Membrane Structure and Function
Cell Membranes

- IN ALL CELLS
- Regulates what enters and leaves the cell
- Protects and supports the cell
- Has 2 layers called a lipid bilayer
Plasma Membrane

- Separates the living cell from its nonliving surroundings.
- Very thin barrier, 8 nm thick
  - 1/8000 of a paper
- Controls traffic into and out of the cell.
- Like all biological membranes, the plasma membrane is **selectively permeable**, allowing some substances to cross more easily than others.
Phospholipids

(a) Chemical structure of a phospholipid

(b) Simplified way to draw a phospholipid

Cell membrane
Properties of Lipids

- 2 parts to the Phospholipid
  - **Hydrophobic** (water-hating) Tail
    - Non-polar
  - **Hydrophilic** (water-loving) Head
    - Polar

- In membrane, form lipid-bilayer
  - Tails facing in towards each other
  - Heads facing out to watery environment inside and outside the cell.
The main macromolecules in membranes are lipids and proteins, but carbohydrates are also important.

- most abundant lipids are phospholipids.
- Phospholipids and most other membrane constituents are **amphipathic molecules** – hydrophobic and hydrophilic regions.

Hydrophilic regions of proteins and phospholipids are in maximum contact with water, and the hydrophobic regions are in a nonaqueous environment within the membrane.
The Fluid Mosaic Model

- **Permeable** – substances are able to cross a membrane
- **Impermeable** – substances cannot pass across it
- most biological membranes are **semipermeable**, meaning that some substances can pass across and others cannot
Semipermeable Membranes

- Small molecules can easily pass through cell membranes
- Large or polar molecules may need help.  
  - **WHY?**
The Fluidity of Membranes

- Phospholipids in the plasma membrane can move laterally (side-to-side) within the bilayer.
  - Why don’t they flip over or leave the membrane?

(a) Movement of phospholipids

- Lateral movement (~10^7 times per second)
- Flip-flop (~ once per month)
Fluidity of Membranes

- Membrane molecules are held in place by relatively weak hydrophobic interactions.
  - Most of the lipids and some proteins drift laterally
- Membrane fluidity is influenced by temperature.
  - As temperatures cool, membranes switch from a fluid state to a solid state as the phospholipids pack more closely.
The type of fatty acid tails in phospholipids affects the fluidity of the plasma membrane.
Membrane fluidity is also influenced by its components.

- Kinks in unsaturated fatty acids prevents tight packing
- Cholesterol acts as a “temperature buffer” for the membrane,
  - At warm temperatures (such as 37°C), cholesterol restrains the movement of phospholipids and reduces fluidity.
  - At cool temperatures, it maintains fluidity by preventing tight packing.
Fluidity (continued)

- To work properly with active enzymes and appropriate permeability, membranes must be about as fluid as salad oil.

- Cells can alter the lipid composition of membranes to compensate for changes in fluidity caused by changing temperatures.
  - For example, cold-adapted organisms such as winter wheat increase the percentage of unsaturated phospholipids in their membranes in the autumn.
Learning Check

How would you expect the saturation levels of membrane fatty acids to differ in plants adapted to cold environments and plants adapted to hot environments?
Membranes are Mosaics of Structure & Function

- A membrane is a collage of different proteins embedded in the fluid matrix of the lipid bilayer.
- Proteins determine most of the membrane’s specific functions.
- The plasma membrane and the membranes of the various organelles each have unique collections of proteins.
Membrane Proteins

• There are two major populations of membrane proteins.
  • **Peripheral proteins** are not embedded in the lipid bilayer at all.
  • **Integral proteins** penetrate the hydrophobic core of the lipid bilayer, often completely spanning the membrane (as *transmembrane* proteins).
• On the cytoplasmic side of the membrane, some membrane proteins connect to the cytoskeleton.
• On the exterior side of the membrane, some membrane proteins attach to the fibers of the extracellular matrix.
Most proteins in the plasma membrane

- Can drift within the bilayer

**EXPERIMENT**
Researchers labeled the plasma membrane proteins of a mouse cell and a human cell with two different markers and fused the cells. Using a microscope, they observed the markers on the hybrid cell.

**RESULTS**

The mixing of the mouse and human membrane proteins indicates that at least some membrane proteins move sideways within the plane of the plasma membrane.
a.) Transport of specific solutes into or out of cells.
b.) Enzymatic activity, sometimes catalyzing one of a number of steps of a metabolic pathway.
c.) Signal transduction, relaying hormonal messages to the cell.
d.) Cell-cell recognition, allowing other proteins to attach two adjacent cells together.
e.) Intercellular joining of adjacent cells with gap or tight junctions.
f.) Attachment to the cytoskeleton and extracellular matrix, maintaining cell shape and stabilizing the location of certain membrane proteins.
Learning Check

- Why don’t these proteins just fly out of the membrane?
- What keeps them in place?
- Think about R-groups?
Cell to Cell Recognition

- Cell-cell recognition, the ability of a cell to distinguish one type of neighboring cell from another, is crucial to the functioning of an organism.
- This attribute is important in the sorting and organization of cells into tissues and organs during development.
- It is also the basis for rejection of foreign cells by the immune system.
- Cells recognize other cells by binding to surface molecules, often carbohydrates, on the plasma membrane.
Transport Proteins

• Proteins assist and regulate the transport of ions and polar molecules

• Specific ions and polar molecules can cross the lipid bilayer by passing through transport proteins that span the membrane.
  
  – *Channel proteins*, have a hydrophilic channel that certain molecules or ions can use as a tunnel through the membrane.
  
  – Example: *aquaporins* – transport of water

  – *Carrier proteins*, bind to molecules and change shape to shuttle them across the membrane.
Two molecules that can cross a lipid bilayer without help from membrane proteins are O₂ and CO₂. What properties allow this to occur?

Why would water molecules need a transport protein to move rapidly and in large quantities across membranes?
Facilitated diffusion

- **Specific proteins** facilitate passive transport of water and selected solutes
- Two types of transport proteins facilitate the movement of molecules or ions across membranes: channel proteins and carrier proteins
  - water channel proteins = **aquaporins**
  - Many **ion channels** function as **gated channels**. These channels open or close in response to the presence or absence of a chemical or physical stimulus.
Facilitated Diffusion (continued)

- Some transport proteins do not provide channels but appear to actually translocate the solute-binding site and solute across the membrane as the transport protein changes shape.
  - These shape changes may be triggered by the binding and release of the transported molecule.
Active Transport

REQUIRES ENERGY!

**Definition:** Movement from a **low concentration** to a **high concentration** using a protein channel
Active Transport

- **Active transport** requires the cell to expend metabolic energy.
- Required to move charged molecules or to move other molecules against their concentration gradient.
- ATP supplies the energy for most active transport.
  - Transfer of phosphate group from ATP to transport protein may cause conformational change needed of transport.
Active Transport
Energy = ATP

- ATP = adenosine triphosphate.
  - This is the compound that directly supplies the energy to do cellular work.
How ATP Works

The release of one of the phosphate groups makes energy available to do cellular work.

- ATP energizes other molecules by transferring one phosphate group.
Example

- **Sodium-potassium pump** actively maintains the gradient of sodium ions (Na\(^+\)) and potassium ions (K\(^+\)) across the plasma membrane of animal cells.
  - Typically, K\(^+\) concentration is low outside an animal cell and high inside the cell, while Na\(^+\) concentration is high outside an animal cell and low inside the cell.
  - The sodium-potassium pump maintains these concentration gradients, using the energy of one ATP to pump three Na\(^+\) out and two K\(^+\) in.
Some ion pumps generate voltage across membranes

- All cells maintain a voltage across their plasma membranes.
- Voltage is electrical potential energy due to the separation of opposite charges.
- The voltage across a membrane is called a **membrane potential**.
- Movement of ions across the membrane involves an electrochemical gradient = two forces involved:
  - One is a chemical force based on an ion’s concentration gradient.
  - The other is an electrical force based on the effect of the membrane potential on the ion’s movement.
Electrogenic pumps

- The sodium-potassium pump is the major electrogenic pump of animal cells.
- In plants, bacteria, and fungi, a **proton pump** is the major electrogenic pump, actively transporting $H^+$ out of the cell.
- Proton pumps in the cristae of mitochondria and the thylakoids of chloroplasts concentrate $H^+$ behind membranes.
Cotransport

- A single ATP-powered pump that transports one solute can indirectly drive the active transport of several other solutes in a mechanism called **cotransport**.
- As the solute that has been actively transported diffuses back passively through a transport protein, its movement can be coupled with the active transport of another substance against its concentration gradient.
Sucrose-proton Cotransport

- One specific transport protein couples the diffusion of protons out of the cell and the transport of sucrose into the cell.
- Plants use the mechanism of sucrose-proton cotransport to load sucrose into specialized cells in the veins of leaves for distribution to nonphotosynthetic organs such as roots.
Bulk Transport

- Large molecules, such as polysaccharides and proteins, cross the membrane via vesicles
  - **Exocytosis**, a transport vesicle budded from the Golgi apparatus is moved by the cytoskeleton to the plasma membrane
  - **Endocytosis**, a cell brings in macromolecules and particulate matter by forming new vesicles from the plasma membrane.
Three Types of Endocytosis

**In phagocytosis**, the cell engulfs a particle by extending pseudopodia around it and packaging it in a large vacuole.

- The contents of the vacuole are digested when the vacuole fuses with a lysosome.

**In pinocytosis**, a cell creates a vesicle around a droplet of extracellular fluid. All included solutes are taken into the cell in this nonspecific process.
Three Types of Endocytosis

- **Receptor-mediated endocytosis** allows greater specificity, transporting only certain substances.
  - Receptor-mediated endocytosis enables a cell to acquire bulk quantities of specific materials that may be in low concentrations in the environment.
  - Human cells use this process to take in cholesterol for use in the synthesis of membranes and as a precursor for the synthesis of steroids.
Endocytosis

Molecular Expressions
Digital Microscopy

Amoeba
(Protozoan)

Through the Nikon Eclipse E600 Microscope with Apodized Phase Contrast
Exocytosis

Exocytosis in Paramecium
Learning Check

• The carbs attached to some proteins and lipids of the plasma membrane are added as the membrane is made and refined in the ER and Golgi. The new membrane then forms transport vesicles that travel to the cell surface. On which side of the vesicle membrane are the carbs?
Review: Passive and active transport compared

Passive transport. Substances diffuse spontaneously down their concentration gradients, crossing a membrane with no expenditure of energy by the cell. The rate of diffusion can be greatly increased by transport proteins in the membrane.

Active transport. Some transport proteins act as pumps, moving substances across a membrane against their concentration gradients. Energy for this work is usually supplied by ATP.

**Diffusion.** Hydrophobic molecules and (at a slow rate) very small uncharged polar molecules can diffuse through the lipid bilayer.

**Facilitated diffusion.** Many hydrophilic substances diffuse through membranes with the assistance of transport proteins, either channel or carrier proteins.
Based on the model of sucrose uptake in this figure, which of the following experimental treatments would increase the rate of sucrose transport into the cell?

- decreasing extracellular sucrose concentration
- decreasing extracellular pH
- decreasing cytoplasmic pH
- adding an inhibitor that blocks the regeneration of ATP
- adding a substance that makes the membrane more permeable to hydrogen ions
Which of the following statements about the role of phospholipids in forming membranes is correct? (Concept 7.1) [Hint]

- Phospholipids are completely insoluble in water.
- Phospholipids form a single sheet in water.
- Phospholipids form a structure in which the hydrophobic portion faces outward.
- Phospholipids form a selectively permeable structure.
- They are triacylglycerols, which are commonly available in foods.
Which of the following would be least likely to diffuse through a plasma membrane without the help of a transport protein? (Concept 7.2) [Hint]

- a large polar molecule
- a large nonpolar molecule
- dissolved gases such as oxygen or carbon dioxide
- a small nonpolar molecule
- Any of the above would easily diffuse through the membrane.
Which of the following statements is true about passive transport? (Concept 7.3) [Hint]

- Passive transport operates independently of diffusion.
- Passive transport operates independently of the concentrations of the substance being transported.
- In passive transport, all movement of the transported molecule stops when its concentration is the same on both sides of the membrane.
- Passive transport does not occur in the human body.
- Passive transport permits the transported molecule to move in either direction, but the majority of transport occurs down the concentration gradient of the molecule.
Which of these statements describes some aspect of facilitated diffusion? (Concept 7.3) [Hint]

- Facilitated diffusion is another name for osmosis.
- Facilitated diffusion of solutes occurs through phospholipid pores in the membrane.
- Facilitated diffusion requires energy to drive a concentration gradient.
- Facilitated diffusion of solutes may occur through protein pores in the membrane.
- There is only one kind of protein pore for facilitated diffusion.
Which one of the following is not in some way involved in facilitated diffusion? (Concept 7.3) [Hint]

- a concentration gradient
- a membrane
- a protein
- an outside energy source
- All of the above are components of facilitated diffusion.
Which of the following is a difference between active transport and facilitated diffusion? (Concepts 7.3 and 7.4) [Hint]

- Active transport involves transport proteins, and facilitated diffusion does not.
- Facilitated diffusion can move solutes against a concentration gradient, and active transport cannot.
- Active transport can move solutes in either direction across a membrane, but facilitated diffusion can only move in one direction.
- Facilitated diffusion involves transport proteins, and active transport does not.
- Active transport requires energy from ATP, and facilitated diffusion does not.
Which of the following statements about the sodium-potassium pump is incorrect? (Concept 7.4) [Hint]

○ The sodium-potassium pump transports $\text{Na}^+$ and $\text{K}^+$ ions across the plasma membrane in opposite directions at the expense of ATP hydrolysis.

○ The sodium-potassium pump creates an electrochemical gradient.

○ The sodium-potassium pump is electrogenic.

○ The sodium-potassium pump causes a pH gradient across the plasma membrane.

○ The sodium-potassium pump creates concentration gradients of both $\text{Na}^+$ and $\text{K}^+$ across the plasma membrane.
Which of the following enables a cell to pick up and concentrate a specific kind of molecule? (Concepts 7.3 and 7.4) [Hint]

- passive transport
- facilitated diffusion
- osmosis
- receptor-mediated endocytosis
- channel proteins
Which of the following processes, normally associated with membrane transport, must occur in order to account for the increase in the surface area of a cell? (Concept 7.5) [Hint]

- endocytosis
- active transport
- receptor-mediated endocytosis
- exocytosis
- flip-flop of phospholipids from one side of the plasma membrane to the other
Active and passive transport of solutes across a membrane typically differ in which of the following ways? (Concept 7.4)

[Hint]

- Active transport is usually against the concentration gradient of the solute, whereas passive transport is always down the concentration gradient of the solute.
- Active transport always involves the utilization of cellular energy, whereas passive transport does not require cellular energy.
- Active transport always requires the use of transport proteins, but passive transport can sometimes be accomplished without a protein.
- The first and second choices are correct.
- The first, second, and third choices are all correct.
Sodium ions are transported down their concentration gradient.

An electrochemical gradient forms across the plasma membrane.

The cell does not expend ATP.

The cell is not expending energy.

Potassium ions are transported down their concentration gradient.
Endocytosis moves materials _____ a cell via _____. (Activity: Exocytosis and Endocytosis)

- into ... facilitated diffusion
- into ... membranous vesicles
- into ... a transport protein
- out of ... diffusion
- out of ... membranous vesicles