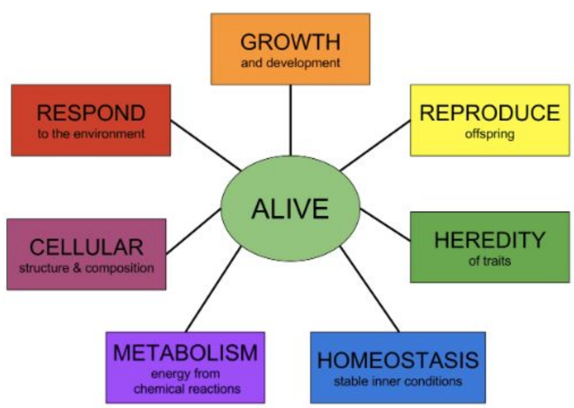
BIO1140: Cell Biology
Lecture 2: Introduction to Cell Biology:
Learning Outcomes: By the end of this class you should be able to:

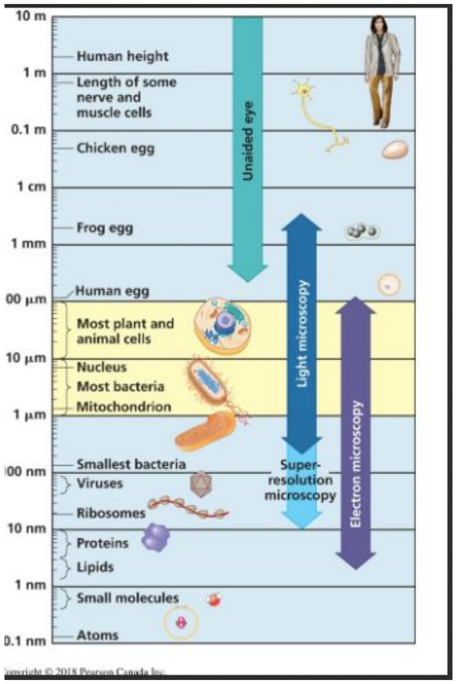
- Describe a set of characteristics that define living organisms
- Define a cell and list the characteristics common to all cells
- Name the two main types of cells and describe the characteristics that distinguish them
- Have an appreciation of the scale of cells and their organelles
- Name and describe the key tenets of cell theory
- Describe how life evolved into cells and how different types of cells evolved from these early cells, providing evidence for these theories
- Describe several different types of microscopes and be able to explain why/when you would use each as a biologist

- Biology is the study of life and living organisms:
    - But what is life?
    - Definition of biology is broad
    - Bio = all-encompassing field of study
    - Life is tricky to define
- All living organisms share several key characteristics or functions
    - Order (Different scale (monomers, how individual cells are organized in an organism), adapt/evolve (short term (stressor) and long term (evolution), grow and develop, homeostasis (internal stability), respond to the environment, process energy, and reproduce
    - However, since it is difficult to define what life is, here is another list
    - 

Biological Levels of Organization:

- A cell is the smallest collection of matter that can be alive. The cell is the fundamental unit of life.
- Biological levels:
    - Atoms, molecules, organelles, cells, tissues, organs and organ systems, organisms, populations and communities, ecosystems
- All below a cell comes together to form cells

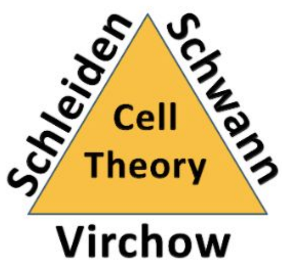
- To help us understand what is going on inside of an animal, it helps to look at the organism from a cells perspective

The Microscope:
- The unaided eye can see objects as small as 0.1 mm
- Most cells are too small to see without additional magnification. To observe them, we use a microscope
- 

Why are Cells Small?:
- The membrane which surrounds the cell allows for the passage of nutrients into and waste out of the cell
- A cell relies in large part on the diffusion of molecules throughout its interior for proper function
- As a cell increases in size, its volume (V) grows faster than its surface area (SA)
    - SA increases by a factor of n^2 but V increases by a factor of n^3
- Small cells have a greater surface area relative to volume allowing for effective metabolism
    - Therefore larger organisms typically have more cells rather than larger cells (smaller cells are more efficient)
    - Why aren't cells infinitely small - cells still need to have metabolic activity
- Diffusion - a process that has to happen in order for life to happen inside of cells (a process of how nutrients come inside of a cell and how the bad stuff leaves the cell

The Microscope:
- First compound microscope = 16^{th} century
- Key discoveries (the mid-1600's):
    - Robert Hooke - examined a thin section of cork and called the pores e observed cells

        - Cork is made from plants. Since the plant is dead, its cells are dead. He was right that there were be a living cell there, however he was examining the dried up cell wall.
    - Antonie van Leeuwenhoek - examined a drop of pond water and reported the presence of 'animalcules'
- The importance of cells wasn't truly recognized until the 1830's when the cell theory, a unifying principle of biology, was first put forward.

The Cell Theory:
- The cell theory states that:
    - All living organisms are composed of one or more cells
    - Cells are the basic structural unit of life
    - All life comes from pre-existing cells
- 

Many Types of Microscopes - Each with a Specific Application:
- In a light microscope (LM), visible light is passed through a specimen and then through a glass lenses
    - Lenses refract (bend) the light so that the image is magnified effectively up to ~1,000 times the size of the actual specimen
    - Resolution limit ~200 nm, most subcellular structures, including organelles are too small to be resolved by standard LM
    - The specimen is usually mounted on some sort of clear slide
    - Staining (dye) or the use of phase-contrast (optical modification to highlight different densities in the cell) can enhance the details of what we can see using light microscopy
    - This microscope doesn't allow us to see the small organelles, however, staining can usually help with this
    - The side effect of staining is usually staining kills the cells
- In fluorescence microscopy, a subtype of light microscopy, specific molecules are visualized with fluorescently-labelled dyes or antibodies
    - Allows for subcellular localization to be determined
        - E.g. nucleus (blue), mitochondria (orange), cytoskeleton (green)
- In confocal microscopy, a laser produces sharper images and allows 3D image reconstruction
    - Super-resolution techniques can further increase resolution to ~40nm
- To view subcellular structures, we must use the electron microscope

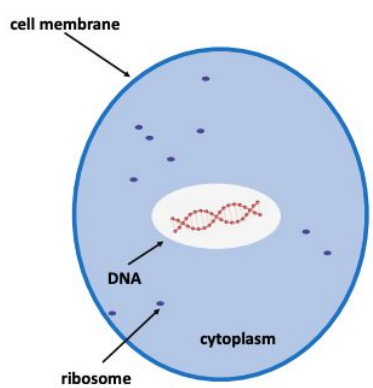
- Scanning electron microscopes (SEMs) focus a beam of electrons onto the surface of a specimen, providing 3D images
- Transmission electron microscopes (TEM) focus a beam of electrons through a specimen, to study internal structures
- Resolution limit ~50 pm

Origins of Life:

- Chemical and physical processes on early Earth may have produced very simple cells through a sequence of stages:
    - Abiotic (non-living) synthesis of small organic molecules
        - E.g. Amino acids and nitrogenous bases
    - Joining of these small molecules into macromolecules
        - E.g. Proteins and nucleic acids
    - The packaging of molecules into protocells (Precursor to cells (not yet living))
        - I.e. Fluid filled compartment enclose by a membrane-like structure
    - Origin of self-replicating molecules
        - E.g. RNA world hypothesis

All cells share four common characteristics:

- 1. Cell membrane - an outer covering that separates the cell's interior from its surrounding environment. Forms a boundary for the cytoplasm.
- 2. Cytoplasm - the jelly-like filling of the cell in which other cellular components are found. Fills the entire cells
- 3. DNA - the genetic material of the cell
- 4. Ribosomes - a complex molecule that synthesizes proteins



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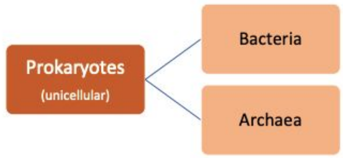
Categories of Cells:

- Prokaryotic cells are characterized as having:
    - No nucleus (pro = 'before', -kary = 'nucleus')
        - DNA in an unbound region called the nucleoid
    - No membrane-bound organelles
    - Cytoplasm bound by a plasma membrane

- Average size = 1-5 um
- 

- The earliest evidence of prokaryotic life ~3.5 billion years ago (stromatolites)

- Eukaryotic cells are characterized as having:
  - DNA in a nucleus bounded by a membranous nuclear envelope (eu = ‘true’, -kary = ‘nucleus’)
  - Membrane-bound organelles
  - Cytoplasm between plasma membrane and nucleus
  - Generally larger than prokaryotic cells, average 10-100 um.

Membrane-bound Organelles:

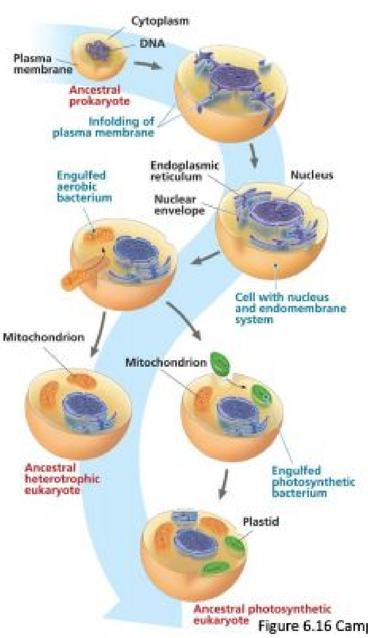
- Mitochondria are found in essentially all eukaryotic cells
- Chloroplasts are found in plants and algae
- Evolution of Eukaryotes:
  - Development of internal membranes
  - The endosymbiotic theory suggests that an early ancestor of eukaryotes engulfed an aerobic (oxygen-using) non-photosynthetic prokaryote
    - The engulfed prokaryotic was maintained within the host cell and became an endosymbiont, eventually evolving into a mitochondrion
  - A second endosymbiotic event involved a photosynthetic prokaryote being engulfed by a eukaryote containing mitochondria
    - This endosymbiont evolved into a chloroplast
  - 

Figure 6.16 Campbell Biology

Evidence for the Endosymbiont Theory:

- Mitochondria and chloroplasts resemble bacteria in numerous ways:
  - Size is about the size of a prokaryote
  - Bound by two outer membranes
  - Grow and reproduce independently in cells using prokaryotic-like mechanisms
  - Contain their own circular DNA molecules
  - Contain free ribosomes to synthesize protein

On the Border of Life - Viruses:

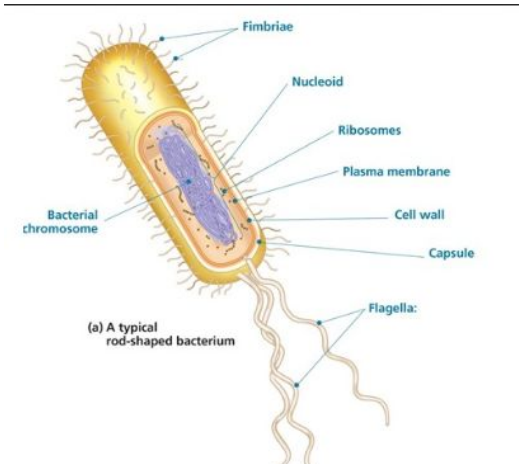
- Viruses are tiny protein capsules that contain nucleic acid structures. They seem to have many of the properties of life but…
  - They do not have a cellular structure (no outer membrane)
  - They do not maintain homeostasis
  - They don't carry out their own metabolism
  - They cannot reproduce without a host

Lecture 3: Complete Cell Parts Catalogue.

Learning Outcomes: By the end of this class, you should be able to:

- Identify and explain the function of the following cell parts:
  - Nucleus, nucleolus, centrosome, cytoskeleton, rough ER, smooth ER, Golgi apparatus, lysosome, ribosome, plasma membrane, peroxisome, central vacuole, mitochondria, chloroplast, flagellum, cell wall.
- Describe where you would find each of the above cell parts (cell type and subcellular localization)
- Identify one human or plant disease in which each cell part is affected.

Prokaryotic Cell:



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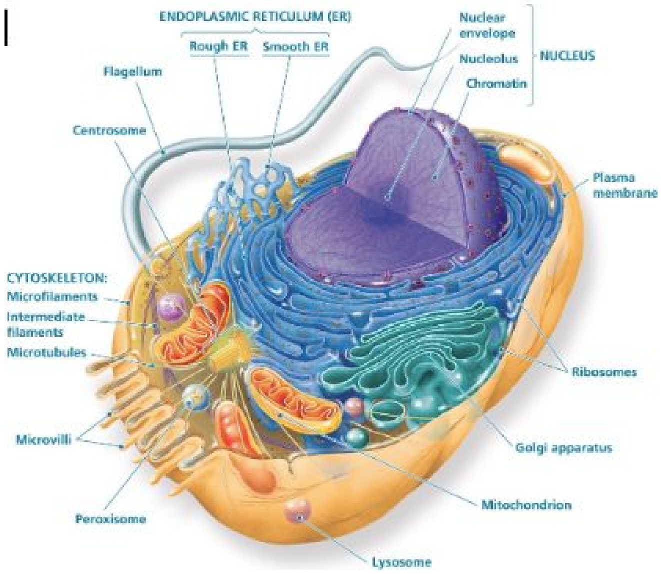
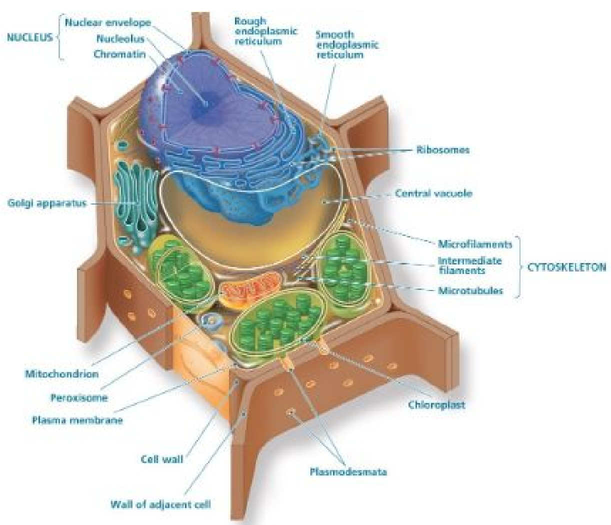
Animal Cell:

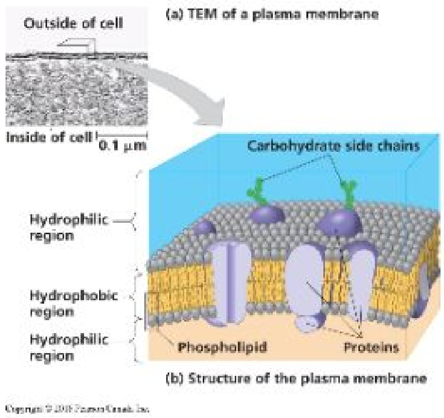
- 

Plant Cell:

- 

Plasma Membrane:

- Found in all cells
- Location - very thin barrier, consisting of a lipid bilayer and associated proteins, which separates the internal and external environments of the cell
- Function - the semipermeable lipid bilayer, allows the passage of sufficient amounts of oxygen, nutrients, and waste to support the cell volume. Also plays a key role in cell communication, cell adhesion and cellular structure



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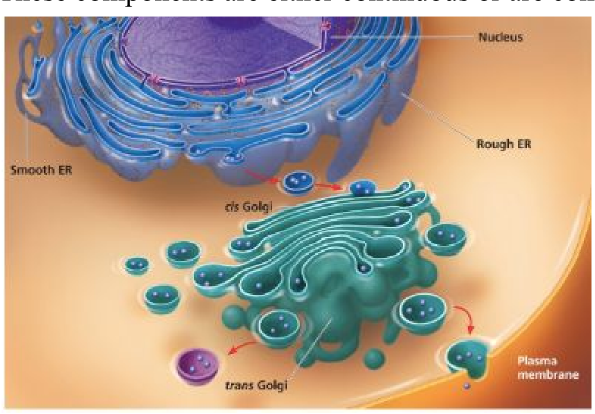
- Dysfunction - cystic fibrosis (CF)
    - In CF, a membrane channel which transports chloride ions across the plasma membrane is defective and leads to changes in water balance in the cell. As a result, affected individuals make very thick sticky mucus which negatively affects breathing and digestion
    - Changes in the lipid composition of cell membranes has also been identified and implicated in many neurodegenerative diseases including Alzheimer's and Parkinson's disease

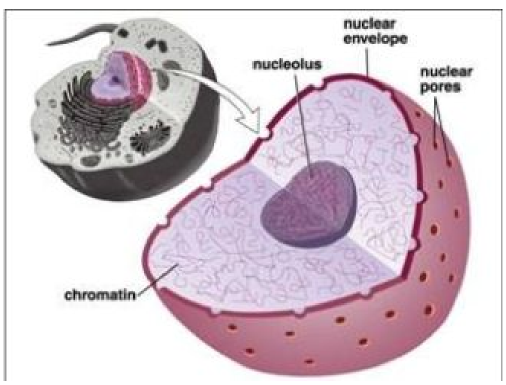
The Endomembrane System:

- The endomembrane system is a complex and dynamic player in the cell compartmental organization
- Components of the endomembrane system include:
    - Nuclear envelope, endoplasmic reticulum, Golgi apparatus, lysosomes, vacuoles, plasma membrane
- These components are either continuous or are connected indirectly via vesicles
- 

Nucleus:

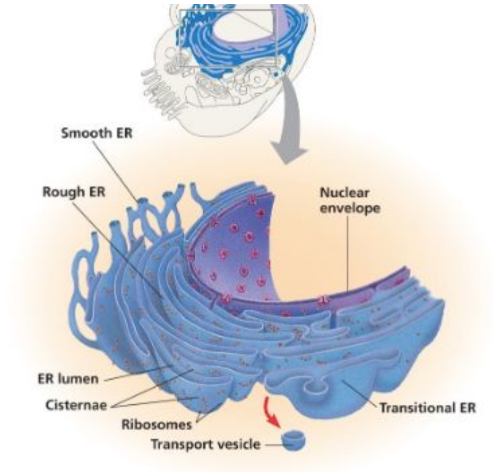
- Found in all eukaryotic cells
- Location:
  - Within the cytoplasm, it is the most visible organelle inside of the cell
  - The nuclear envelope encloses the nucleus and is a double membrane (each consists of a distinct lipid bilayer)
  - Pores regulate entry and exit of molecules from the nucleus
  - The nuclear lamina, a protein matrix, helps maintains its shape
- Function:
  - The nucleus contains most of the cell's genetic material
    - Within the nucleus, the deoxyribonucleic acid (DNA, that contains these genes) is organized into discrete units called chromosomes
- Dysfunction:
  - Hereditary diseases (aka - genetic diseases) arise due to changes in the DNA housed in the nucleus
    - One example is Down syndrome, which occurs when there is a third copy of chromosome 21

Nucleolus:



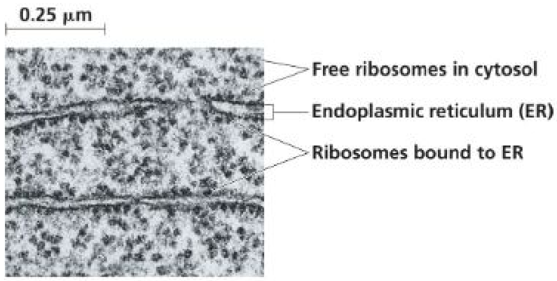
- Found in all eukaryotic cells
- Location - a visible density within the nucleus, it is not membrane bound
  - Its appearance differs across the cell cycle
  - It is composed of the rRNA genes, rRNA (ribosomal ribonucleic acid) and associated proteins
- Function: the nucleolus is the site of rRNA synthesis and ribosome assembly
- Dysfunction: Given its role in generating all of the cell's protein (via the ribosomes it manufactures), nucleolar stress often leads to induction of programed cell death. If cell death does not occur, cancer may develop

Endoplasmic Reticulum (ER):

- 

- The ER is the biosynthetic factory of the cell.
- It is found in all eukaryotic cells
- Location - the ER is a membranous structure found within the cytoplasm
  - The ER membrane is continuous with the nuclear envelope
  - ER accounts for more than half of the total membranes in many eukaryotic cells
  - Its internal compartment is known as the ER lumen
- The ER has two distinct structural regions:
  - Smooth ER, which lacks ribosomes
  - Rough ER, the surface is studded with ribosomes
- Functions of the Smooth ER:
  - Synthesizes lipids, metabolizes carbohydrates, detoxifies drugs and poisons, stores calcium ions
- Functions of the Rough ER
  - Has ribosomes on its outer surface, which synthesizes proteins and glycoproteins (proteins modified with covalently linked carbohydrates)
    - This includes: proteins of the endomembrane system, proteins that will be embedded in the outer cell membrane, and proteins to be secreted from the cell (e.g protein hormones, enzymes)
  - Produces transport vesicles, which distribute lipids and proteins to other components of the endomembrane system
    - The ER is a "membrane factory" for the cell
- Dysfunction of the ER:
  - There are a number of ER-related disorders, most occur due to improper protein folding. When there is an accumulation of misfolded proteins, it overwhelms the quality control centre of the rough ER
  - One example is Huntington's disease which is caused by the misfolding of the Huntingtin protein (HTT). Accumulation of HTT leads to neuronal death.

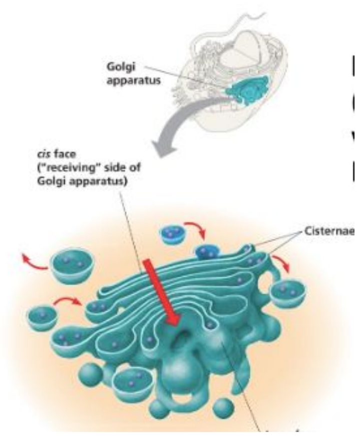
Ribosomes:

- 

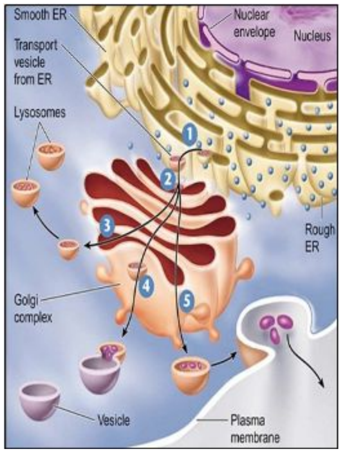
TEM showing ER and ribosomes

- Ribosomes are small complexes made up of both rRNA and protein. They are not membrane bound
- Found in all cells (eukaryotic and prokaryotic)
- Location:
  - In the cytosol as free cytosolic ribosomes (all cells)
  - On the surface of the endoplasmic reticulum as ER-bound ribosomes (eukaryotes only)
  - They are also found within mitochondria and chloroplasts (eukaryotes)
- Function:
  - Carry out protein synthesis. This is the translation of RNA into protein
- Dysfunction:
  - Collectively the diseases which arise due to impaired ribosome development and/or function are known as ribosomopathies
    - E.g. dyskeratosis congenital

Golgi Apparatus:

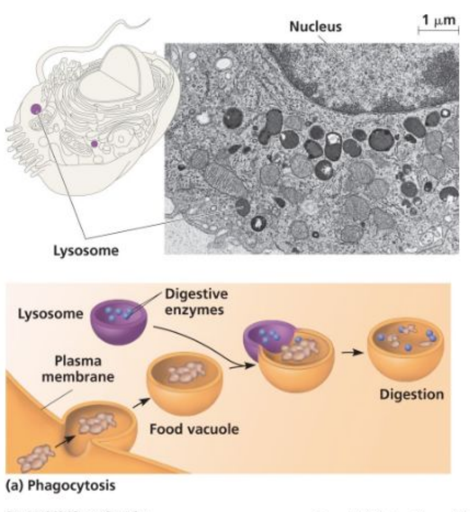
- 

- The Golgi apparatus (also called the Golgi body) is the shipping and receiving center of the cell
- It is found in all eukaryotic cells
- Location: it is a series of flattened membranous sacs (imagine a stack of pita bread) called cisternae found within the cytoplasm, is generally in proximity to the ER
- Travel Through the Golgi Apparatus:

    - 

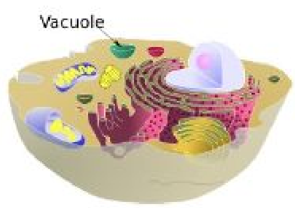
    - The receiving side of the Golgi apparatus is called the cis face (#2 in the diagram); the opposite side is the trans face (#4/5)
    - Transport vesicles from the ER (#1) fuse with the cis face and empty their contents into the lumen of the Golgi apparatus
    - As the proteins and lipids travel through the Golgi, they are further modified so they can be sorted and packaged accordingly (#3,4 or 5)
- Function:
    - Modifies products from the ER
        - E.g. glycosylation - adding carbohydrate groups to proteins and lipids
    - Manufactures some macromolecules (mainly carbohydrates)
    - Sorts and packages materials into transport vesicles
- Dysfunction: Achondrogenesis Type 1A
    - A genetic mutation leads to the production of a non-functional protein required for normal Golgi apparatus structure and function
    - Chondrocytes, cells which produce cartilage, are most strongly affected by this mutation which leads to severely impaired cartilage and bone formation

Lysosomes:

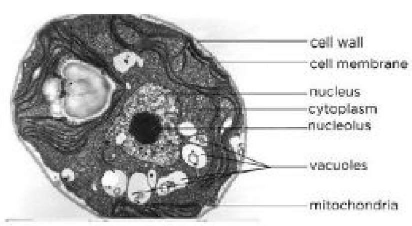
- 

- Lysosomes are the digestive compartment within the cell.
    - The appearance (size/number/shape) of lysosomes can be highly variable
- They are found in all eukaryotic cells
    - There has been some debate about their existence in plant cells but current evidence indicates that they are present although they are thought of as specialized vacuoles that carry out lysosome-like functions
- Location: membrane-bound compartment within the cytoplasm
    - The specific properties of this membrane allow the lysosomal compartment to be more acidic than the rest of the cell
- Function: Digestion via enzymatic hydrolysis of macromolecules (proteins, fats, polysaccharides, and nucleic acids)
    - Some cells can engulf another cell by phagocytosis; forming a food vacuole
    - A lysosome fuses with the food vacuole and digests the molecules inside of it
- Lysosomes also recycle the cell's own organelles and macromolecules in a process called autophagy ('auto' = self, 'phagy' = eating)
- Dysfunctions:
    - There are many lysosomal storage disorders most of which arise from genetic defects that produce non-functioning or poorly functioning lysosomal enzymes
    - The most severe form is I-cell disease in which specific cell types have lysosomes devoid of almost all hydrolytic enzymes
        - In these cells, digestion of macromolecules does not occur and the material that should have not been broken down instead accumulates and forms visible inclusions in the cell

Vacuoles:



Sketch of a Vacuole in an Animal Cell (https://en.wikipedia.org/wiki/Vacuole)



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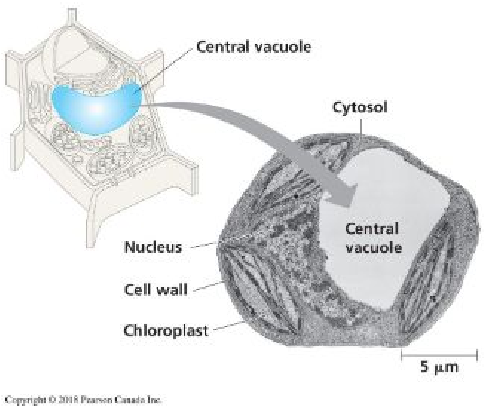
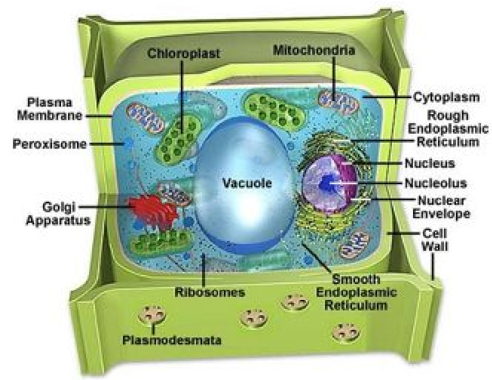
- Found in all eukaryotic cells
    - Plant = one large central vacuole (most of the volume of the cell)
    - Animal = many smaller vacuoles

- Location: Membrane-bound structure found within the cytoplasm, they are derived from the ER and Golgi (endomembrane system)
- Function: predominantly storage but varies by cell type
  - Food vacuoles are formed by phagocytosis
  - Contractile vacuoles (protists), pump excess water out of cells
  - Central vacuoles (plant cells) hold organic compounds and water





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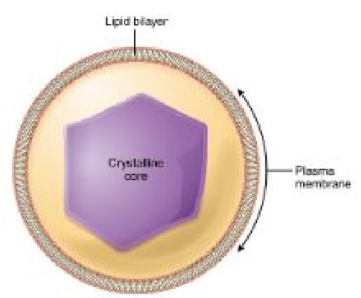
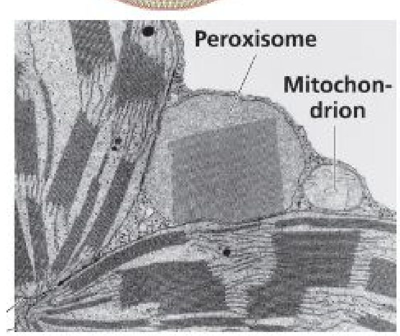
- Dysfunction: Danon's disease (occurs in humans)
  - In affected individuals, the fusion of vacuoles to lysosomes occurs very slowly. This means that the number of vacuoles in each cell is abnormally high
    - Accumulation of vacuoles in the cell, resulting in the breakdown of muscle cells, which can have a fatal effect as the heart muscles are affected

Peroxisomes:





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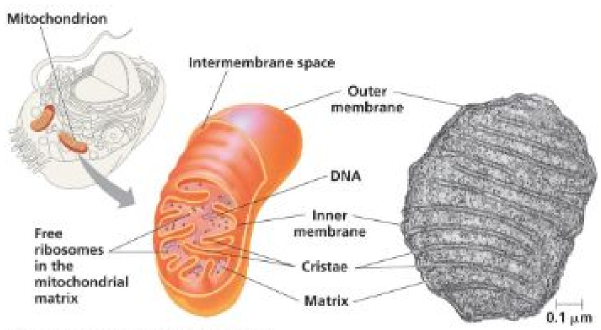
- Peroxisomes are specialized metabolic compartments
  - Their origin and relation to other organelles remains unclear

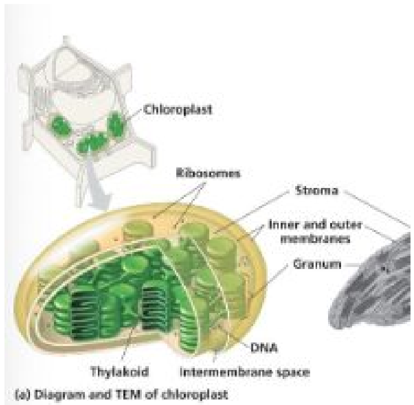
- Found in virtually all eukaryotic cells
- Location: found within the cytoplasm, they are surrounded by a single membrane
- A crystalloid enzyme core is apparent in some peroxisomes
- Function:
    - Peroxisomes break down organic molecules by the process of oxidation to produce hydrogen peroxide
        - Hydrogen peroxide is in turn quickly converted to oxygen and water
    - Peroxisomes perform reactions with many different metabolic functions
        - E.g breakdown of fatty acids and amino acids necessary to produce other biomolecules such as cholesterol and phospholipids
- Dysfunction: Zellweger syndrome:
    - A metabolic disorder in which peroxisomes fail to develop or are non-functional. This results in significant impairments to nervous system development due to low myelin production

Mitochondria:



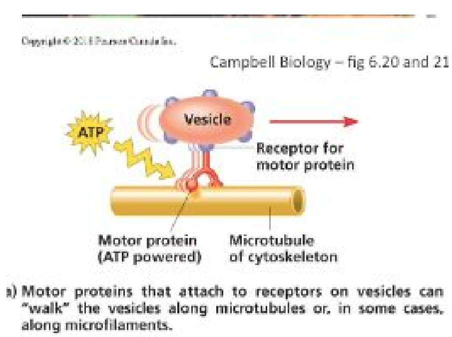
- (a) Diagram and TEM of mitochondrion
- They are found in virtually all eukaryotic cells
- Location: they are a double membrane-bound organelle found within the cytoplasm
    - The outer membrane is smooth and the inner membrane folds into cristae increasing its surface area
    - The inner membrane creates two aqueous compartments: intermembrane space and the mitochondrial matrix
- Function: they carry out cellular respiration, a metabolic process that converts stored energy (macromolecules) to ATP using oxygen
- Dysfunction: Congenital Lactic Acidosis:
    - A mutation in the mitochondrial DNA causes mitochondrial enzyme deficiencies which affect the ability of cells to metabolize carbohydrates and fats, ultimately producing a build up of lactic acid in the body

Chloroplasts:

- 

- Chloroplasts capture light energy
- They are found in plants and algae
- Location: found within the cytoplasm, chloroplasts are surrounded by two membranes
    - The internal compartment is filled with an aqueous solution called the stroma
    - The internal thylakoid membranes contain chlorophyll and form membranous sacs
        - Thylakoids are interconnected and stacked to form grana
        - Inside of the thylakoids is a compartment called the thylakoid lumen
- Function: Carry out photosynthesis:
    - A metabolic process that uses the energy from sunlight to fix carbon (from CO_2) and uses it to generate energy-rich organic molecules such as glucose
- Dysfunction: Leaf chlorosis:
    - Insufficient chlorophyll is produced, resulting in reduced photosynthetic activity and altered pigmentation (pale, yellow or white leaves)
    - Leaves ultimately die as they are unable to produce sufficient carbohydrates

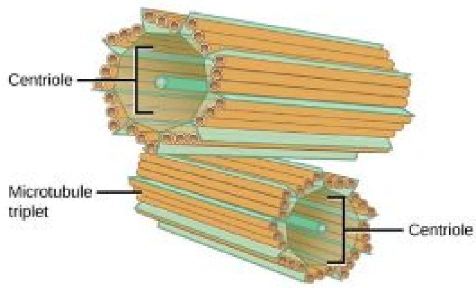
Cytoskeleton:

- 

- The cytoskeleton is a network of protein fibres that extend throughout the cytoplasm
- All cells have a cytoskeleton (prokaryotes and eukaryotes)
- Function:
    - It organizes the cell's structures and activities, anchoring many organelles
    - It helps to support the cell and maintain its shape
    - The cytoskeleton interacts with motor proteins to produce cell motility
    - Inside the cell, vesicles can travel along cytoskeleton "tracks"

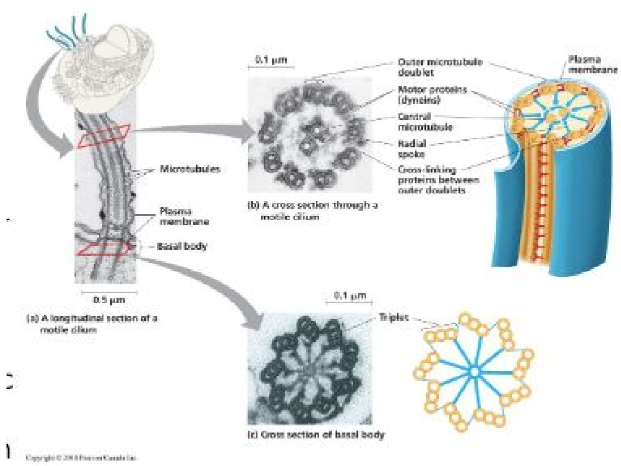
- Dysfunction: Alzheimer’s Disease:
    - Neurofibrillary tangles arise when the Tau protein, which normally stabilizes the microtubule component of the cytoskeleton becomes phosphorylated and dissociates, destabilizing the microtubules
    - This leads to impaired transport and communication in the cell and ultimately death

Centrosome and Centri:

- 

- Another important function of the microtubule component of the cytoskeleton is chromosome separation during cell division
- In many animal cells, microtubules grow out from a centrosome near the nucleus
- The centrosome is known as the “microtubule-organizing center”
    - In animal cells, the centrosome consists of a pair of centrioles at right angles to one another
    - Most plant cells do not have centrioles, instead, microtubules originate from many small nucleation sites within the cytoplasm
- Dysfunction: linked with cancer:
    - Increase in centrosome number lead to abnormal mitotic spindle formation and ultimately chromosome instability. Chromosome instability in turn causes may cancers including breast, prostate, colon, and brain cancers

Cilia and Flagella:



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- Microtubules control the beating of cilia and flagella, locomotor appendages which protrude from some eukaryotic cells (e.g. spermatozoa)
- Abnormal flagellar morphology affects sperm motility and can contribute to male factor infertility
- Cilia and flagella share a common structure:
    - A core of microtubules encased by the plasma membrane
    - A basal body that provides an anchor
    - A motor protein called dynein that drives the bending movements
- They are different from prokaryotic flagella which are composed of a protein called flagellin and move in a rotary pattern

Cell Wall:

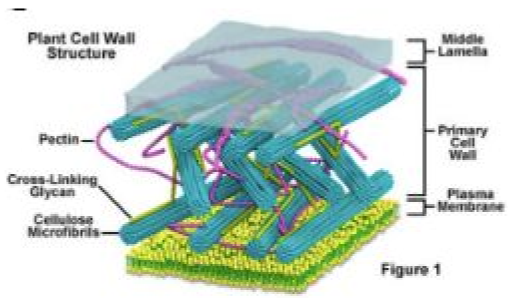


Figure 1

- https://micro.magnet.fsu.edu/cells/plants/cellwall.html
- The cell wall is an extracellular structure that distinguishes plant cells from animal cells
- Prokaryotes, fungi and some protists also have cell walls
- The prokaryotic cell wall is made up of peptidoglycan (a polymer of sugar and amino acids)
- Plant cell walls are made of cellulose (a type of polysaccharide) embedded in other polysaccharides and protein
- Function: cell wall protects, maintains shape, and prevents excessive uptake of water in plant cells
- Dysfunction: Bacterial soft rot occurs when plants are infected with a bacteria which secretes pectolytic enzymes that can break down its cell wall. They do this in order to digest the intracellular contents of the plant, fueling its own bacterial growth.

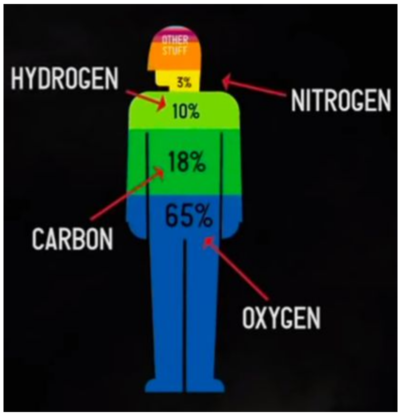
Lecture 4: The Chemistry of Life

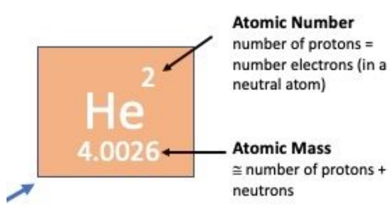
Learning Outcomes: By the end of this class, you should be able to:

- Identify the elements necessary for life and discuss their relative abundance
- Describe the types of chemical bonds present in macromolecules and explain the importance of each within a biological context
- Appreciate and be able to describe the importance of water in biology
- Explain the importance and function of buffers
- Name the 4 main classes of macromolecules and identify their biological functions
- Know the individual building blocks for each class of macromolecules and describe how they assemble to form these macromolecules

- Recognize the chemical properties underlying the structure of macromolecules and explain the importance of this structure in determining the function and localization of the macromolecule within the cell

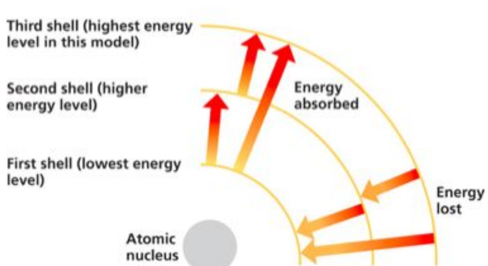
Organisms are composed of matter which is composed of elements:

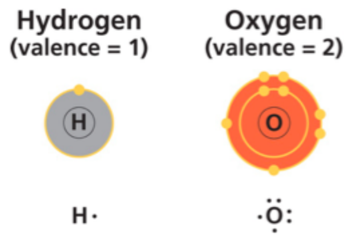
- 

- 96% of living matter is made up of 4 elements:
  - Oxygen (65%) > Carbon (18%) > Hydrogen (10%) > Nitrogen (3%)
- The remaining 4% is other stuff:
  - Calcium, phosphorus, magnesium, potassium, chlorine, sulphur, sodium,
- A number of trace elements (less than 0.01%) are required for life, including
  - Iron - necessary for O_2 transport as part of hemoglobin
  - Iodine - necessary for hormone production in the thyroid
  - Copper - necessary for many metabolic enzymes (e.g. cytochrome c oxidase)
- The properties of an element depend on the structure of its atoms
  - 

  - An atom is the smallest unit of matter that retains the properties of an element

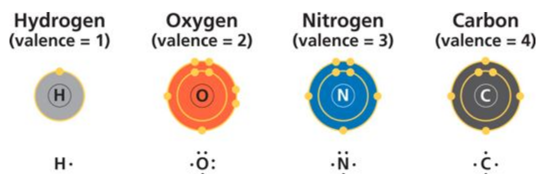
Electron Distribution and Energy:

- 



- The electrons in each atom are organized into shells, each a characteristic distance from the nucleus
    - Electrons in each shell possess different potential energy
        - I.e potential to do work
    - Closer to the nucleus = less energy
- The chemical properties of an atom are determined by its electron distribution

Electrons determine how atoms interact:



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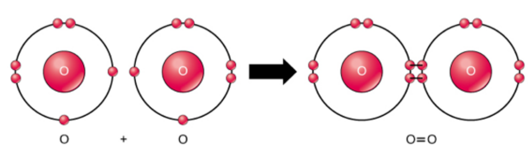
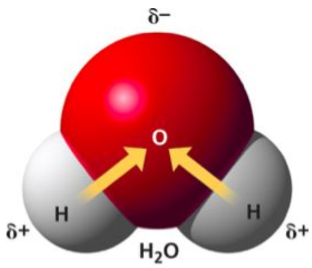
- When atoms approach each other in a chemical reaction, it is their electrons which interact with one another, specifically the electrons in their outer shell or valence
- Chemical reactions are changes in the distribution of electrons between atoms
    - Chemical bond: the attractive force that links atoms together forming molecules
        - Atoms with a complete outer valence = inert
        - Atoms with an incomplete valence = reactive (trying to achieve a complete outer valence)

Covalent Bonds:

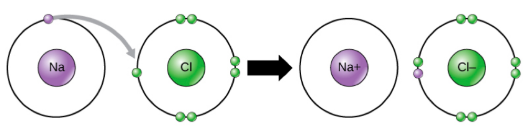


- A covalent bond is the sharing of a pair of valence electrons by two atoms
- In a covalent bond, shared electrons count as part of each atom's valence shell
- More than one set of electrons can be shared
    - E.g. double bond is seen in O_2
- Atoms in a molecule attract electrons to varying degrees
- Electronegativity refers to an atom's attraction for the electrons in a covalent bond

- The more electronegative an atom is, the more strongly it pulls shared electrons towards itself
- There are two different types of covalent bonds:
    - Nonpolar covalent bonds where atoms share electrons equally
    - Polar covalent bonds where one atom is more electronegative and the atoms do not share electrons equally
- The presence of polarized bonds relates to the reactivity of molecules
- 

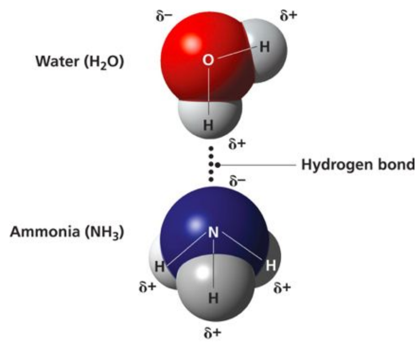
Bonds Have Different Strengths:
- Covalent bonds are strong bonds
    - Strong bonds are very important -> they allow atoms to form molecules but they take energy to break
- The attraction between molecules or parts of a large macromolecule are generally governed by weaker noncovalent bonds

Ionic Bonds:

- 

- Ionic bonds are formed when valence electrons are given up or gained by bonding partners in a compound
    - This occurs when the attraction for an electron is significantly different between atoms

Hydrogen Bonds:



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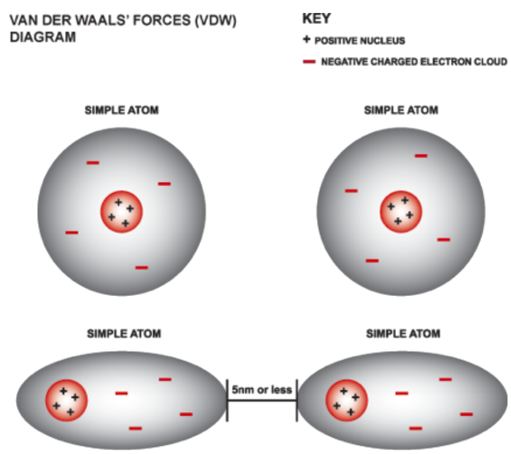
- A hydrogen bond forms when a hydrogen atom covalently bound to an electronegative atom is also attracted to another electronegative atom
- In living cells, electronegative partners are usually oxygen or nitrogen

Van der Waals Interactions:

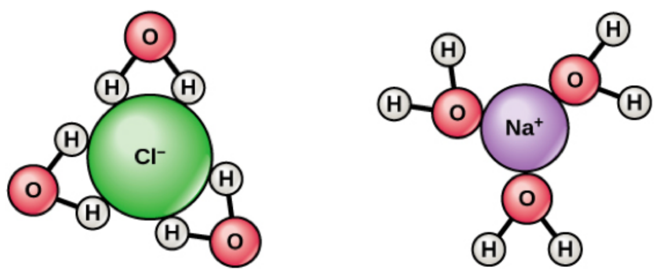


- When two atoms come within 5 nanometers of each other, there will be a slight interaction between them, thus causing polarity and a slight attraction.
- Asymmetrically distributed electrons in molecules or atoms can result in momentary "hot spots", or dipoles, of positive or negative charges
- Van der Waals interactions are attractions that occur between molecules which are physically close to one another that arise due to these momentary dipoles
- Van der Waals attractions are strong enough to allow a gecko to walk up a wall. Their attractions are so strong that they can hold a significant mass

Bonds Have Different Strengths:

- Covalent > Ionic > Hydrogen > Van der Waals
- Why are weak bonds important?:
  - They:
    - Reinforce the shapes of molecules
    - Help molecules adhere to each other
    - Their reversibility can be advantageous
  - Weak chemical bonds 'add up'

Water:

- Is the most critical molecule for life
    - The human body is 60-70% water
- Why?
    - The chemical bonds between hydrogen and oxygen within the water are polar covalent bonds
    - All 3 atoms in a water molecule can form hydrogen bonds
- These hydrogen bonds underlie water's various biological functions, including:
    - Its ability to adopt different states
    - Its heat capacity/heat of vaporization
    - Its cohesive properties (surface tension)
    - Its solvent properties
- Water is the solvent of life:
    - Water can dissolve more substances than any other solvent
    - The compounds dissolved or mixed in with the water are the solute
        - Ions (e.g. NaCl) and polar (e.g. sugar) molecules can dissolve in water
            - When table salt (NaCl) is mixed in water, spheres of hydration are formed around the individual ions separating them
        - 

        - Non-polar molecules (e.g. proteins) can also dissolve in water if they have polar or ionic regions

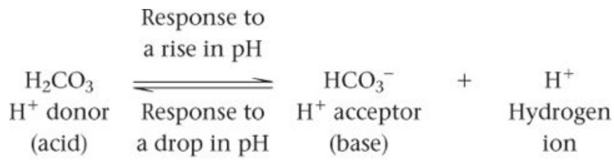
Hydrophobic Interactions:

- When mixed together, nonpolar molecules will cluster together to reduce contact with polar molecules
- Hydrophobic interactions are used to describe this relationship between the:
    - Polar; hydrophilic ("hydro" = water and "philic" = loving) molecules
    - Non-polar, hydrophobic ("hydro" = water "phobic" = fearing) molecules
- This isn't a true bond type, but biologically it is a very important type of interaction

Acids, Bases and pH:

- The pH scale is used to describe whether a solution is acidic or basic
    - Solutions with high H^+ concentration are acidic
    - Solutions with high OH^- concentration are basic
- Water is in a state of dynamic equilibrium where its molecules dissociate at the same rate they are being formed
    - $H_2O_{(l)}$ <-> $H^+_{(aq)}$ + $OH^-_{(aq)}$
    - Therefore the concentrations of H^+ and OH^- are equal in pure water

- Adding acids or bases to water will modify the concentrations of H^+ and OH^-
- Most biological fluids (including the environment of the cell) have pH values in the range of 6 to 8
- Buffers minimize changes in concentrations of H^+ and OH^- in a solution
  - Buffers contain a weak acid and corresponding base, which combine reversibly with H^+ ions



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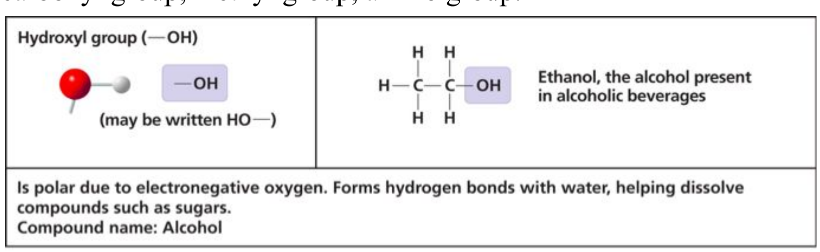
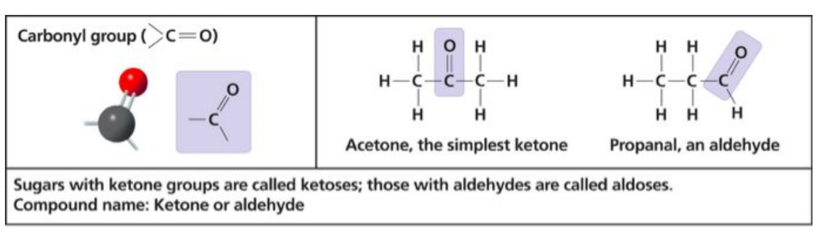
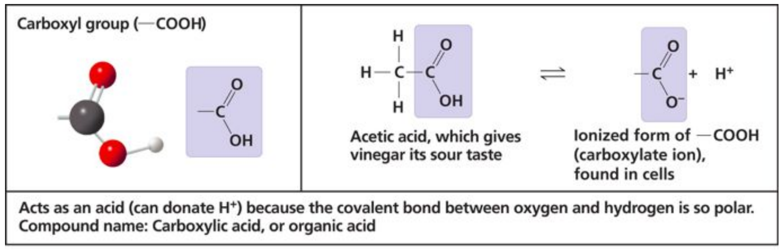
Carbon:

- The chemistry of life centers around carbon
- Simplest organic molecules are the hydrocarbons
- Most biomolecules are not hydrocarbons, they contain other functional groups
- Functional groups:
  - Functional groups are the components of organic molecules involved in chemical reactions:
    - They typically have one or more electronegative atom
    - The number and arrangement of functional groups give organic molecules their unique properties
  - These seven functional groups are the most important in the chemistry of life:
    - Hydroxyl group, a sulfhydryl group, a carbonyl group, a phosphate group, a carboxyl group, methyl group, amino group.
    - 

    - 



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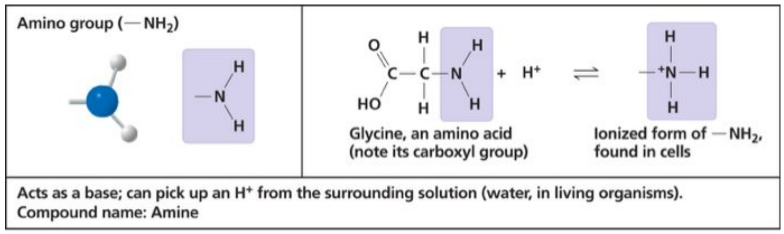

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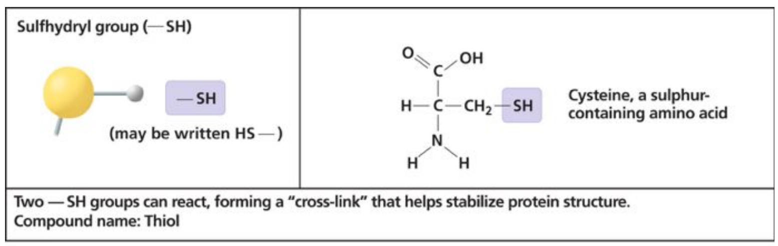

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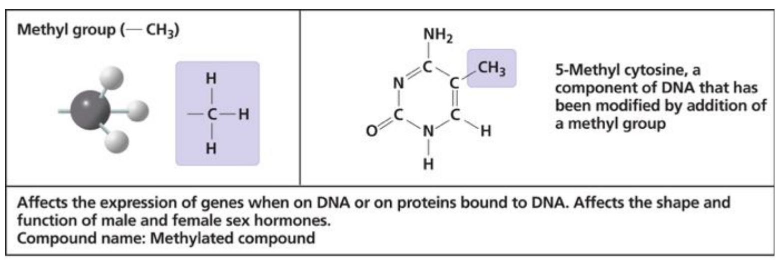

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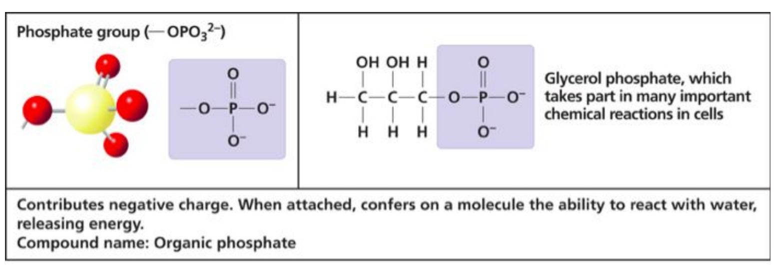

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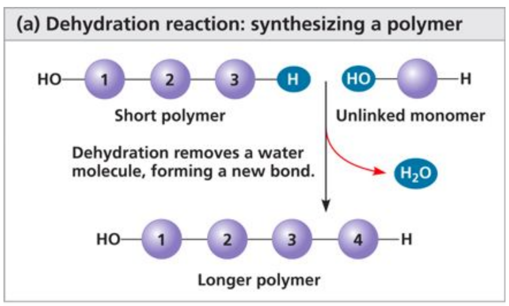
- Macromolecules are the large carbon-based molecules that carry out the functions of life
  - Their molecular structure and function are inseparable
- Macromolecules are divided into four major categories:
  - Carbohydrates, lipids, proteins and nucleic acids

The diversity of Macromolecules:

- Each cell has thousands of different macromolecules
    - Macromolecule content varies among cell types, varies more between individuals of a species and even more between different species
- An immense variety of macromolecules can be built from a small set of organic building blocks
    - Ultimately the distinctive properties of each macromolecule come down to its:
        - Carbon skeleton
        - The functional groups attached to it

Building Macromolecules:

- Three of life's macromolecules are polymers:
    - Carbohydrates (polysaccharides), proteins, and nucleic acids
- A polymer is a long molecule consisting of many similar building blocks
- The smaller, repeating molecules that serve as building blocks are called monomers
- Monomers are joined together via a dehydration or polymerization reaction
- Polymers can be broken back down into its component monomers by a hydrolysis reaction



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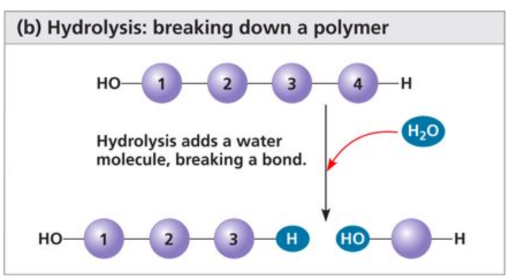

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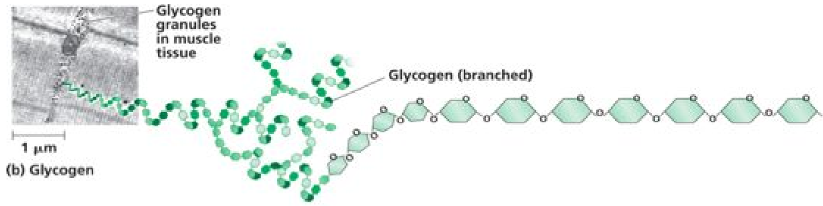
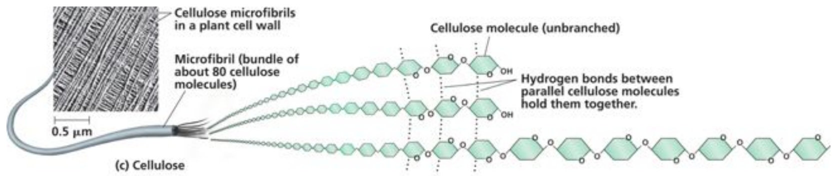
Carbohydrates:

- Include simple sugars (monosaccharides) and the polymers (polysaccharides) built from them
    - The structure and function of a polysaccharide is determined by:
        - Its sugar monomers
        - The positions and types of bonds connecting them
    - Carbohydrates provide the cell with chemical energy and have many storage and structural roles
    - Example: Polymers of glucose:
        - Glycogen is a major energy store in animal cells

- Cellulose is a major component of plant walls
- 

- 

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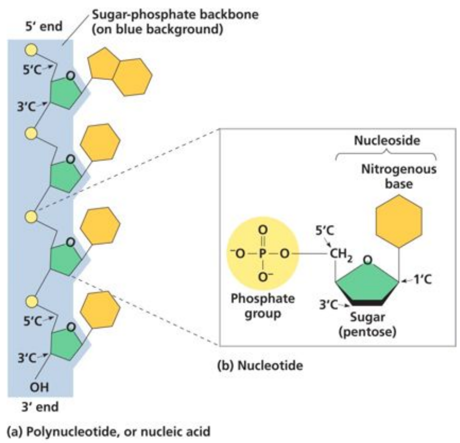
Nucleic Acids:

- Nucleic acids are polymers call polynucleotides
- Each polynucleotide is made of monomers called nucleotides
- There are two types of nucleic acids
    - Deoxyribonucleic acid (DNA)
    - Ribonucleic acid (RNA)



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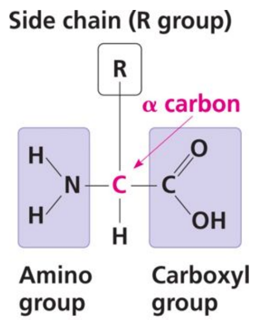
Proteins:

- A protein is a biologically functional molecule that consists of one or more polypeptides
    - Polypeptides are unbranched polymers composed of amino acid monomers
- Protein makes up more than 50% of the dry mass of most cells
- The function of proteins in the cell are vast and include:
    - Catalyzing chemical reactions (enzymes)
    - Structural support
    - Storage
    - Transport
    - Cellular communications
    - Movement
    - Defence against foreign substances

- Protein structure and function:
    - Polypeptides range in length from a few to more than a thousand amino acids
    - The sequence of amino acids determines a protein's three-dimensional structure
    - Protein structure determines its function
        - Function usually depends on the ability to recognize and bind other molecules
- Amino acid monomers:
    - Amino acids are organic molecules with carboxyl and amino groups
    - All proteins are polymers constructed from the same set of 20 amino acids
    - Amino acids differ in their properties due to differing side chains, called R groups



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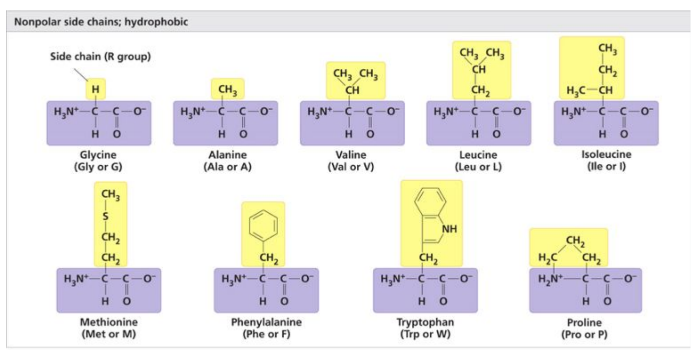
    - Nonpolar amino acids:



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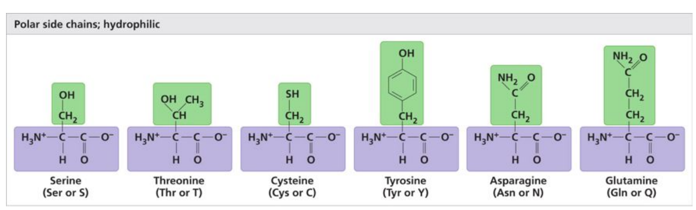
    - Polar amino acids:



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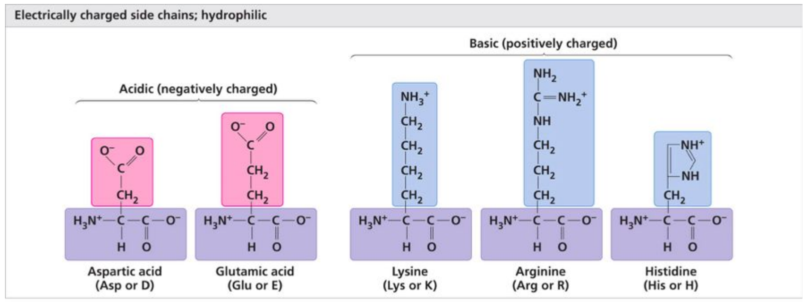
    - Electrically Charged Amino Acids:



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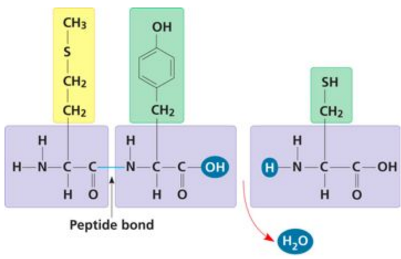
- Proteins - Primary Structure:
  - Primary structure, the sequence of amino acids, is much like the order of letters in a long word
    - Amino acids are joined by peptide bonds
  - The primary structure is determined by inherited genetic information



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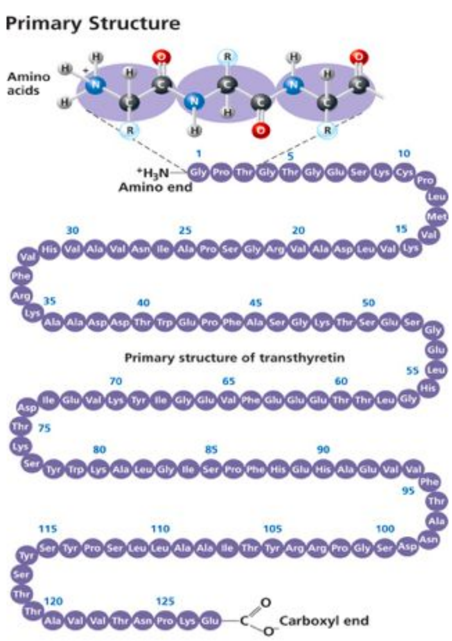

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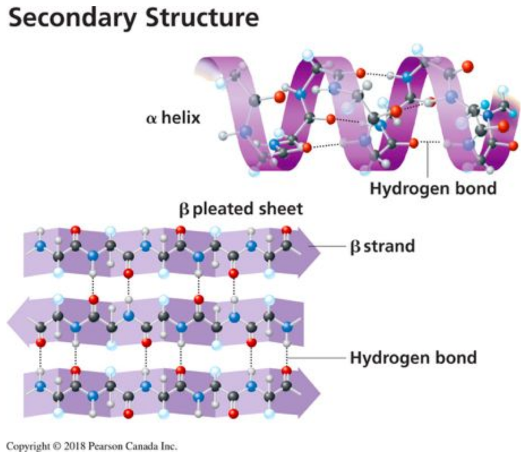
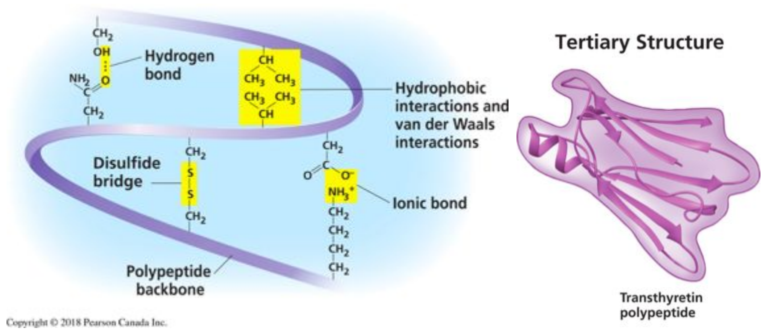
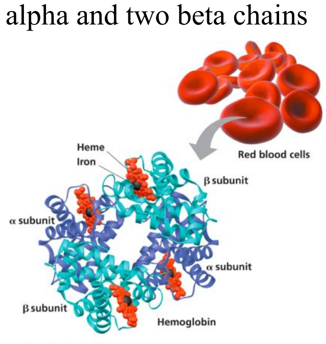
- Proteins - Secondary Structure:
  - Secondary structure results from hydrogen bonds between the constituents of the peptide backbone
  - Typical secondary structures include:
    - Coil called an alpha helix

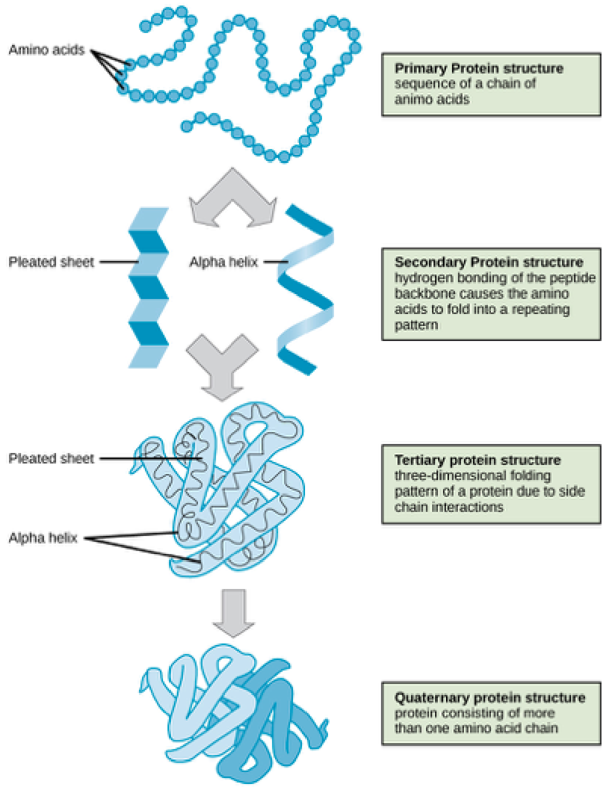
        - A folded structure called a beta pleated sheet

    - 

- Proteins - Tertiary Structure:
    - Tertiary structure is the overall shape of a polypeptide. It is determined by the interactions between the R groups of the amino acids
    - Interactions between R groups include hydrogen bonds, ionic bonds, hydrophobic interactions and Van der Waals interactions
    - Strong covalent bonds called disulphide bridges to reinforce the protein’s structure
    - 

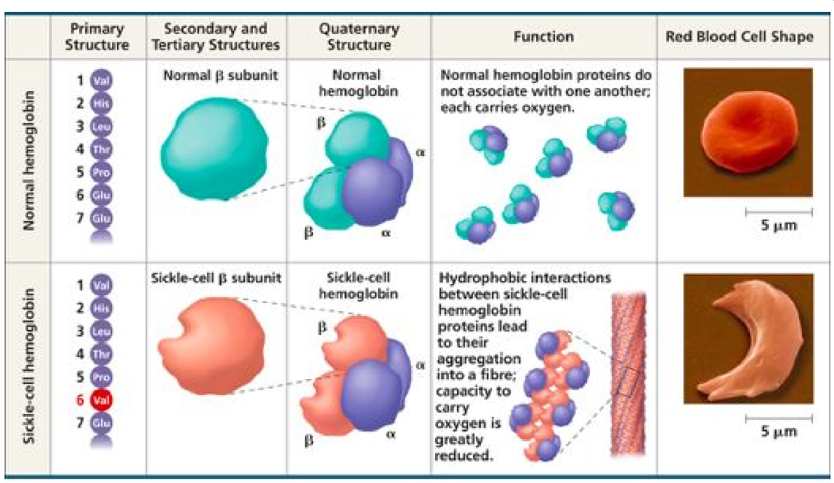
- Proteins - Quaternary Structure
    - Quaternary structure develops when two or more polypeptide chains form one macromolecule
        - Example: Hemoglobin is a globular protein consisting of four polypeptides: two alpha and two beta chains
        - 

- Putting all the pieces of protein structure together:
    - The four levels of protein structure can be observed in this illustration



Sickle-Cell Disease:

- A change in primary structure can affect a protein's structure and function
- The sickle-cell disease results from an amino acid substitution in hemoglobin



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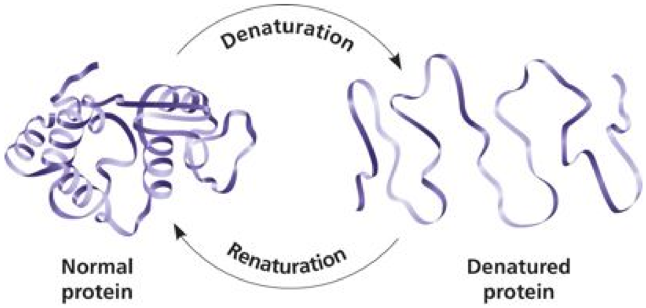
What else determines protein structure?:

- In addition to primary structure, physical and chemical conditions can affect protein structure
- Alterations in pH, salt concentration, temperature, or other environmental factors can cause a protein to denature or unravel
    - Denatured proteins are biologically inactive

- Improper protein structure is implicated in many diseases
  - E.g. Alzheimer’s and mad cow disease



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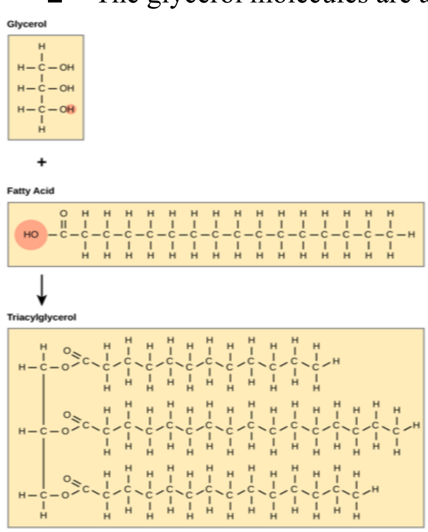
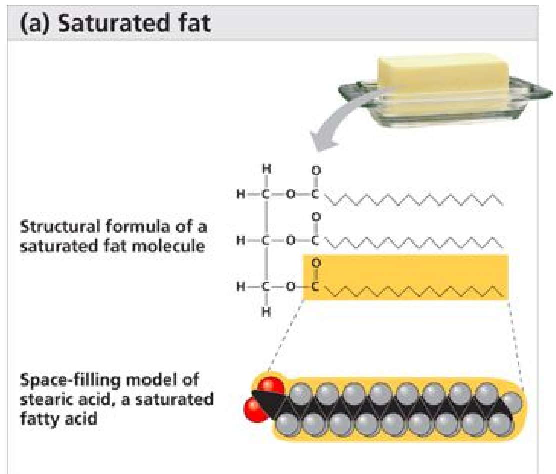
Lipids:

- Lipids are the one class of biomolecules that do not form polymers
  - The unifying feature of lipids is that they have little or no affinity for water (hydrophobic), this is because they consist mostly of hydrocarbons which are nonpolar
- Functions of lipids include:
  - Long-term energy storage
  - Provide insulation from the environment for plants and animals
  - Serve as building blocks for some hormones
  - An important component of cellular membranes
- Biologically important classes of lipids include:
  - Fats, waxes, steroids, phospholipids
- Fats:
  - Fats (triacylglycerol or triglyceride) are constructed from glycerol and three fatty acids
    - Glycerol is three-carbon alcohol with a hydroxyl attached to each carbon
    - Fatty acids consist of a carboxyl group linked to a long hydrocarbon chain (generally 4-20 carbon)
      - The fatty acids can all be the same, or of two or three different kinds
    - The glycerol molecules are attached to the fatty acids via an ester linkage
  - 

- Types of Fats:
  - Fatty acids vary in carbon chain length, number and location of double bonds each of which affects the properties of the fats they are a part of
  - Saturated fatty acids do not have double bonds
    - Solid at room temperature



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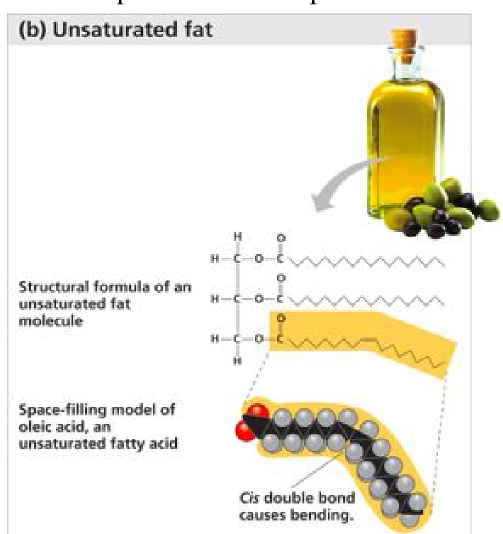
  - Unsaturated fatty acids have one or more double bonds
    - Can be liquid at room temperature



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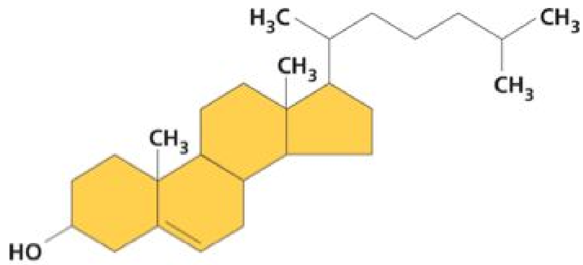
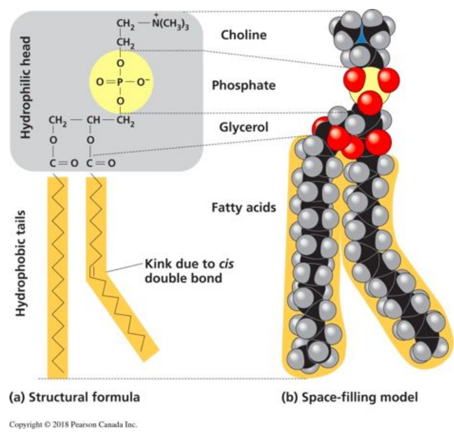
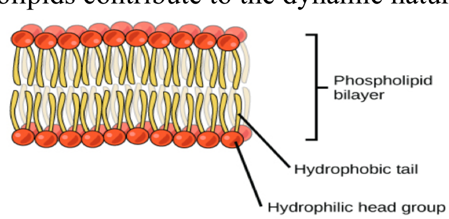
- Waxes:
  - Waxes are long fatty acid chains esterified to long chain alcohols
  - They are hydrophobic and prevent water from sticking to surfaces
  - They are found on the feathers of some aquatic birds and on the surface of leaves from certain plants
- Steroids:
  - Steroids are lipids with a carbon skeleton consisting of four fused rings

- Cholesterol is a component of animal cell membranes and a precursor for many types of steroid hormones (e.g. cortisol, estrogen and testosterone)
- 

- Phospholipids:
  - In phospholipids (diacylglycerol) two fatty acids and a phosphate group are attached to glycerol
    - The two fatty acid tails are hydrophobic
    - The phosphate head group is hydrophilic
      - The phosphate may be modified by the addition of charged or polar chemical groups
  - 

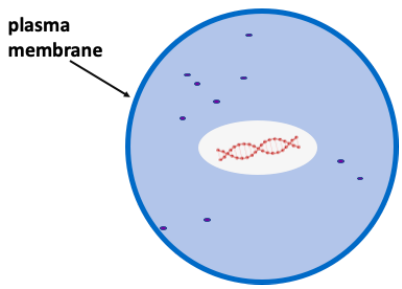
  - Phospholipids are major constituents of the plasma membrane
    - When phospholipids are added to water, they spontaneously self-assemble into a bilayer, due to their structure
      - The hydrophilic head groups of the phospholipids face the aqueous solution
      - The hydrophobic tails are sequestered in the middle of the bilayer
    - Phospholipids contribute to the dynamic nature of the plasma membrane
    - 

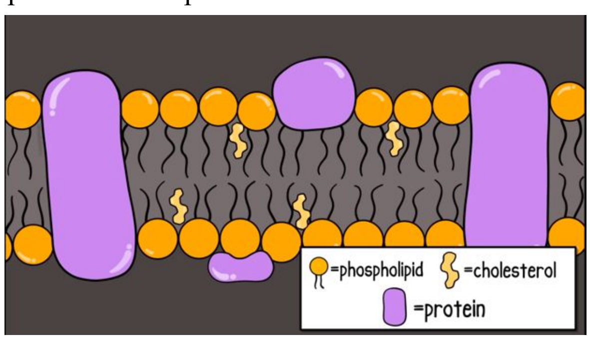
Lecture 5: Cell Membranes:

Learning Outcomes: By the end of this class you should be able to:

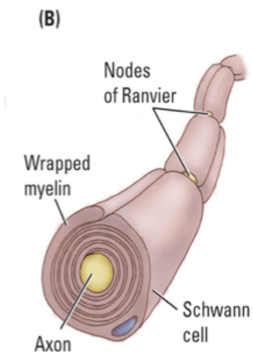
- Describe the general properties and functional role of membranes in the cell, with an emphasis on the plasma membrane
- Clearly explain the composition of the plasma membrane and be able to explain how variations in the composition may benefit an organism or specific cell type
- Understand the fluid mosaic model of the cell membrane and be able to draw and/or label a model of it
- Describe how the properties of each type of macromolecule contribute to the overall behaviour and function of the plasma membrane
- Explain how the plasma membrane is synthesized and how this contributes to its asymmetric nature

Plasma Membrane:

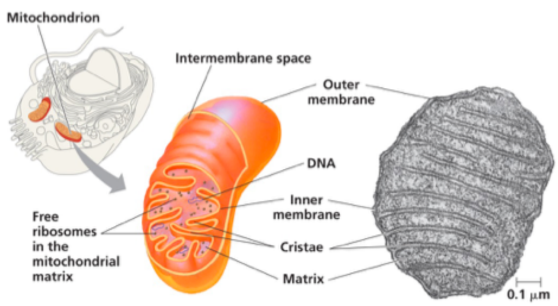
- 

- The plasma membrane (PM) is the boundary that separates a living cell from its surroundings
- This is a very thin barrier ~5-10 nm
- The plasma membrane exhibits selective permeability, allowing some substances to cross it more easily than others
    - This allows the internal and external cellular environments to differ from one another
- The composition of the plasma membrane
    - 

    - Proteins ~50%
    - Lipids ~40%
        - Phospholipids
        - Cholesterol
    - Carbs ~10%
- Membrane composition varies:



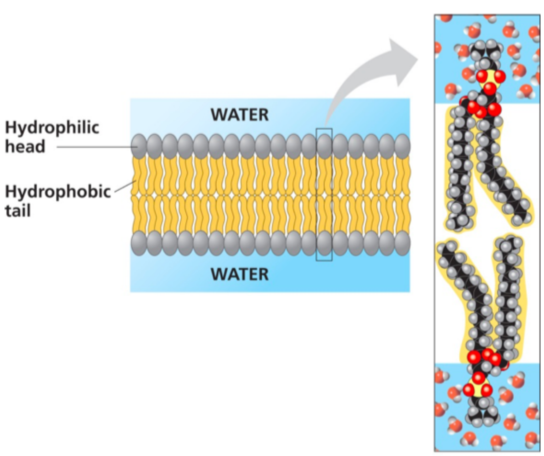
- Myelin, an outgrowth of a specialized cells' membrane that insulates neuronal axons, contains only 18% proteins and 76% lipid
- The plasma membrane of human red blood cells is 30% lipid



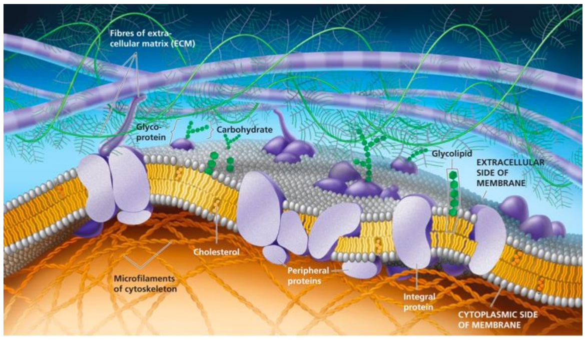
- The mitochondrial inner membrane contains 76% protein and only 24% lipid

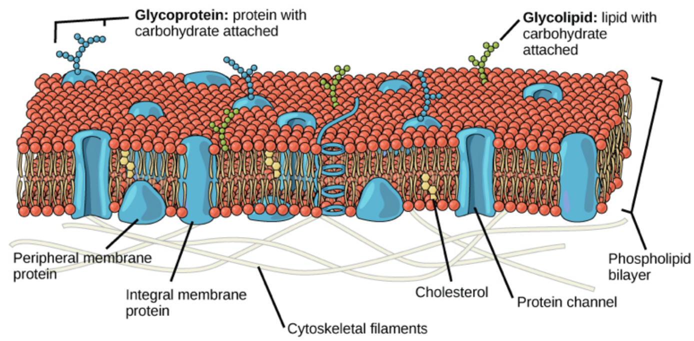
Phospholipids:

- Phospholipids are amphipathic molecules, containing hydrophobic and hydrophilic regions
  - The amphipathic nature of phospholipids results in a bilayer structure in an aqueous environment
- The phospholipid bilayer, held together by weak hydrophobic interactions, exists as a stable boundary between two aqueous compartments

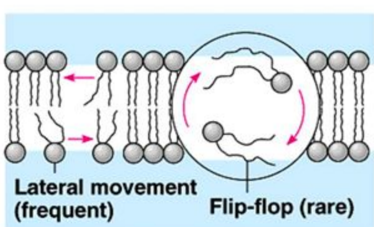


Fluid Mosaic Model:

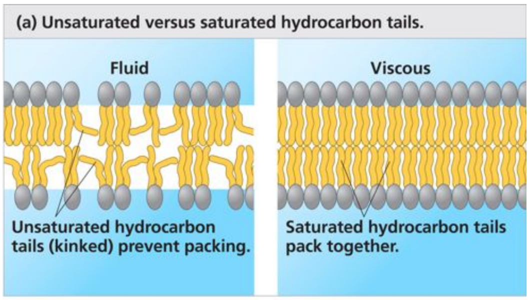
- Model of a typical animal cell plasma membrane
- 

- 

Membrane Fluidity:

- Membranes are not static
  - Phospholipids and proteins in the plasma membrane can move within the bilayer
    - Most move/drift laterally, rarely a molecule flip-flops transversely (between layers of the membrane)
  - For membranes to work properly they must be fluid
  - Temperature has a significant effect on fluidity
    - As temperatures cool, membranes go from a fluid state to a solid state
- 

(a) Movement of phospholipids
- The temperature at which a membrane solidifies depends on its lipid composition
- This is due to the effect of double bonds on a phospholipid packing
- Membranes rich in unsaturated fatty acids are more fluid than those rich in saturated fatty acids



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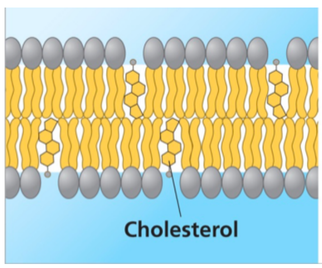
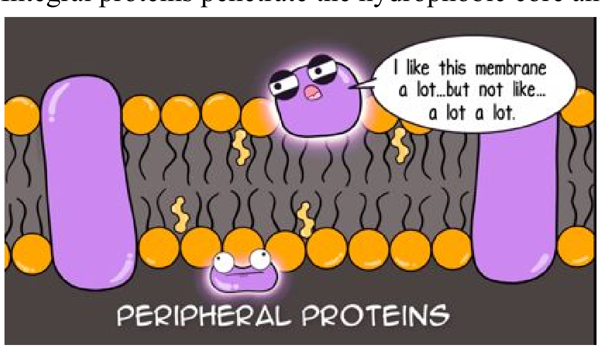
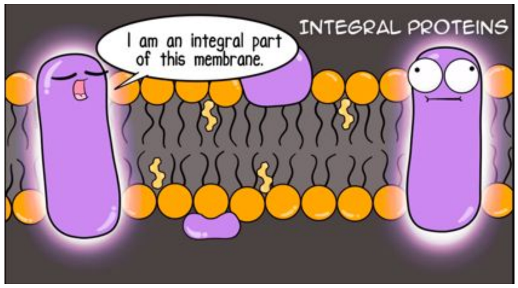
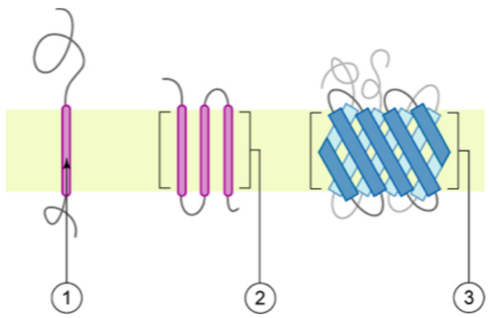
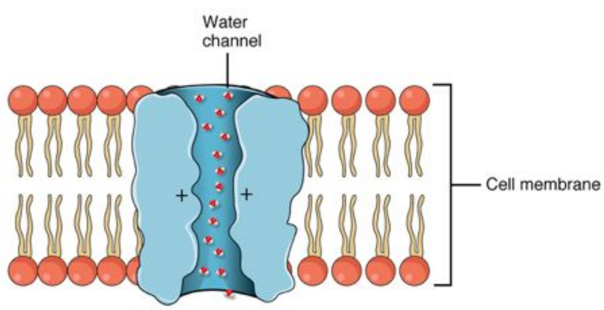
- Membrane fluidity and cholesterol:
  - The steroid lipid, cholesterol has different effects on membrane fluidity at different temperatures
    - At warm temperatures, it restrains the movement of phospholipids, preventing the membrane from becoming too fluid
    - At cool temperatures, it maintains fluidity by preventing tight packing
  - 

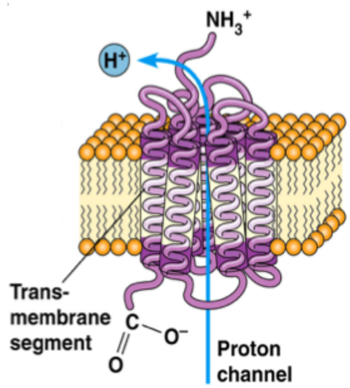
Membrane Proteins:

- A membrane is a mosaic of different proteins, often grouped together, embedded in the fluid matrix of the lipid bilayer
- Proteins determine most of the membrane's specific functions
- There are two types of membrane proteins
  - Peripheral proteins are found on the surface of the membrane and are attached to either integral proteins or phospholipids
  - Integral proteins penetrate the hydrophobic core and are embedded in the membrane
  - 

- 

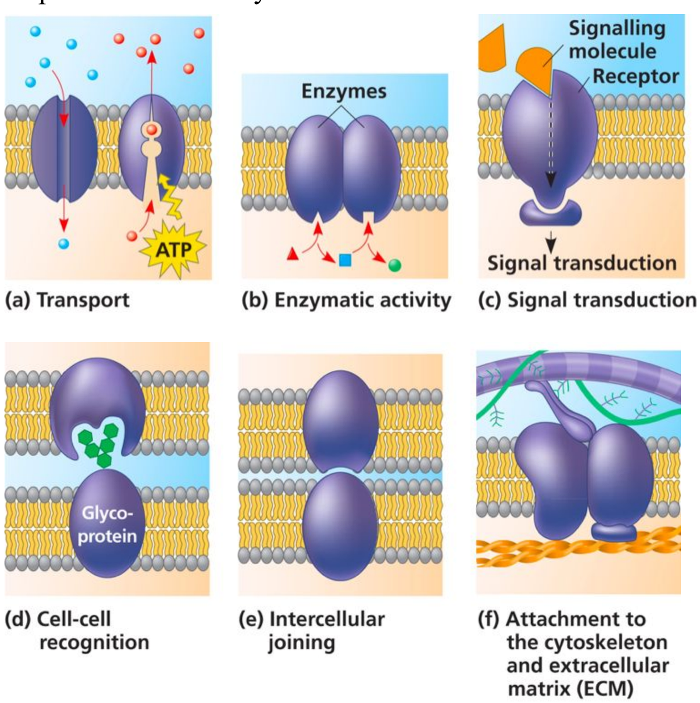
- Integral proteins
    - Integral proteins penetrate the hydrophobic core of the phospholipid bilayer and are embedded in the membrane
    - The hydrophobic regions of integral protein consist of one or more stretches of nonpolar amino acids, often coiled into alpha helices
    - The locations and number of hydrophobic regions determine how they arrange within the bilayer
    - 

    - Integral proteins do not have to cross both layers of the membrane
- Those that do span the membrane are called transmembrane proteins
- These transmembrane domains can be organized to create a hydrophilic channel through the membrane. (e.g. aquaporin)
- 

- 

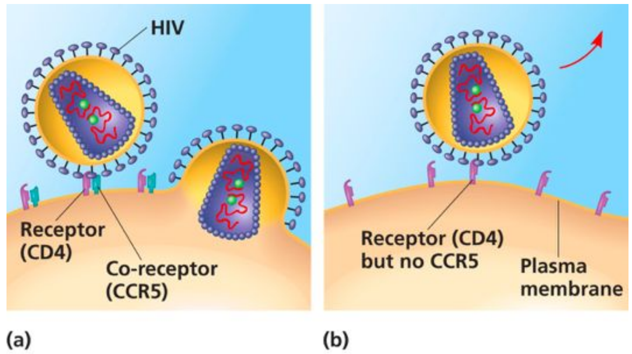
(b) Bacteriorhodopsin

Membrane proteins have many functions:

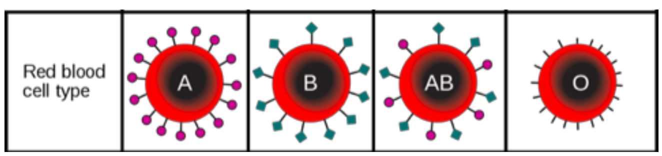
- 

(a) Transport (b) Enzymatic activity (c) Signal transduction
(d) Cell-cell recognition (e) Intercellular joining (f) Attachment to the cytoskeleton and extracellular matrix (ECM)

-
- Example - Clinical Importance:
    - HIV must bind to the immune cell surface protein CD4 and a "co-receptor" CCR5 in order to infect a cell
    - HIV cannot enter the cells of resistant individuals that lack CCR5

- 

Carbohydrates:

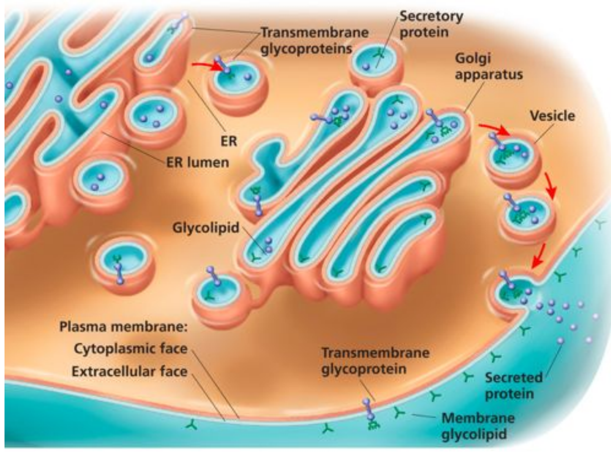
- Located only on the exterior surface of the plasma membrane, covalently bound to either:
  - Proteins = glycoproteins, or lipids = glycolipids, considered together = glycocalyx
- Function - cell-cell recognition and attachment, increase the hydrophilicity of the cell (higher interaction with the extracellular environment)
- Carbohydrates of the plasma membranes vary among species, individuals, and even cell types in an individual
  - E.g. blood type reflects the variation in the carbohydrate component of the glycoprotein on the surface of the red blood cells
- 

Membrane Sidedness:

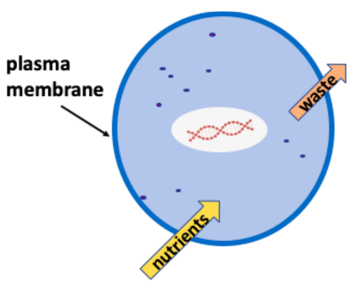
- Plasma membranes are asymmetric; the inner surface differs from the outer surface
- Examples:
  - Interior proteins anchor fibres of the cytoskeleton to the membrane
  - Exterior proteins bind to the extracellular matrix
  - Glycoproteins and glycolipids are only on the outer leaflet
  - Different phospholipid composition:
    - The inner leaflet has more phosphatidylcholine and sphingomyelin
    - The outer leaflet has more phosphatidylethanolamine and phosphatidylserine

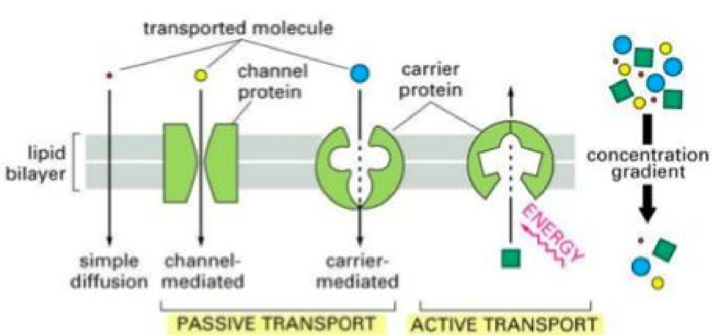
Membrane Synthesis:

- Asymmetrical distribution of plasma membrane components is determined when the membrane is built by ER and Golgi apparatus
- Lipids and proteins are synthesized in the endoplasmic reticulum (ER), proteins may acquire carbohydrates here
- Vesicles travel from the ER to the cis face of the Golgi apparatus where they fuse
- In the Golgi, lipids may acquire carbohydrates

- Vesicles with membrane proteins, secretory proteins and glycolipids bud off of the trans-face of the Golgi
- Vesicles travel to the plasma membrane where they fuse releasing their contents into the extracellular space
- The internal layer of the vesicle lipid bilayer is now on the outer surface of the cell membrane and the vehicle's outer lipid layer is in the internal leaflet of the plasma membrane
- 

Introduction to Transport Across the PM:

- Plasma membranes are selectively permeable, regulating the cell molecular traffic
  - Hydrophobic (nonpolar) molecules can dissolve in the lipid bilayer and pass through membrane rapidly
  - Hydrophilic (polar) molecules do not cross membrane easily
    - Various transport proteins allow hydrophilic substances to pass across the membrane
- 

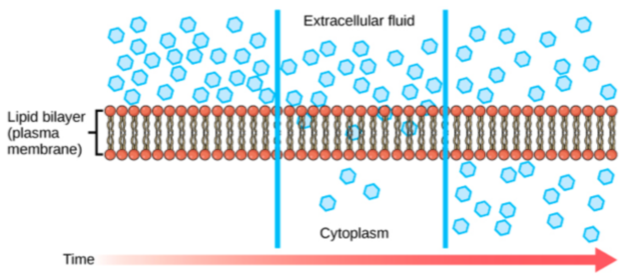
- 

Lecture 6: Transport Across Cell Membranes

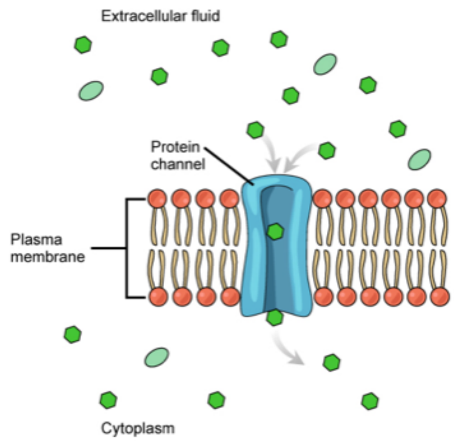
Learning Outcomes: by the end of this class you should be able to:

- Name, describe and compare several types of transport across a cell membrane, including:
  - Passive transport, facilitated diffusion, osmosis, active transport, cotransport, bulk transport (including each subtype)
- Describe the reason why a given molecule would be transported using one type of transport or another and provide an example for each type of transport

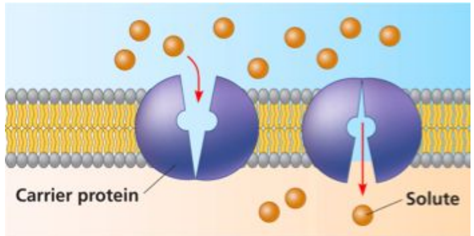
Diffusion:

- Diffusion is the tendency for molecules to spread out evenly into the available space
  - This is a spontaneous process driven by the thermal energy of the molecules involved
- Each molecule moves randomly but substances diffuse down their concentration gradient (high concentration to low concentration)
- Diffusion of a substance across a biological membrane is also known as passive transport
  - No energy is expended by the cell to make it happen
- Only small nonpolar molecules can diffuse readily through biological membranes (e.g. O_2, CO_2 and steroid hormones)
- 

- Many factors affect diffusion rates:
  - Concentration gradients - greater difference, faster diffusion
  - Mass of the molecules - smaller molecules diffuse more quickly
  - Temperature - molecules move faster when temperatures are higher
  - Solvent density - dehydration increases the density of cytoplasm - reduces diffusion rates
  - Solubility - more nonpolar (lipid-soluble) materials diffuse faster
  - Surface area - increased surface area speeds up diffusion rates
  - Distance travelled - the greater the distance, the slower the rates; important factor affecting upper limit of cell size
  - Pressure - in some cells (i.e. kidney cells), blood pressure forces solution through membranes, speeding up diffusion rates
- Facilitated diffusion:
  - Facilitated transport (a.k.a. Facilitated diffusion) moves substances down their concentration gradients through integral membrane proteins
    - Ions and small polar molecules diffuse across the membrane this way
  - There are two types of facilitated transport proteins:
    - Channel proteins
    - Carrier proteins

- Channel Proteins:
    - Channel proteins provide corridors that allow a specific molecule or ion to cross the plasma membrane
        - Some are open all the time
        - Other are gated and only open when a specific signal is received
    - Important examples:
        - Aquaporins - specific to water
        - Muscle cells have gated ion channels allowing muscle contraction when opened
    - 

- Carrier Proteins:
    - Carrier proteins are specific to a particular substance
    - They bind to that substance, change conformation (shape) and translocated or "carry" it to the other side
        - Many allow movement in either direction, as concentration gradients change
    - Important example - glucose transport proteins (GLUTS)



(b) A carrier protein

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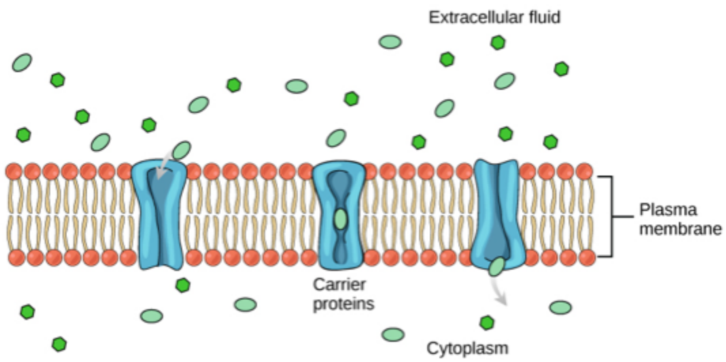
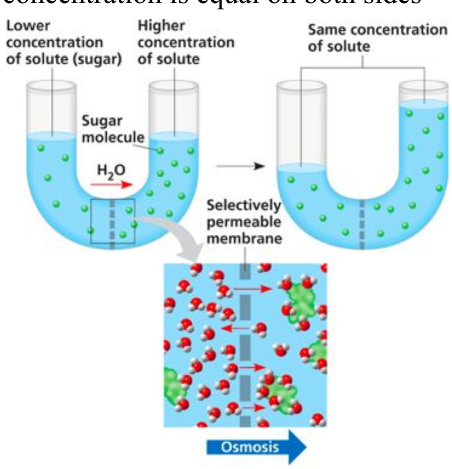


How the water crosses the membrane:

- Even though it is polar, water can diffuse passively across the plasma membrane
    - This isn't an easy journey
- Water can also travel across the plasma membrane through aquaporin channels

Diffusion of water - a special case

- Osmosis is the diffusion of water across a membrane
- The difference in water concentration occurs when a solute cannot pass through the selectively permeable membrane
    - When this occurs, "free" water diffuses across the membrane from the region of lower solute concentration to the region of higher solute concentration until the solute concentration is equal on both sides



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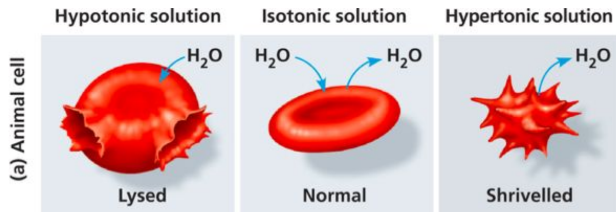
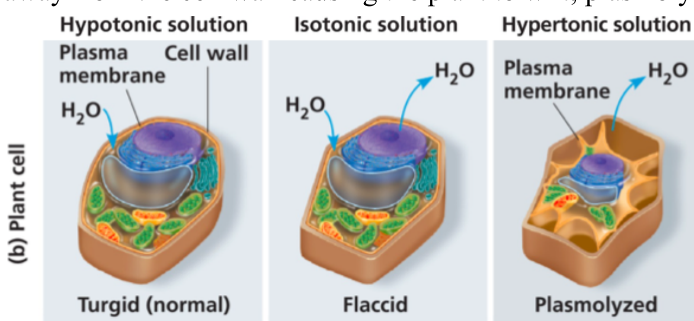
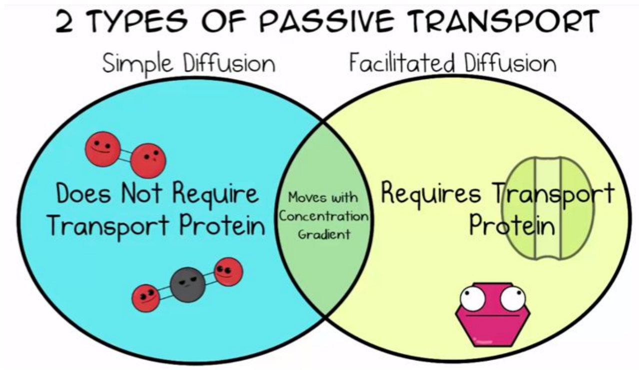
- Water balance of cells:
    - Tonicity refers to the ability of a surrounding solution to cause cells to gain or lose water
    - Isotonic solution: solute concentration is the same as that inside the cell -> no net water movement across the plasma movement
        - Animal cells function best when extracellular fluids are isotonic
    - Hypertonic solution: solute concentration is greater than that inside of the cell -> cell loses water
    - Hypotonic solution: solute concentration is less than that inside of the cell -> cell gains water
    - 

- Water Balance in Plant Cells
    - The cell walls help maintain water balance
        - A plant cell in hypotonic solution swells until wall opposes uptake; it is turgid (firm)
        - A plant cell in an isotonic environment, no net movement of water; it is flaccid (limp)
        - In a hypertonic environment, plant cells lose water, and plasma membrane pulls away from the cell wall causing the plant to wilt; plasmolysis (usually lethal)
        - 

Osmoregulation:

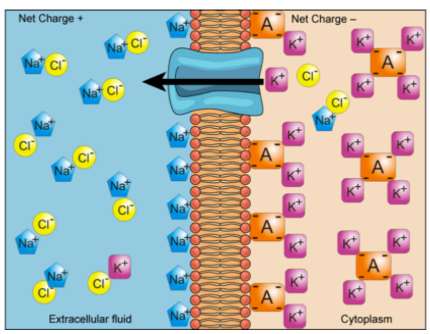
- Hypertonic or hypotonic environments create osmotic problems for organisms
- Osmoregulation, the control of solute concentrations and water balance, is a necessary adaptation for life in such environments
    - Freshwater protists, like paramecia and amoebas, use contractile vacuoles, to pump water out of their cells so they do not burst since they are hypertonic to their environment



The gradients observed across the plasma membrane in living systems are more complex and involve both:

- Chemical gradients -> the difference in concentration
- Electrical gradients -> the difference in charge

The interior of living cells is electrically negative with respect to the extracellular fluid in which they are bathed.

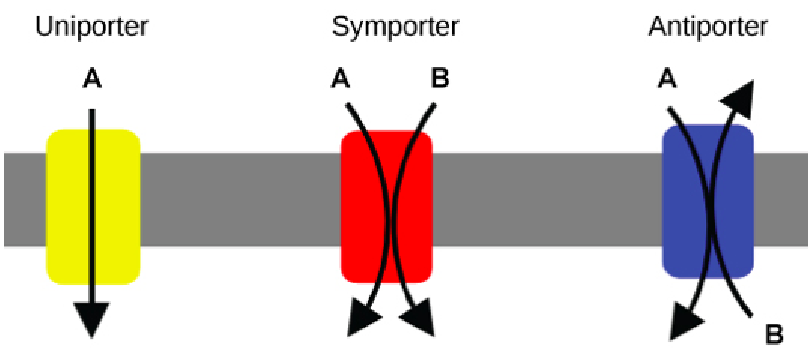
- Na^+ - the concentration gradient of sodium tends to drive it into the cell, and its electrical gradient (a positive ion) also drives it in towards to the negatively charged interior
- K^+ - the electrical gradient of K^+ (a positive ion), also drives it into the cell, but the concentration gradient of K^+ drives K^+ out of the cell
- 

Active Transport:

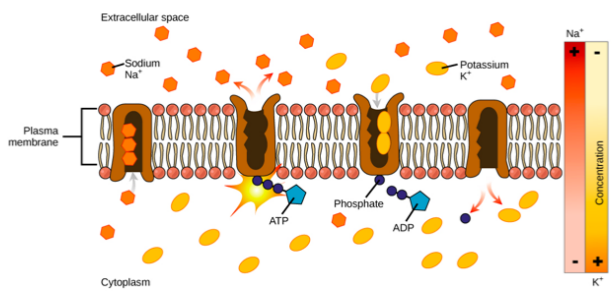
- Active transport uses energy, usually in the form of ATP, to move a substance against:
  - Its concentration gradient -> from low to high concentration, or
  - Its electrochemical gradient
    - E.g. H^+ ions to a solution that is more positive
    - E.g. An electrical gradient, where the cytoplasm contains more negatively charged molecules (more neg ions and proteins) than the extracellular fluid, is critical for proper cell functioning

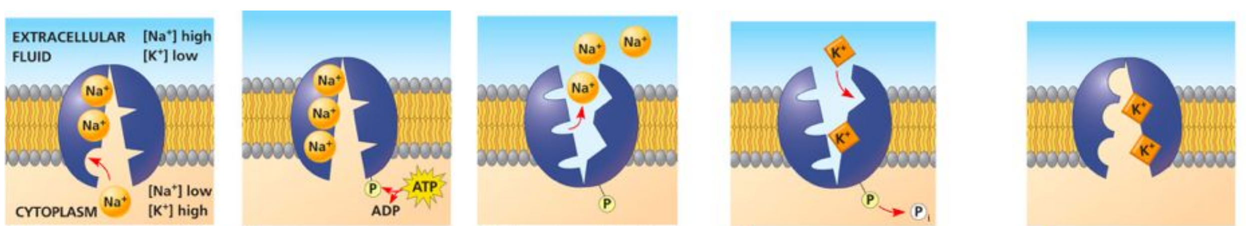
Carrier Proteins:

- Active transport occurs through transmembrane, integral carrier proteins called pumps. There are 3 types of pumps:
  - Uniporter carries one molecule or ion
  - Symporter carries two different molecules or ions, in the same direction
  - Antiporter carries two different molecules or ions, in different directions



- The sodium-potassium pump is an important example of an active transport system
  - It mores 3 Na^+ out and 2 $K^{+>}$ into the cell using 1 ATP
  - This is an antiporter pump
  - This is an electrogenic pump which means that it is a transport protein that generates a voltage across a membrane





1 Cytoplasmic Na+ binds to the sodium-potassium pump. The affinity for Na+ is high when the protein has this shape.
2 Na+ binding stimulates phosphorylation by ATP.
3 Phosphorylation leads to a change in protein shape, reducing its affinity for Na+, which is released outside.
4 The new shape has a high affinity for K+, which binds on the extracellular side and triggers release of the phosphate group.
5 Loss of the phosphate group restores the protein's original shape, which has a lower affinity for K+.

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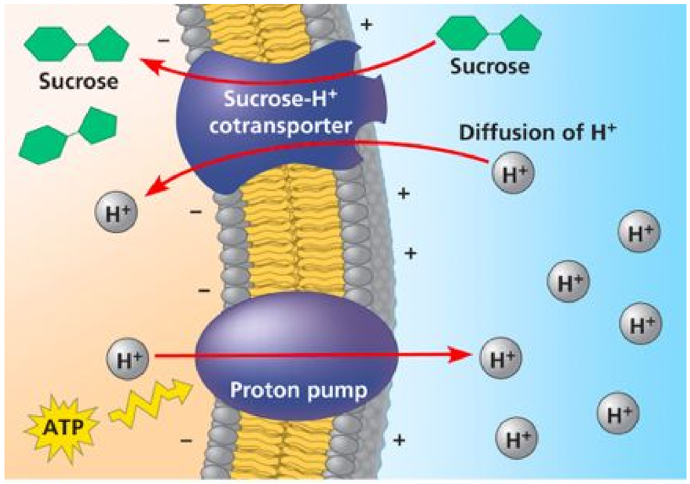
Cotransport: Coupled Transport by a Membrane Protein:

- Cotransport occurs when active transport of a solute indirectly drives transport of other solutes
- Plants commonly use a hydrogen ion gradient to drive active transport of nutrients into the cell



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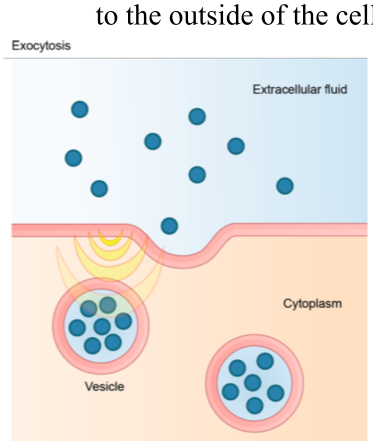
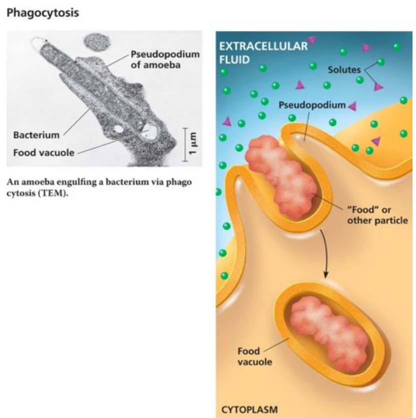
Bulk Transport:

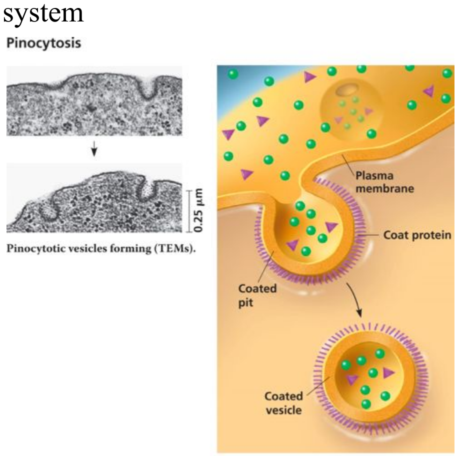
- Sometimes cells need to import or export molecules/particles (such as polysaccharides and proteins) that are too large to pass through a transport protein
- Bulk transport is another type of active transport (energy is required) used in these cases
    - Bulk export is called exocytosis
    - Bulk import is called endocytosis. There are 3 subtypes
        - Phagocytosis (cell eating)
        - Pinocytosis (cell drinking)
        - Receptor-mediated endocytosis
- Exocytosis:
    - In exocytosis, transport vesicles migrate to the membrane, fuse with it, and release their contents to the outside of the cell
    - Examples:
        - Secretory cells use exocytosis to release their products
            - Neurons release neurotransmitters to communicate with neighbouring cells
            - Pancreatic cells release insulin
        - Exocytosis is used by plants to deliver proteins and carbohydrates from the Golgi to the outside of the cell for cell wall formation
    - 

- Phagocytosis:
    - During phagocytosis, a wall engulfs a particle to form a membrane-bound vacuole
    - Vacuoles fuse with lysosomes to digest the particle
    - Example: white blood cells phagocytose bacterias to protect the body from it



An amoeba engulfing a bacterium via phagocytosis (TEM).

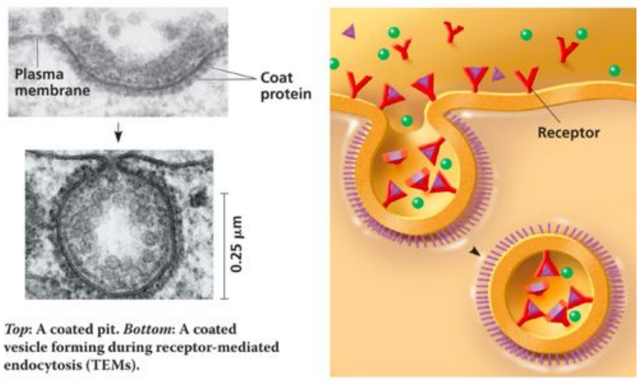
    -
- Pinocytosis:
    - In pinocytosis, extracellular fluid is "gulped" into tiny membrane-bound vesicles
    - Internalized vesicles fuse with lysosomes to digest its contents
    - Example: an important part of the surveillance of the environment by cells of the immune system



Pinocytotic vesicles forming (TEMs).

    -
- Receptor-Mediated Endocytosis:
    - In receptor-mediated endocytosis, binding of ligands (a specific molecule that binds specifically to a receptor site of another molecule) to receptors embedded in the membrane triggers vesicle formation/internalization
    - Example: human cells use receptor-mediated endocytosis to take in cholesterol for membrane synthesis and the production of steroid hormones

- Receptor-Mediated Endocytosis

  Top: A coated pit. *Bottom*: A coated vesicle forming during receptor-mediated endocytosis (TEMs).

Summary:

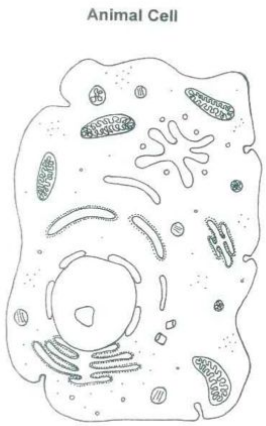
Transport Method	Active/Passive	Material Transported
Diffusion	Passive	Small-molecular weight material
Osmosis	Passive	Water
Facilitated transport/diffusion	Passive	Sodium, potassium, calcium, glucose
Active transport	Active	Sodium, potassium, calcium
Co-transport	Active	Amino acids, lactose
Phagocytosis	Active	Large macromolecules, whole cells, or cellular structures
Pinocytosis	Active	Small molecules (liquids/water)
Receptor-mediated endocytosis	Active	Large quantities of macromolecules

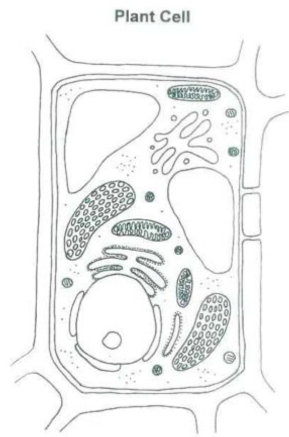
Lecture 7 - The Cytoskeleton and Extracellular Matrix:

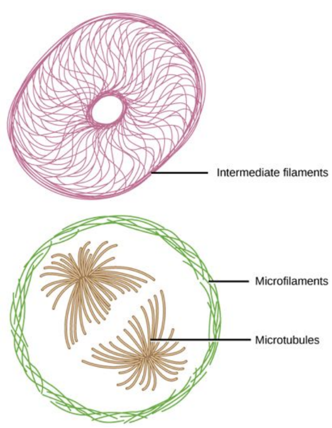
Learning Outcomes: By the end of this class, you should be able to:

- Describe how the interior of a eukaryotic cell is organized (note - this outcome spans over several lectures)
- Name the three components of the cytoskeleton, describe their composition and relate it to their role in the cell
- Describe the importance of motor proteins and their interaction with the cytoskeleton
- Describe what the extracellular matrix is made of, how the cell interacts with it and why it is important to cells
- Identify the main types of eukaryotic cell-cell interactions and their characteristics

Free Floating Organelles:

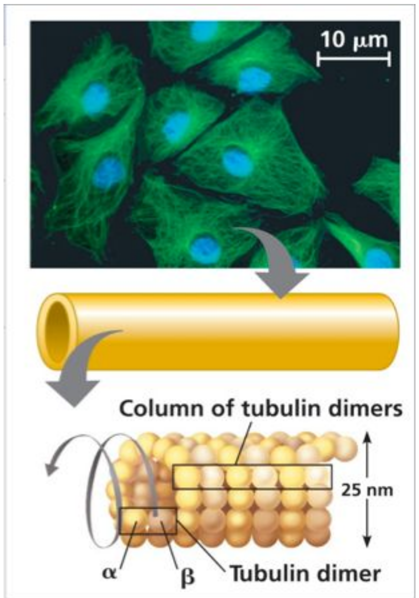




The Cytoskeleton:
- The cytoskeleton is a network of protein fibres extending throughout the cytoplasm
- It is composed of 3 types of fibres, each of varying size and function:
    - Microfilaments, microtubules, intermediate filaments
- Generally, they act together to:
    - Organize the cells' structure, anchor the organelles, facilitate cellular activities
- 

- The cytoskeleton is dynamic
    - It is changing and moving all of the time
    - It is tied with the flagella
        - Flagella is a type of microtubule

Microtubule:
- Microtubules are hollow rods about 25 nm in diameter
- They are made up of tubulin
    - Tubulin itself is a protein dimer (a protein made up of 2 polypeptide chains)
- Functions:
    - Shaping the cell (resist compression), guiding movement of organelles and vesicles, separating chromosomes during cell division
- This kind of protein would have a quaternary structure



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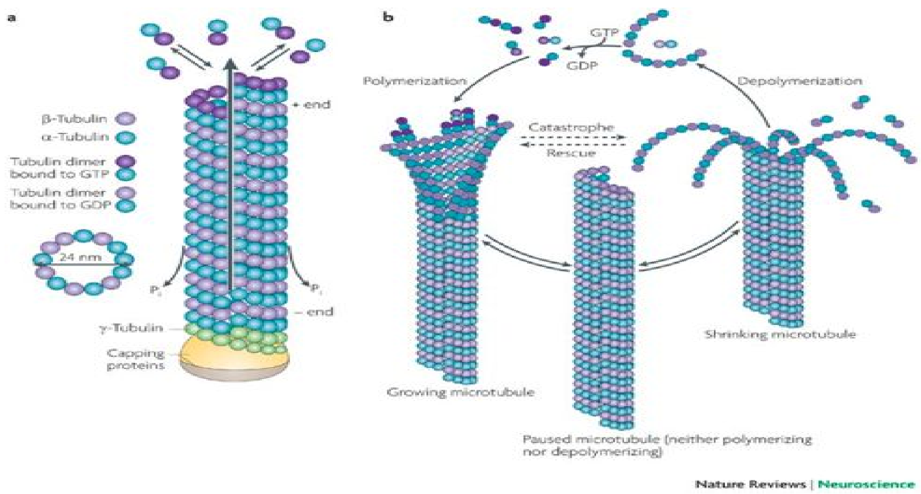
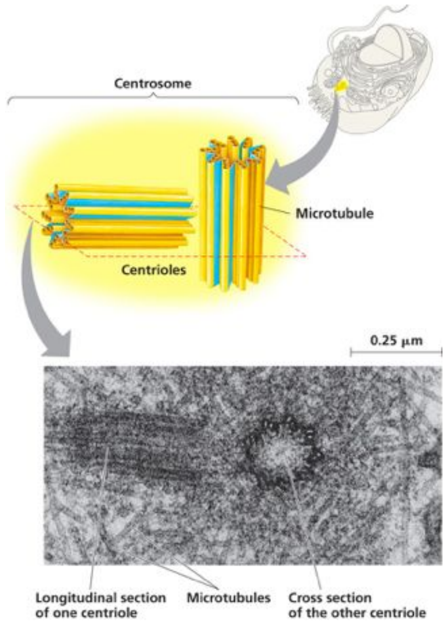
- Microtubule dynamics:
    - Microtubules grow/shrink through the addition/removal of tubulin dimers at either end of the polymer
    - Microtubules are asymmetrical, with one end (the plus end) allowing for the addition/removal of tubulin at a significantly faster rate than the other (the minus end)



- Microtubules and centromeres:
    - The minus end of the microtubule is generally anchored to the microtubule organizing centers (MTOCs)
        - The primary MTOC in an animal cell is called the centrosome, and it is usually located adjacent to the nucleus
        - In animal cells, the centrosome has a pair of centrioles, each with nine triplets of microtubules arranged in a ring
        - Other eukaryotic cells organize microtubules by other means



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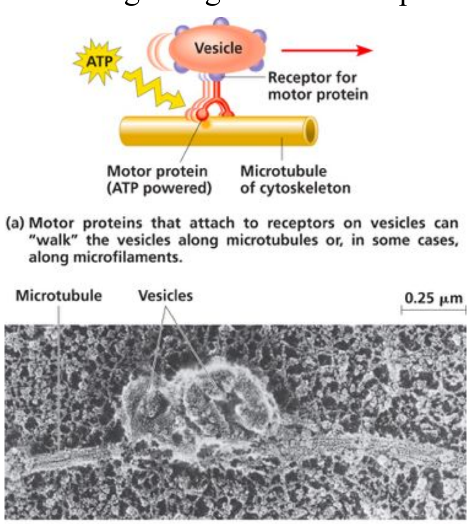
- Microtubules and Cell Motility:
    - Cell motility refers to both:
        - Changes in cell location (e.g. swimming sperm)
        - Movement of cell parts (e.g. movement of vesicles within the cell)
    - This involves the interaction between the cytoskeleton and motor-proteins which convert chemical energy into mechanical energy
        - E.g. A vesicle 'walking' along the cytoskeleton to its destination
        - E.g Invagination of the plasma membrane during phagocytosis



(a) Motor proteins that attach to receptors on vesicles can "walk" the vesicles along microtubules or, in some cases, along microfilaments.

(b) In this SEM of a squid giant axon (a nerve cell extension), two vesicles containing neurotransmitters move toward the axon's tip.

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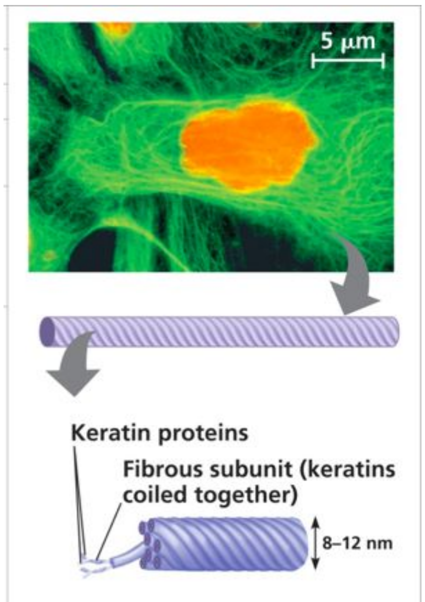
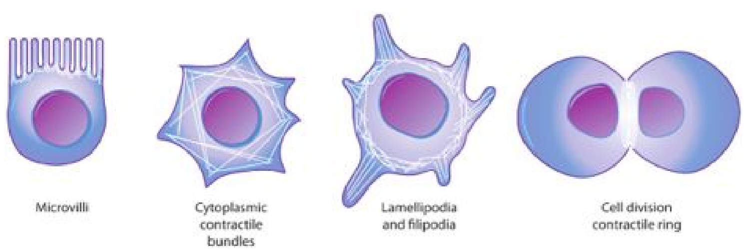
Intermediate Filaments:

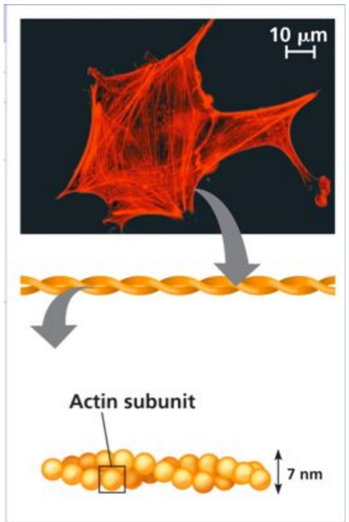
- Intermediate filaments range in diameter from 8-12 nm and are composed of different proteins
    - E.g. Keratin, which organizes into cables
- They are one of the more permanent structures of the cytoskeleton
    - Even after the death of a cell, the intermediate filament network persists
        - E.g. the outer layer of dead skin cells is full of keratin
- They support cell shape and fix organelles in place
    - E.g. The nucleus sits within a 'cage' of intermediate filaments (nuclear lamina)



Microfilaments:

- Microfilaments are solid rods about 7 nm in diameter, built as a twisted double chain of actin subunits
- Their structural role is to bear tension, resisting pulling forces within the cell
- It often forms a 3-D network called the cortex just inside the plasma membrane but can be organized in a variety of ways to support different cell shapes
    - E.g. Make up the core of intestinal microvilli





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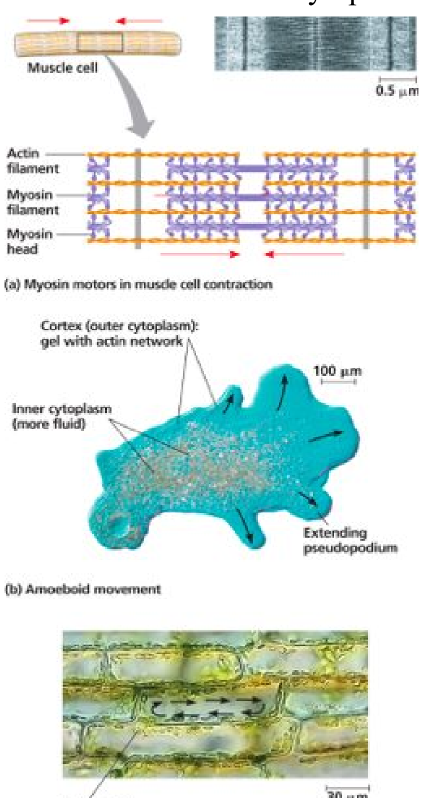
- Microfilaments and cell motility:
    - Microfilaments that function in cellular motility contain the protein myosin in addition to actin, allowing for various types of movement
    - Examples:
        - Contractions in muscle cells, Ameboid movement of cells, The circular flow of cytoplasm in plant cells known as cytoplasmic streaming



(a) Myosin motors in muscle cell contraction

(b) Amoeboid movement

(c) Cytoplasmic streaming in plant cells

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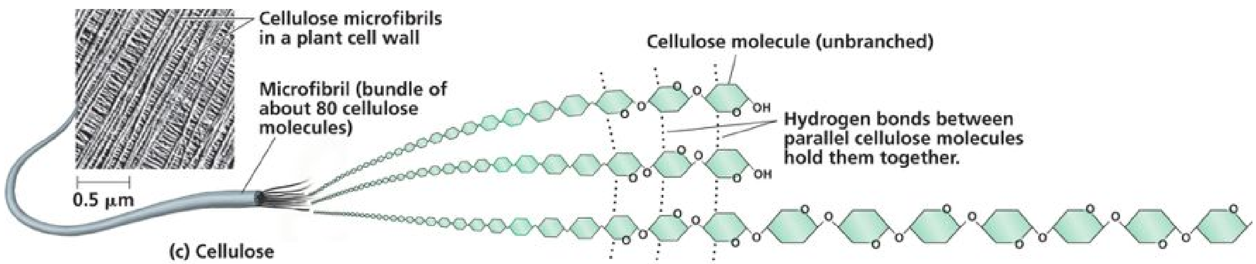
Extracellular Structures and the Connection Between Cells:

- Cells in animals and plants are organized into tissues, organs and organ systems
- Most cells synthesize and secrete materials external to the plasma membrane to permit this organization while also maintaining means of communicating with one another
- These extracellular structures include:
    - Cell walls of plants, extracellular matrix (ECM) of animal cells, intercellular junctions

Plant Cell Wall:

- Functions of the plant cell wall include:
    - Maintaining the shape of the cell, preventing excessive water uptake, acting as a barrier to infection
- Plant cell walls are made of cellulose embedded in other polysaccharides and protein



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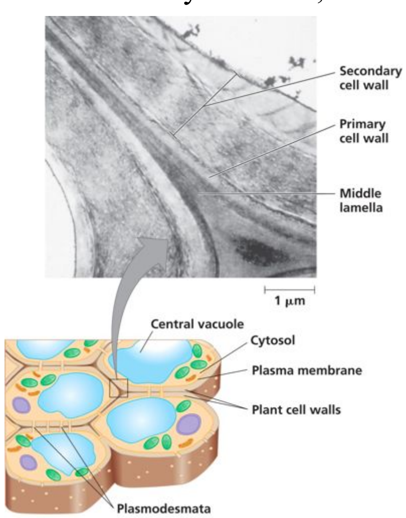
- Plant cell walls vary in composition and thickness
- They have multiple layers;
    - Primary cell wall, middle lamella, secondary cell wall (in some cells)



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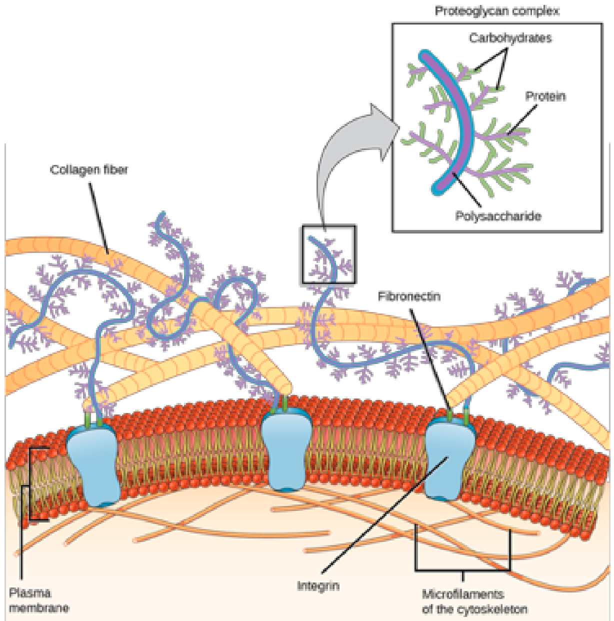
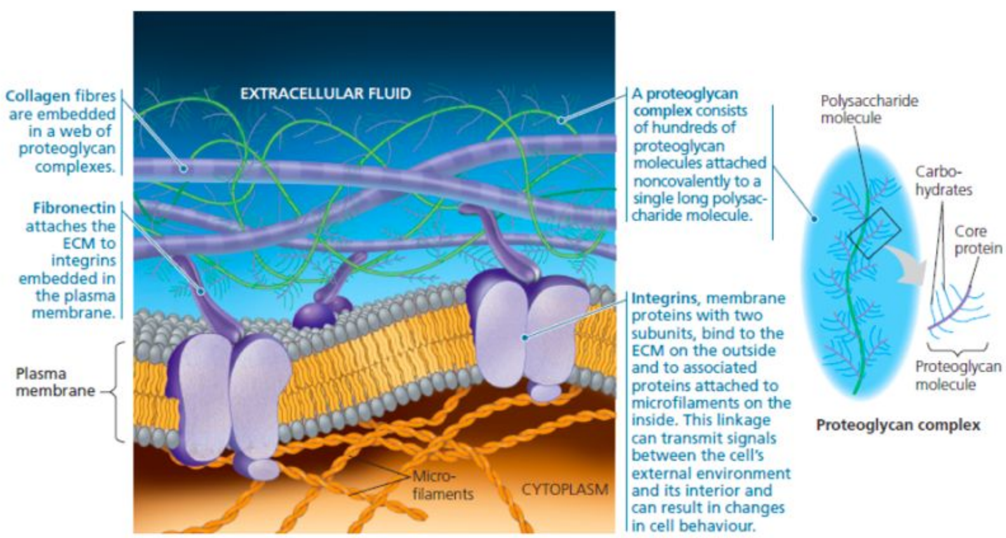
Extracellular Structures in Animals Cells:

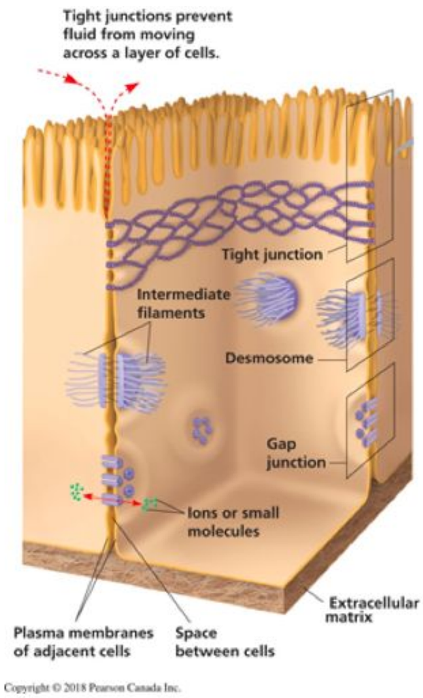
- Animal cells lack walls but have an elaborate extracellular matrix (ECM)

- Functions of the ECM include:
    - Support, adhesion, movement, regulation
- Components of the ECM:
    - The ECM is made up of:
        - Fibrous glycoproteins such as collagen and fibronectin
        - Carbohydrate-rich glycoproteins called proteoglycans
    - Cells attach to the ECM by integrin proteins:
        - Integrins can transmit information between the ECM and the cytoskeleton, integrating what is happening both inside and outside of the cell
    - 

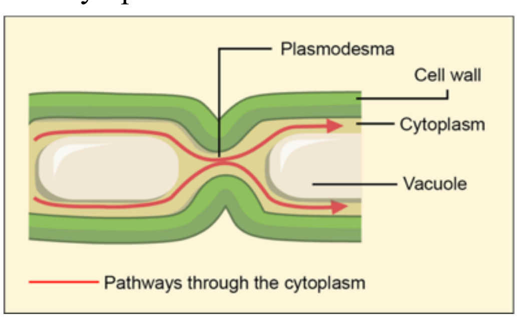
    - 

The molecular composition and structure of the ECM vary from one cell type to another. In this example, three different types of ECM molecules are present: proteoglycans, collagen, and fibronectin.

Intercellular Junctions:

- Intercellular junctions provide direct channels of communication between cells
- Plants - plasmodesmata
- In animal cells there are 3 main types of junctions:
  - Tight junctions, desmosomes, gap junctions
- 

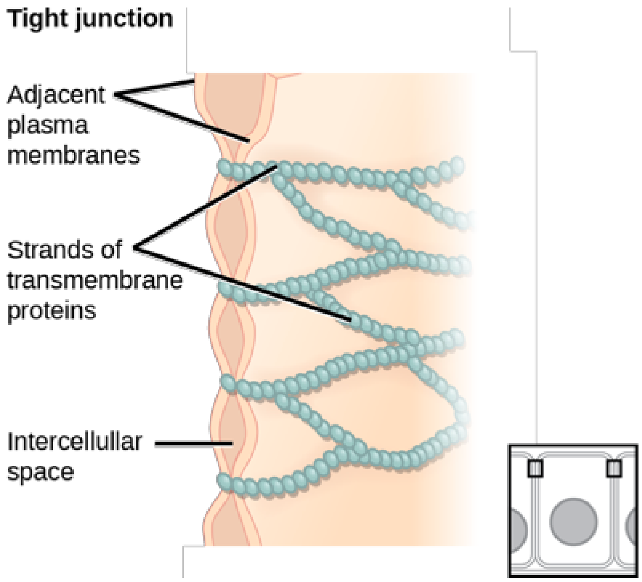
Communication Across the Cell Wall:

- Plasmodesmata are channels between the cell walls of adjacent plant cells which connect their cytoplasm and allow materials to move from cell to cell
- 

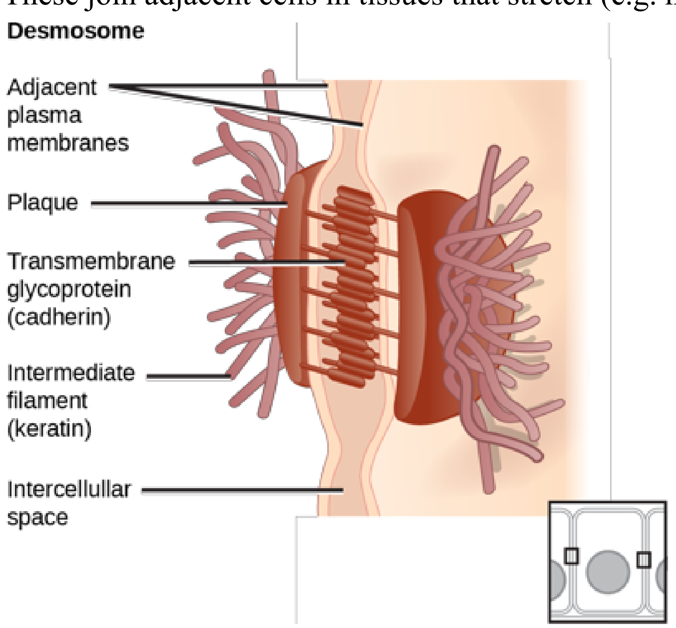
Tight Junctions:

- Tight junctions are watertight seals between animal cells that prevent materials from leaking between the cells
  - The PMs are pressed rightly against each other and bound together by proteins
- They are often found between the epithelial cells that line internal organs and cavities

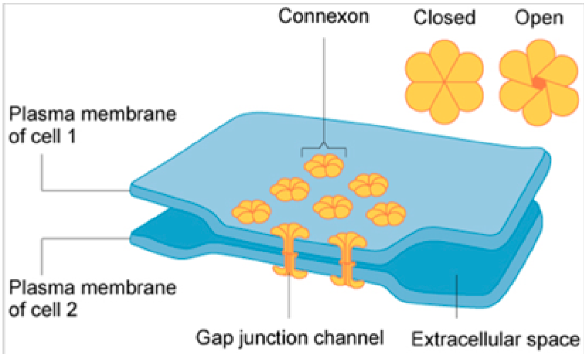
    - E.g. tight junctions make blood vessels watertight

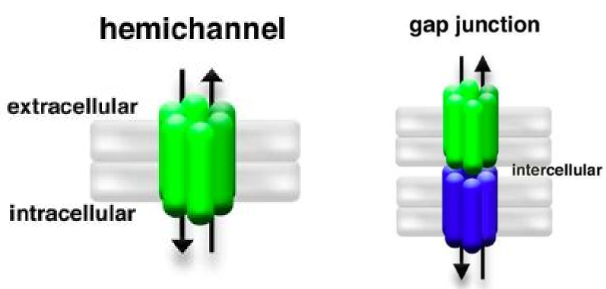
- 

Desmosomes:

- Desmosomes are anchoring junctions that form when cadherins (a type of transmembrane protein) when adjacent cells interact
    - Think of them as a spot weld or rivet
- Desmosomes are tied into the cytoskeleton by their interaction with intermediate filaments
- These join adjacent cells in tissues that stretch (e.g. heart, lungs, muscles)
- 

Gap Junctions:

- 6 connexins proteins assemble to form a channel through the plasma membrane called a connexon or hemichannel
- When the connexons of adjacent cells are aligned, they can dock creating a channel between the cells called a gap junction
- Hemichannels and gap junctions allow ions, and other small signalling molecules to travel through them
- 

- 

Lecture 10 - Introduction to Metabolism

Learning Outcomes: by the end of this class you should be able to:

- Define metabolism and explain the basic functioning of a metabolic pathways including the two general categories of reaction which make up these pathways
- Explain what bioenergetics is and where the energy needed to operate cells comes from, distinguishing between autotrophs and heterotrophs
- Understand what energy is and how it relates to the cell's ability to do work (chemical, mechanical, or transport)
- Explain what is meant by an open system and a closed system
  - Be able to discuss the impact and meaning of these two systems of life
- Identify and explain the principles of thermodynamics
- Explain what free energy is and its impact on the direction of metabolic reactions (i.e. spontaneous/exergonic vs non-spontaneous/endergonic reactions)
- Recognize a molecule of ATP and explain its role in the cell
- Explain how enzymes can reduce the activation energy of chemical energy

- Describe some factors which may affect the activation or inhibition of enzymes (more on this next lecture)
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