INTRODUCTION TO THE CELL

Introduction

- Our understanding of nature often goes hand in hand with the invention and refinement of instruments that extend our senses.
  - In 1665, Hooke used a crude microscope to examine a piece of bark from an oak tree. Hooke compared the structures he saw to "little rooms"—*cellulae* in Latin—and the term "cell" stuck.
  - Leeuwenhoek used more refined lenses to describe living cells from blood, sperm, and ponds.
- Since the days of Hooke and Leeuwenhoek, improved microscopes and techniques have vastly expanded our view of the cell.

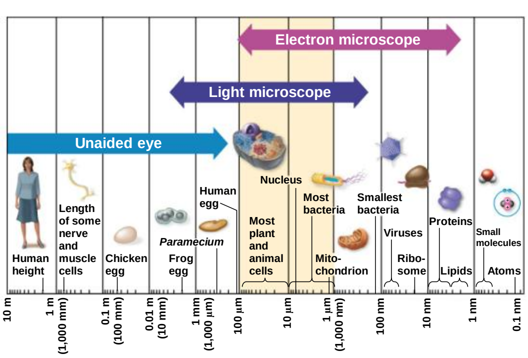
Microscopes reveal the world of the cell

- The **light microscope** can display living cells.
- The greater magnification and resolution of **scanning** and **transmission electron microscopes** reveal the ultrastructure of cells.
  - *Magnification* is the increase in an object's image size compared with its actual size.
  - *Resolution* is a measure of the clarity of an image. In other words, it is the ability of an instrument to show two nearby objects as separate.

▲ Figure 4.1A Light micrograph of the unicellular organism *Paramecium*

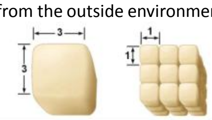
▲ Figure 4.1B Scanning electron micrograph of *Paramecium*

Figure 4.1e_3



Most cells are tiny

- As an object increases in volume, its surface area also increases, but not at the same rate → great biological significance for two reasons:
  - The volume of a cell determines the amount of chemical activity it carries out per unit of time.
  - The surface area of a cell determines the amount of substances that can enter it from the outside environment, and the amount of waste products that can exit to the environment.



Total volume	27 units³	27 units³
Total surface area	54 units²	162 units²
Surface-to-volume ratio	2	6

Prokaryotic cells are structurally simpler than eukaryotic cells

- All cells are classified as either **prokaryotic** or **eukaryotic**
- All cells have a plasma membrane, DNA, ribosomes, and **cytosol**.

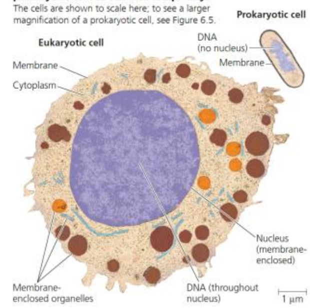
- A **prokaryotic** cell does not typically have membrane-enclosed internal compartments; in particular, it does not have a nucleus.

- Bacteria & archaea

- Genetic material (DNA) of **eukaryotic** cells is contained in a special membrane-enclosed compartment called the *nucleus*. Eukaryotic cells also contain other membrane-enclosed compartments in which specific chemical reactions occur.

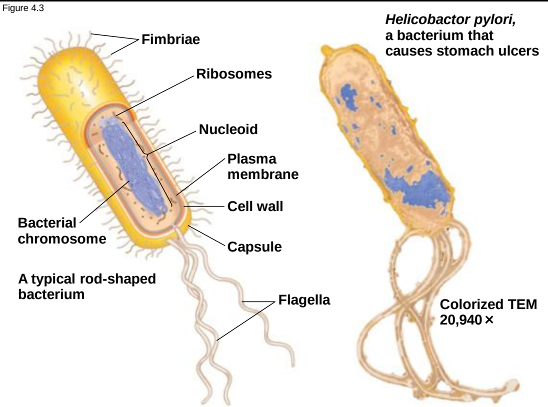
- Protists, plants, fungi, and animals

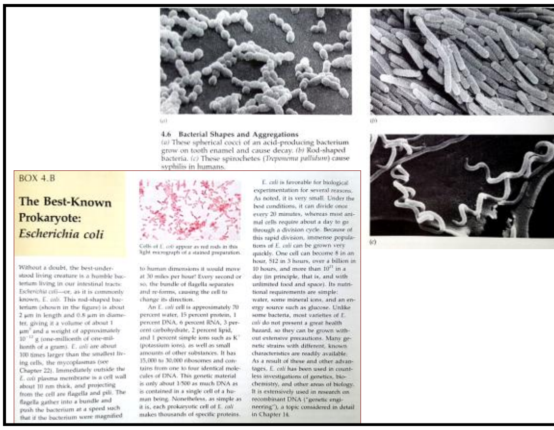
Figure 1.4 Contrasting eukaryotic and prokaryotic cells in size and complexity. The cells are shown to scale here; to see a larger magnification of a prokaryotic cell, see Figure 6.5.



- All cells share certain characteristics. Every cell is enclosed by a membrane that regulates the passage of materials between the cell and its surroundings.
- Single-celled microorganisms—bacteria (singular, *bacterium) and archaea (singular, archaean)*—are prokaryotic.
- All other forms of life, including plants and animals, are composed of eukaryotic cells.

Figure 4.3





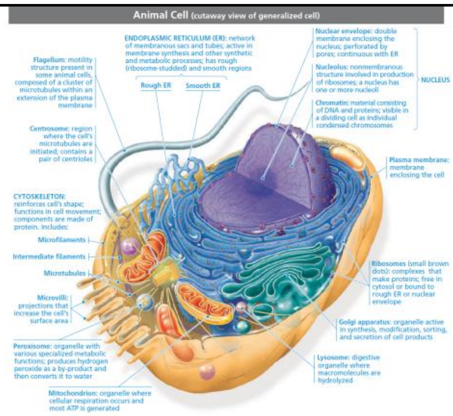
Eukaryotic cells are partitioned into functional compartments

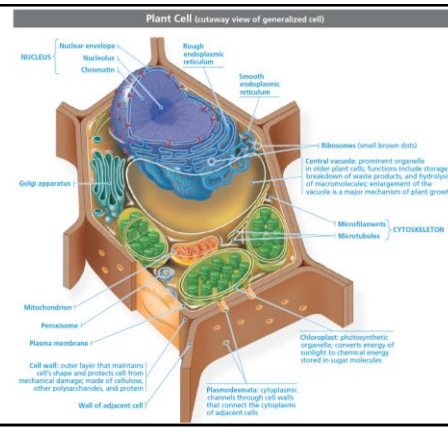
- Membrane-enclosed **organelles** compartmentalize a cell's activities.
- The organelles and other structures of eukaryotic cells can be organized into four basic functional groups:
  1. The nucleus and ribosomes carry out the genetic control of the cell.
  2. Organelles involved in the manufacture, distribution, and breakdown of molecules include the endoplasmic reticulum, Golgi apparatus, lysosomes, vacuoles, and peroxisomes.

Eukaryotic cells are partitioned into functional compartments

3. Mitochondria in all cells and chloroplasts in plant cells function in energy processing.
4. Structural support, movement, and communication between cells are the functions of the cytoskeleton, plasma membrane, and plant cell wall.

Checkpoint question Identify the structures in the plant cell that are not present in the animal cell.





Many organelles are connected in the endomembrane system

- Many of the membranes within a eukaryotic cell are part of the **endomembrane system**.
- Many of these organelles interact in the
  - synthesis,
  - distribution,
  - storage, and
  - export of molecules.

The endomembrane system regulates protein traffic and performs metabolic functions

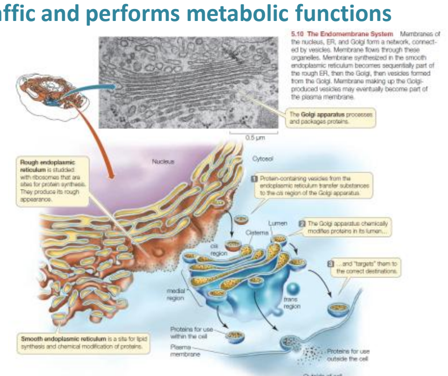
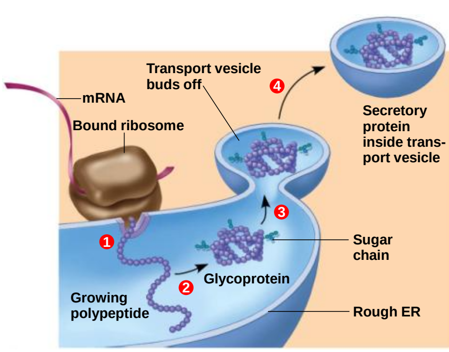
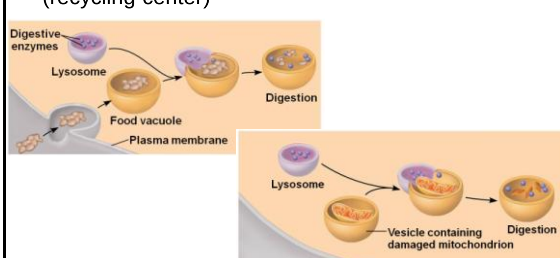


Figure 4.8b



Lysosomes are digestive compartments within a cell

- Lysosomes house enzymes that break down ingested substances and damaged organelles. (recycling center)



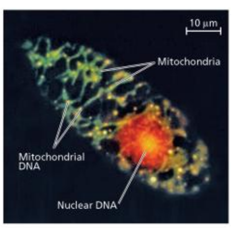
Energy-Converting Organelles

Mitochondria harvest chemical energy from food

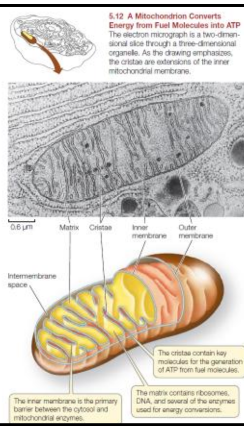
- **Mitochondria** are organelles that carry out cellular respiration in nearly all eukaryotic cells.
- Mitochondria have two internal compartments.
  1. The intermembrane space is the narrow region between the inner and outer membranes.
  2. The **mitochondrial matrix** contains the mitochondrial DNA, ribosomes, and many enzymes that catalyze some of the reactions of cellular respiration.

Checkpoint question What is cellular respiration?

Mitochondrion



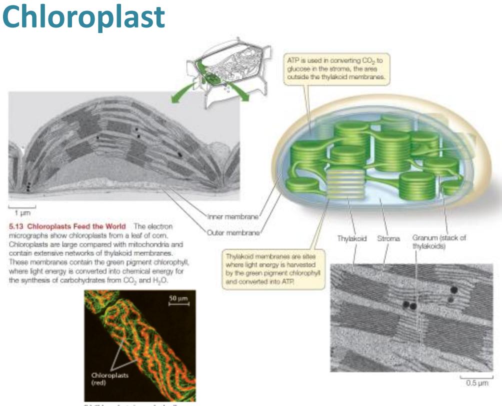
(b) Network of mitochondria in *Euglena* (LM)



Chloroplasts convert solar energy to chemical energy

- Photosynthesis is the conversion of light energy from the sun to the chemical energy of sugar molecules.
- **Chloroplasts** are the photosynthesizing organelles of plants and algae.

Chloroplast

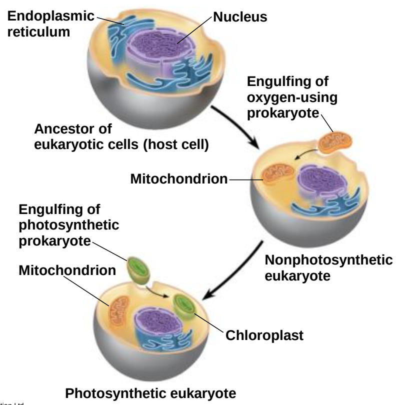


(b) Chloroplasts in an algal cell

Mitochondria and chloroplasts evolved by endosymbiosis

- The **endosymbiont theory** states that mitochondria and chloroplasts were formerly small prokaryotes that began living within larger cells.

Checkpoint question All eukaryotes have mitochondria, but not all have chloroplasts. What is the evolutionary explanation?



THE CYTOSKELETON AND CELL SURFACES

The cell's internal skeleton helps organize its structure and activities

- The **cytoskeleton** includes **microfilaments**, **intermediate filaments**, and **microtubules**. Their functions include
  - maintenance of cell shape,
  - anchorage and movement of organelles,
  - amoeboid movement,
  - muscle contraction.

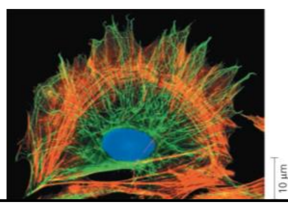
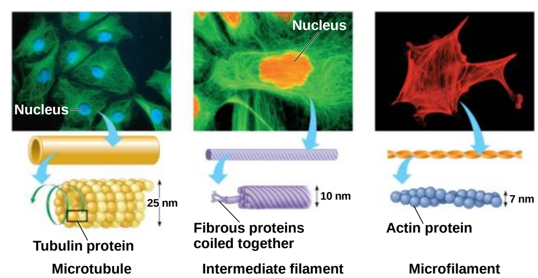
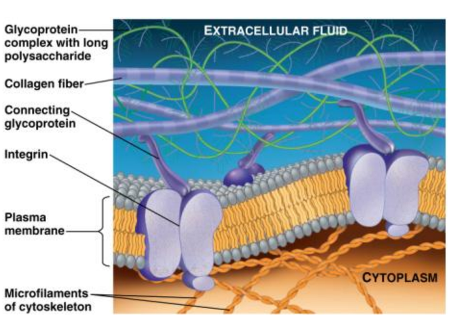


Figure 4.16



Extracellular Matrix (ECM)



Review: Eukaryotic cell structures can be grouped on the basis of four main functions

- Eukaryotic cell structures can be grouped on the basis of four functions:
  1. genetic control,
  2. manufacturing, distribution, and breakdown of materials,
  3. energy processing, and
  4. structural support, movement, and intercellular communication.

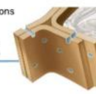
Table 4.22_1

TABLE 4.22 Eukaryotic Cell Structures and Their Functions

1. Genetic Control	
Nucleus 	DNA replication, RNA synthesis; assembly of ribosomal subunits (in nucleolus)
Ribosomes	Polypeptide (protein) synthesis
2. Manufacturing, Distribution, and Breakdown	
Rough ER	Synthesis of membrane lipids and proteins, secretory proteins, and hydrolytic enzymes; formation of transport vesicles
Smooth ER	Lipid synthesis; detoxification in liver cells; calcium ion storage in muscle cells
Golgi apparatus 	Modification and sorting of ER products; formation of lysosomes and transport vesicles
Lysosomes (in animal cells and some protists)	Digestion of ingested food or bacteria and recycling of a cell's damaged organelles and macromolecules
Vacuoles	Digestion (food vacuole); water balance (contractile vacuole); storage of chemicals and cell enlargement (central vacuole in plant cells)
Peroxisomes (not part of endomembrane system)	Diverse metabolic processes, with breakdown of toxic hydrogen peroxide by-product

Table 4.22_2

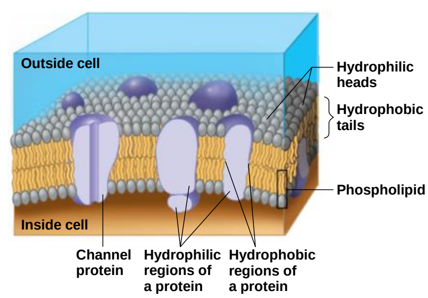
TABLE 4.22 Eukaryotic Cell Structures and Their Functions

3. Energy Processing	
Mitochondria 	Cellular respiration: conversion of chemical energy in food to chemical energy of ATP
Chloroplasts (in plants and algae)	Photosynthesis: conversion of light energy to chemical energy of sugars
4. Structural Support, Movement, and Communication Between Cells	
Cytoskeleton (microfilaments, intermediate filaments, and microtubules) 	Maintenance of cell shape; anchorage for organelles; movement of organelles within cells; cell movement (crawling, muscle contraction, bending of cilia and flagella)
Plasma membrane	Regulate traffic in and out of cell
Extracellular matrix (in animals)	Support; regulation of cellular activities
Cell junctions 	Communication between cells; binding of cells in tissues
Cell walls (in plants)	Support and protection; binding of cells in tissues

Membrane Structure and Function

Figure 4.2b

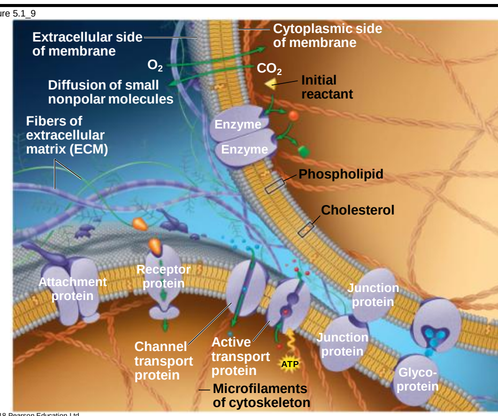
The structure of a plasma membrane



Membranes are fluid mosaics of lipids and proteins with many functions

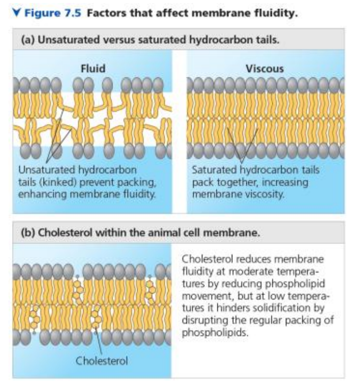
- Biologists use the **fluid mosaic model** to describe a membrane's structure—diverse protein molecules suspended in a fluid phospholipid bilayer.
- The plasma membrane exhibits **selective permeability**.
- The proteins perform various functions.

Figure 5.1_9



Plasma membrane **carbohydrates** are **recognition sites**

- Membrane carbohydrates are usually short, branched chains of fewer than 15 sugar units. Most are covalently bonded to proteins, which are thereby **glycoproteins.**
- The carbohydrates on the extracellular side of the plasma membrane vary from species to species, among individuals of the same species, and even from one cell type to another in a single individual. The diversity of the molecules and their location on the cell's surface enable membrane carbohydrates to function as markers that distinguish one cell from another.
  - E.g. the four human blood types designated A, B, AB, and O reflect variation in the carbohydrate part of glycoproteins on the surface of red blood cells.

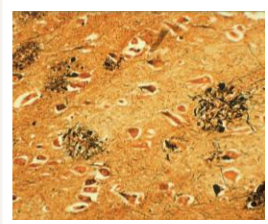


EVOLUTION CONNECTION: The spontaneous formation of membranes was a critical step in the origin of life

- Phospholipids spontaneously self-assemble into simple membranes.
- The formation of membrane-enclosed collections of molecules was a critical step in the evolution of the first cells.

Checkpoint question In the origin of a cell, why would the formation of a simple lipid bilayer membrane not be sufficient? What else would have to be part of such a membrane?

Dr. Alzheimer's Patient Frau Auguste D., who died in 1906, was the first patient described with progressive dementia by Dr. Alois Alzheimer.

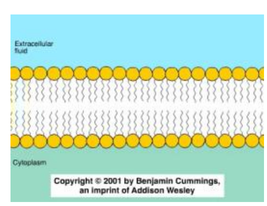


Plaques in the Brain At autopsy, the brain of an Alzheimer's disease patient accumulates plaques (dark fibers in this micrograph) composed of protein fragments produced by an enzyme in the nerve cell membrane.

Membrane structure results in selective permeability

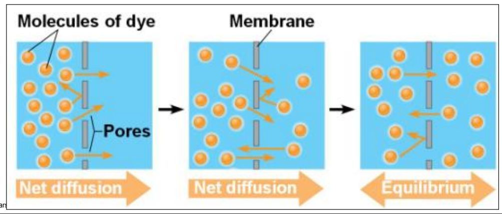
- Control of the cell's internal composition is very significant.
- Membrane determines what substances enter or leave a cell or organelle.
  - The processes of **passive transport do not require any input** of outside energy to drive them (*no metabolic energy).*
  - The processes of **active transport require the input of chemical energy** from an outside source (*metabolic energy).*

Animation: Membrane Selectivity



Passive transport is diffusion across a membrane with no energy investment

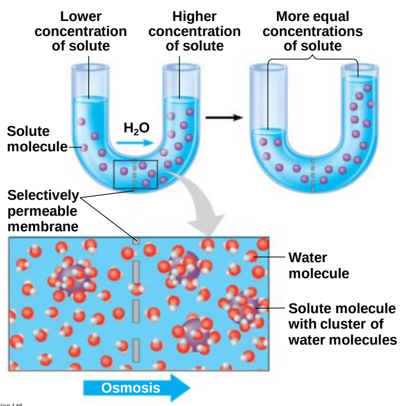
- **Diffusion** is the tendency of particles to spread out evenly in an available space.
- Diffusion across a cell membrane does not require energy, so it is called **passive transport**.



Osmosis is the diffusion of water across a membrane

- The diffusion of water across a selectively permeable membrane is called **osmosis**.
- If a membrane, permeable to water but not to a solute, separates two solutions with different concentrations of solute, water will cross the membrane, moving down its own concentration gradient, until the solute concentration on both sides is equal.

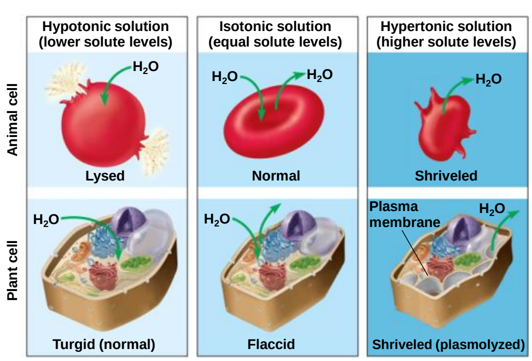
Figure 5.4



Water balance between cells and their surroundings is crucial to organisms

- **Tonicity** is a term that describes the ability of a surrounding solution to cause a cell to gain or lose water.
- Cells shrink in a **hypertonic** solution.
- Cells swell in a **hypotonic** solution.
- In **isotonic** solutions, animal cells are normal, but plant cells are flaccid.

Figure 5.5

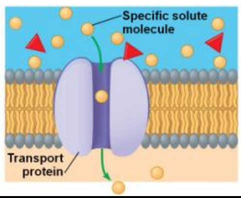


Transport proteins can facilitate diffusion across membranes

- Hydrophobic substances easily diffuse across a cell membrane.
- However, polar or charged substances do not easily cross cell membranes.
- Instead, polar or charged substances move across membranes with the help of specific transport proteins, called **facilitated diffusion**, which
  - does not require energy and
  - relies on the concentration gradient.

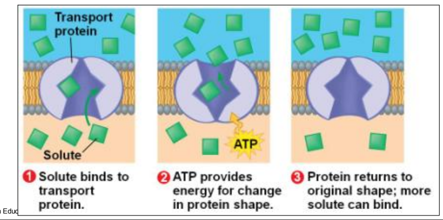
Transport proteins can facilitate diffusion across membranes

- Transport proteins help specific substances diffuse across the membrane down their concentration gradients and thus requires no input of energy.
- The very rapid diffusion of water into and out of certain cells is made possible by a protein channel called an **aquaporin**.

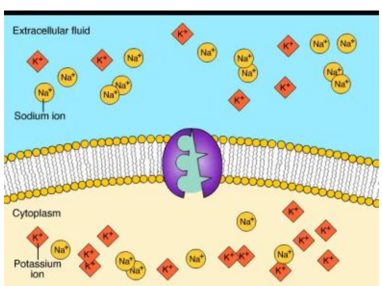


Cells expend energy in the active transport of a solute

- In **active transport**, a cell must expend energy to move a solute *against* its concentration gradient.
- The energy molecule ATP supplies the energy for most active transport.



Animation: Active Transport



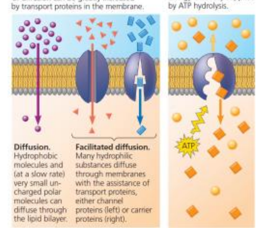
Membrane Transport Mechanisms

	SIMPLE DIFFUSION	FACILITATED DIFFUSION	ACTIVE TRANSPORT
Cellular energy required?	No	No	Yes
Driving force	Concentration gradient	Concentration gradient	ATP hydrolysis (against concentration gradient)
Membrane protein required?	No	Yes	Yes
Specificity	No	Yes	Yes

Figure 7.16 Review: passive and active transport.

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 (or electrochemical) gradients. Energy is usually supplied by ATP hydrolysis.



Exocytosis and endocytosis transport large molecules across membranes

- A cell uses two mechanisms to move large molecules across membranes.
  1. **Exocytosis** is used to export bulky molecules, such as proteins or polysaccharides.
  2. **Endocytosis** is used to take in large molecules.
- In both cases, material to be transported is packaged within a vesicle that fuses with the membrane.

Animation: Exocytosis and Endocytosis Introduction