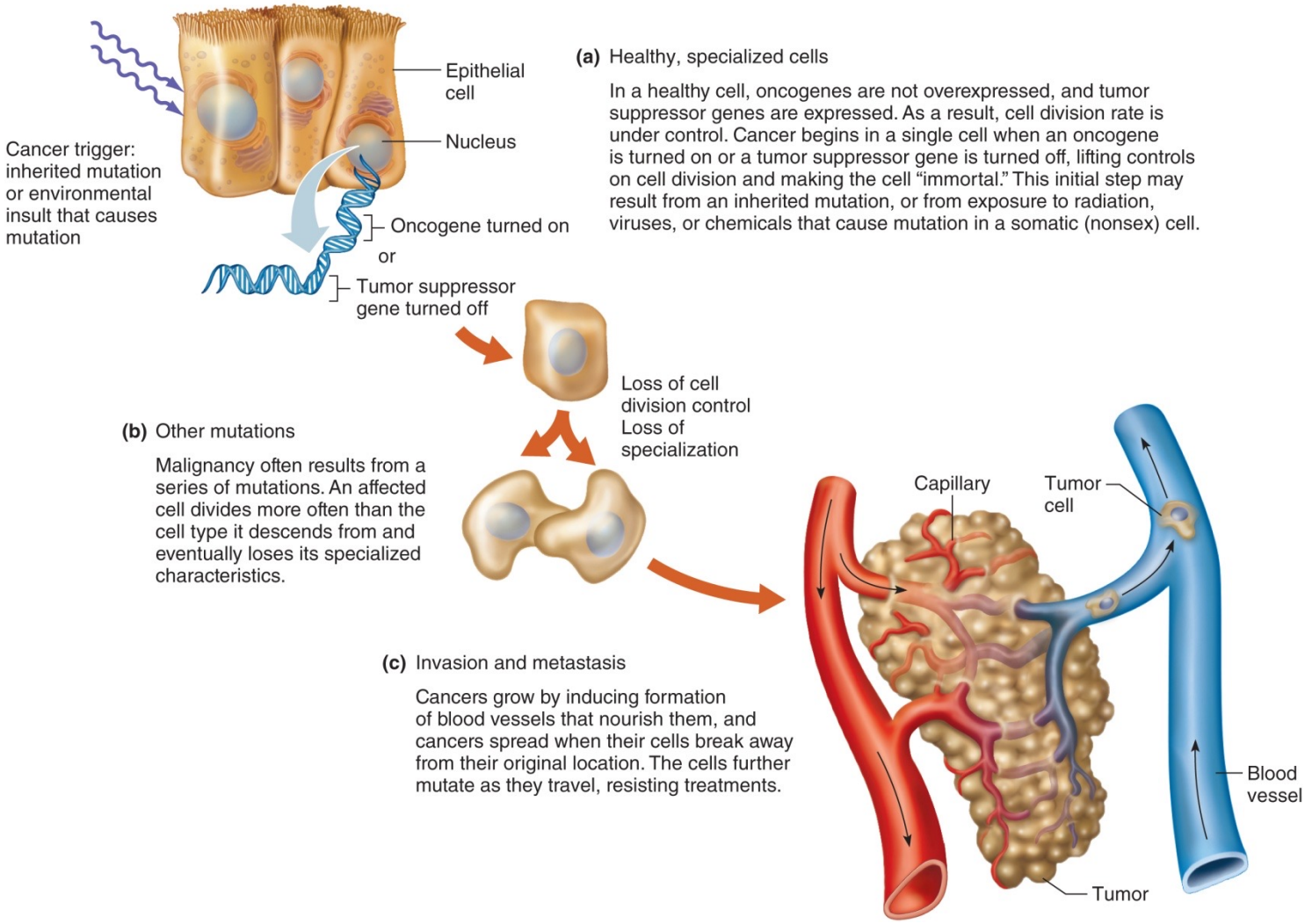
- 2 types of tumors:
  Benign: Remains in local area
  Malignant: invasive, cancerous, can spread or metastasize
- 2 major types of genes cause cancer:
  Oncogenes: abnormal forms of genes that control cell cycle, but are overexpressed
  Tumor Suppressor Genes: Normally limit mitosis, but if inactivated/removed, cannot regulate mitosis
- Cancer cells called “immortal,” since they do not stop dividing after 40-60 divisions

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Steps in Development of Cancer

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3.6: Stem and Progenitor Cells

Differentiation: process of specialization of cells

Stem cell:

- Can divide to form two new stem cells (called self-renewal)
- Can also divide to form a stem cell and a progenitor cell
- Can differentiate as any of many cell types

Progenitor cell:

- Partially specialized stem cell, daughter of stem cell
- Can divide to become any of a restricted number of cells; called a "committed" cell

Totipotent: Daughter cells that can specialize to become any cell type

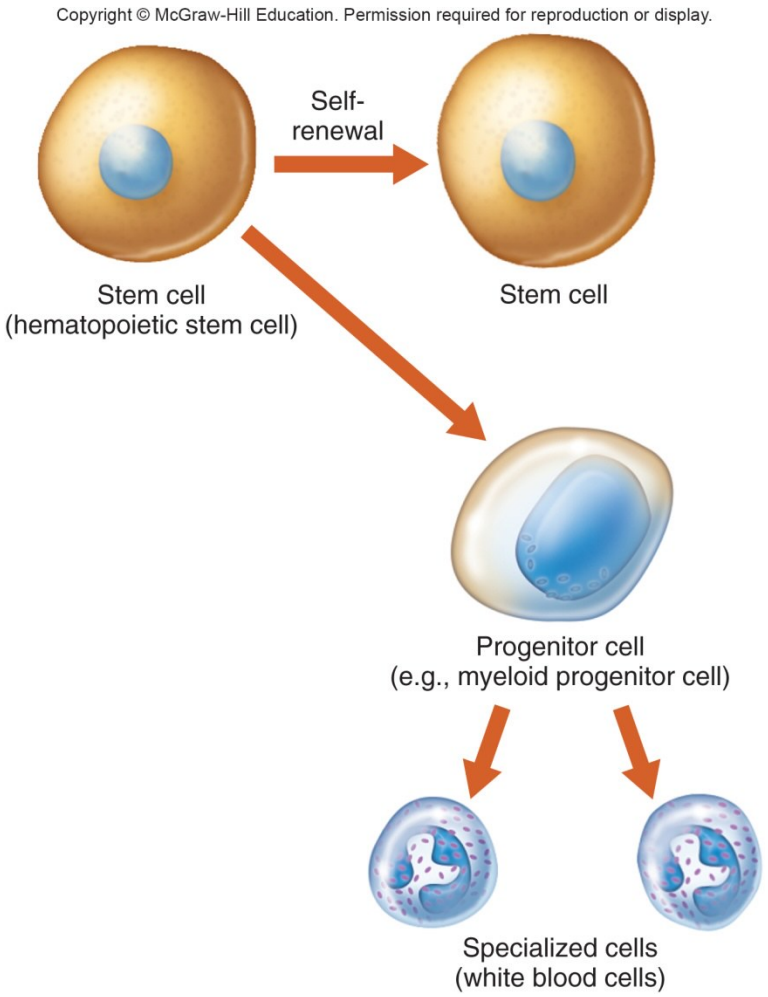
Examples: Fertilized egg, cells of early embryo

Pluripotent: Daughter cells that can become a limited number of cell types

Examples: Stem cells of later development, progenitor cells

Stem and Progenitor Cells

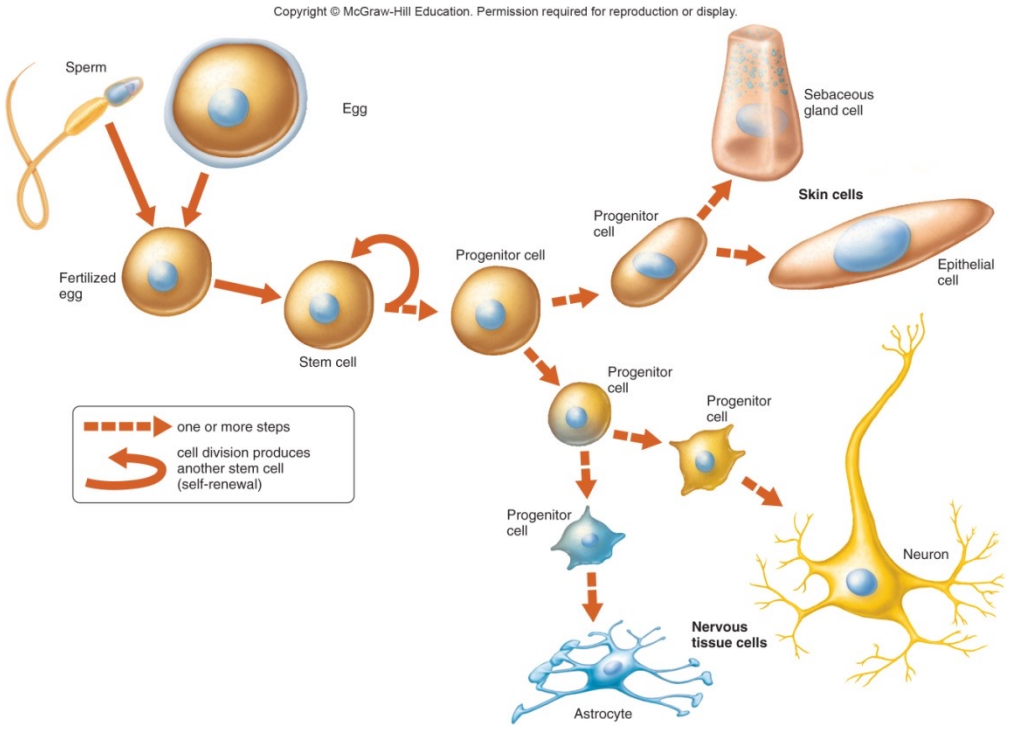
Example of stem and progenitor cells in the formation of blood cells in the red bone marrow:



Differentiation of Cells

Differentiation: The maturation and specialization of cells

A fertilized egg has the ability to produce any type of human cell, while partially differentiated cells can only produce some types or a single type of cell.



From Science to Technology

Stem Cells to Study and Treat Diseases

- Stem and progenitor cells are required for growth and healing
- Regenerative Medicine:
  Field of study, that uses body's ability to generate new cells to treat diseases and injuries; includes stem cell technology

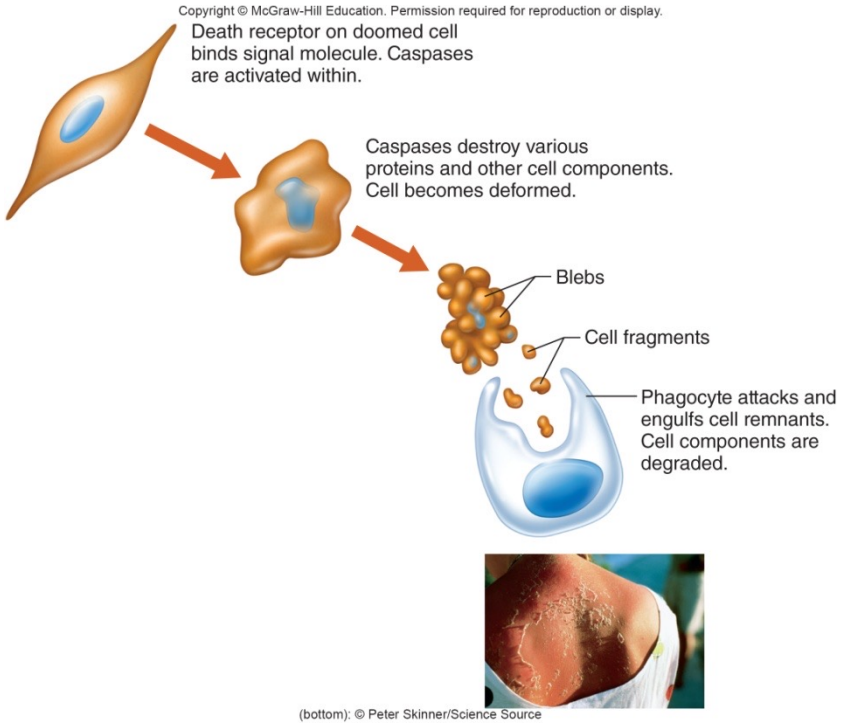
Sources of stem cells for research, treating disease/injuries:

- Donor stem cells, such as umbilical cord cells
- Stem cells from patient: either from natural site, such as bone marrow, or reprogrammed differentiated cells grown in cell culture

3.7: Cell Death

Apoptosis:

- Programmed cell death
- Normal part of development
- A continuous, stepwise process
- Removes webbing between fetal fingers and toes
- Protective, peels away damaged skin cells after sunburn

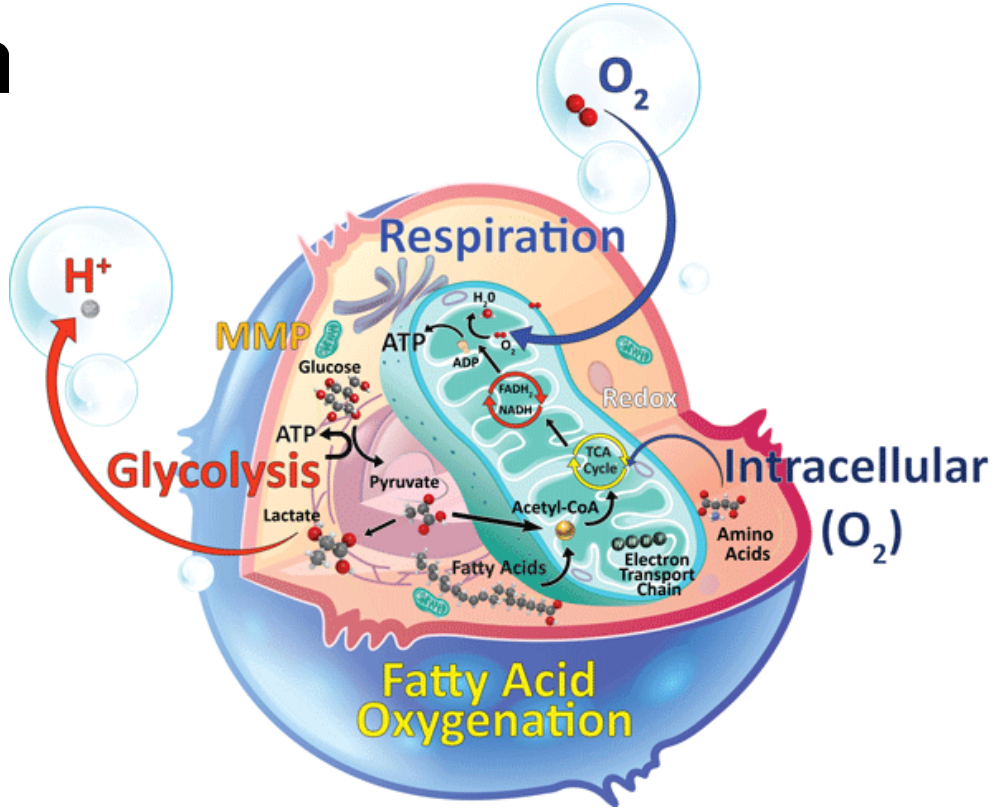


Necrosis:

- Cell death from damage
- Not a normal process

Ch 4:
Cellular Metabolism

Miriah Smith, MS, MAT

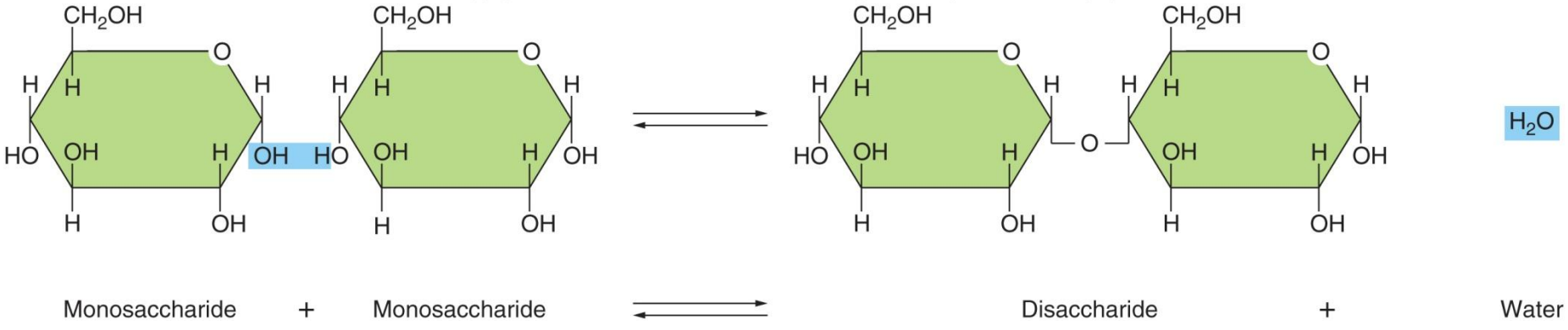


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4.1: Metabolic Processes

- Metabolism = sum all chemical reactions in the body
- **Cellular Metabolism** = sum of all chemical reactions occurring in a cell
- Metabolic reactions usually occur in pathways or cycles
- 2 types of metabolic reactions:
  - **Anabolism:** small molecules are built into larger ones; requires energy
  - **Catabolism:** larger molecules are broken down into smaller ones, releases energy

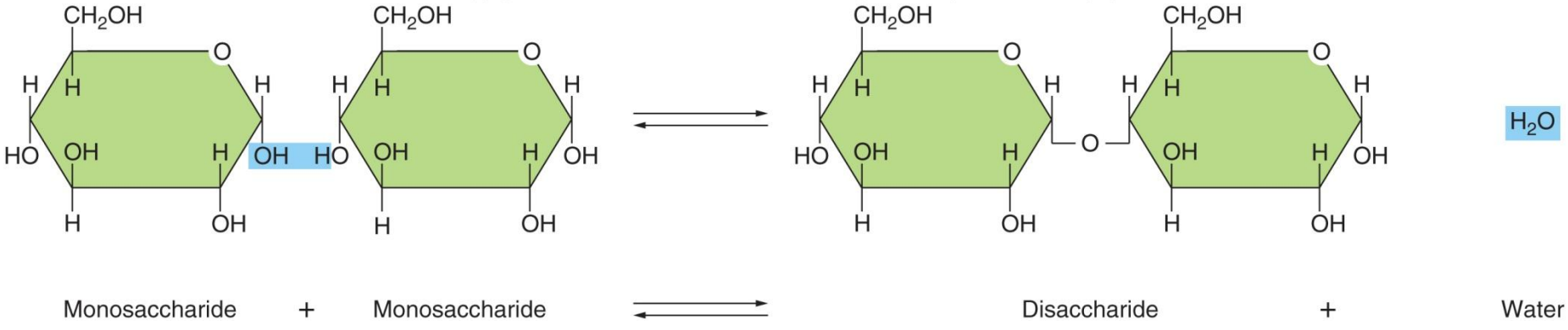
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Anabolism

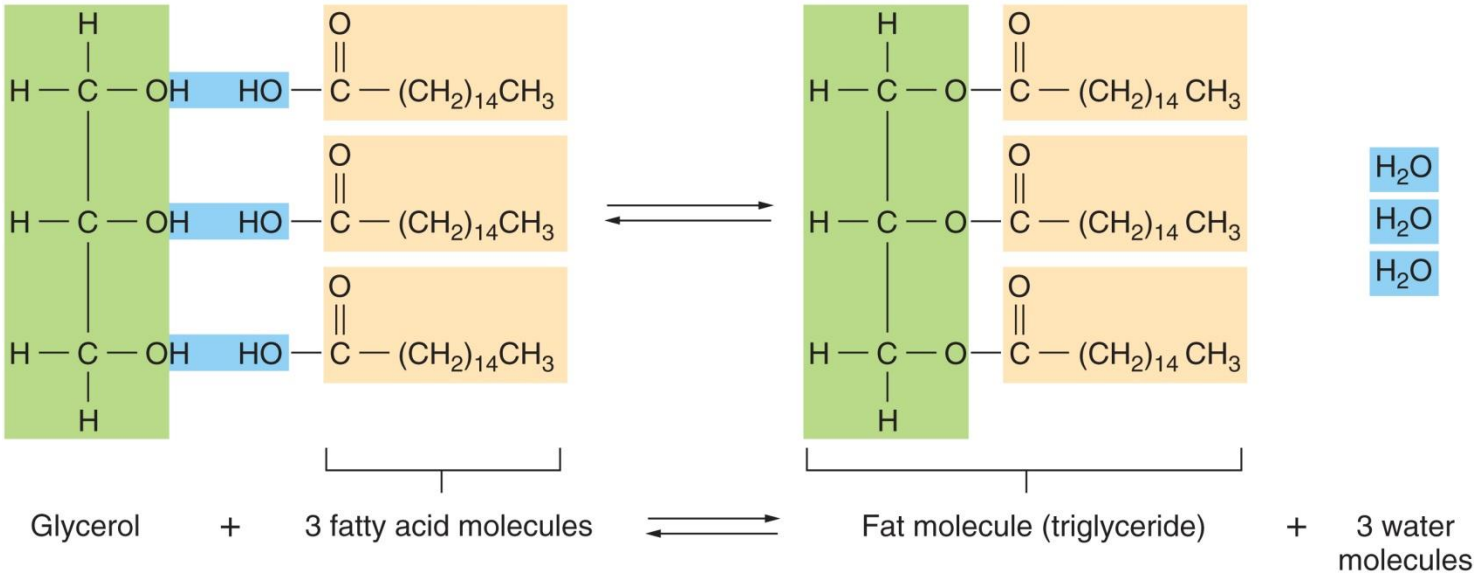
- **Anabolism** provides materials for maintenance, cellular growth and repair. Requires ATP made during catabolism.
- Example: **Dehydration synthesis**
  - Smaller molecules are bound together to form larger ones
  - H_2O produced in the process
  - Used to produce polysaccharides, proteins, triglycerides

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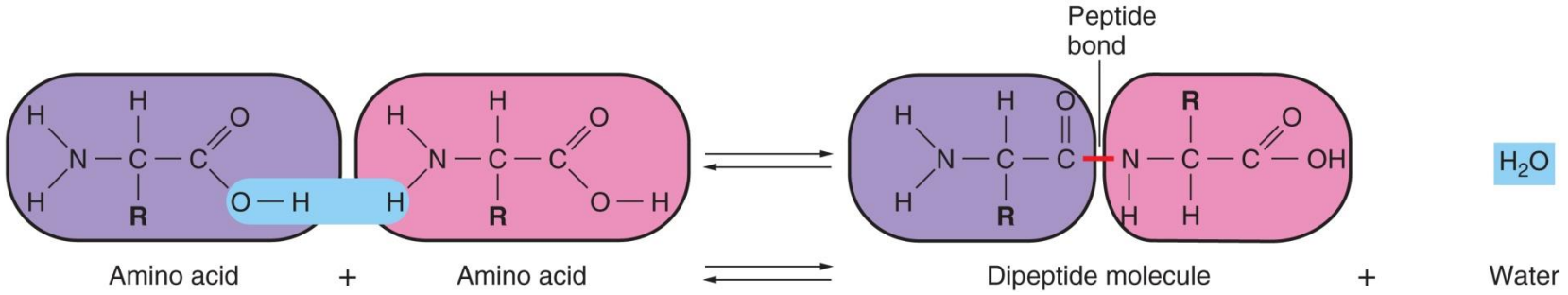


Anabolism

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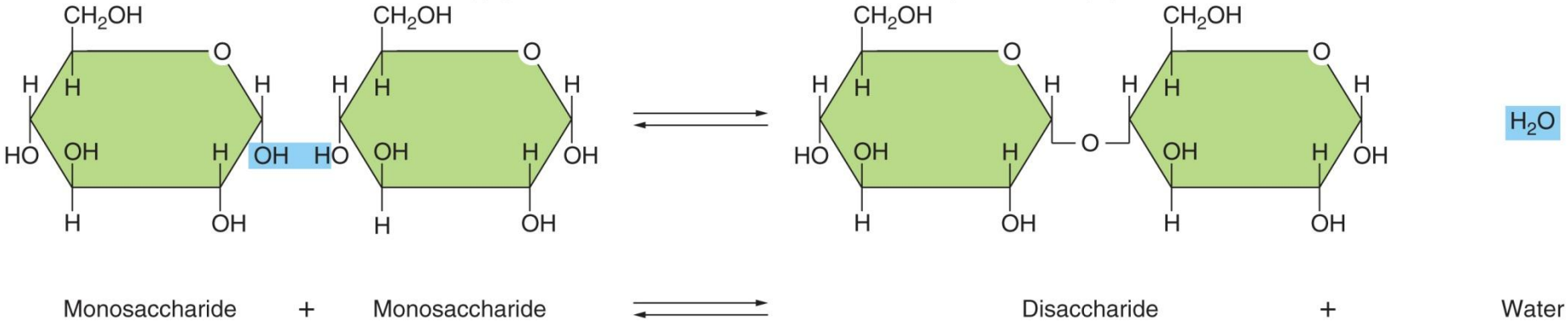
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Catabolism

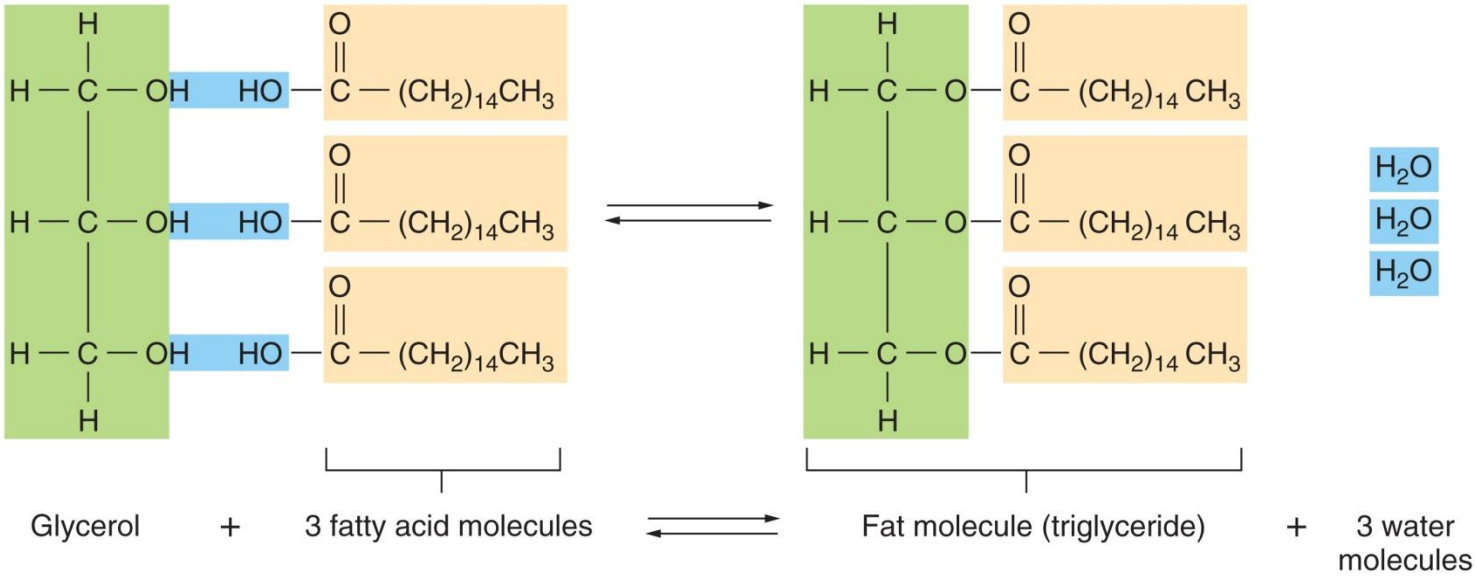
- **Catabolism** breaks down larger molecules into smaller ones; ATP is produced
- Example: **Hydrolysis**
  - Used to decompose carbohydrates, proteins, lipids
  - Uses H_2O to split the substances
  - Reverse of dehydration synthesis

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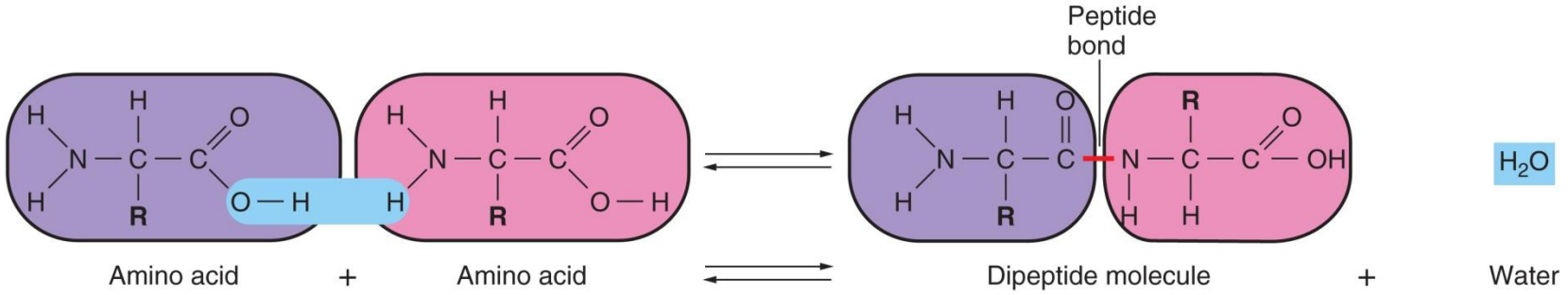


Catabolism

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4.2: Control of Metabolic Reactions

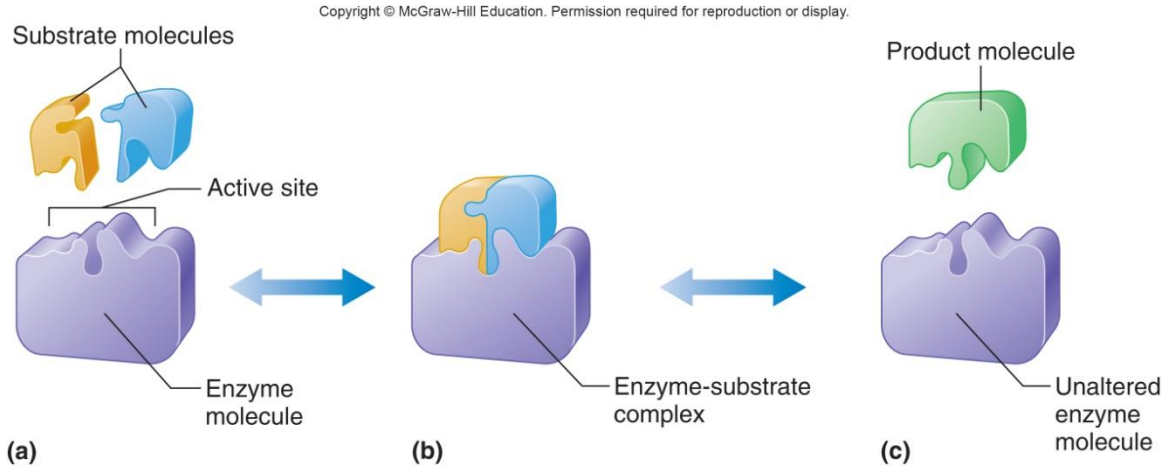
- Rates of catabolism and anabolism must be carefully controlled
- Breakdown/energy-releasing reactions must occur at rates that balance with build-up/energy-utilizing reactions
- Imbalances in reaction rates can damage or kill a cell
- Different types of cells conduct specialized metabolic processes
- All cells perform catabolic and anabolic reactions
- **Enzymes** control rates of both catabolic and anabolic reactions

Enzyme Action

Enzymes (protein catalysts):

- Globular proteins that catalyze specific reactions
- Increase rates of chemical reactions
- Lower the activation energy necessary to start reactions
- Not consumed in the reaction, so are used repeatedly
- Each enzyme is specific to a particular substrate
- Ability to recognize substrate depends on shape of active site of enzyme

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Factors that Affect Enzyme Action

- Shape of enzyme (conformation) is vital to its functioning
- Factors that can alter conformation of an enzyme:
  - Excess heat
  - Radiation
  - Electricity
  - Specific chemicals
  - Extreme pH values
  - Some poisons
- **Denaturation:** Inactivation of an enzyme (or any other protein), due to an irreversible change in its conformation
- Denaturation results in an enzyme being unable to bind to its substrate

From Science to Technology 4.1

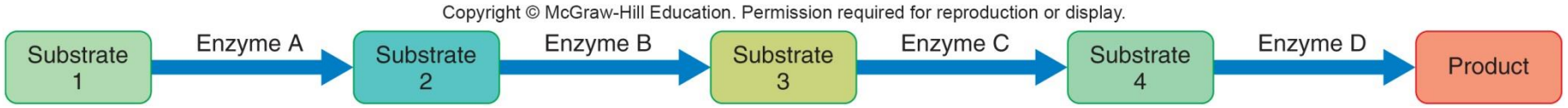
The Human Metabolome

- "Metabolome" = all small molecules that are part of the metabolism in a cell, tissue, organ, or organism
- Human Metabolome Database stores vast amounts of information about these molecules, also called "metabolites"
- Estimated that human cells have at least 2,500 metabolites, but less than half have been identified
- Metabolites are being analyzed, and added to database to record concentrations in different cells under various conditions, pathways and enzymes that interact with them, drug and food interfaces
- Information is being used in toxicology, drug discovery, diagnosis, screening of newborns, transplant monitoring

Metabolic Pathways

Metabolic Pathways:

- Series of enzyme-controlled reactions leading to formation of a product
- Each new substrate is the product of the previous reaction



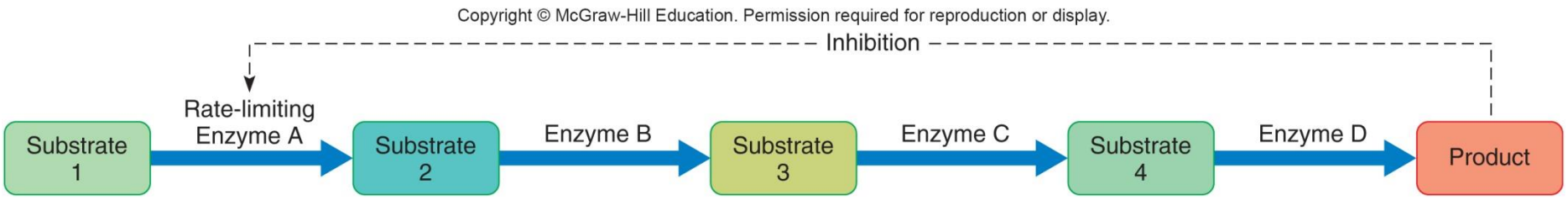
Names of enzymes often:

- Contain name of substrate
- End in –ase
- Examples: lactase, protease, lipase

Metabolic Pathways

- Each step of a pathway is catalyzed by a different enzyme
- A regulatory enzyme that catalyzes one step of pathway typically sets rate for entire reaction sequence
- Number of molecules of this enzyme is limited
- Called the **rate-limiting enzyme**
- Often the first enzyme in the reaction sequence
- In some pathways, end product inhibits rate-limiting enzyme; this is example of **negative feedback**

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Cofactors and Coenzymes

Cofactor:

- Non-protein substance that combines with enzyme to activate it
- Some help fold active site into proper conformation
- Some help bind enzyme to substrate
- Can be ion, element, or small organic molecule (coenzyme)

Coenzyme:

- Organic molecule that acts as cofactor
- Most are vitamins

Clinical Application 4.1

Inborn Errors of Metabolism

- Deficient or absent enzyme blocks metabolic pathway that it catalyzes
- Results in accumulation of enzyme's substrate, and a deficiency of its product

- Example: Phenylketonuria (PKU)

  Missing/nonfunctional enzyme blocks conversion of amino acid, phenylalanine, into the amino acid, tyrosine. Excess phenylalanine enters blood and poisons the brain. Can be treated with special diet.

4.3: Energy for Metabolic Reactions

- **Energy** is the capacity to change something, or the ability to do work
- Common forms of energy:
  Heat, light, sound, electrical energy, mechanical energy, chemical energy

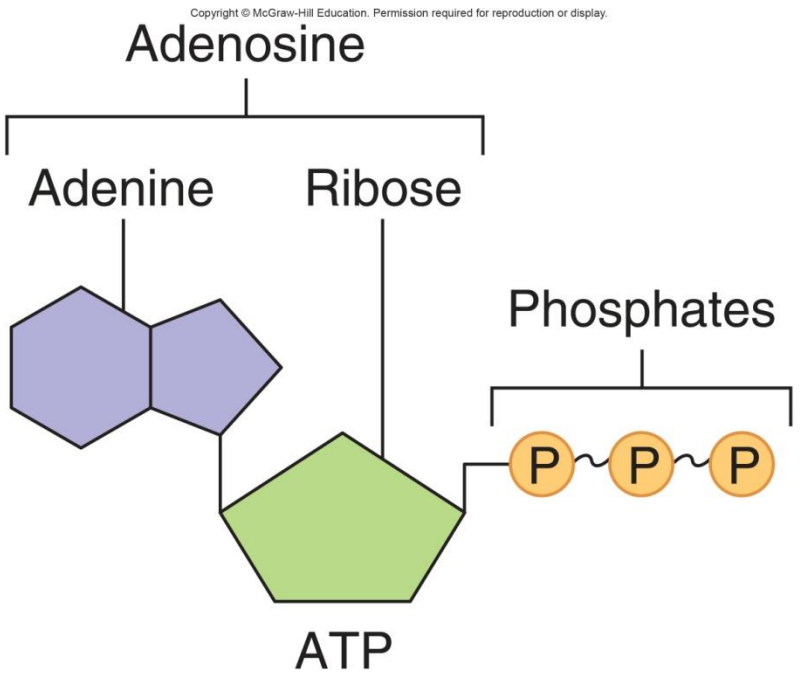
- Energy cannot be created or destroyed, but can be changed from one form to another.

- **Cellular respiration:** process that transfers energy from molecules, and makes it available for cellular use

- Most metabolic reactions use chemical energy.

ATP Molecules

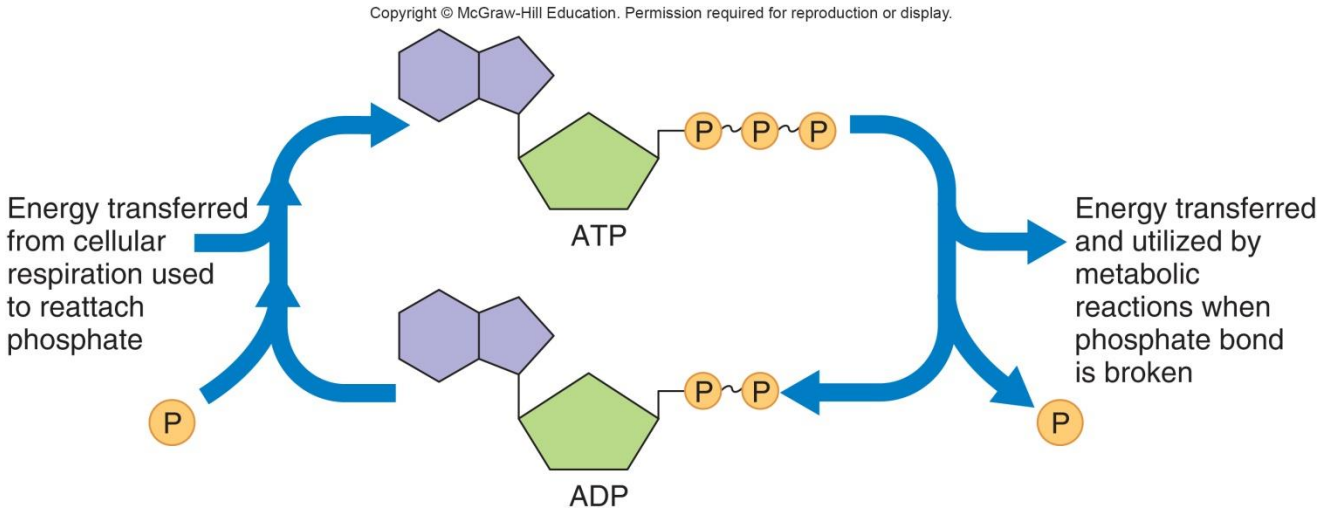
- **ATP (Adenosine Triphosphate)** carries energy in a form the cell can use
- Main energy-carrying molecule in the cell; energy from ATP breakdown is used for cellular work
- Consists of 3 portions:
  - Adenine
  - Ribose (a sugar)
  - 3 phosphates in a chain
- Second and third phosphates are attached by high-energy bonds; energy can be quickly transferred to other molecules



ATP Molecules

- When ATP loses terminal phosphate, it becomes **Adenosine Diphosphate (ADP)**
- ADP can be converted back into ATP by attaching a third phosphate; called **phosphorylation**
- Phosphorylation requires energy from cellular respiration
- ATP and ADP cycle back and forth between cellular respiration and energy-utilizing reactions

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Release of Chemical Energy

- Many metabolic processes require chemical energy, which is stored in ATP
- Energy is held in chemical bonds, and released when bonds are broken
- Oxidation releases energy from glucose
- Energy is then used to power cellular metabolism
- In cells, enzymes initiate oxidation by lowering activation energy
- Energy is transferred to ATP:
    - 40% is released as chemical energy
    - 60% is released as heat; maintains body temperature

4.4: Cellular Respiration

Cellular Respiration of glucose occurs in 3 interconnected reaction sequences:

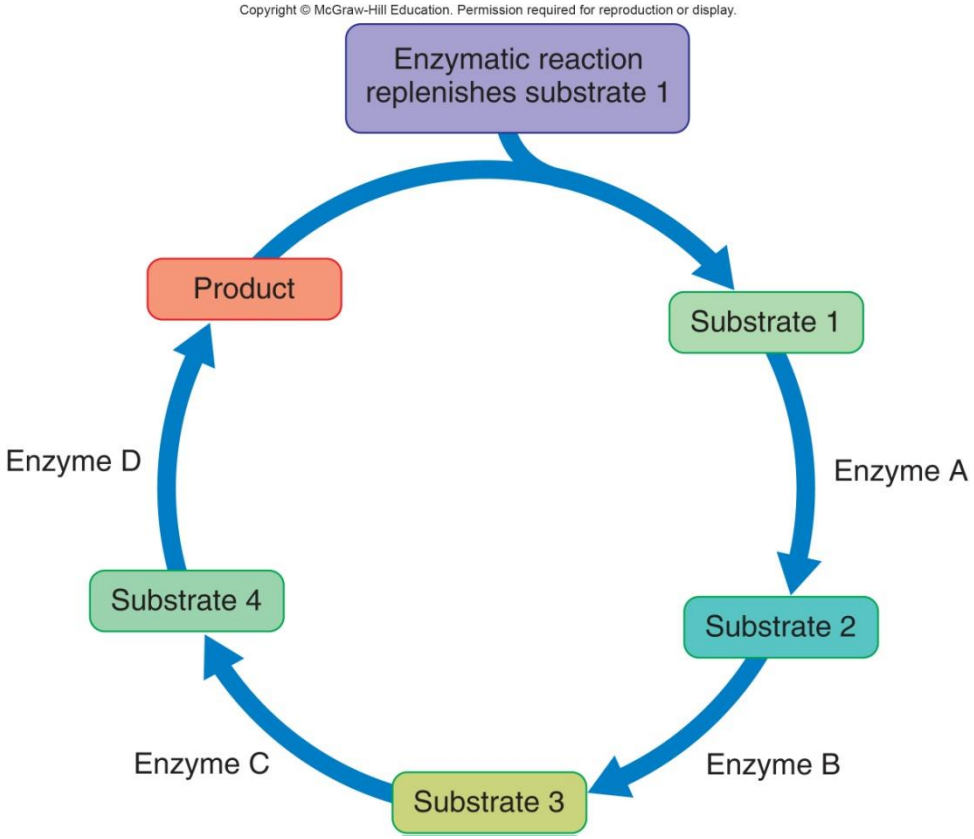
- Glycolysis (anaerobic)
- Citric acid cycle (aerobic)
- Electron transport chain / oxidative phosphorylation (aerobic)

- Glycolysis and the Electron Transport Chain are stepwise reaction sequences.

- Citric Acid Cycle occurs in a cycle; final product reacts to replenish original substrate

Cellular Respiration

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- A metabolic pathway is a <u>cycle</u> when product reacts to replenish original substrate
- <u>Example</u>: Citric acid cycle

Cellular Respiration: Overview

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Glycolysis

1. The 6-carbon sugar glucose is broken down in the cytosol into two 3-carbon pyruvic acid molecules with a net gain of 2 ATP and the release of high-energy electrons.

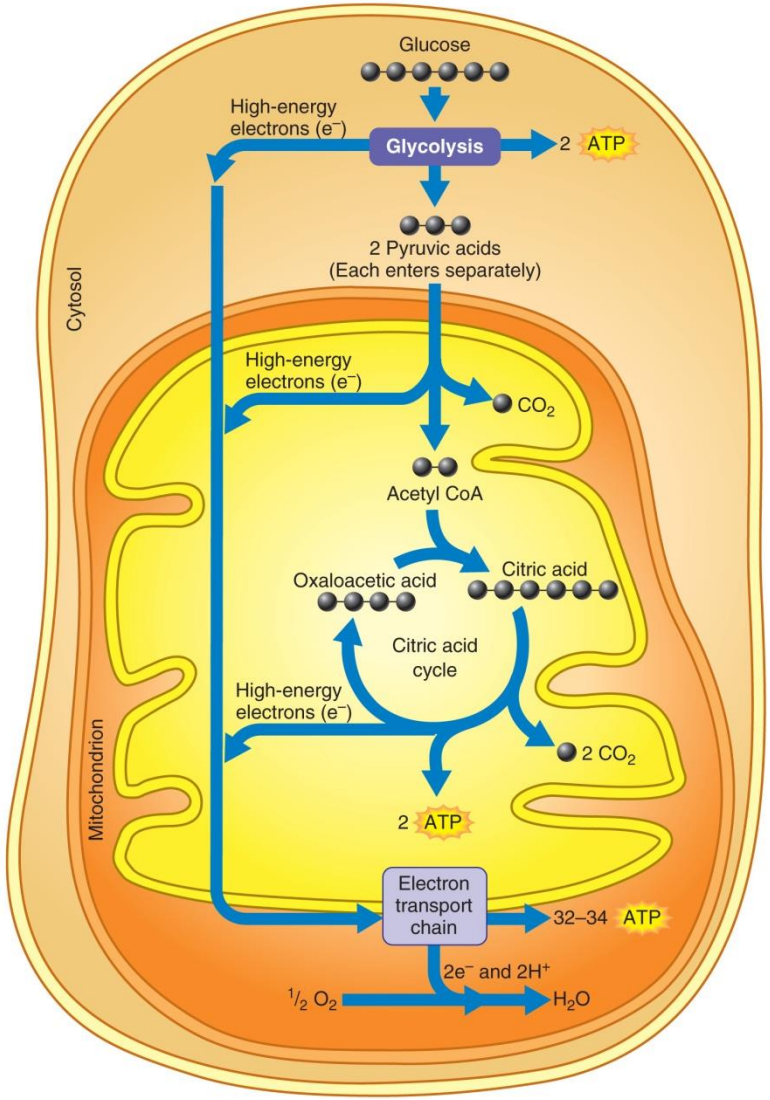
Citric Acid Cycle

2. The 3-carbon pyruvic acids generated by glycolysis enter the mitochondria separately. Each loses a carbon (generating CO_2) and is combined with a coenzyme to form a 2-carbon acetyl coenzyme A (acetyl CoA). More high-energy electrons are released.

3. Each acetyl CoA combines with a 4-carbon oxaloacetic acid to form the 6-carbon citric acid, for which the cycle is named. For each citric acid, a series of reactions removes 2 carbons (generating 2 CO_2's), synthesizes 1 ATP, and releases more high-energy electrons. The figure shows 2 ATP resulting directly from 2 turns of the cycle per glucose molecule that enters glycolysis.

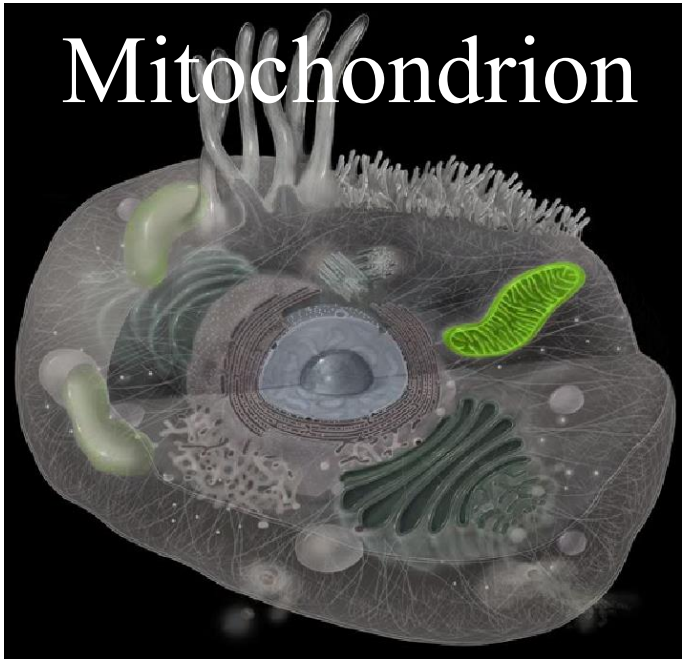
Electron Transport Chain

4. The high-energy electrons still contain most of the chemical energy of the original glucose molecule. Special carrier molecules bring the high-energy electrons to a series of enzymes that transfer much of the remaining energy to more ATP molecules. The electrons eventually combine with hydrogen ions and an oxygen atom to form water. The function of oxygen as the final electron acceptor in this last step is why the overall process is called aerobic respiration.



Cellular Respiration

- Cellular respiration of glucose requires a supply of glucose and O_2.
- Products of cellular respiration:
  - Carbon dioxide
  - Water
  - ATP (chemical energy, 40%)
  - Heat (60%)



Includes 2 types of reactions:

Aerobic reactions: require O_2, and make most of ATP

Anaerobic reactions: do not require O_2, and make little ATP

Glycolysis

Glycolysis:

- First reaction sequence of glucose breakdown
- Series of 10 reactions
- Breaks down glucose (6-carbon) into 2 pyruvic acid (3-carbon) molecules
- Occurs in cytosol
- Anaerobic phase of cellular respiration
- Yields 2 ATP molecules per glucose molecule broken down

3 phases of glycolysis:

1. Phosphorylation of glucose
2. Splitting/cleavage of glucose into 2 3-carbon molecules
3. Production of NADH, ATP, and 2 molecules of pyruvic acid

Glycolysis

Phases of glycolysis:

Phase 1: Phosphorylation

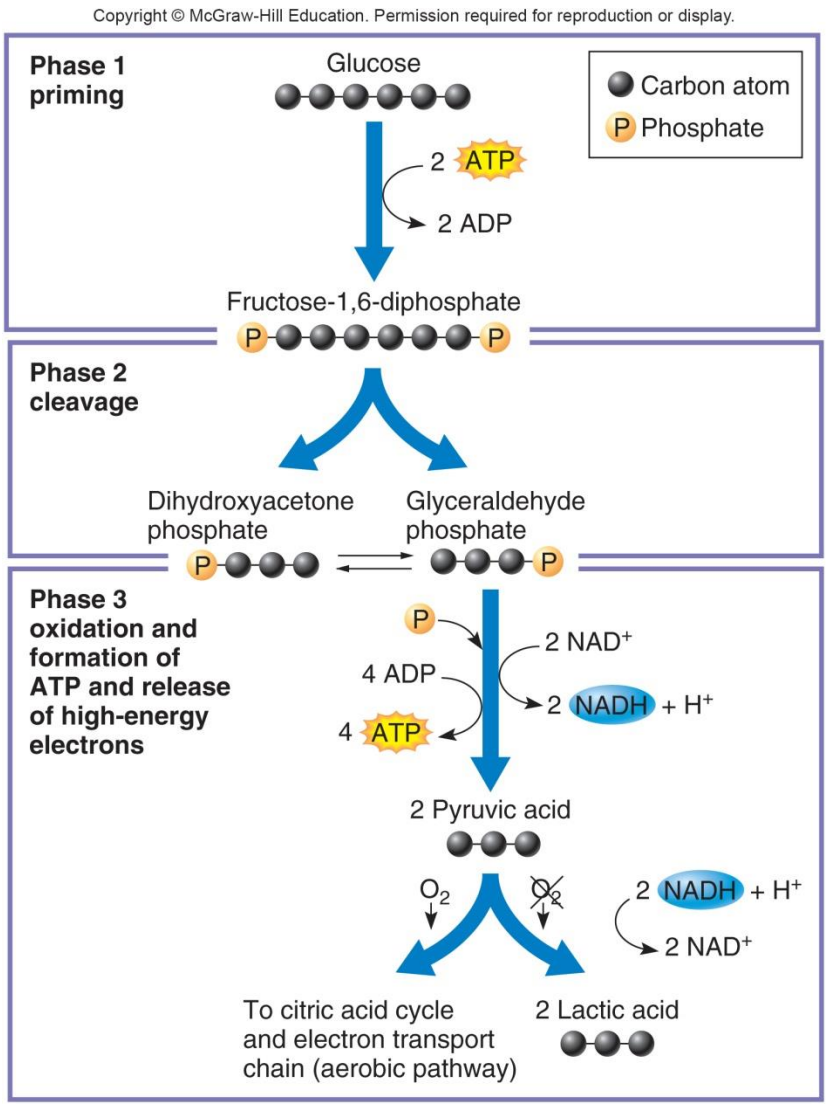
- Glucose is phosphorylated
- 2 ATP used

Phase 2: Splitting

- 6-C molecule cleaves into 2 3-carbon molecules

Phase 3: ATP formation and release of electrons

- 2 pyruvic acid formed
- 4 ATP formed
- 2 NADH and H^+ formed



Anaerobic Reactions

- In presence of O_2, NADH and H^+ deliver electrons to the electron transport chain, with oxygen as final electron acceptor

- In absence of O_2 , there is no electron acceptor
- NADH and H^+ deliver electrons and H^+ back to pyruvic acid, to form **lactic acid**
- Buildup of lactic acid inhibits glycolysis
- ATP production is decreased

- Glycolysis produces much less ATP than aerobic respiration
- There is net gain of 2 ATP per molecule of glucose broken down

Aerobic Reactions

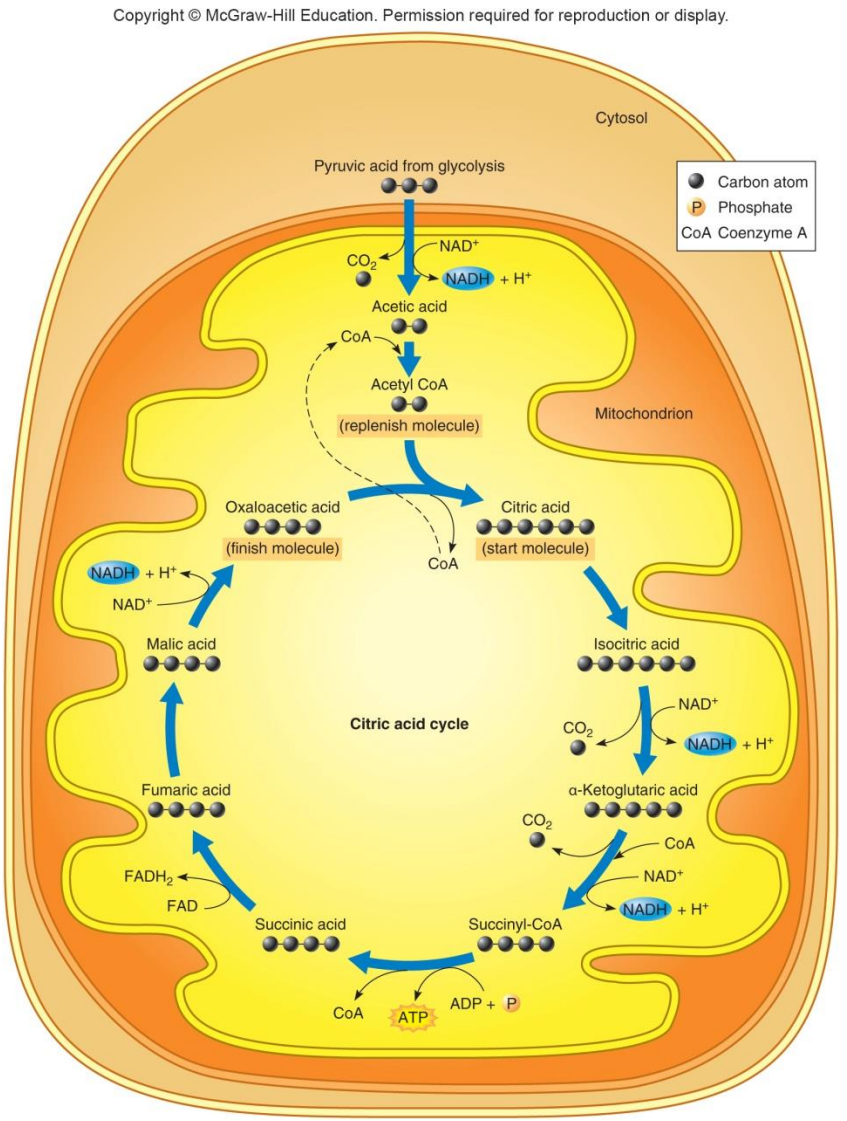
- In presence of O_2, pyruvic acid enters aerobic pathways

- Aerobic reactions include:
  - Synthesis of Acetyl Coenzyme A
  - Citric acid cycle
  - Electron transport chain

- Begins with pyruvic acid moving from cytosol to mitochondria
- Pyruvic acid is used to produce Acetyl CoA
- End products are CO_2, H_2O, and up to 36 ATP per molecule of glucose

Citric Acid Cycle

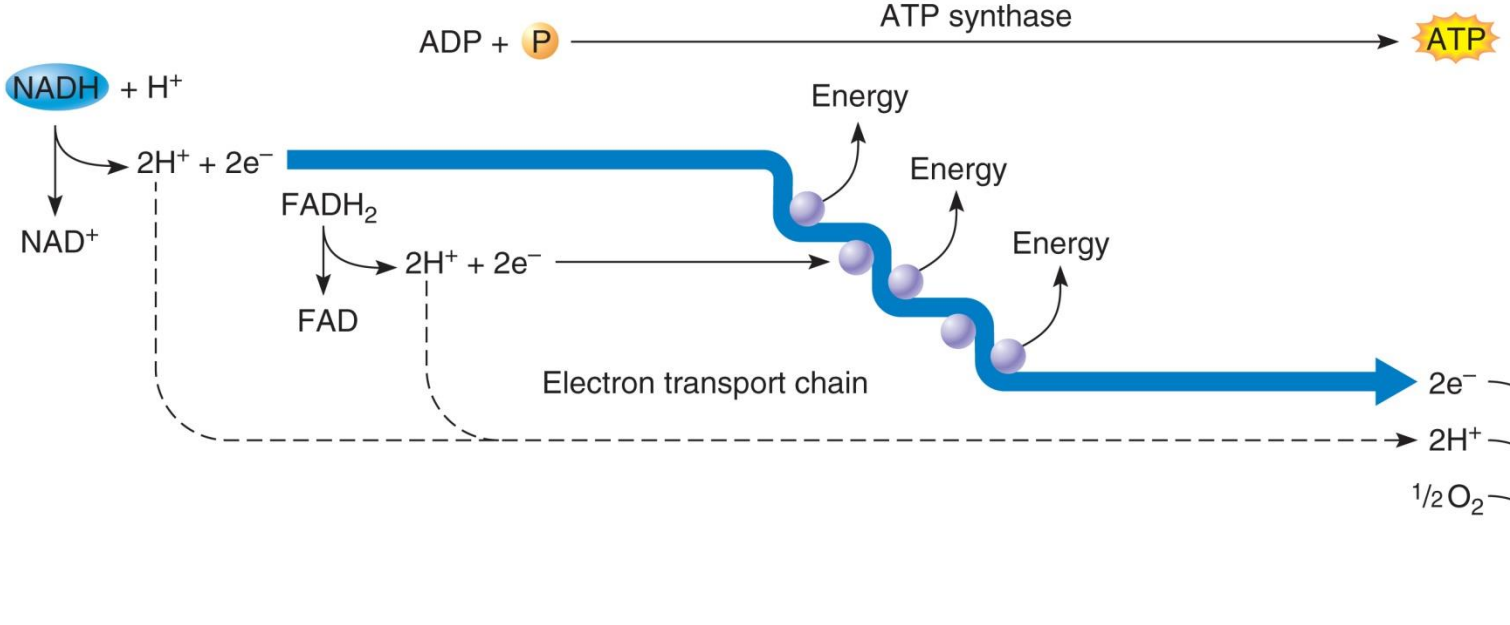
- Begins when acetyl CoA combines with oxaloacetic acid to produce citric acid
- Citric acid is changed into oxaloacetic acid through a series of reactions
- Cycle repeats as long as pyruvic acid and O_2 are available
- <u>For each citric acid molecule</u>:
  - 1 ATP is produced
  - 8 hydrogen atoms are transferred to NAD^+ and FAD
  - 2 CO_2 are produced



Electron Transport Chain

- NADH and $FADH_2$ carry hydrogen and high energy electrons to the ETC
- ETC is a series of enzyme complexes (electron carriers) located in the inner membrane of mitochondria
- Energy from electrons is transferred to the enzyme ATP synthase
- ATP synthase uses energy to catalyze phosphorylation of ADP to ATP
- H_2O is formed (oxygen is the final electron "carrier")

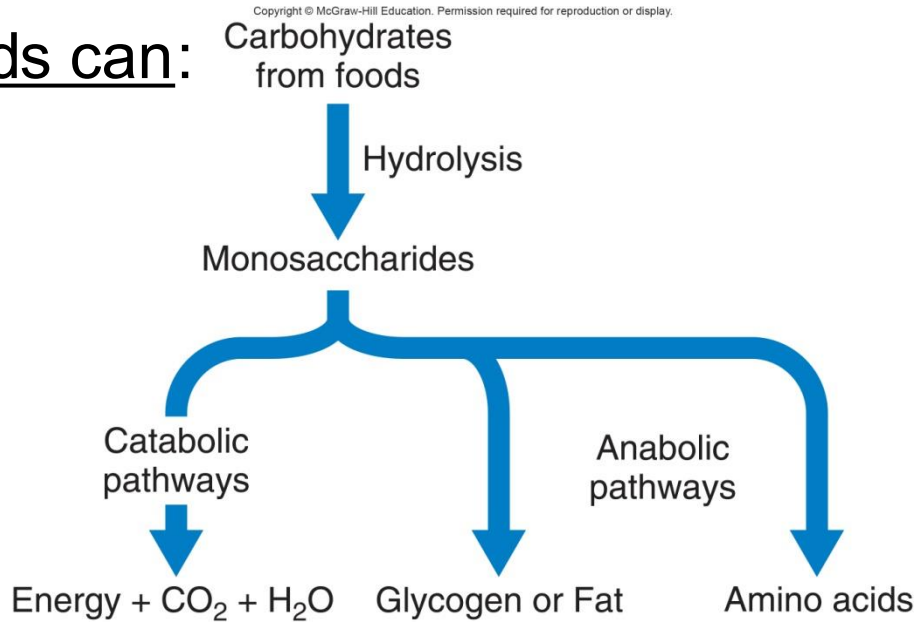
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Carbohydrate Storage

Carbohydrate molecules from foods can:

- Enter **catabolic pathways** for energy production
- Enter **anabolic pathways** for storage
- React to form some of the amino acids



Excess glucose can be converted into and stored as:

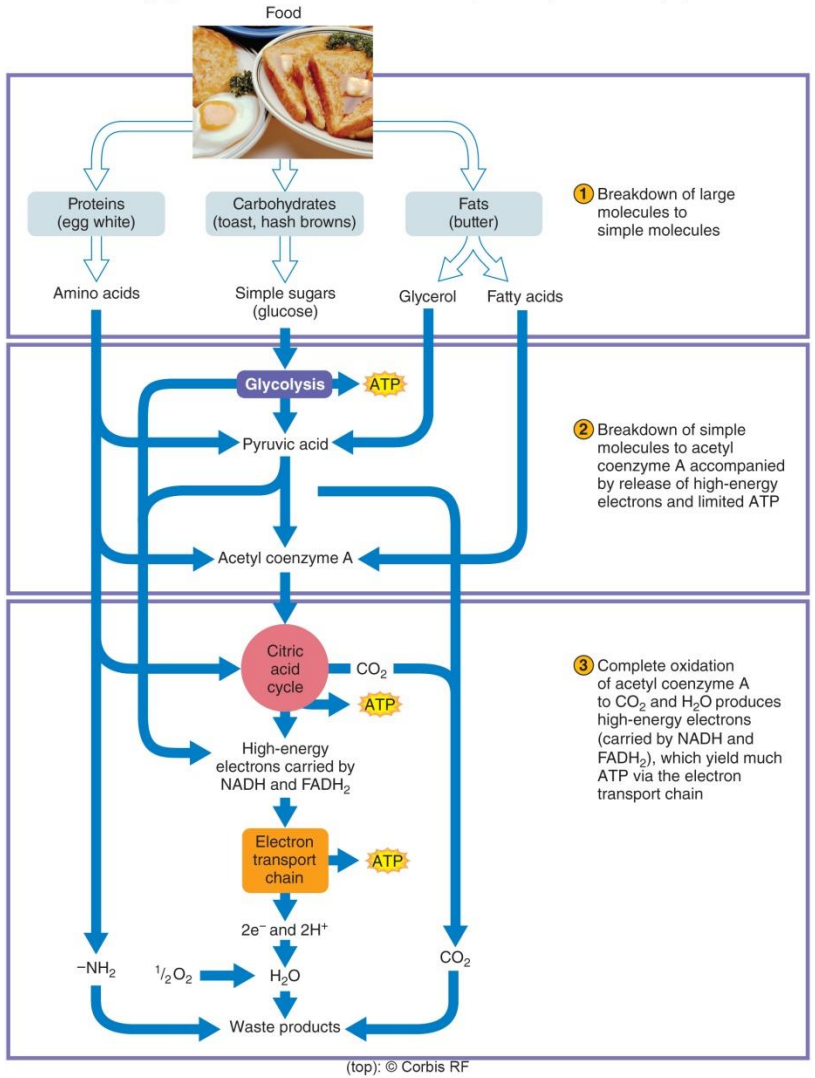
- **Glycogen:** Most cells, but liver and muscle cells store the most
- **Fat** to store in adipose tissue





Summary of Catabolism of Proteins, Carbohydrates, and Fats

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(top): © Corbis RF

4.5: Nucleic Acids & Protein Synthesis

- Information that instructs a cell to synthesize certain proteins is stored on the sequence of **Deoxyribonucleic acid (DNA)**.
- DNA is the genetic material

- DNA stores instructions on how to produce proteins that function as:
  - Enzymes
  - Blood proteins
  - Structural proteins of muscle and connective tissue
  - Antibodies
  - Cell membrane components

Genetic Information

- **Genetic information:**

  Instructions to tell cells how to construct proteins; stored in DNA sequence

- **Gene:**

  Sequence of DNA that contains information for making 1 protein

- **Genome:**

  Complete set of genetic information in a cell

- **Exome:**

  Small portion of the genome that codes for proteins

- **Gene Expression:**

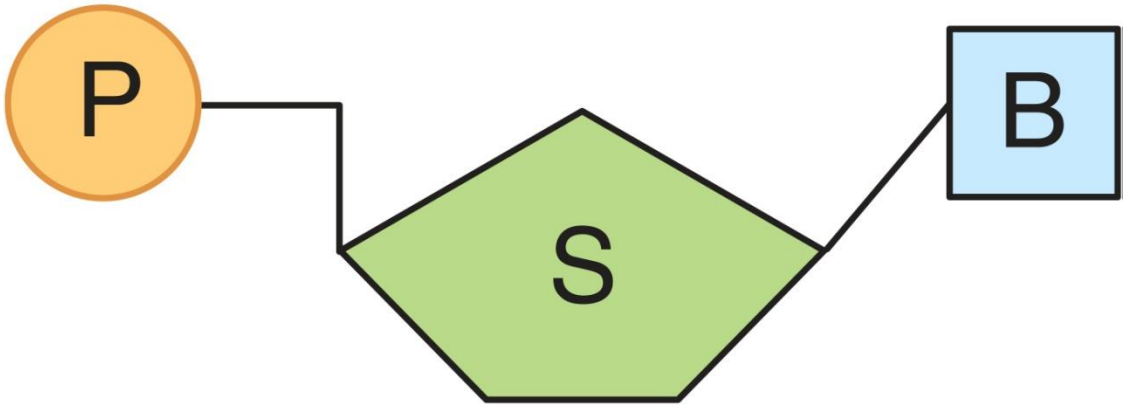
  Control of which proteins are produced in each cell type, in what amount, and under which circumstances

The Structure of DNA

Nucleotides are building blocks of DNA, and consist of:

- 5-carbon sugar, deoxyribose
- A phosphate group
- A nitrogenous base (adenine, cytosine, guanine, or thymine)

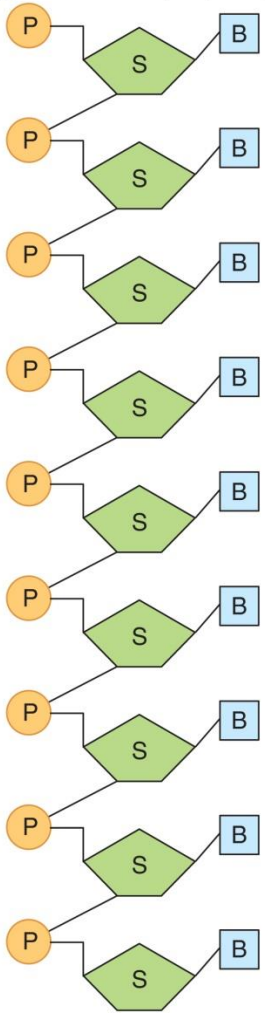
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- DNA resembles ladder twisted into a spiral (double helix)
- Backbone of each strand is a sugar-phosphate chain
- Bases from the 2 complementary strands link together by hydrogen bonds: C – G, A – T

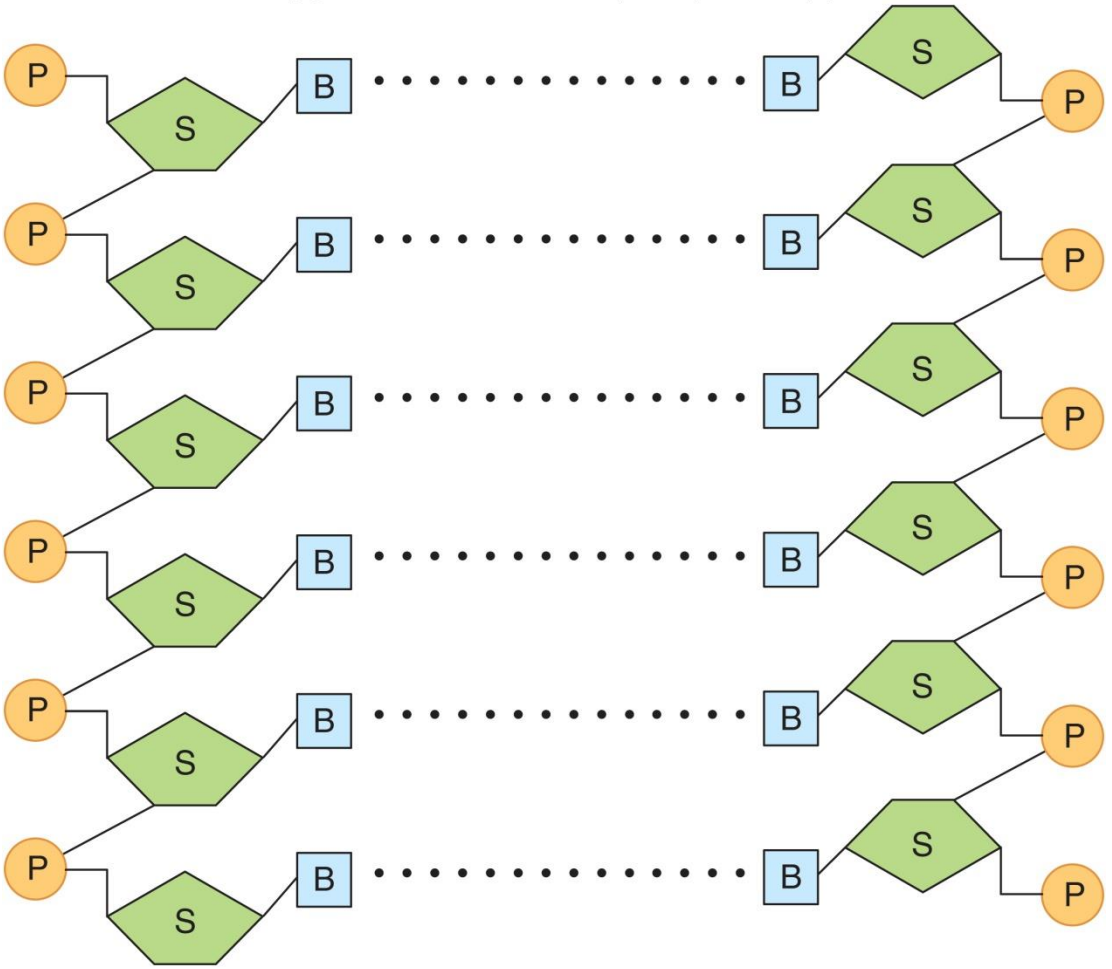
The Structure of DNA

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Chain of nucleotides

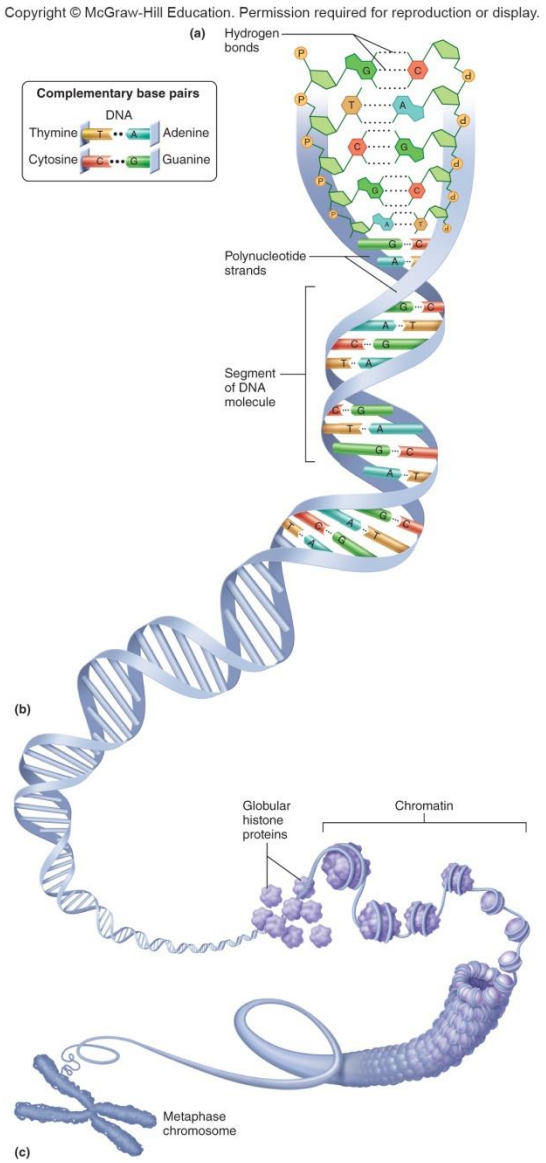
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Double strand of DNA

The Structure of DNA

- 2 nucleotide chains, twisted into a double helix
- Each nucleotide consists of a 5-C sugar (deoxyribose), a phosphate, and a nitrogenous base (adenine, guanine, cytosine or thymine)
- Hydrogen bonds hold the bases together
- Bases pair specifically (A-T and C-G); this is called Complementary Base Pairing
- DNA wraps about histone proteins to form chromosomes



From Science to Technology 4.2

DNA Profiling Frees a Prisoner

- Human genome contains 3.2 billion bits of information
- DNA profiling/DNA fingerprinting compares the most variable parts of genome among individuals
- DNA profiling is used for:
    1. Identifying human remains at crime scenes or natural disasters
    2. To check for family relationships, paternity
    3. To establish innocence in criminal cases, such as rape

Hundreds of prisoners have been freed due to DNA profiling.

DNA Replication

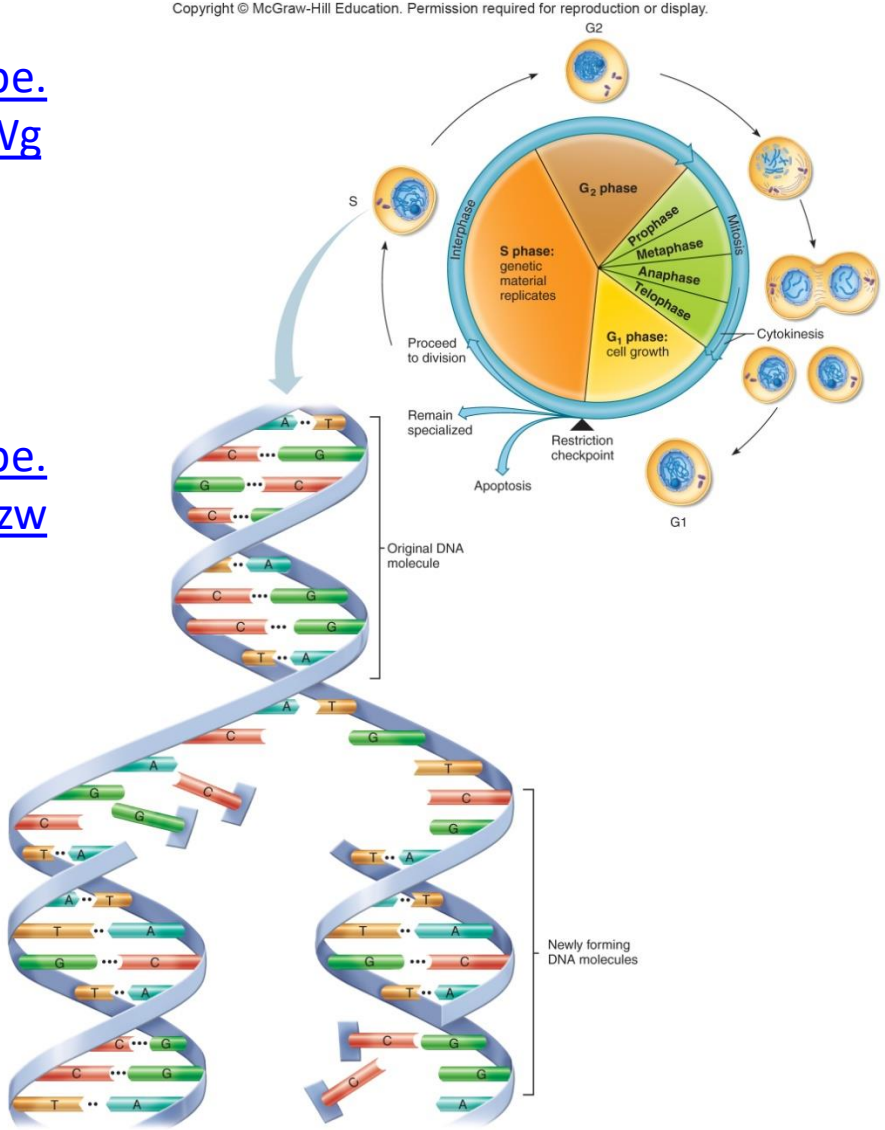
- When cell divides, each daughter cell must receive identical DNA
- **DNA Replication:** process that produces an exact copy of a DNA molecule
- Occurs during interphase
- Steps in DNA replication:
    1. Hydrogen bonds break between base pairs
    2. Strands unwind and separate
    3. New nucleotides pair with exposed bases, under direction of DNA polymerase
    4. Other enzymes connect new sugar-phosphate backbone

DNA Replication

https://www.youtube.com/watch?v=TNKWgcFPHqw

Crashcourse video:
https://www.youtube.com/watch?v=8kK2zwjRV0M

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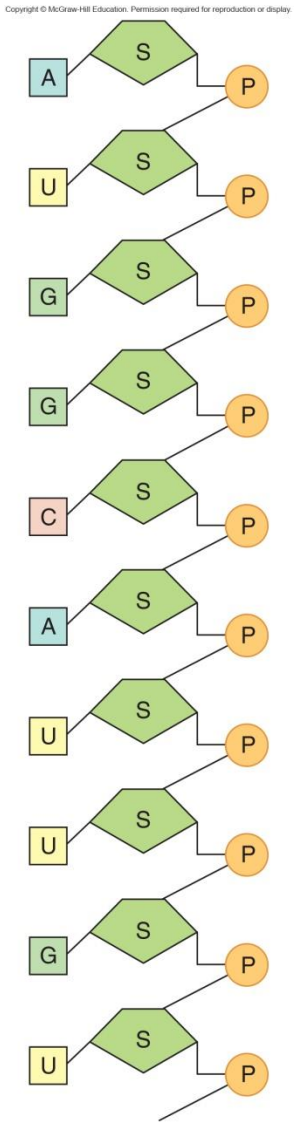


Genetic Code

- Genetic information stores correct sequence of amino acids for a polypeptide chain
- **Triplet code:** a sequence of 3 nucleotides that represents an amino acid, or signals beginning or end of a protein
- Sequence of bases in a gene determines the amino acid sequence in a polypeptide
- DNA stores master copy of genetic code, and remains in the nucleus
- Protein synthesis occurs in cytoplasm
- RNA (ribonucleic acid) copies and transfers information from DNA to the cytoplasm

RNA Molecules

- Single strand of nucleotides
- Each nucleotide contains: ribose, phosphate, base (Adenine, Guanine, Cytosine, and Uracil --instead of Thymine)
- Complementary base pairing in RNA: A—U, C—G
- Much shorter than DNA
- **Transcription:** Process of copying DNA sequence onto an RNA sequence
- **Messenger RNA (mRNA)**: Carries genetic code from DNA to ribosome
- RNA Polymerase: Enzyme that catalyzes the formation of mRNA from the proper strand of DNA



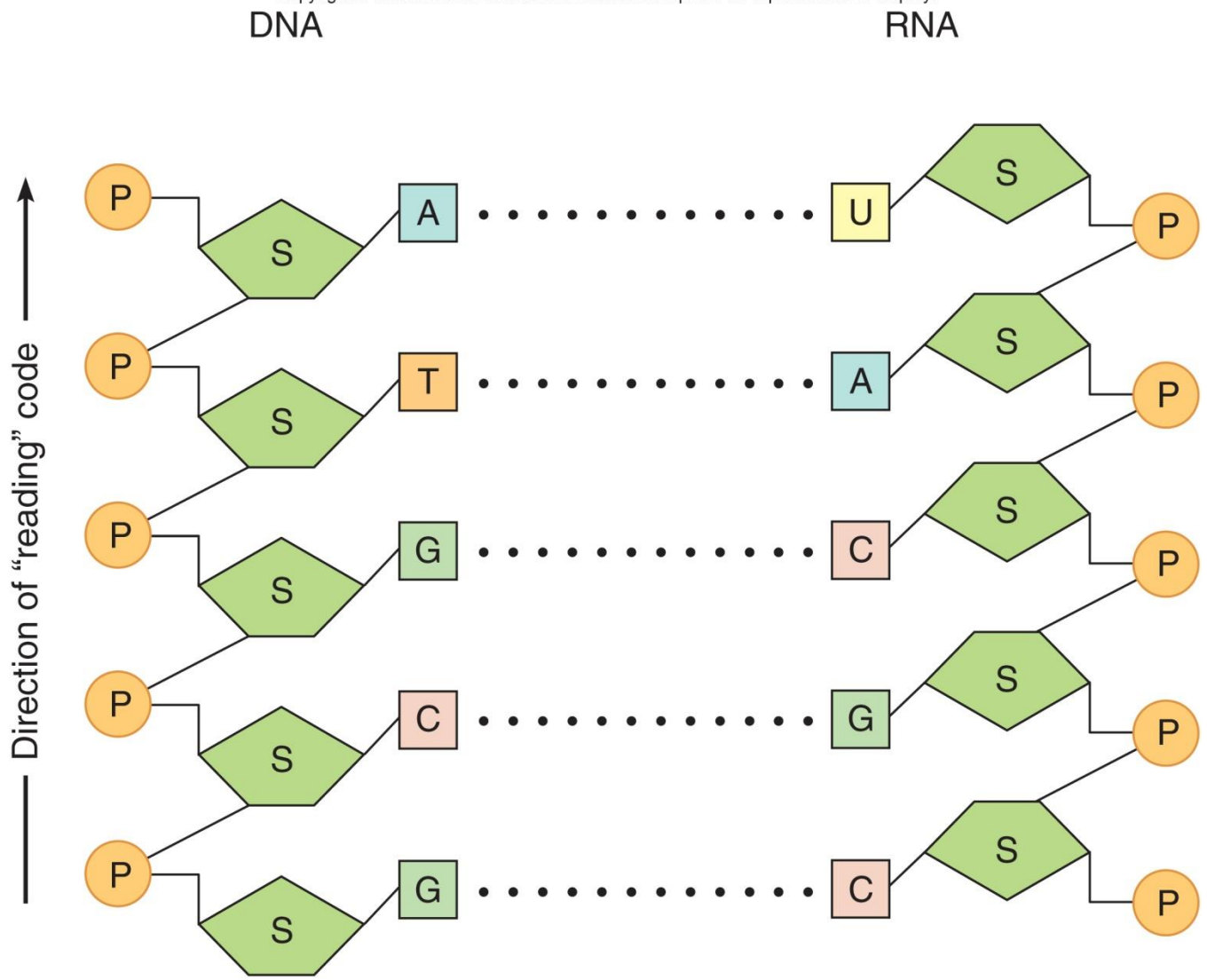
RNA Molecules

Steps in Transcription of mRNA:

- RNA polymerase recognizes correct strand of DNA to copy
- A section of DNA unwinds to expose the gene coding for the particular protein
- Complementary mRNA nucleotides pair with the DNA bases (uracil is used in RNA, instead of thymine)
- Termination signal indicates end of gene
- New mRNA strand is released, and DNA rewinds into double helix
- The mRNA now leaves the nucleus through a nuclear pore, and attaches to a ribosome in the cytoplasm.

Transcription of mRNA

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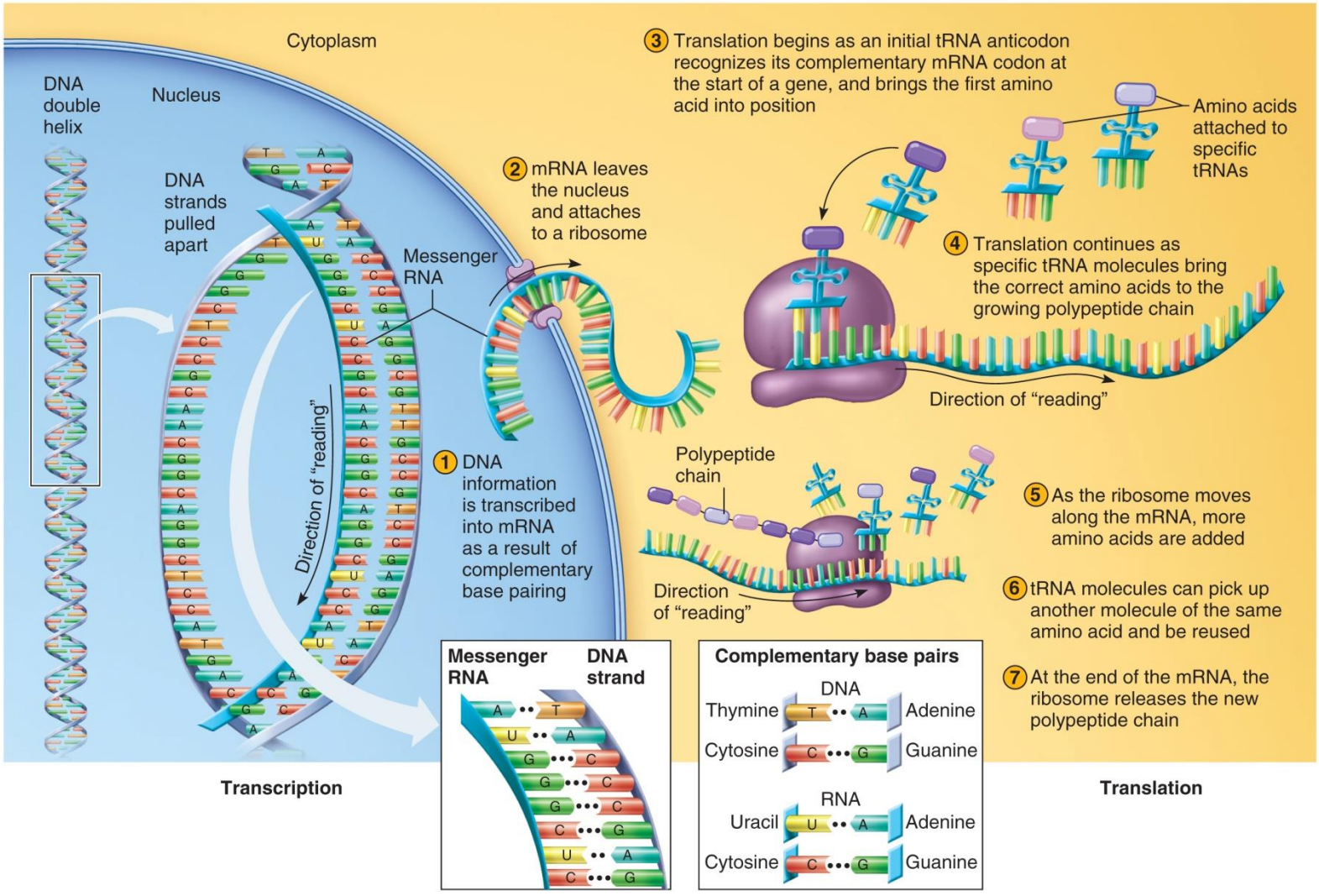


Translation

- Each amino acid is specified by a sequence of 3 bases in DNA, called **Codons**
- Protein synthesis occurs in cytoplasm
- mRNA leaves nucleus and binds to ribosome, to act as template for protein synthesis
- At the ribosome the genetic code, carried by mRNA, is used to synthesize a protein
- **Translation:** Process of converting the genetic code, carried by mRNA, into a sequence of amino acids that becomes a protein

Protein Synthesis

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Protein Synthesis

- Protein synthesis requires that amino acids are added to growing polypeptide chain in proper sequence
- **Transfer RNA (tRNA)** aligns amino acids during protein synthesis, along the mRNA strand on the ribosome
- tRNA binds to its amino acid, transports it to a ribosome, binds to the mRNA according to its sequence, and adds its amino acid to the growing polypeptide chain
- Each tRNA contains a sequence of 3 nucleotide bases, the anticodon, which binds to the complementary codon on the mRNA strand
- As ribosome moves down mRNA, each tRNA brings in its amino acid to be added to the growing protein

Protein Synthesis

- There are 20 types of amino acids
- There are 64 possible codons (3-base sequences) on mRNA
- Most codons correspond to amino acids
- 1 – 4 mRNA codons code for each amino acid
- The **Initiation codon**, AUG, codes for Methionine and signals the start of a protein
- 3 codons are **Stop codons**, signaling the end of a protein; these do not have corresponding tRNAs
- For each mRNA codon coding for an amino acid, there is a corresponding tRNA anticodon

mRNA Codons

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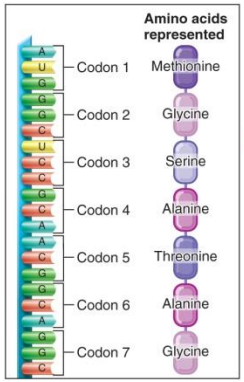
TABLE 4.2 Codons (mRNA Three-Base Sequences)

First Letter	SECOND LETTER: U		C		A		G		Third Letter
U	UUU	phenylalanine (phe)	UCU	serine (ser)	UAU	tyrosine (tyr)	UGU	cysteine (cys)	U
	UUC		UCC		UAC		UGC		C
	UUA	leucine (leu)	UCA		(UAA)	STOP	(UGA)	STOP	A
	UUG		UCG		(UAG)	STOP	UGG	tryptophan (trp)	G
C	CUU	leucine (leu)	CCU	proline (pro)	CAU	histidine (his)	CGU	arginine (arg)	U
	CUC		CCC		CAC		CGC		C
	CUA		CCA		CAA	glutamine (gln)	CGA		A
	CUG		CCG		CAG		CGG		G
A	AUU	isoleucine (ile)	ACU	threonine (thr)	AAU	asparagine (asn)	AGU	serine (ser)	U
	AUC		ACC		AAC		AGC		C
	AUA		ACA		AAA	lysine (lys)	AGA	arginine (arg)	A
	(AUG)	START methionine (met)	ACG		AAG		AGG		G
G	GUU	valine (val)	GCU	alanine (ala)	GAU	aspartic acid (asp)	GGU	glycine (gly)	U
	GUC		GCC		GAC		GGC		C
	GUA		GCA		GAA	glutamic acid (glu)	GGA		A
	GUG		GCG		GAG		GGG		G

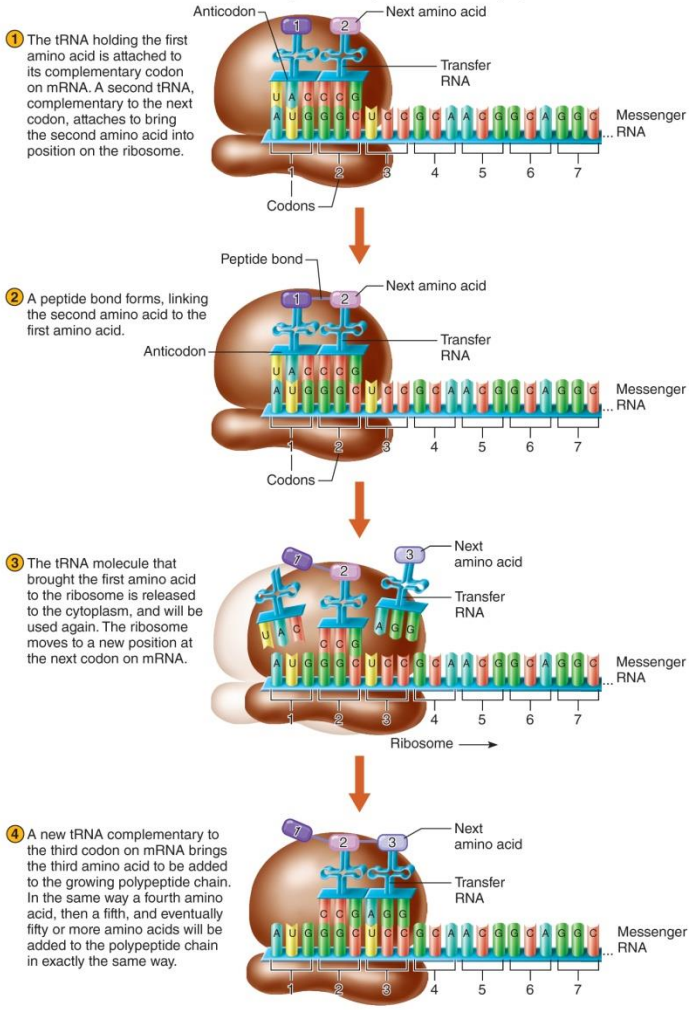
Most amino acids have 2 – 4 mRNA codons that code for them.

mRNA Codons

Part of a mRNA molecule, showing codons and the amino acids they represent:

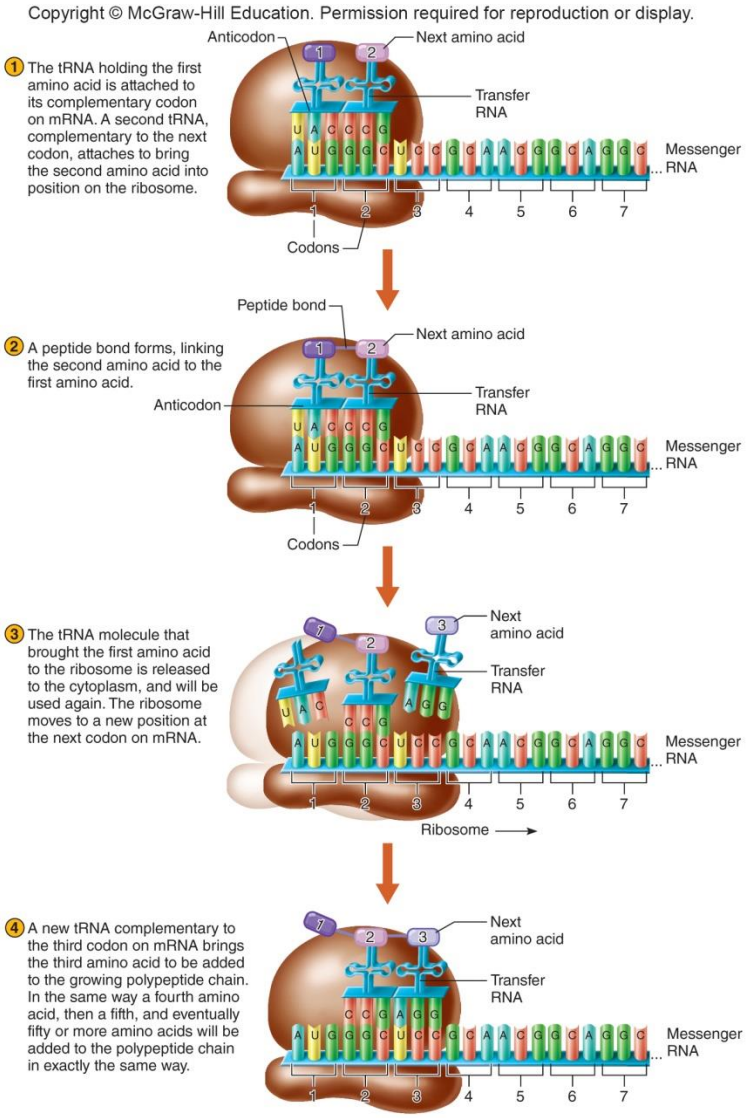


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Protein Synthesis

- Protein synthesis occurs on ribosomes
- mRNA is used as a template for protein synthesis
- tRNA brings amino acid to ribosome, and binds to mRNA, to add its amino acid to the growing protein chain



Protein Synthesis

- **Ribosomes:**

  Organelles composed of **Ribosomal RNA (rRNA)** and protein molecules
- Composed of 2 unequal subunits
- Binding of tRNA and mRNA occurs in association with a ribosome
- Ribosome moves down mRNA molecule, bringing in tRNAs carrying the proper amino acid to add to the growing protein chain
- Amino acids are joined by peptide bonds
- When ribosome reaches a “stop” codon, the protein is released
- Ribosomes, mRNA, and rRNA can be used repeatedly

Summary of Protein Synthesis

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TABLE 4.3 Protein Synthesis

Transcription (In the Nucleus)
1. RNA polymerase binds to the DNA base sequence of a gene.
2. This enzyme unwinds and exposes part of the DNA molecule.
3. RNA polymerase moves along one strand of the exposed gene and catalyzes synthesis of an mRNA, whose nucleotides are complementary to those of the strand of the gene.
4. When RNA polymerase reaches the end of the gene, the newly formed mRNA is released.
5. The DNA rewinds and closes the double helix.
6. The mRNA passes through a pore in the nuclear envelope and enters the cytoplasm.

Translation (In the Cytoplasm)
1. A ribosome binds to the mRNA near the codon at the beginning of the messenger strand.
2. A tRNA molecule that has the complementary anticodon brings its amino acid to the ribosome.
3. A second tRNA brings the next amino acid to the ribosome.
4. A peptide bond forms between the two amino acids, and the first tRNA is released.
5. This process repeats for each codon in the mRNA sequence as the ribosome moves along its length, forming a chain of amino acids.
6. The growing amino acid chain folds into the unique conformation of a functional protein.
7. The completed protein molecule is released. The mRNA, ribosome, and tRNA are recycled.

https://www.youtube.com/watch?v=gG7uCskUOrA

Crashcourse video:

https://www.youtube.com/watch?v=itsb2SqR-R0

4.6: Changes in Genetic Information

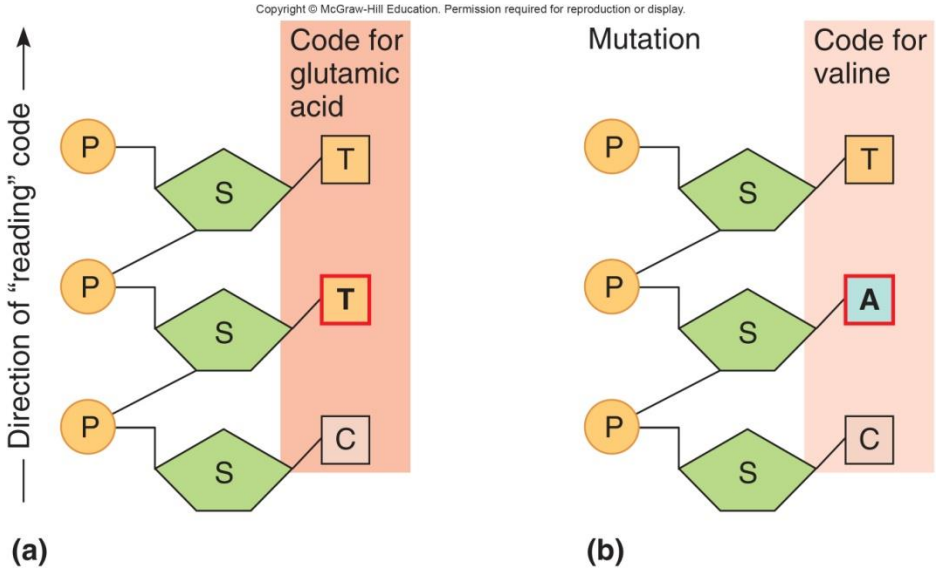
- 99.9% of human genome sequences are the same among all people

- 0.1% of the genome that varies among people includes:
  - DNA sequences that affect health
  - DNA sequences that affect appearance
  - DNA base variations that have no observable effects

Nature of Mutations

- **Mutations:** Changes in the DNA sequence
- Mutations occur when bases are changed, added, or deleted
- Mutations can be:
  a. Spontaneous: due to insertion of unstable base into DNA sequence
  b. Induced: due to exposure to **mutagens**, chemicals or radiation that cause mutation

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Nature of Mutations

- Some mutations are not harmful, and do not affect health

- Many mutations affect health, by changing the amino acid sequence, resulting in a nonfunctional or missing protein

  Example: Duchenne muscular dystrophy results from a mutation in the gene coding for dystrophin; muscle cells collapse, resulting in severe muscle weakness

- Rarely, a mutation provides an advantage to health

  Example: A mutation protects some people against HIV; the receptor to which the virus binds is incomplete

Protection Against Mutation

- **DNA Repair:**

  Correction of a mismatched nucleotide by a Repair Enzyme

- Nature of genetic code:

  Since often 2 – 4 codons specify the same amino acid, some mutations would result in production of the same amino acid, which would not affect the protein

- Having 2 copies of each chromosome:

  If one copy is mutated, the other copy may provide enough of gene's normal function to maintain health