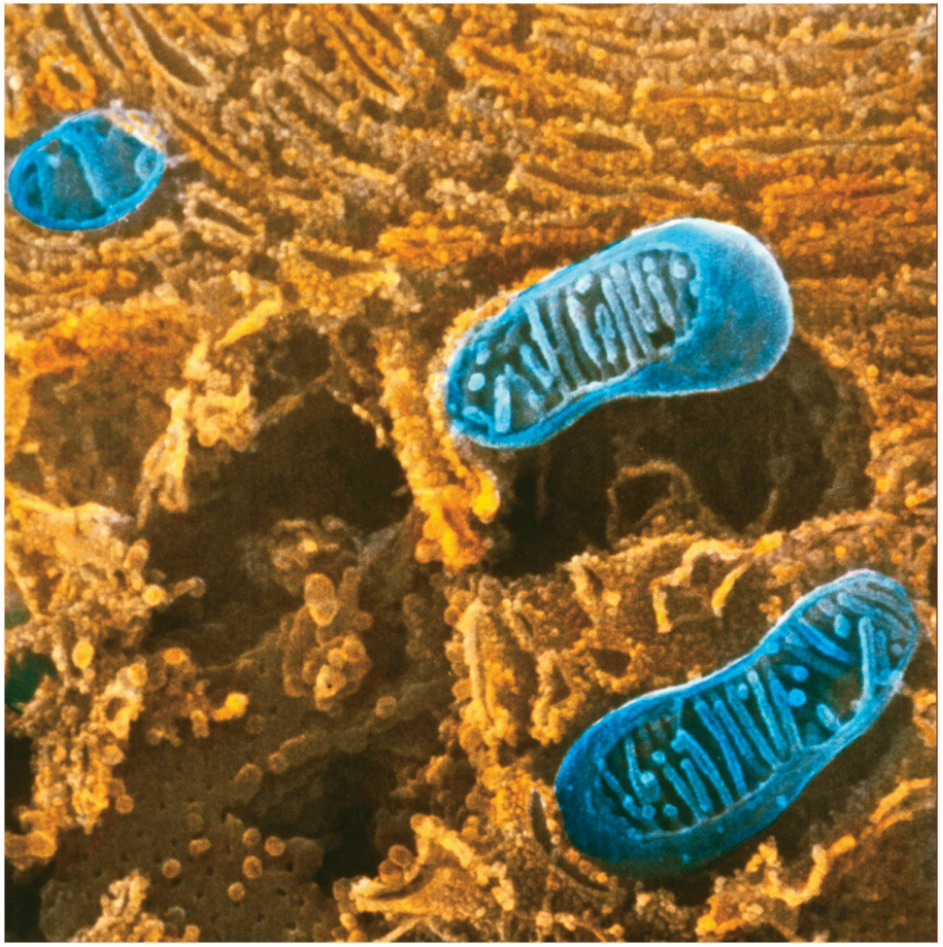
Chapter 3.1

Cell Form & Function



The Modern Cell Theory

This is the Most Important Theory in Biology

#1 - All living organisms are composed of cells.

#2 - The cell is the structural organization of all organisms (unicellular and multicellular life forms).

#3 - All cells come from preexisting cells (not from nonliving matter)

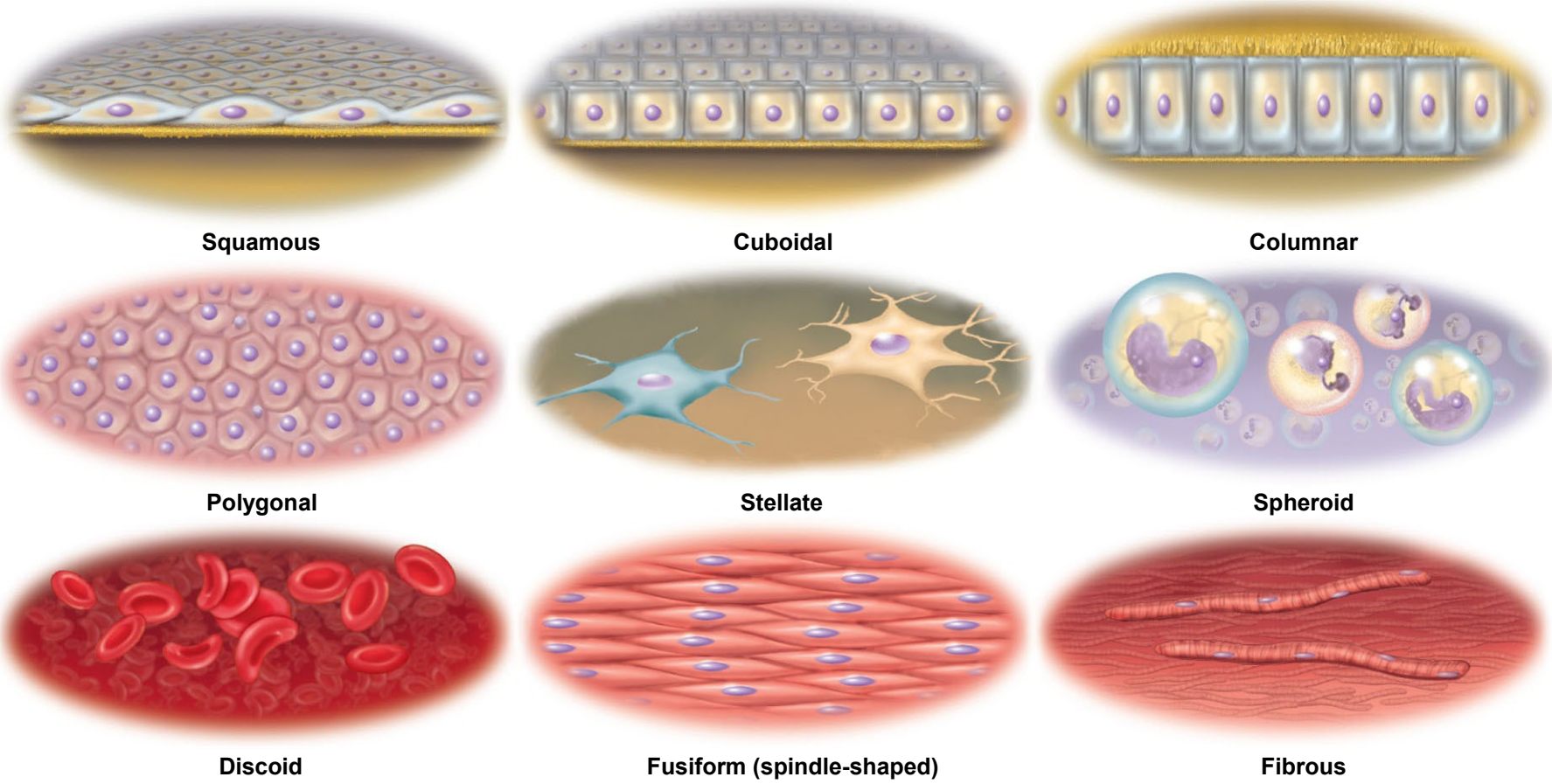
Therefore.....

Cells of all species have many fundamental similarities in their chemical composition and metabolism.

And all life can trace their ancestry to the same original cells. This occurred over 3.5 billion years ago!

Note: the universe formed 13.8 billion years in the "big bang" // earth formed 4.5 bya and the first cell formed 3.5 bya (Note – new science suggest universe could be as old as 26 billion years old!)

Human Cell Come in Many Shapes



50 trillion cells in the human body

Cell Shapes

- **About 200 different types of cells in the human body with many different shapes**
- Squamous **- thin and flat with nucleus creating bulge**
- Polygonal **- irregularly angular shapes with 4 or more sides**
- Stellate **– starlike shape**
- Cuboidal **– squarish and about as tall as they are wide**
- Columnar **- taller than wide**
- Spheroid **to** Ovoid **– round to oval**
- Discoid **- disc-shaped**
- Fusiform **- thick in middle, tapered toward the ends**
- Fibrous – **threadlike shape**

Cell Size and Number

- Human cell size // most between 10 -15 micrometers (μm) in diameter *(test answer = 15 micrometers)*
    - RBC = 7.5 μm
    - egg cells (very large)100 μm diameter // barely visible to the naked eye
    - nerve cell upto 1 meter long // longest human cell but too slender to be seen with naked eye
    - estimated 50 trillion cells in human body
    - typical cell weights 1 nanogram // see “Article of Interest” / cell biology - to see how this was calculated

Limitation for Cell Size

As cells grow their surface area increases by a factor of “2” but their volume increases by a factor of “3”

Surface area of a cell is proportional to the square of its diameter

Volume of a cell is proportional to the cube of its diameter

Nutrient absorption and waste removal utilize surface area

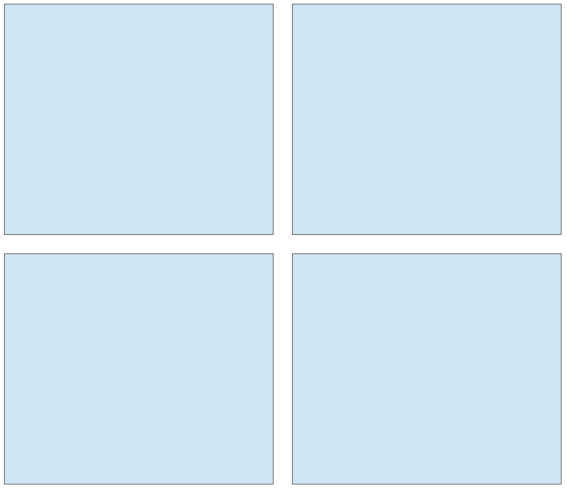
Cell volume increase faster than the cells' surface area

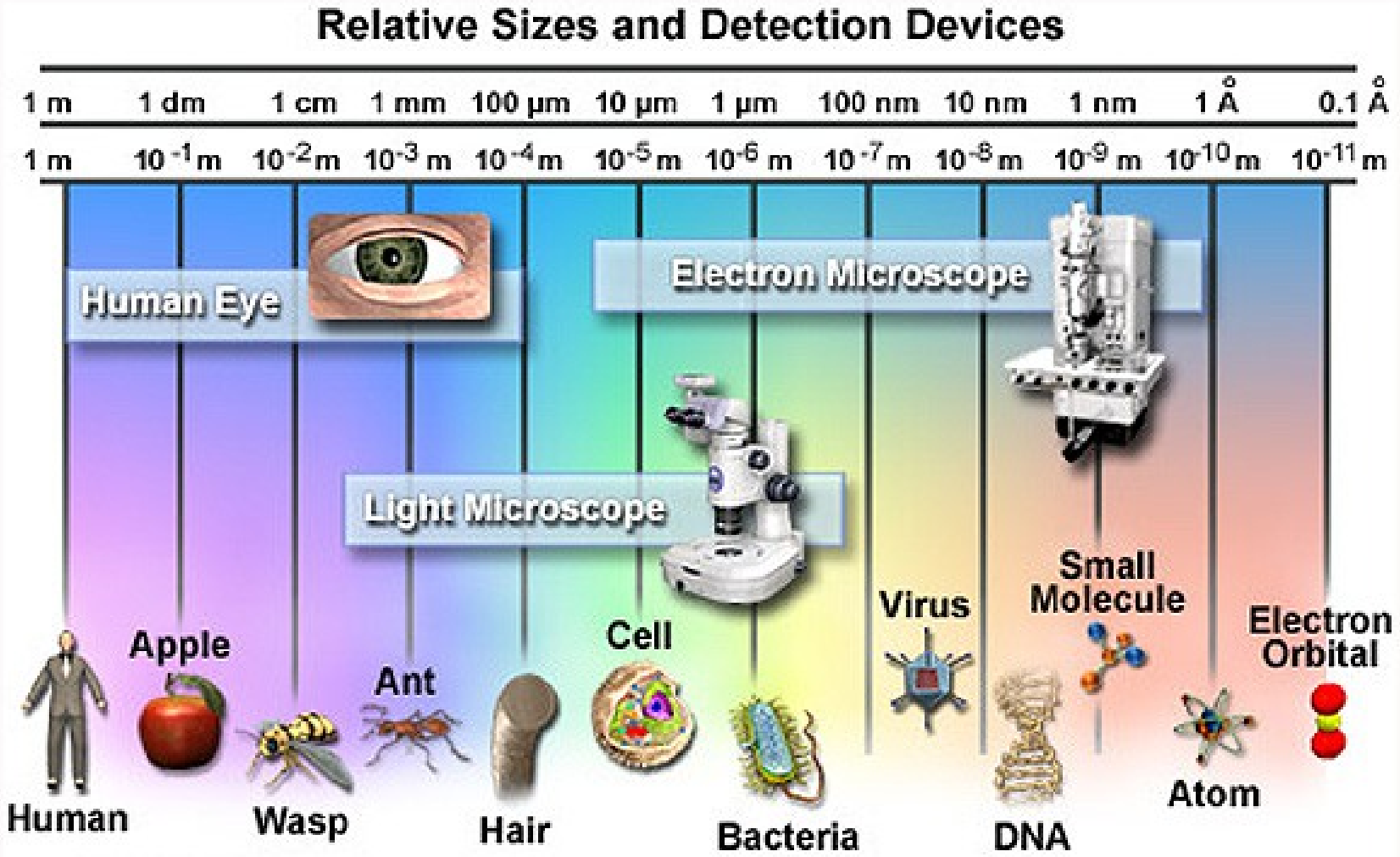
Therefore, it is the lack of surface area that limits the size of cell as it enlarge.

- A and B have the same volume. Which strucure has the most surface area?

A

B





1 micron = 1 x 10^{-6} meters = 0.000001 meters

We need to revisit the idea of homeostasis.

Homeostasis is the ability of a system to resist change. In the human body, our organs function to resist change in the internal environment. This is the interstitial fluid around our cells.

The interstitial fluid is in a state of dynamic equilibrium. Some organs bring nutrients to the interstitial fluid and the nutrients are transported into the cell's cytoplasm. The cells metabolize the nutrients for growth, repair, or to make new cells and make waste products.

The cells export the metabolic waste products into the interstitial fluid. Now other organs will excrete the waste products from our bodies. Negative and positive feedback mechanisms regulate organ functions to make homeostasis possible. Disease or death occurs when homeostasis fails.

What is the significance of the internal environment, dynamic equilibrium, feedback mechanisms, interstitial space, and organ systems?

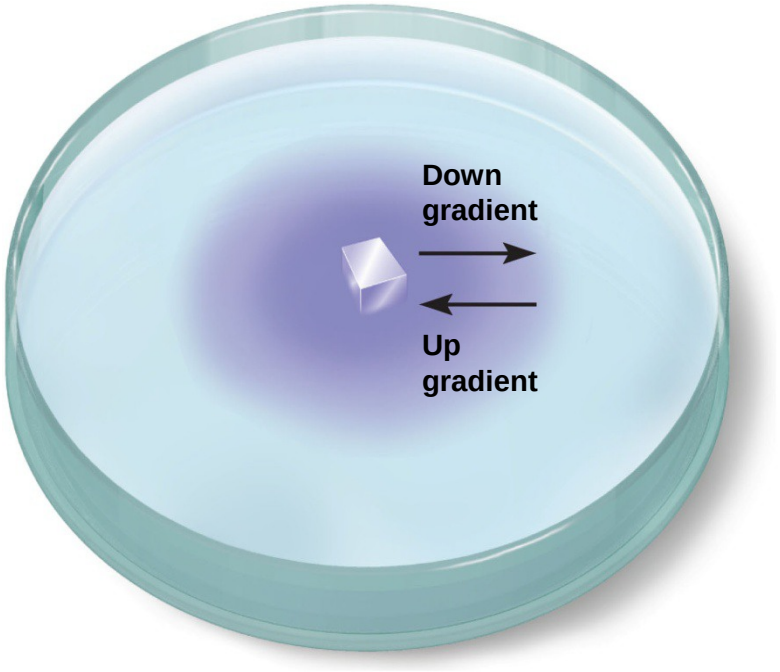
- How are nutrients delivered to the internal environment?
- How are nutrients moved into cells?
- How are nutrients used by cells? What is metabolism?
- What are metabolic waste products?
- How do nutrients and waste products cross the plasma membrane?

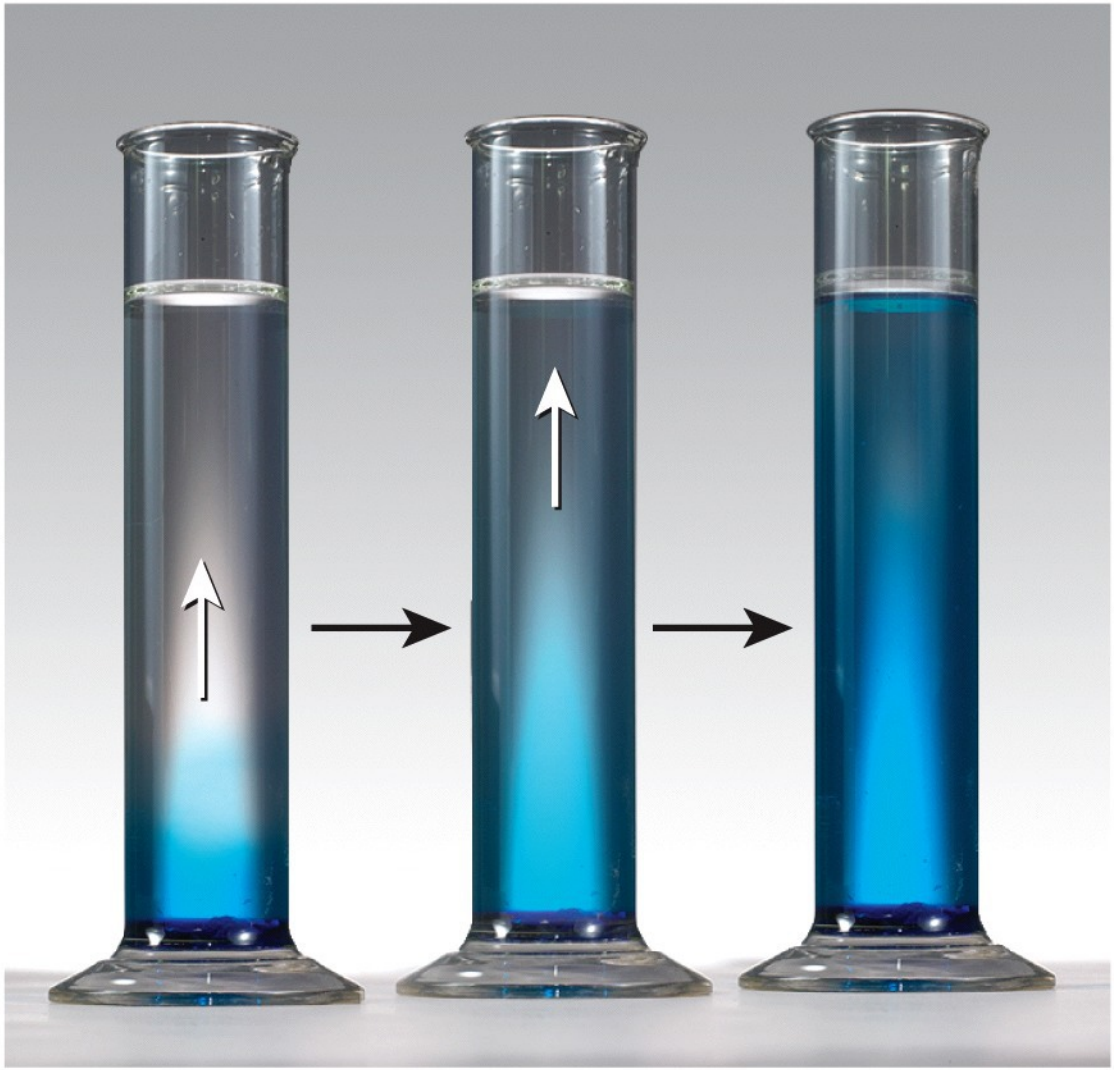
What physical forces move solute and solvent?

(Diffusion VS Osmosis VS Filtration)

Diffusion = Passive Process

- Movement of particles from area of high concentration to area of low concentration
- Occurs because the solute are very small and have a moment of spontaneous motion (these particles jiggle!).
- Diffusion is the movement of the solute down their concentration gradient // concentration of a substance differs between two points
- No energy needed to move particles





Andy Washnik

Beginning (a)

Intermediate (b)

Equilibrium (c)

Diffusion Rates

- Factors affecting diffusion rate through a membrane
  - temperature - ↑ **temp.,** ↑ **motion of particles**
  - molecular weight - **larger molecules move slower**
  - steepness of concentrated gradient - ↑**difference,** ↑ **rate**
  - membrane surface area - ↑ **area,** ↑ **rate**
  - membrane permeability - ↑ **permeability,** ↑ **rate**

- Please note: You do not need a membrane for diffusion. It is the movement of a solute from high to low concentration. However, diffusion of a solute may occur across membrane from high to low concentration if the solute is soluble in the membrane or the membrane contain pores through which the solute can diffuse.

Osmosis

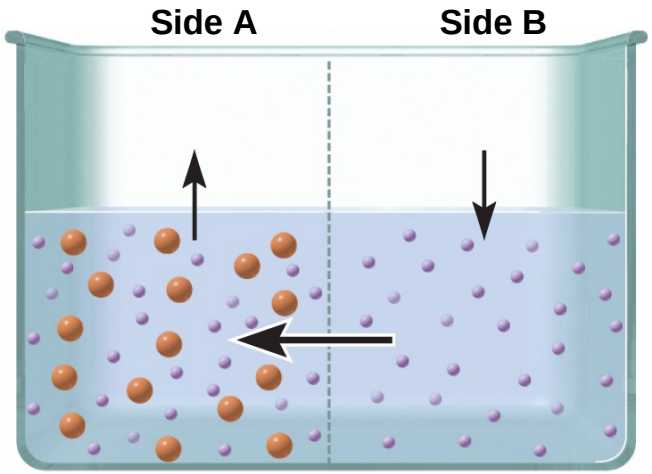
- Osmosis is the diffusion of water across a "semi-permeable" membrane

- Osmosis requires a semi-permeable membrane (i.e. selective) that allows water molecules to move across the membrane but restricts colloids

  - water moves from side with higher water concentration to the side with lower water concentration *(side with low tonicity to area of high tonicity)*

  - reversible attraction of water to solute particles that forms hydration spheres

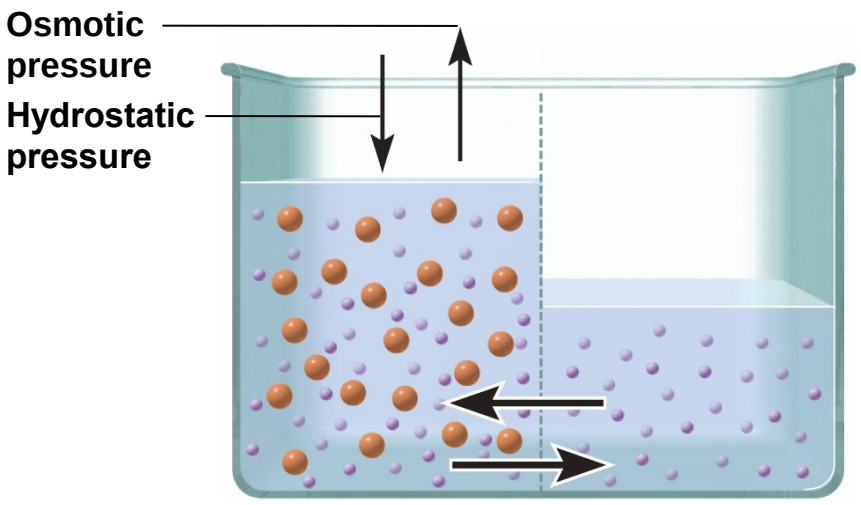
  - makes those water molecules less available to diffuse back to the side from which they came



Water Diffusion

Osmotic Pressure

- Water diffuses across semipermeable membrane into area with high tonicity (high concentration of solute particles)
- The increase in osmosis pressure moves the water column up
- Downward hydrostatic force will reach equilibrium and stop the osmosis



(b) 30 minutes later

Osmolarity

- One osmole equals a specific number of particles disolved in water
  - Note: 1M NaCl (1 mole Na^+ ions + 1 mole Cl^- ions) therefore - 1M NaCl = 2 osm/L
- Osmolarity – number of osmoles of solute per liter of solution
- Osmolality – number of osmoles of solute per kilogram of water
  - osmolality similar to molarity at concentration of body fluids – less than 1% difference
- Physiological solutions are expressed in milli-osmoles per liter (mOsm/L) /// **blood plasma = 300 mOsm/L**
- Avogadro's number is a dimensionless quantity, and has the same numerical value of the Avogadro constant when given in base units. (6.022140857 × 10 23 “solute particles” per mole)

Tonicity Describes the Relative Solute Particle Between to Environment

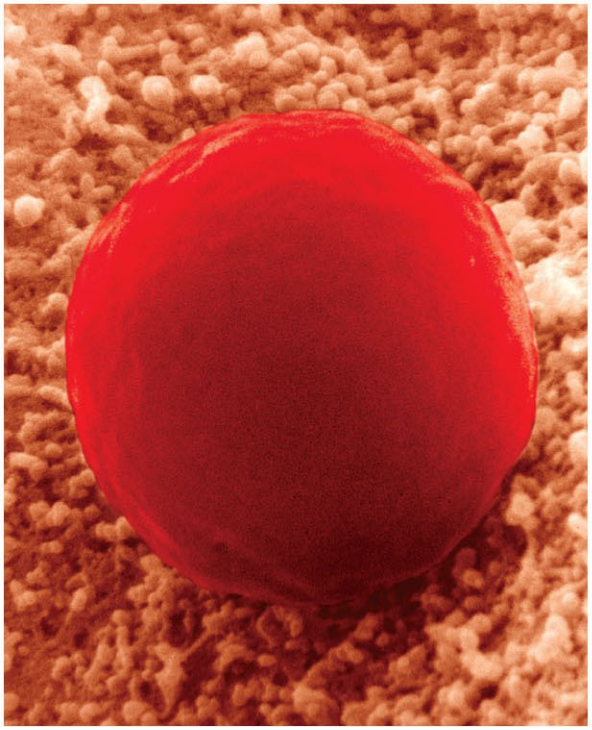
- **High tonicity is the ability of the solution around the cell to affect the fluid volume and pressure of a cell ///** depends on concentration and permeability of solute

- **Hypotonic solution ///** has a lower concentration of non-permeating solutes than intracellular fluid (ICF) and a high water concentration
  - If you put a cells (high tonicity) into hypotonic environment it will absorb water, swell and may burst (lyse)

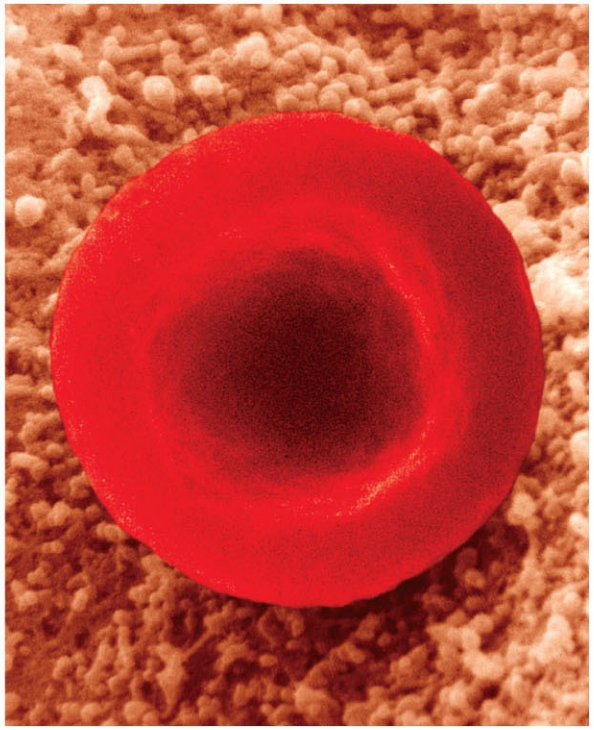
- **Hypertonic solution ///** has a higher concentration of non-permeating solutes - low water concentration
  - cells lose water + shrivel (crenate)

- **Isotonic solution**
  - concentrations in cell and ICF are the same
  - cause no changes in cell volume or cell shape
  - normal saline

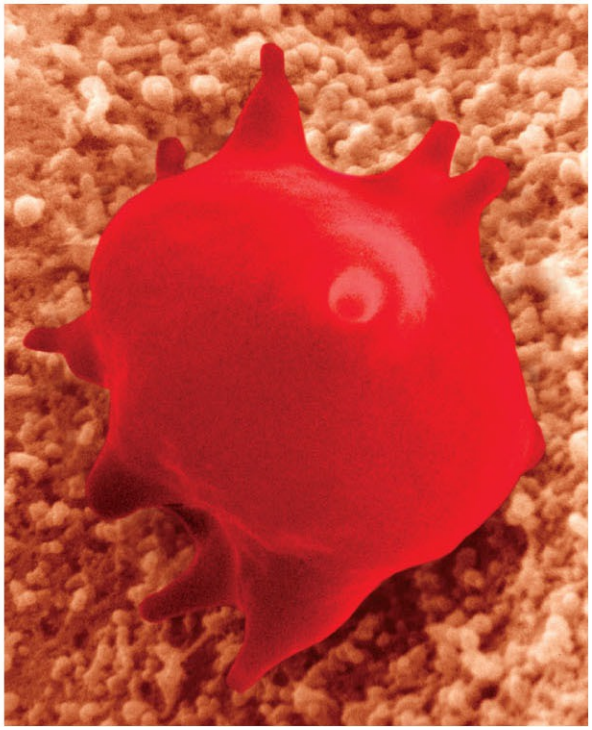
Effects of Tonicity on RBCs



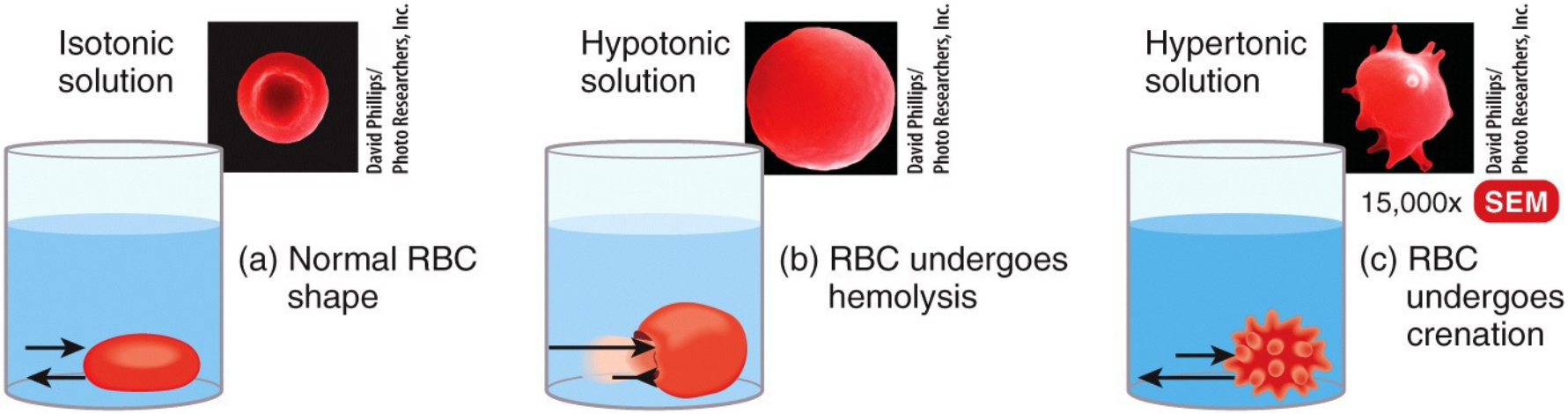
(a) Hypotonic



(b) Isotonic



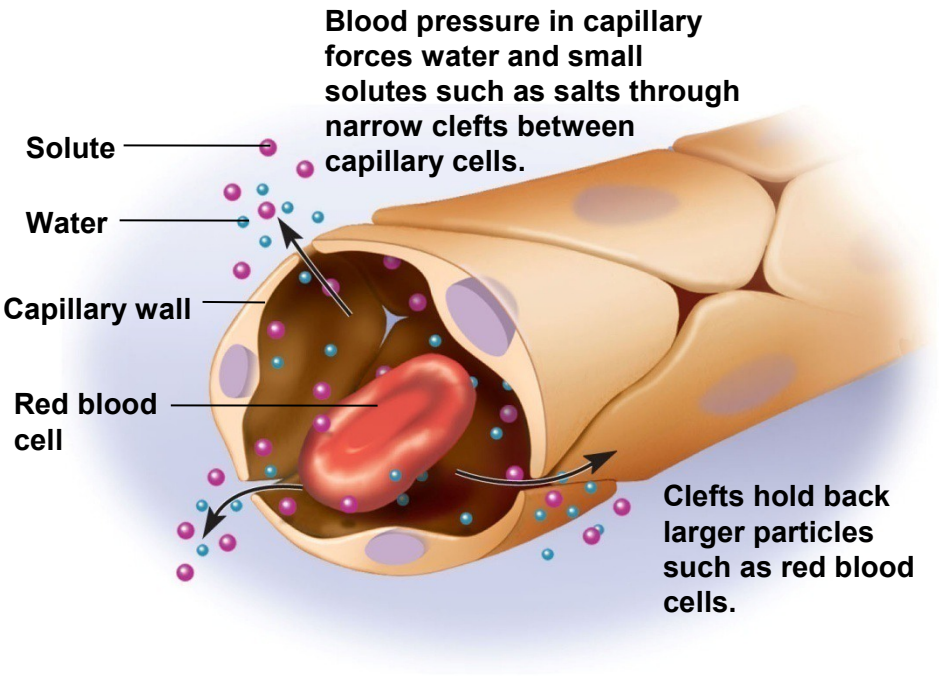
(c) Hypertonic


Isotonic solution
David Phillips/ Photo Researchers, Inc.
(a) Normal RBC shape
Hypotonic solution
David Phillips/ Photo Researchers, Inc.
(b) RBC undergoes hemolysis
Hypertonic solution
David Phillips/ Photo Researchers, Inc.
15,000x
SEM
(c) RBC undergoes crenation

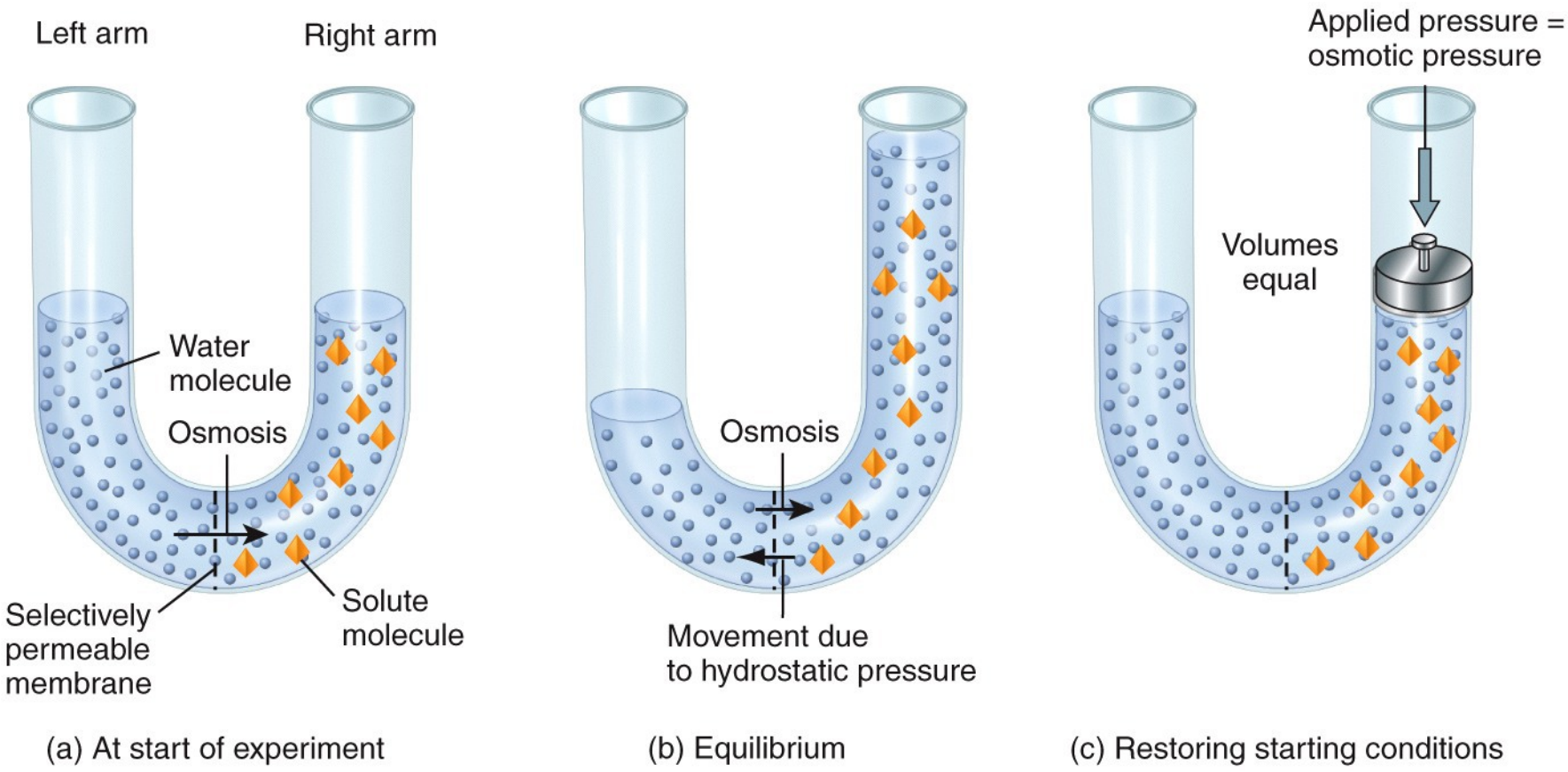
Filtration

- Filtration - process in which water molecules and extremely small solutes are forced to move through a selectively permeable membrane by hydrostatic pressure (i.e. reverse osmosis!)

- Think of a plunger being pushed down a column of water forcing water to move across a semi-permeable membrane at the bottom of the water column.



Examples // filtration of nutrients through gaps in blood capillary walls into tissue fluids // filtration of wastes from the blood in the kidneys while holding back blood cells and proteins



Filtration = Reverse Osmosis

Aquaporins

Aquaporins are channels formed by proteins in plasma membrane specialized for passage of water

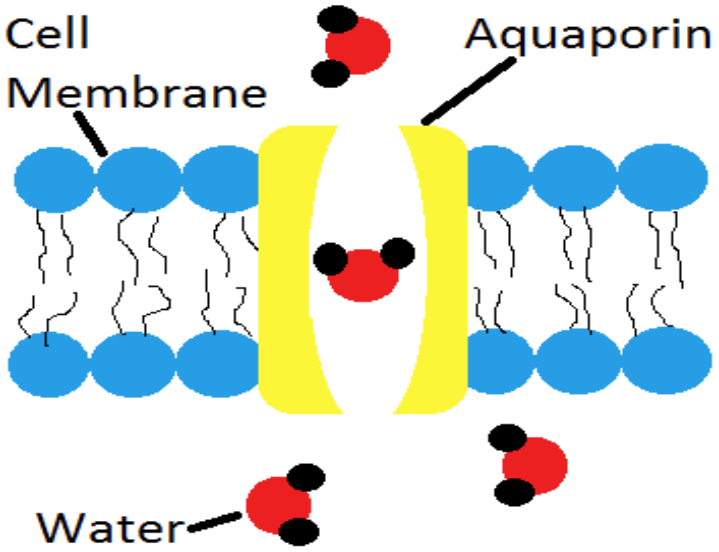
Channels are used to move small particles and charged particles across a membrane

Cells can increase the rate of osmosis by installing more aquaporins

Or decrease rate by removing them

Aquaporin “channel” and water molecule have the same diameter

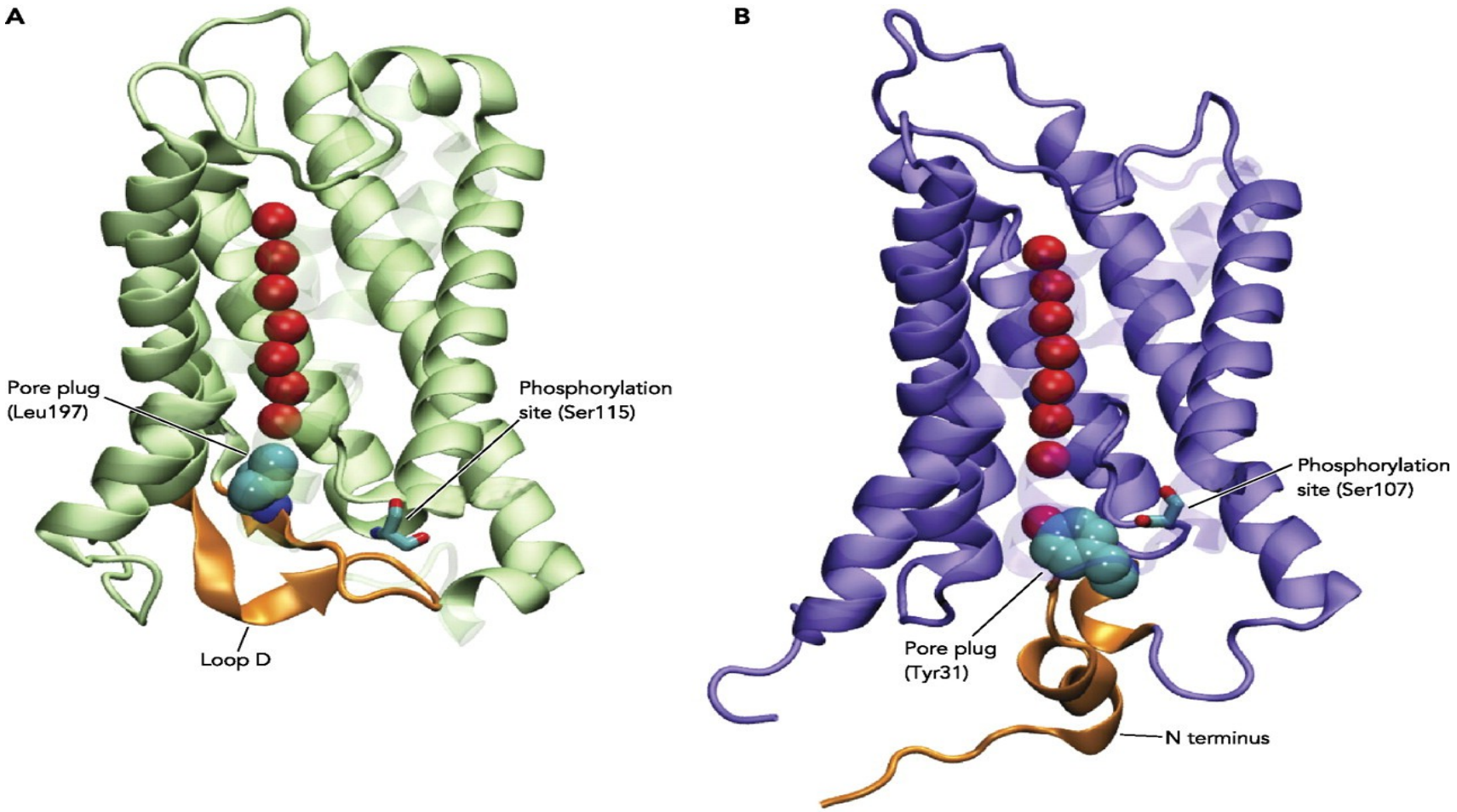
Also, significant amounts of water may diffuse through the hydrophobic phospholipid regions of the plasma membrane due to kinks formed by double bonds in fatty acids create water passageways



Note: aquaporins are stored in cytoplasm and can be rapidly inserted into plasma membrane upon receiving proper signal (e.g. antidiruetic hormone)

If more aquaporins are required then new protein synthesis must be initiated

Aquaporins



The aquaporins are a family of small membrane-spanning proteins (monomer size approximately 30 kDa) that are expressed across plasma membranes in many cells types involved in fluid transport (e.g. kidney tubules).

Fluid Compartments of the Human Body

Intra-cellular Fluid (ICF) - 60%

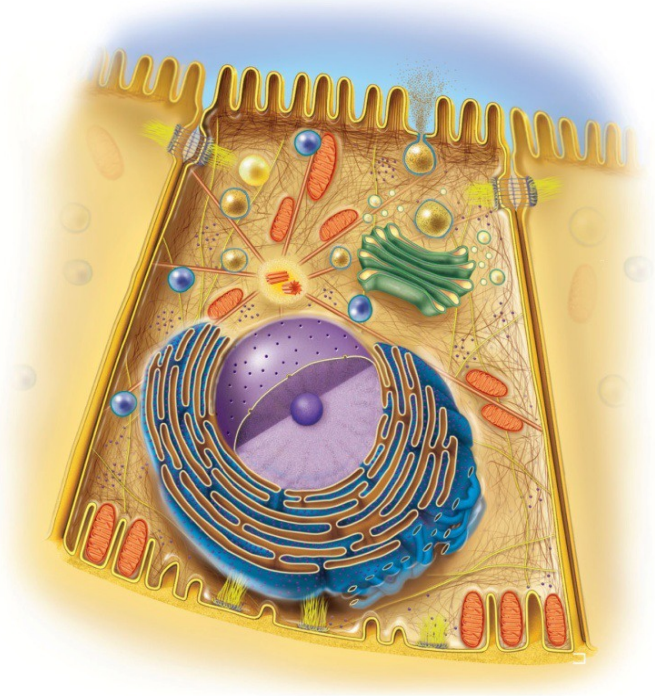
Cytoplasm – between plasma membrane and nuclear membrane

Nucleoplasm – fluid inside nucleus

Extra-cellular fluid (ECF) // fluid outside of cell // two compartments - 40%*

Between cells = Interstitial Fluid

Inside blood vessels = Vascular Fluid



Note apical vs basal surfaces

*(approximation – does not take into account minor volumes in other locations)

The Organelles of the Cell

These are the functional “working parts” of a cell

Some organelles are encapsulated by a unit membrane

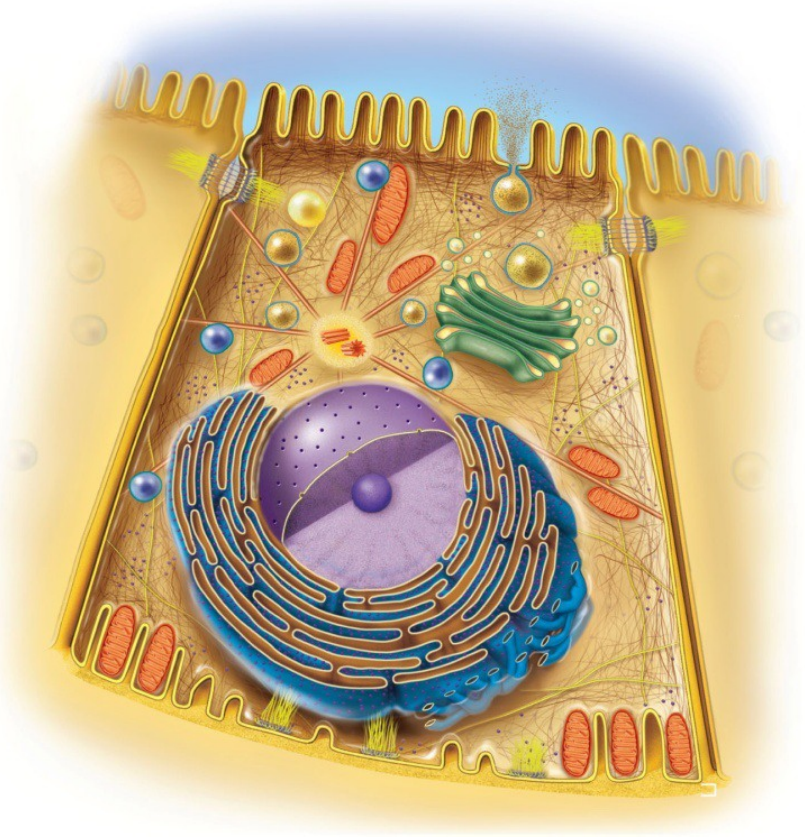
Some organelles do not have unit membranes

Membrane organelles are able to “isolate” chemical reactions within their “enclosed environment”

The concept of “form and function” apply to the type and quantity of organelles within a cell

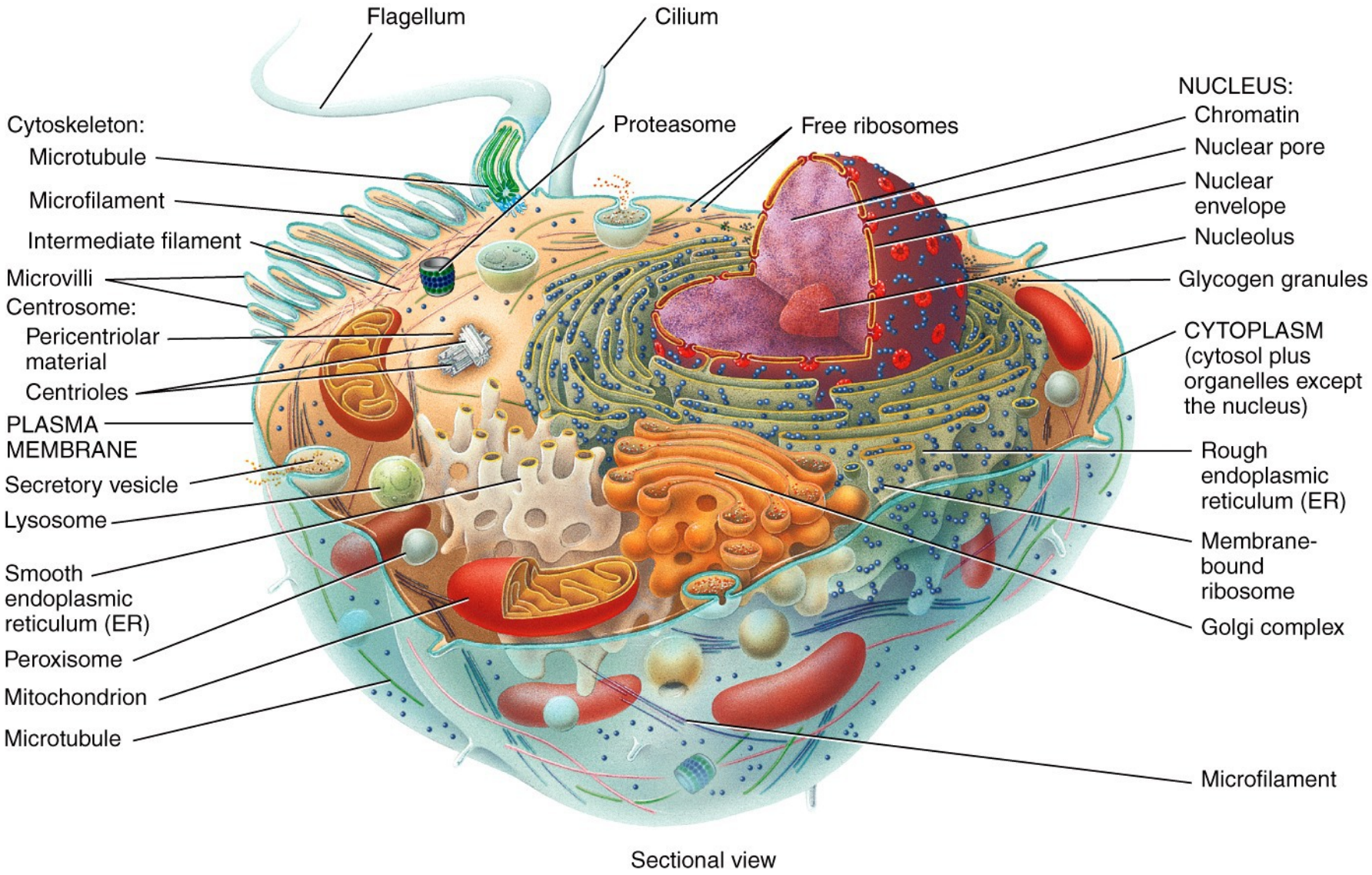
The plasma membrane is an organelle that forms the outer margin around the cell // plams membranes are “active structures” /// regulate what enters and leaves a cell

Parts of a Cell



Note: structure and function of organelles to follow

- **Plasma (cell) membrane**
  - surrounds cell
  - made of proteins and lipids
  - composition and function can vary from one region of the cell to another
- **Cytoplasm inside plasma membrane contain**
  - organelles
  - cytoskeleton
  - cytosol = intracellular fluid (ICF)
- **Nucleus most prominent organelle**
  - 40% of cytoplasmic volume
  - chromosomes / genes
  - nuclear envelope
  - nuclear plasma



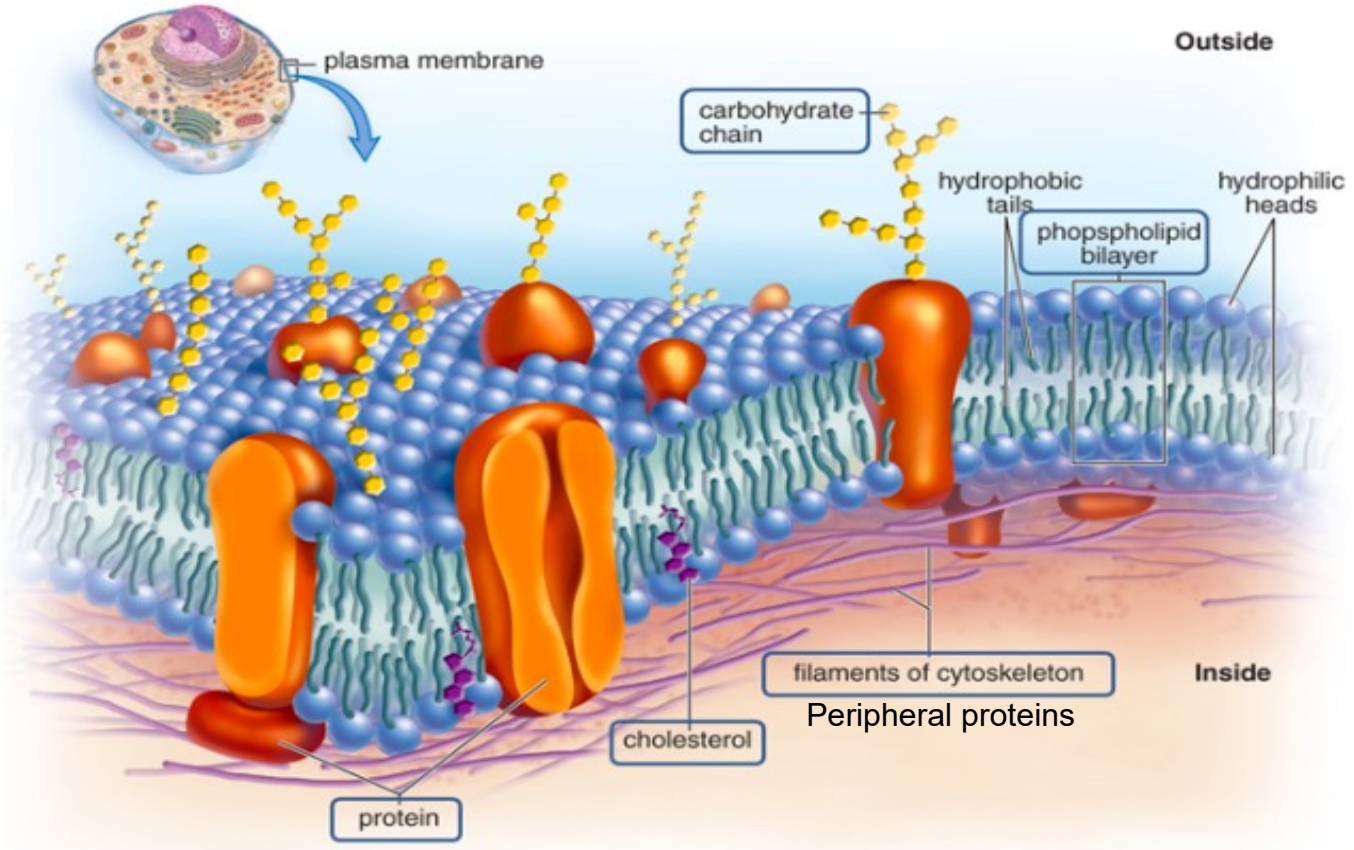
Sectional view

This illustrates most of the organelles that may be found in a cell, however.

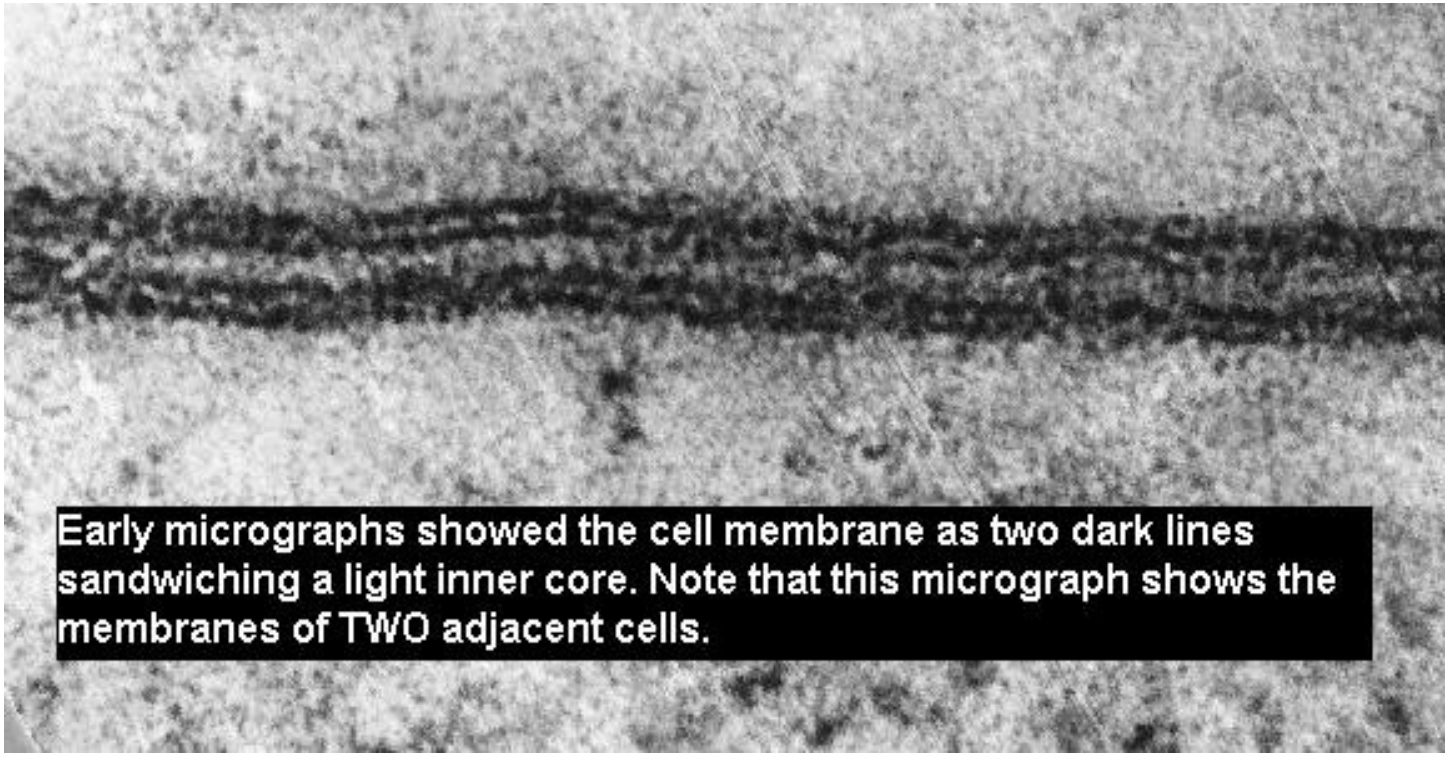
No single cell will have all of these organelles.

The Fluid Mosaic Model of the Plasma Membrane

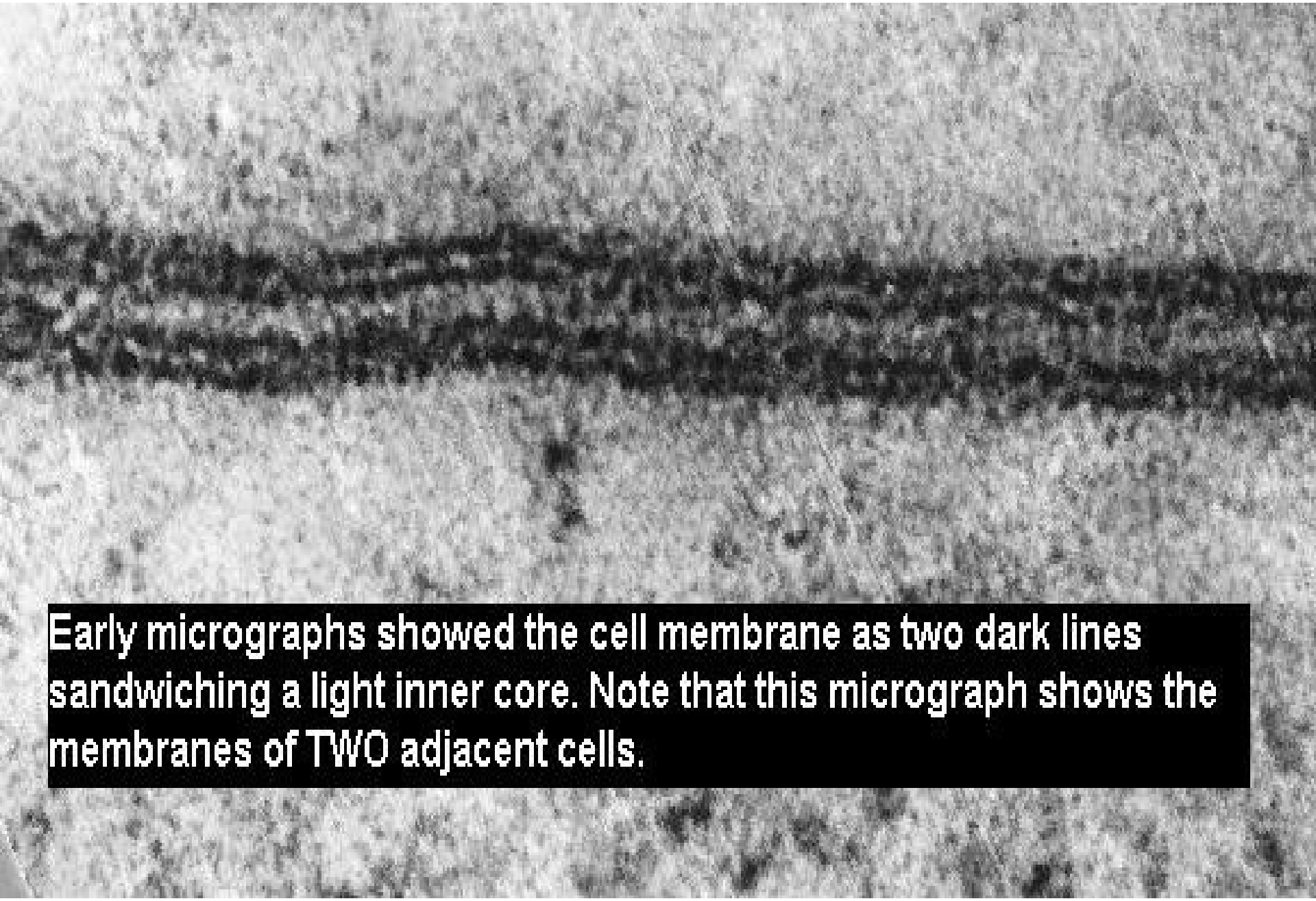
The plasma membrane is a continually moving sea of fluid lipids // The mosaic is the many different proteins dispersed between the lipids – some move like icebergs while others are anchored at specific locations like islands



Plasma Membrane is a Phospholipid Bilayer



- defines cell boundaries
- amphipathic molecules // a molecule that has both polar and non polar regions
- governs interactions between other cells /// controls passage of materials in and out of cell
- intracellular face – side that faces cytoplasm
- extracellular face – side that faces outward
- composite of different types of molecules



Early micrographs showed the cell membrane as two dark lines sandwiching a light inner core. Note that this micrograph shows the membranes of TWO adjacent cells.

Membrane Chemical Structure

- 98% of molecules in plasma membrane are lipids

- 75% of these lipids are phospholipids
  - amphiphilic molecules arranged in a bilayer (amphiphilic?)
  - hydrophilic phosphate heads face water on each side of membrane
  - hydrophobic tails – directed toward the center, avoiding water
  - drift laterally from place to place // movement keeps membrane fluid

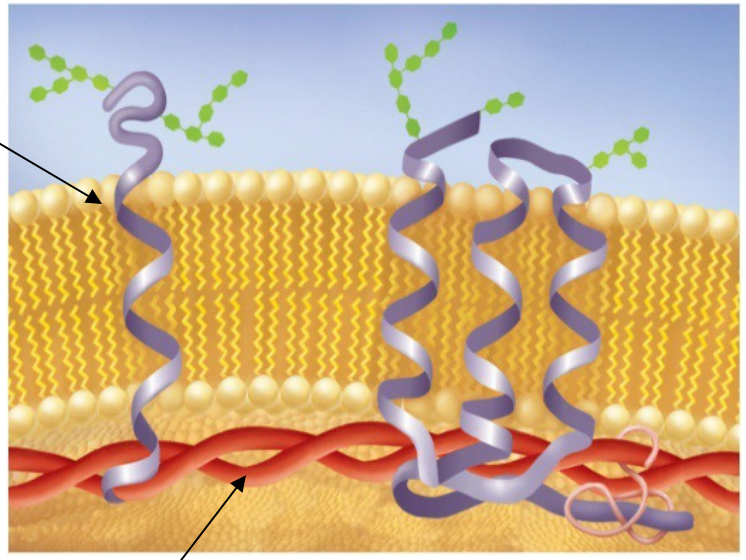
Membrane Chemical Structure

- Cholesterol
  - 20% of the membrane lipids
  - holds phospholipids still // cholesterol's -OH units link to fatty acids
  - at normal temperature makes membrane stronger and stiffen membrane
  - form "rafts" within phospholipid bilayer
- Glycolipids
  - 5% of the membrane lipids
  - phospholipids with short carbohydrate chains on extracellular face
  - contributes to glycocalyx = carbohydrate coating on the cells surface // (More to come about glycocalyx)
- Proteins and Glycoproteins (see next slide)

Integral vs Peripheral Proteins

- Membrane proteins
  - 2% of the molecules in plasma membrane
  - 50% of its weight

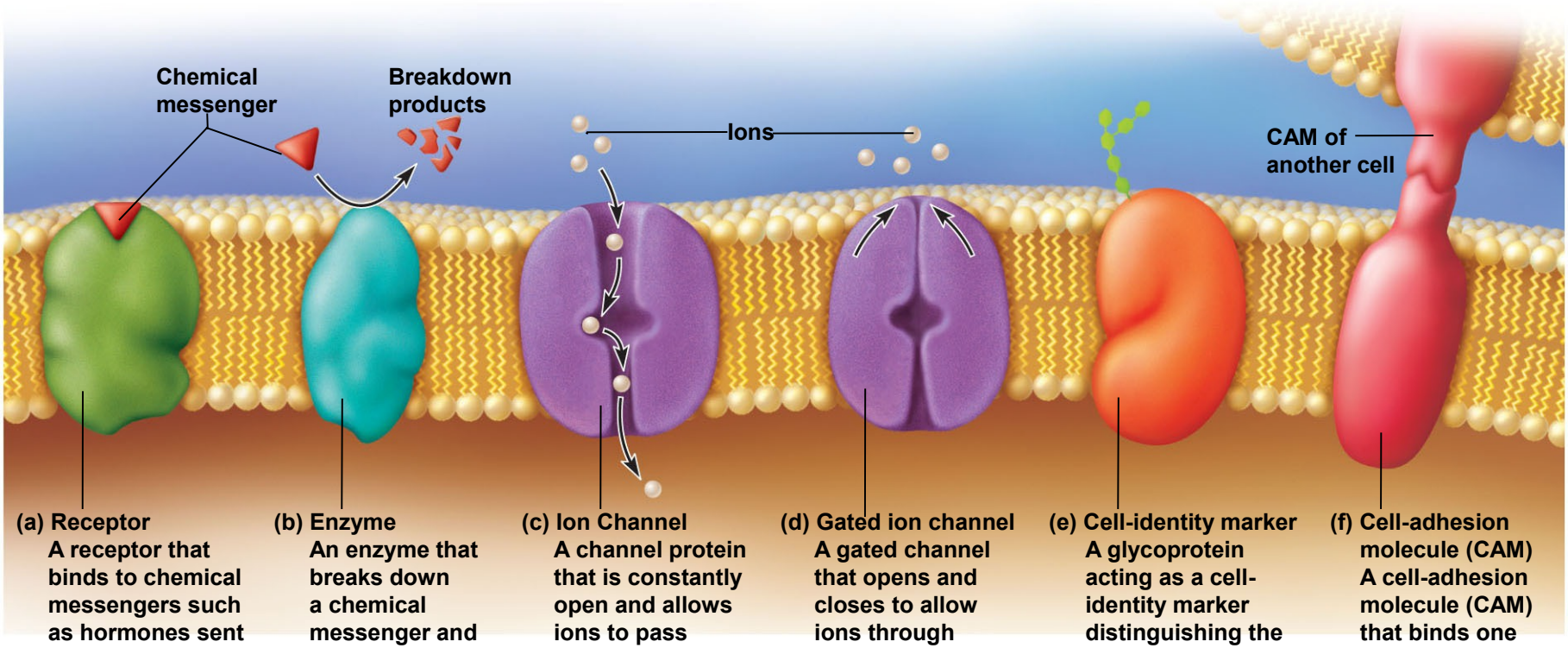
- Transmembrane proteins (Integral proteins)
  - pass through membrane
  - have hydrophilic regions in contact with cytoplasm and extracellular fluid
  - have hydrophobic regions that pass back and forth through the lipid of the membrane
  - most are glycoproteins
  - can drift about freely in phospholipid film
  - Other transmembrane protein anchored to cytoskeleton



- Peripheral proteins
  - actin molecules
  - adhere to the intracellar face of the membrane
  - usually tethered to the cytoskeleton
  - Integral proteins may bond to peripheral proteins

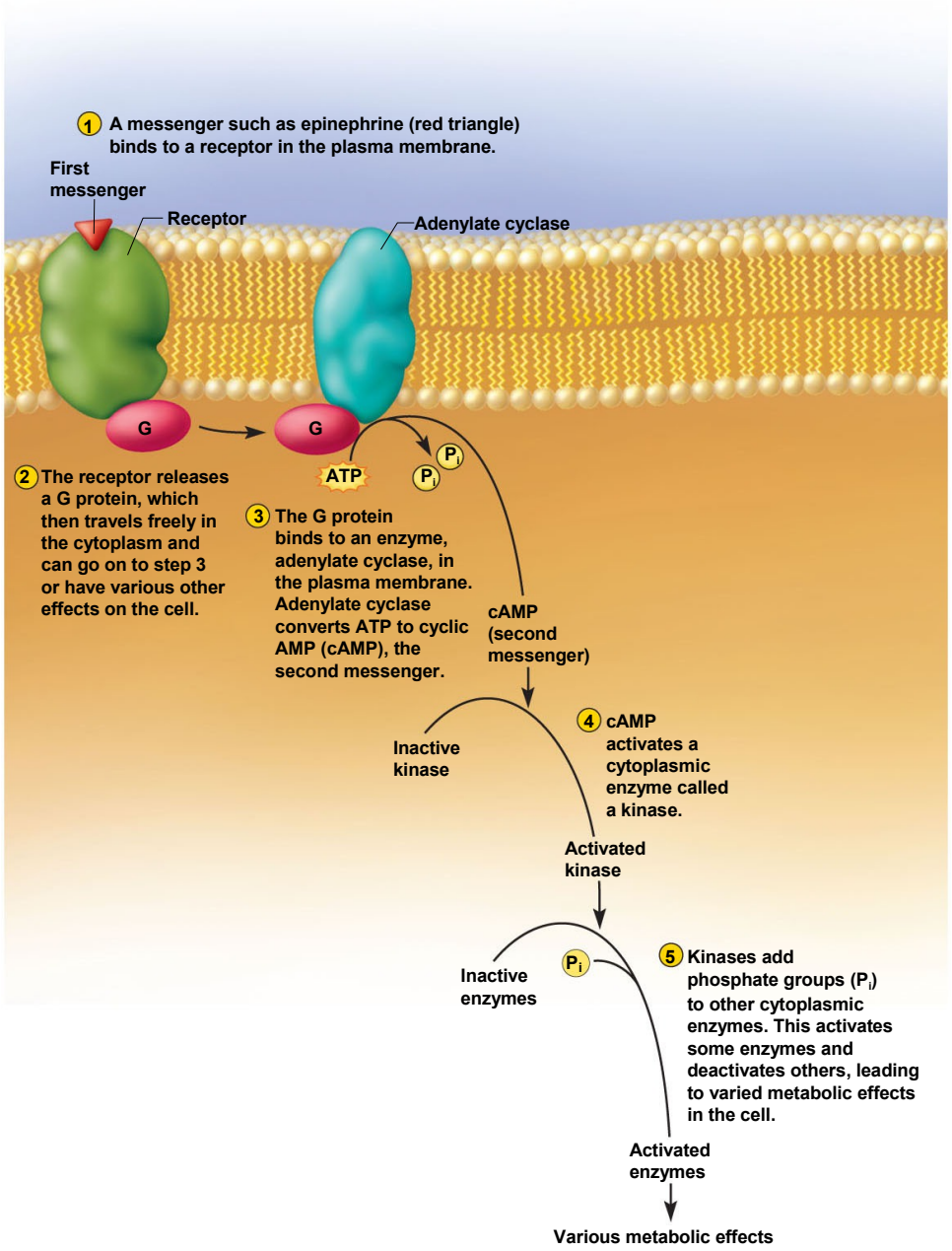
Functions of Membrane Proteins

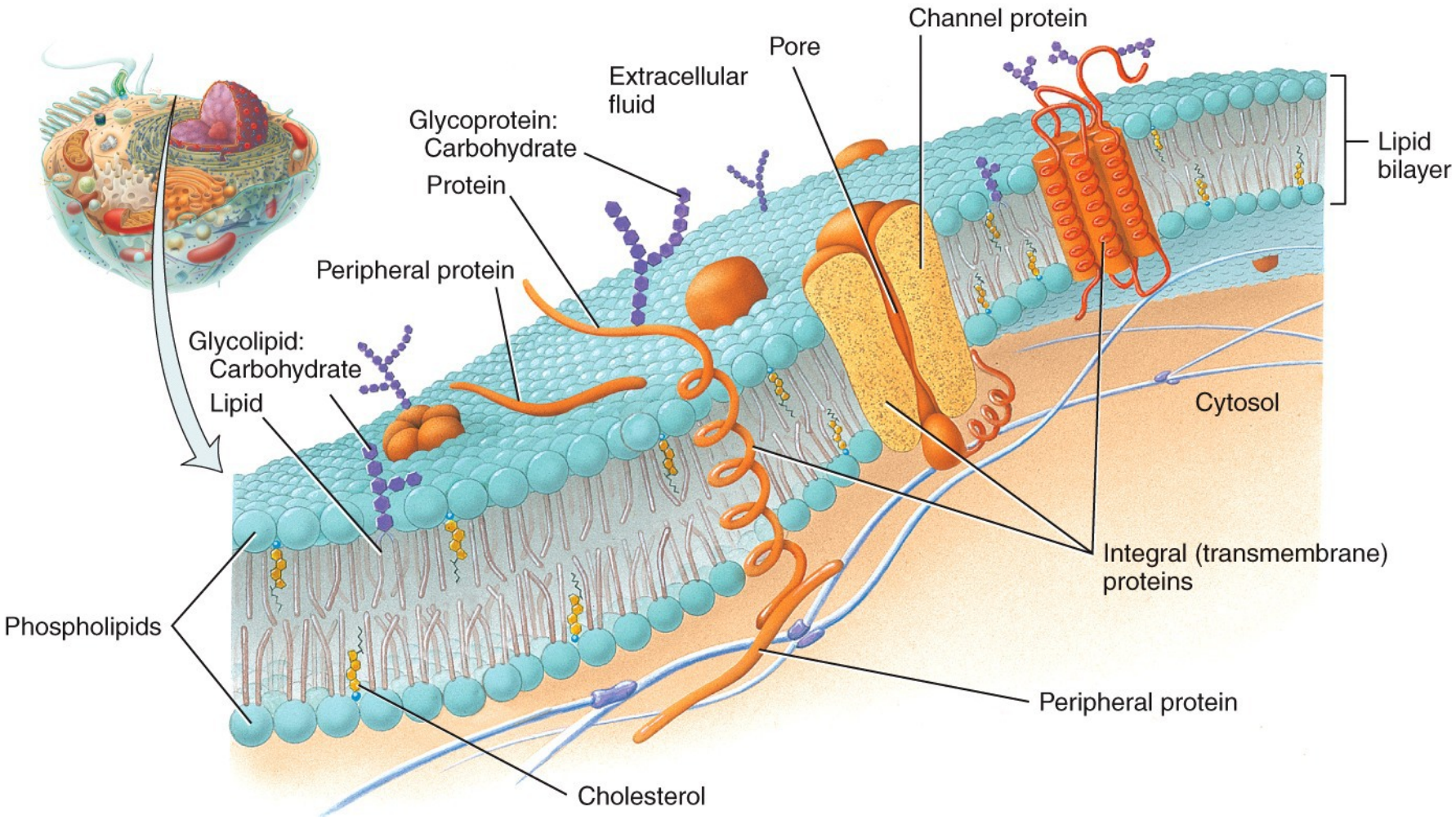
This will be on test: receptors, second-messenger systems, enzymes, ion channels, carriers, cell-identity markers, cell-adhesion molecules



Second Messenger Systems

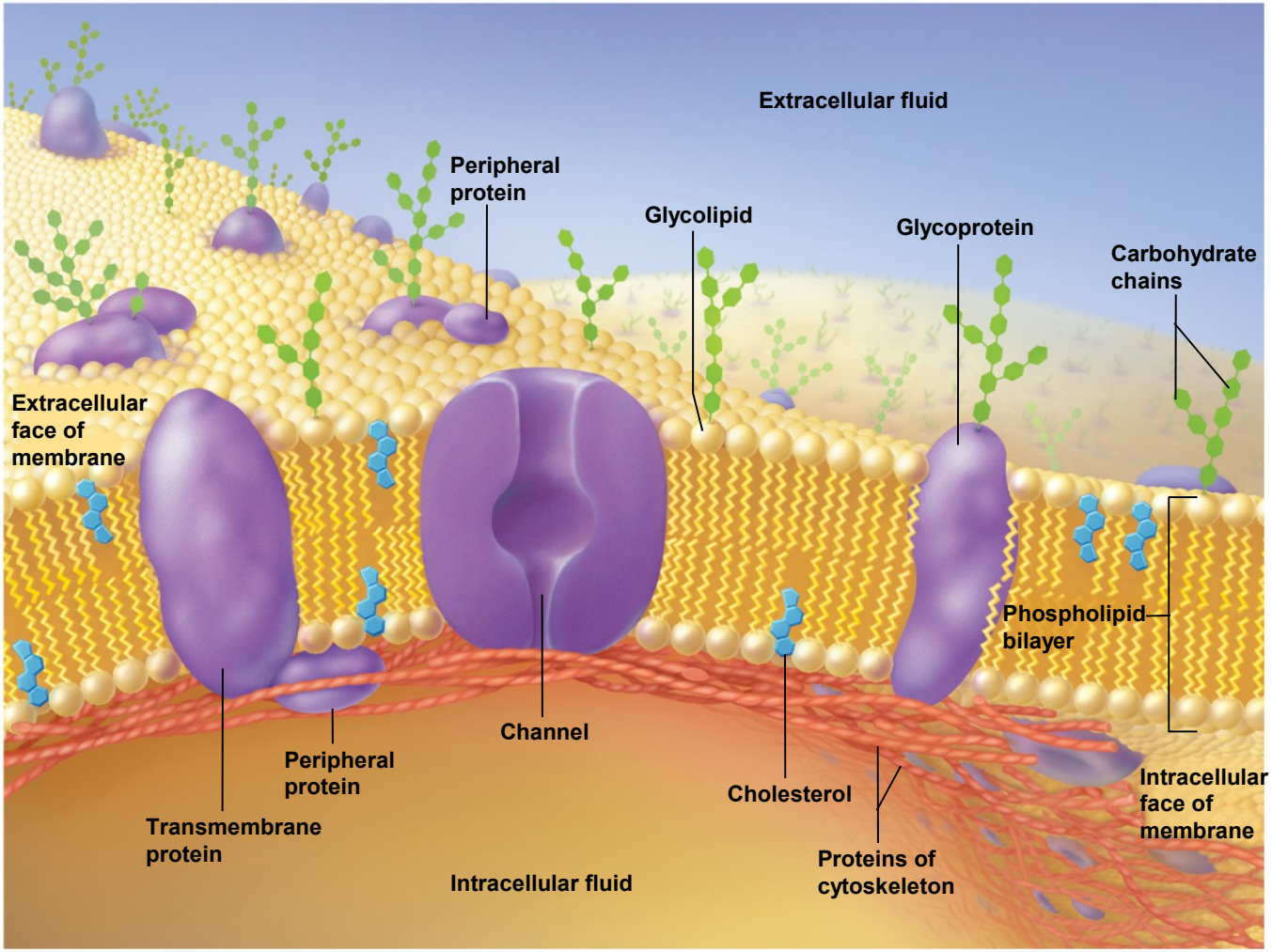
A Special Type of Integral Protein





Neighboring lipid molecules change places about 10 million times per second // double bonds in fatty acids create “kinks” which makes membrane more fluid like

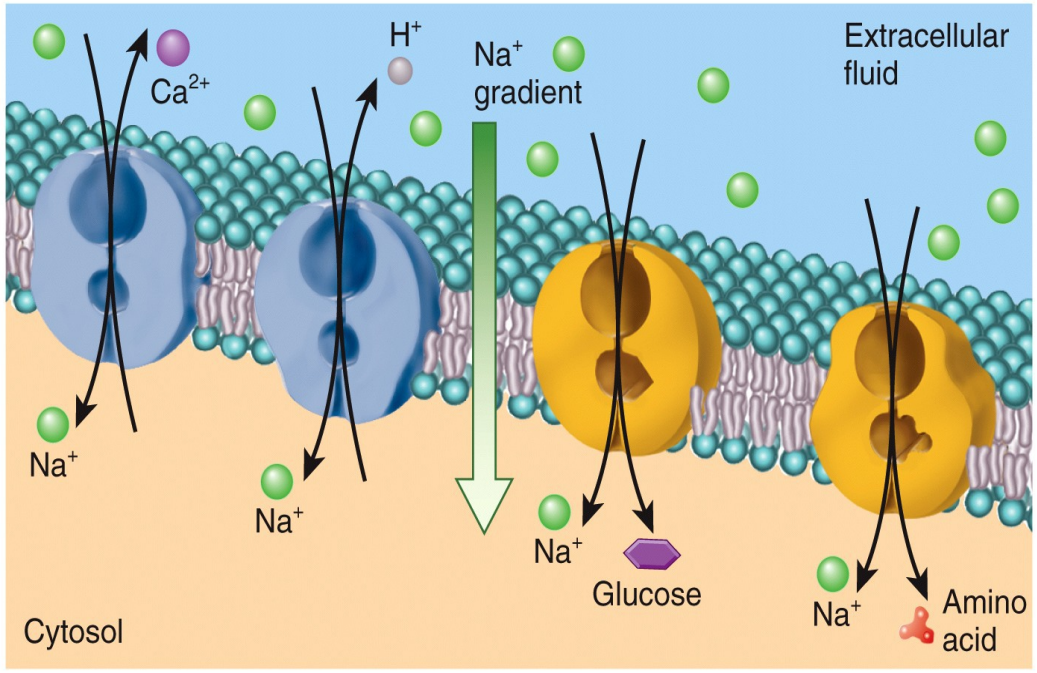
Both small and large particles must pass through the plasma membrane. How does this occur?



Oily film of lipids with diverse proteins embedded

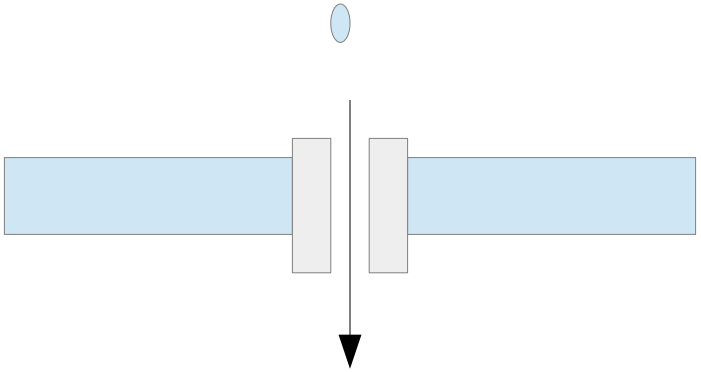
(See video)

What terms are used to describe solute transport by transmembrane protein channels across plasma membrane? Uniport – Antiport – Symport.



(a) Antiporters

(b) Symporters



Uniport

Types of Membrane Carriers

- Uniport // carries only one solute at a time

- Symport // carries 2 or more solutes simultaneously in same direction (cotransport)

- Antiport // carries 2 or more solutes in opposite directions (countertransport)

  - What is the most important antiport in human physiology?
    the sodium-potassium ATP-ase pump that brings in two K^+ and removes three Na^+ from cell's cytoplasma /// active – uses ATP – pumps both ions against their concentration gradient /// every cell in your body has this pump!

What are “identity proteins”?

- Glycoproteins and glycolipids contribute to the formation of the glycocalyx
  - carbohydrates on outer surface of the cell is the glycocalyx
  - acts like a cell’s ‘identification tag’
- These sugars enables our immune system to identify our cells (“self”) from foreign cells (non-self cells) // i.e. antigen
- Note: glyco = glucose // so your cells are “sugar” coated!

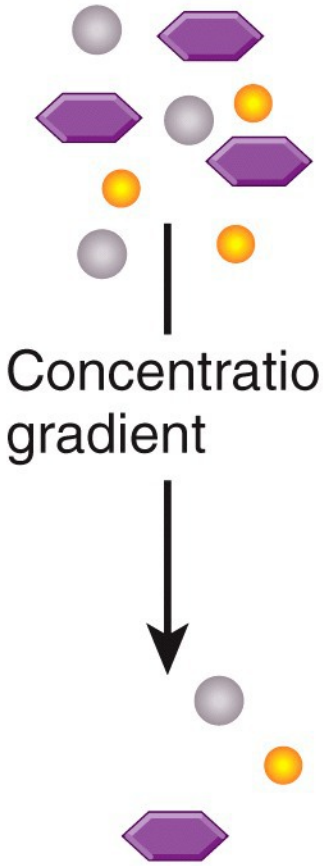
Membrane Permeability

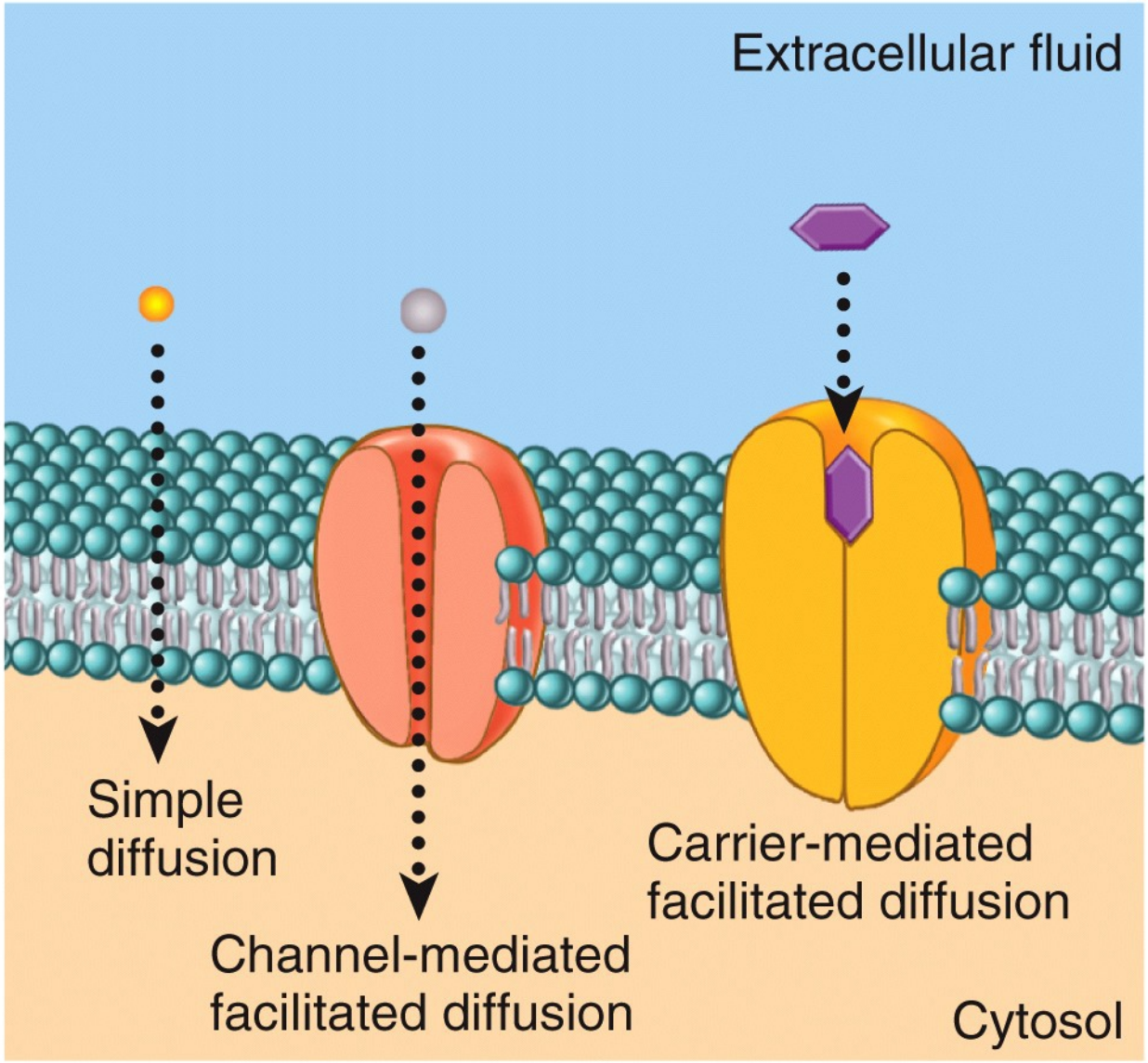
- Permeable vs impermeable
- *Our plasma membranes are selective permeability (know this /// best description)*
- Permeable to nonpolar molecules (i.e. hydrophoic) like oxygen, carbon dioxide, steroids
- Moderately permeable to small uncharged polar molecules (water and urea)
- Impermeable to ions (i.e. hydrophillic) and larger molecules with surface charges (like amino acids and glucose)
- This allows plasma membranes able to create solute *concentration gradients and electrical gradients across membrane*

When considering small solute, there are two forms of movement across the plasma membrane

- **Passive process**
  - **Solute moves "down" concentration gradient (diffusion)**
  - **No energy required**
  - **Hydrophobic molecules may diffuse across plasma membrane**
  - **Hydrophillic molecules must use a channel**
- **Active process**
  - **Solute moves "up" concentration**
  - **Requires "ATP"**
  - **Requires a carrier (i.e. transmembrane protein)**

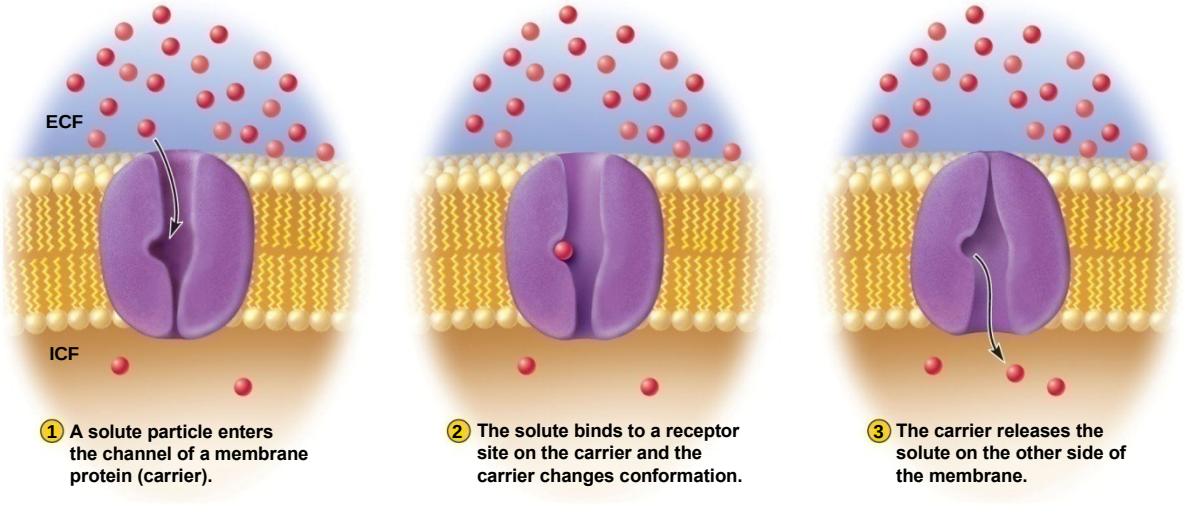
Different Types of Diffusion // All Are Passive!!!



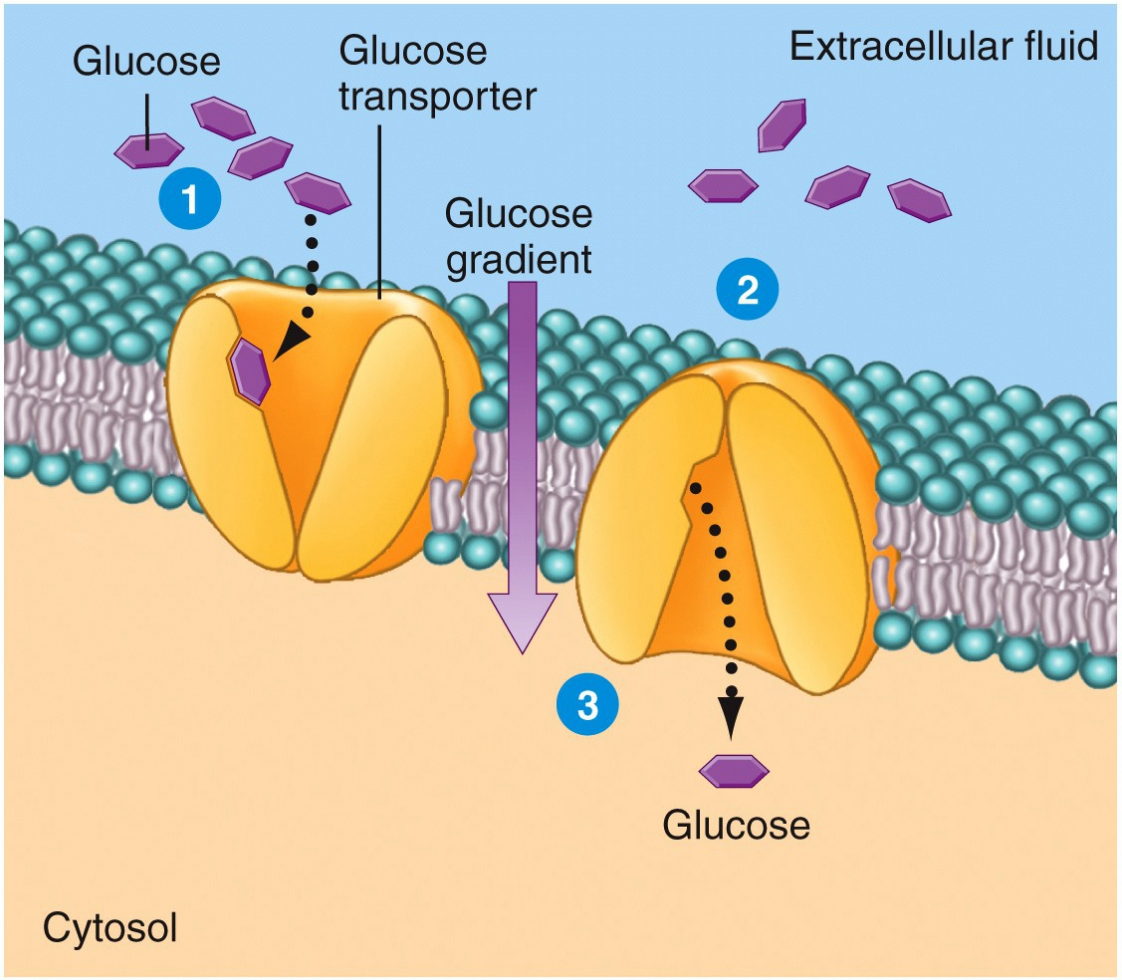


Facilitated Diffusion / Passive Process

- carrier-mediated transport of solute through a membrane down its concentration gradient (diffusion!)
- does not consume ATP
- solute attaches to binding site on carrier, carrier changes confirmation, then releases solute on other side of membrane
- allows solute to “transit” membrane // without integral protein solute would not be able to diffuse through membrane



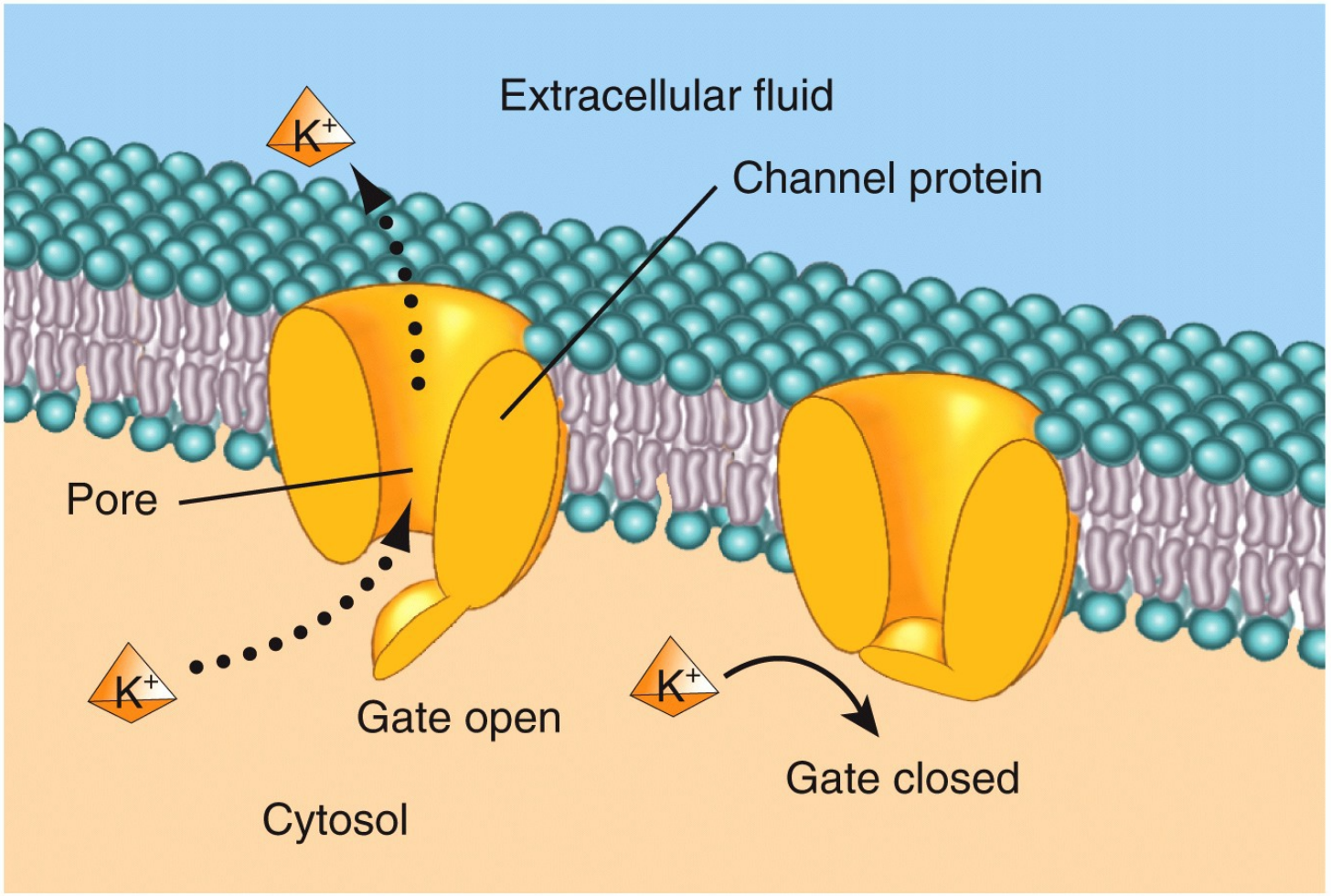
Facilitated Diffusion / Passive Process



Carrier-mediated Facilitated Diffusion

Regulated Facilitated Diffusion

"Gates" are open and closed by using one of these three stimuli: Ligands, Voltage, or Mechanical



Details of the K^+ channel

About Energy for Active Process

- Energy is required to move solutes against a concentration gradient

- Two possible sources of energy

  - (1) Hydrolysis of adenosine triphosphate – ATP (e.g. sodium-potasium-ATPase pump)

  - (2) Energy stored in the form of an ionic concentration gradient // secondary active transport (e.g. sodium-glucose co-transport)

- Channel carrier proteins are called “pumps” // the most common and most important = sodium-potassium ATP pump // antiport moving sodium and potassium in opposite directions.

Sodium-Potassium “ATP-ase” Pump

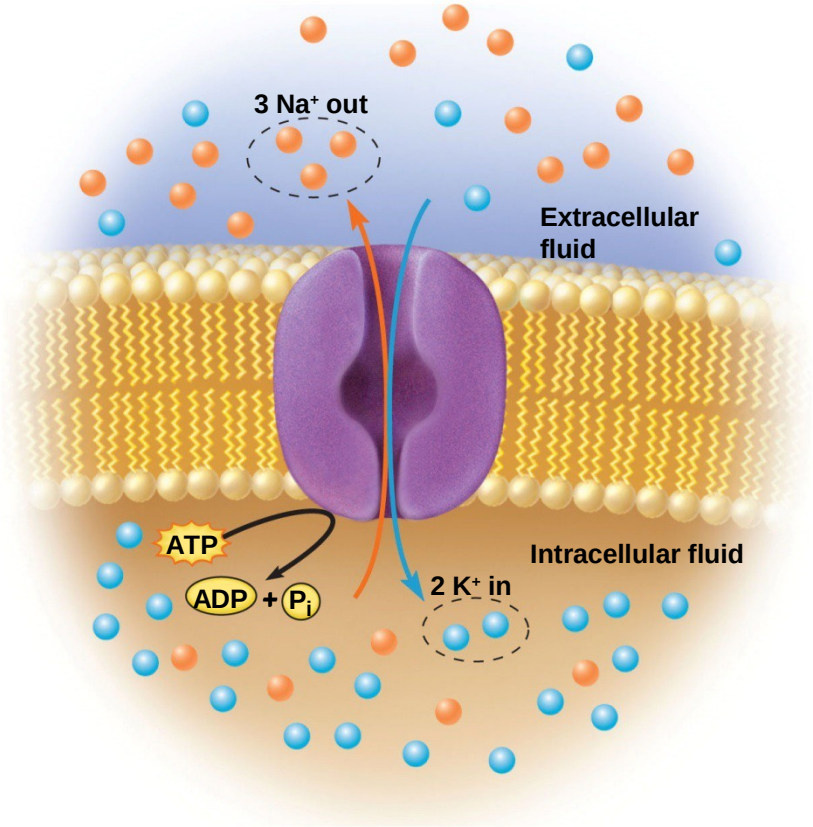
- each pump cycle consumes one ATP which is used to moves three Na+ ions out of the cell and move two K+ ions into the cell against their concentration gradients

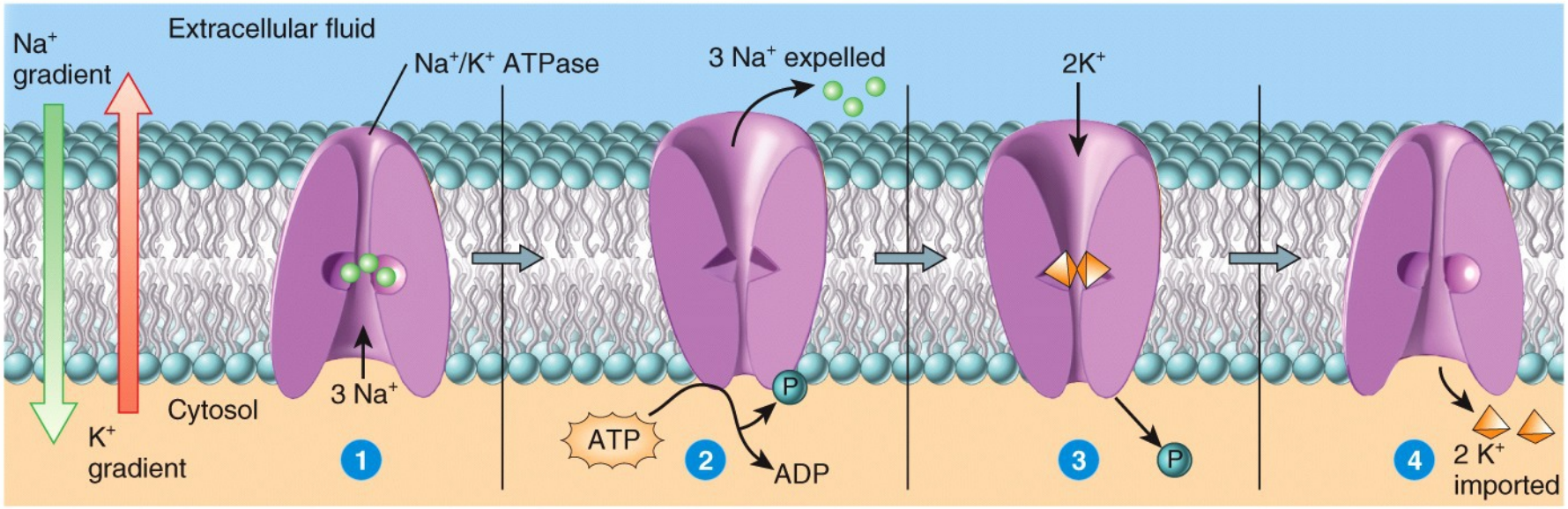
- keeps the K+ concentration higher inside the cell while keeping the Na+ concentration higher outside the cell (ECF)

- required because there are channels that slowly leak Na^+ and K^+ ions across the plasma membrane

  - half of the daily calories consumed each day are used to power the Na+ - K+ ATP pump

  - 70% of the energy consumed by brain // due to high level of action potentials created by neurons!!!





3 sodium ions (Na^+) from the cytosol bind to the inside surface of the sodium–potassium pump.

Na^+ binding triggers ATP to bind to the pump and be split into ADP and P (phosphate). The energy from ATP splitting causes the protein to change shape, which moves the Na^+ to the outside.

2 potassium ions (K^+) land to the outside surface of the pump and cause the P to be released.

The release of the P causes the pump to return to its original shape, which moves the K^+ into the cell.

1 2 3 4

Note: both sodium and potassium are moved against their concentration gradient. This requires ATP!

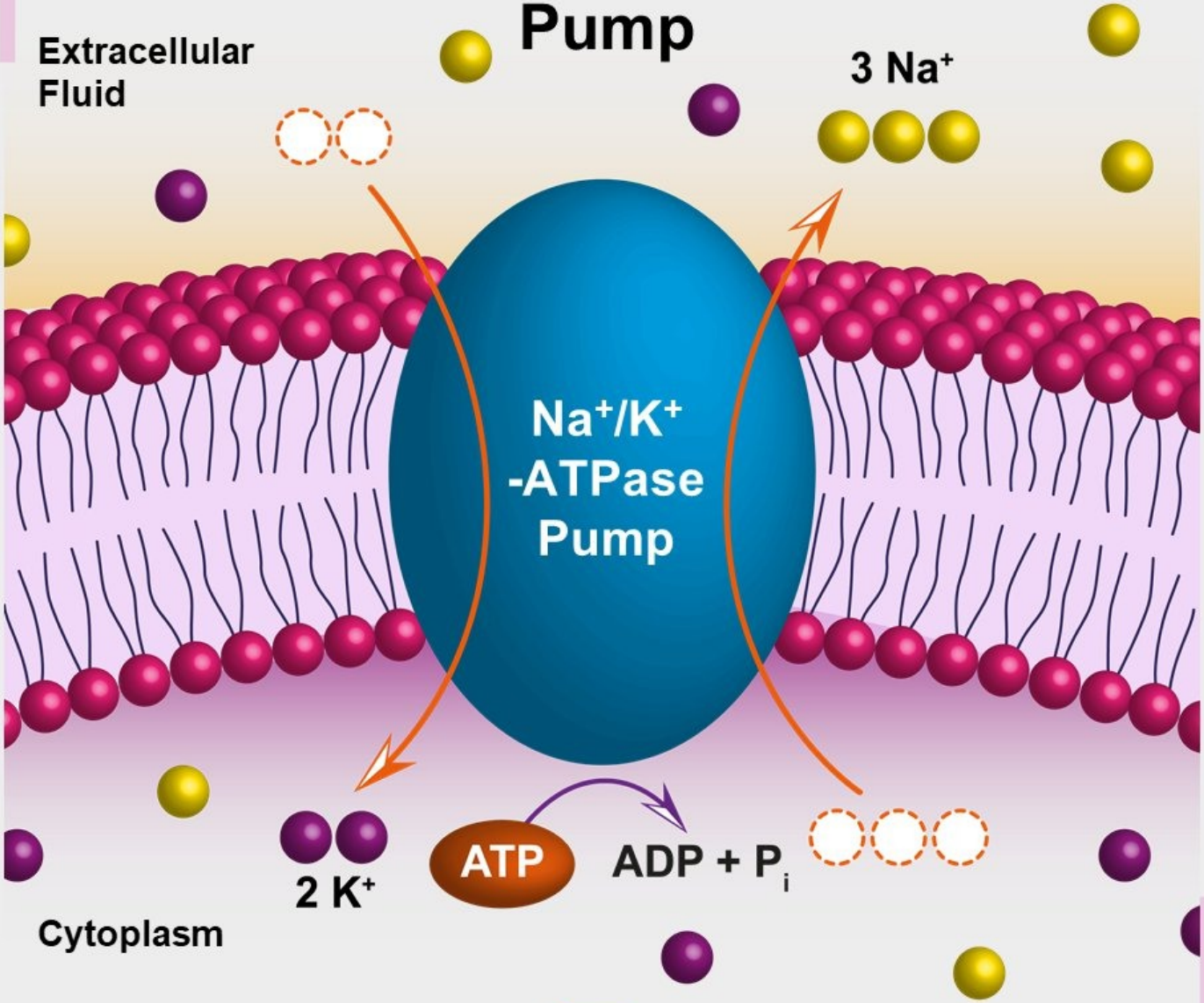
Functions of Na^+-K^+ ATP Pump

- Regulation of cell volume
  - "fixed anions" attract cations causing osmosis
  - cell swelling stimulates the Na^+- K^+ pump to ↓ ion concentration, ↓ osmolarity and cell swelling
- Heat production
  - thyroid hormone increase # of Na+ - K+ pumps
  - consume ATP and produce heat as a by-product
- Maintenance of a membrane potential in all cells
  - pump keeps inside more negative, outside more positive
  - necessary for nerve and muscle function

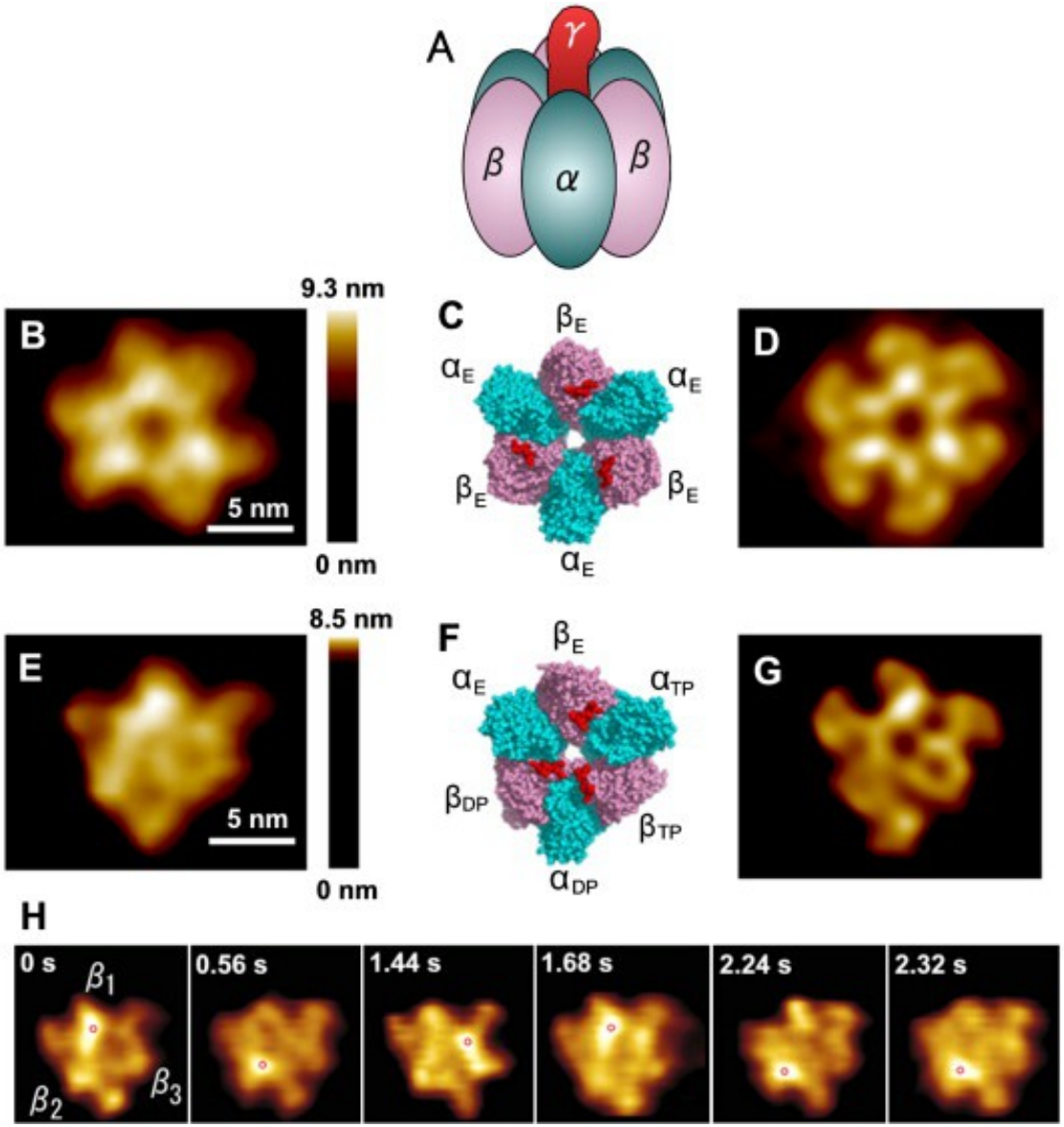
Functions of Na^+ - K^+ ATP Pump

- Secondary active transport system / another role of the sodium-potassium pump / glucose co-transport
  - Steep concentration gradient maintained between one side of the membrane and the other – (like water behind a dam)
    - The sodium-potassium pump's function // On basal side of the cell // powered by ATP
  - Sodium-glucose transport protein (SGLT)
    - simultaneously binds Na+ and glucose and carries both into the cell
    - On apical surface of the cell
    - does not consume ATP

The Sodium-Potassium Pump

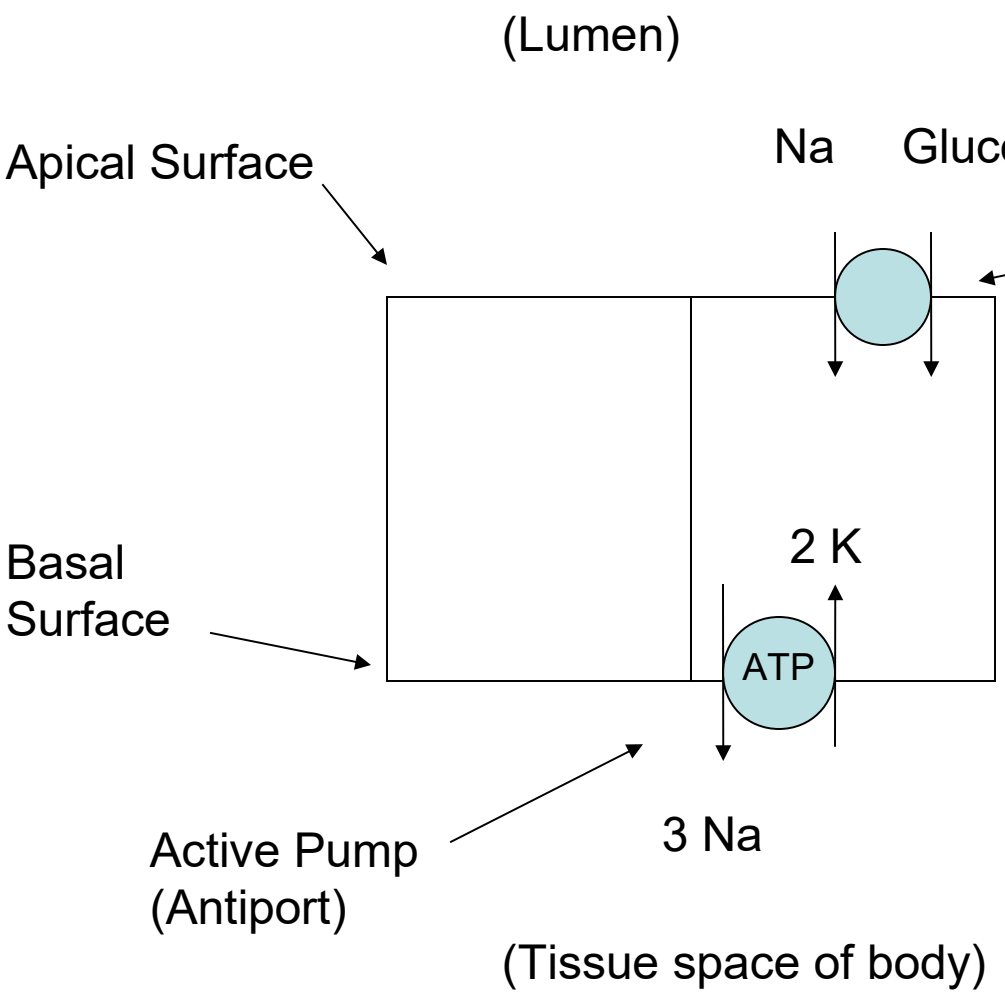


Na^+ - K^+ ATP Pump


A
γ
β
α
β
B
9.3 nm
5 nm
0 nm
C
βE
αE
αE
βE
βE
αE
D
E
8.5 nm
5 nm
0 nm
F
βE
αE
αTP
βDP
βTP
αDP
G
H
0 s
β1
β2
β3
0.56 s
1.44 s
1.68 s
2.24 s
2.32 s

Secondary Active Transport

(Powered by the Sodium Potassium ATP Pump)



the antiport (active pump) uses ATP to lower the intracellular concentration of Na

this creates a concentration gradient that favors the movement of sodium from the lumen into the cell (passive – no ATP required)

then glucose is co-transported passively with the sodium using a symport pump

Transport Maximum for Carrier-Mediated Transport

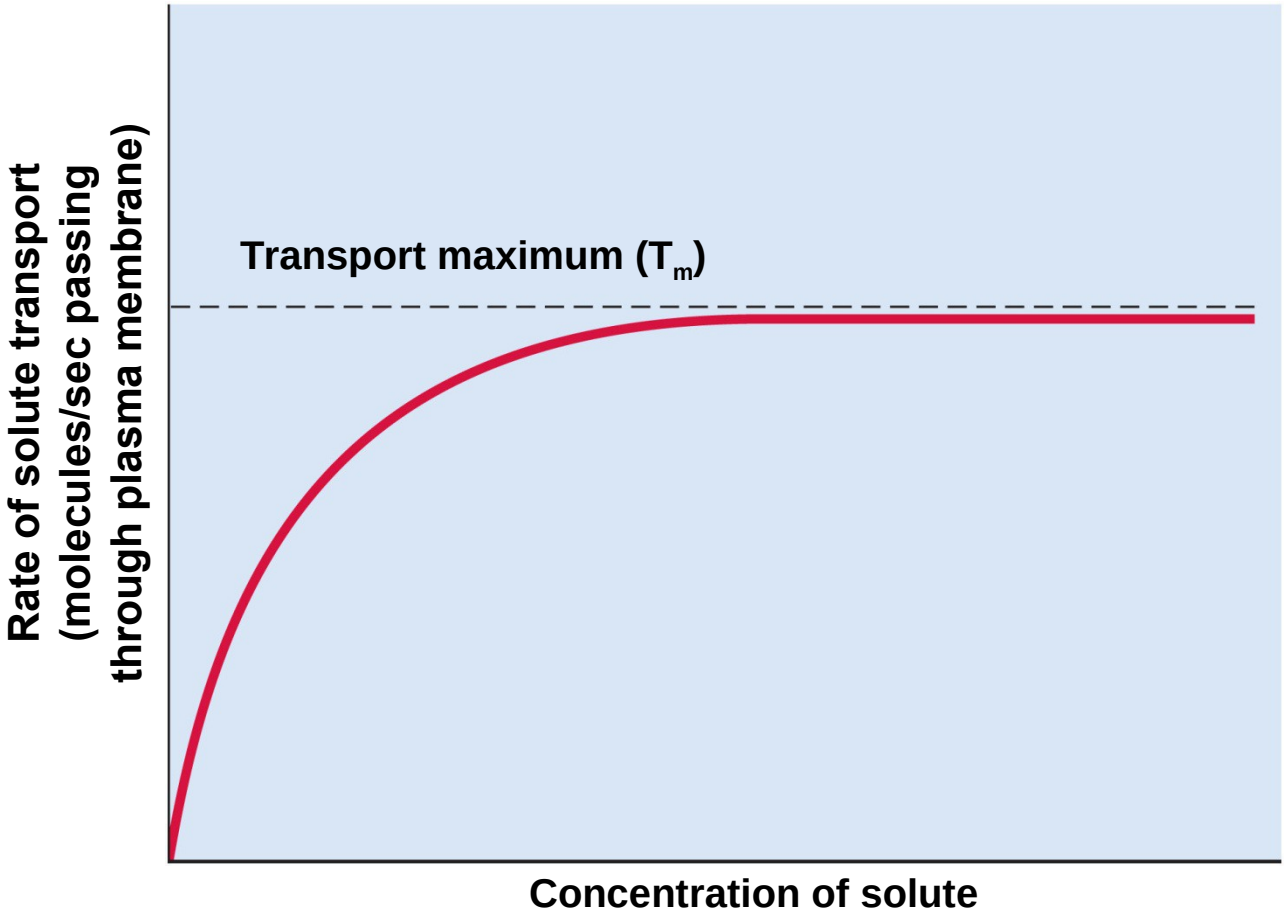
Carrier Saturation:

As the solute concentration rises, the rate of transport rises until carriers are saturated!

Think of a bus with empty seats. As the bus travels down the road it picks up people. But when all the seats are filled then the bus can not pick up more people!!!

Once Transport Maximum (T_m) reached then increasing conc. of ligand will not result in an increase of movement across membrane

Membrane Carrier Saturation



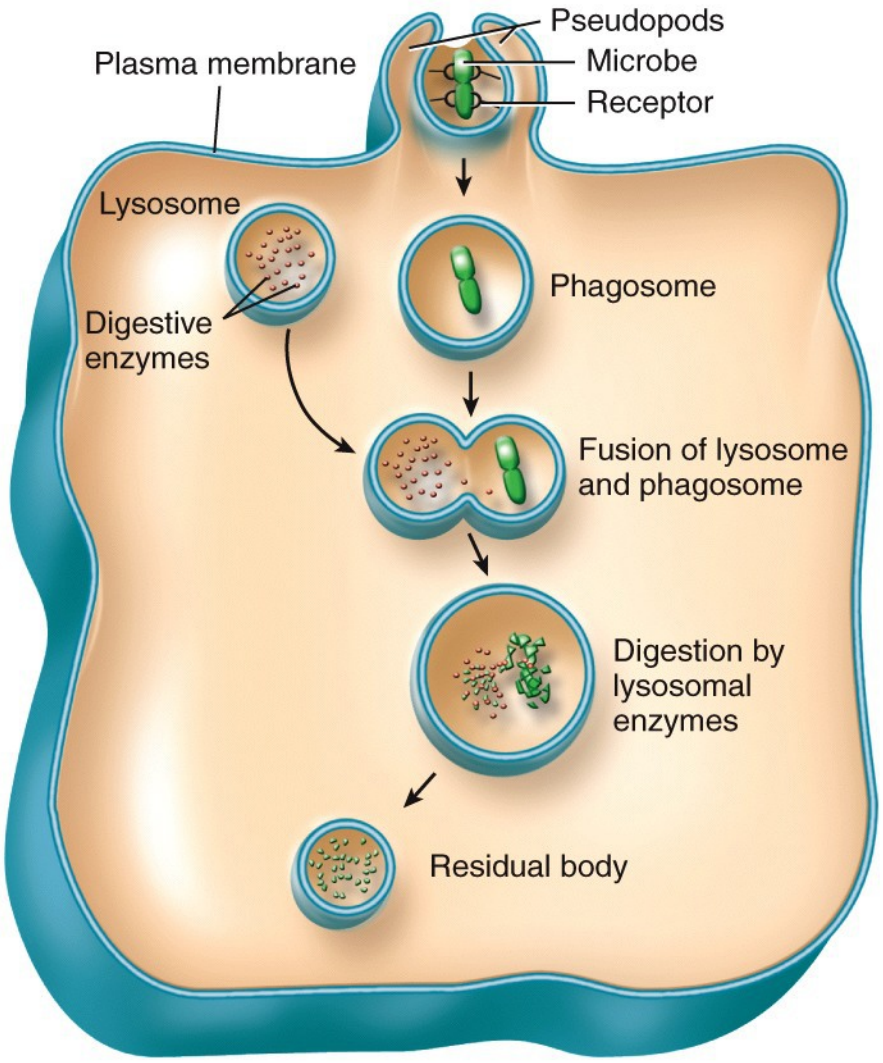
This explains why glucose under normal conditions is not in the urine but at high concentration glucose “spills” into the urine (becomes an osmotic diuretic).

Transport Vesicles

Cells Use Transport Vesicles to Move Large Particles *(too large to pass through a channel)* Across the Plasma Membrane

- These mechanisms are “active” / Why? Because ATP is used to “make transport membranes vesicles”.
- Transport vesicles are used to move “large particles” or “globs of liquids” across plasma membrane.
- Endocytosis (enter cell) vs exocytosis (exit cell)
- Endocytosis // different types
  - receptor mediated endocytosis
  - Phagocytosis
  - pinocytosis

Phagocytosis

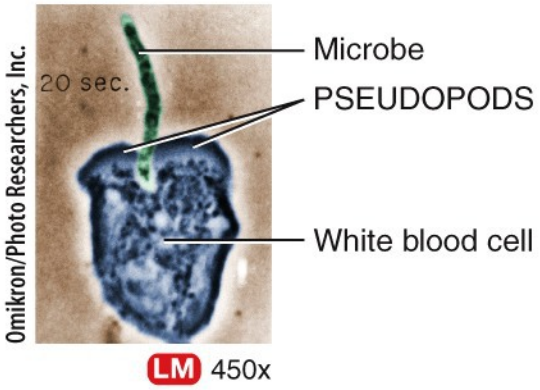


(a) Diagram of the process

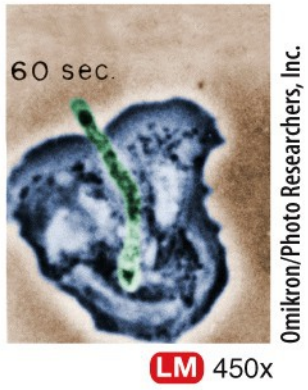
Phagocytosis is an example of endocytosis used by WBC.

Macrophage and Neutrophils are WBC that use this process.

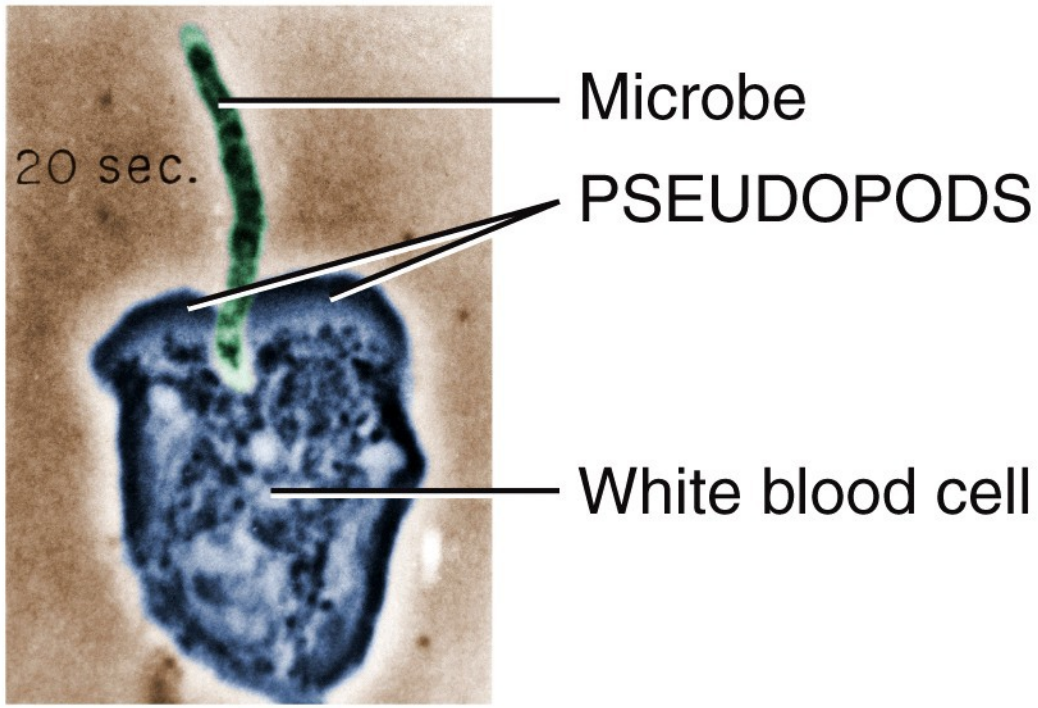
When WBC engulf large particles like bacteria we call it phagocytosis. Whe other type of cells engulf large food particles we call it endocytosis. (see video)



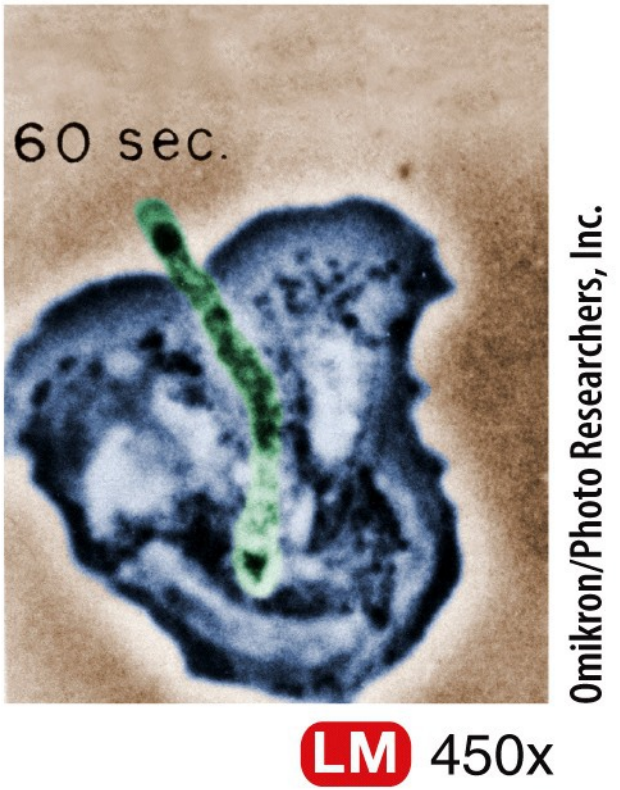
(b) White blood cell engulfs microbe



(c) White blood cell destroys microbe

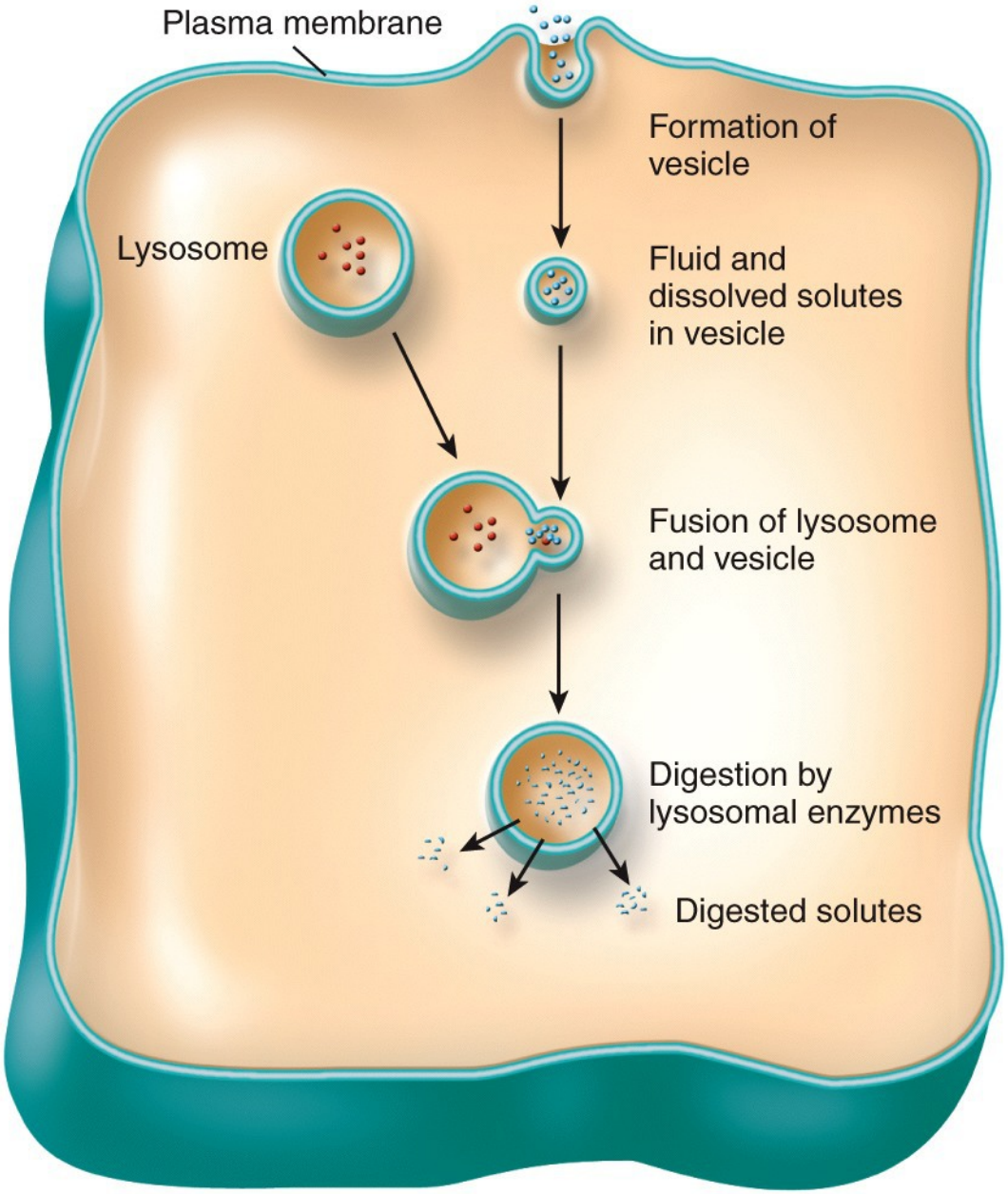


(b) White blood cell engulfs microbe



(c) White blood cell destroys microbe

(see video)



Endocytosis

Transports solids and liquids across plasma membrane

If liquids then called pinocytosis

Common to most cells

Note – no receptors are required for this process.

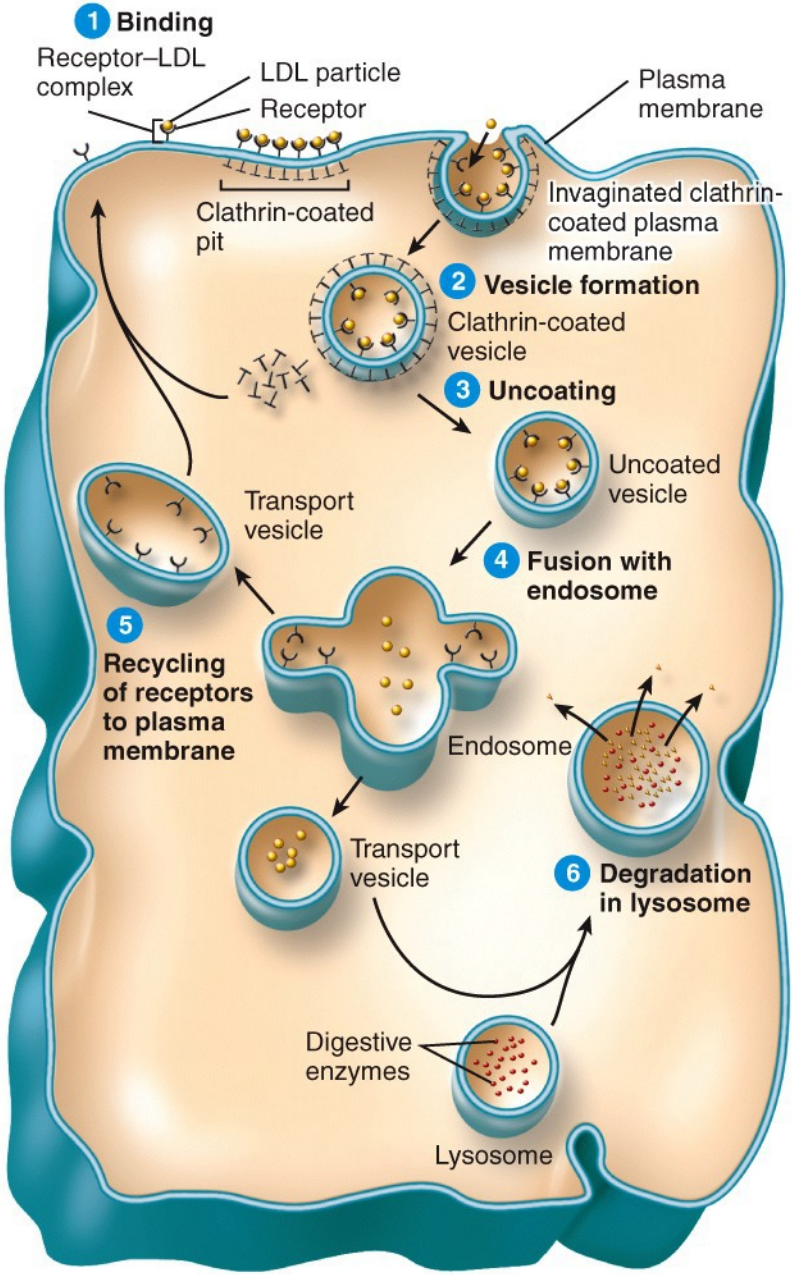
Receptor Mediated Endocytosis

This illustration shows LDL (low density lipoprotein particles) binding to a LDL-receptor. After binding, the plasma membrane "pinches inward",

Many different type of receptors

Several steps follow to unpack the vesicle and recycle the receptors.

This mechanism is used by the Human Immunodeficiency Virus to enter human cells. This is the first step in the disease mechanism for AIDS (acquired immunodeficiency disease).



Exocytosis & Transcytosis

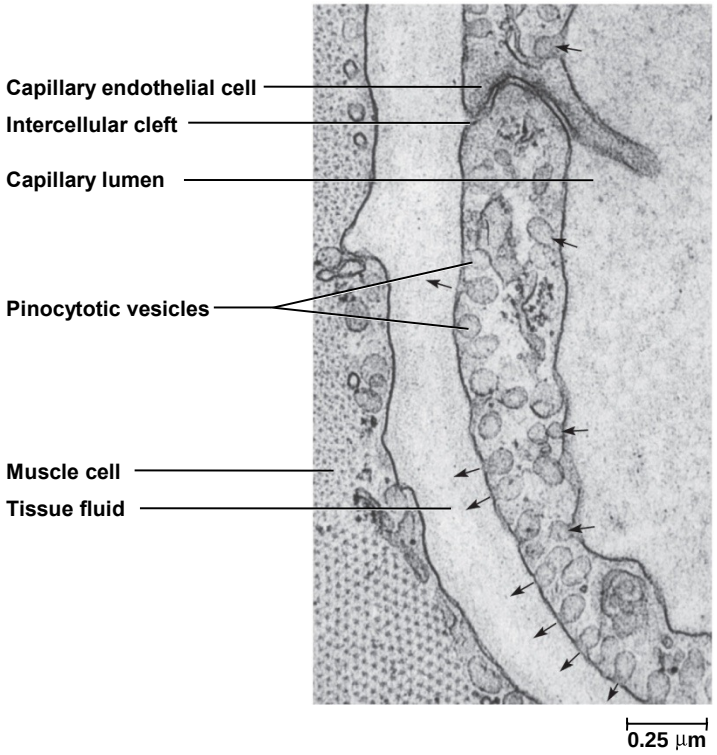
Exocytosis

- moves large particles out of cell
- used by secretory cells / e.g. digestive enzymes, hormones, neurotransmitters
- segments of cell membrane lost during endocytosis are regained during exocytosis

Transcytosis

- occurs most often endothelial cells lining blood vessels
- solute move between blood and interstitial space (e.g. mother antibodies cross into placenta)

Transcytosis



- Transport of material across the cell by capturing it on one side and releasing it on the other

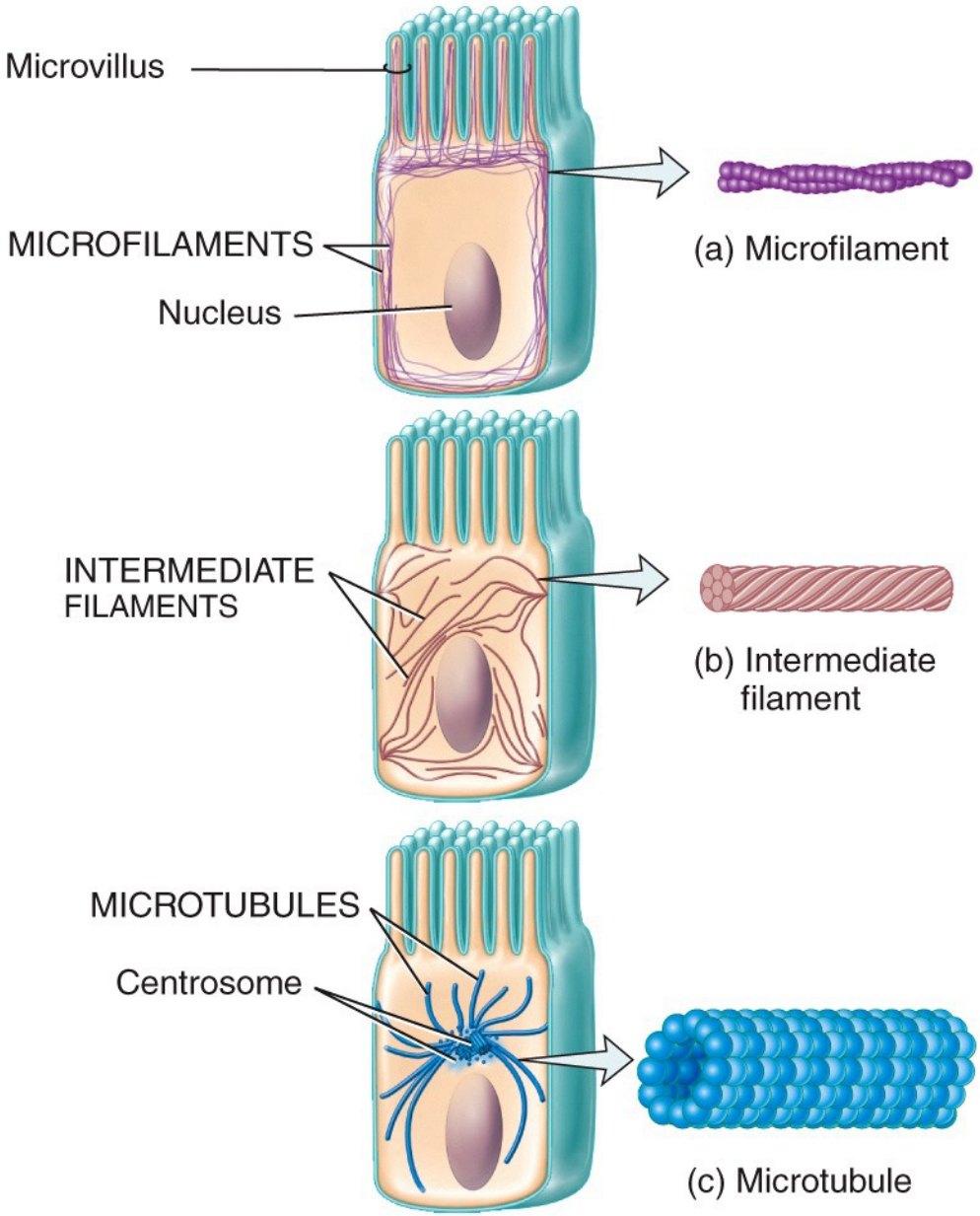
- Receptor-mediated endocytosis moves it into cell and exocytosis moves it out the other side // This is how insulin moves between compartments in your body!

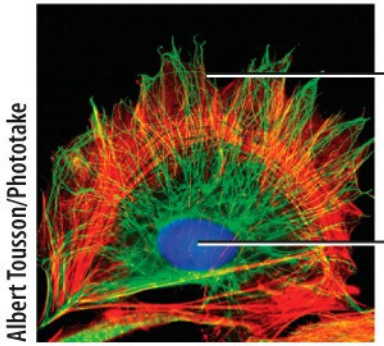
Cytoplasm

- Three major components
  - Cytosol (intracellualr fluid / hydrated proteins – gell state) // 75 – 90% fluid // site of many of the chemical reactions of the cell
  - Cytoskeleton // composed of three different protein filaments
  - Organelles // specialized structures / some organelles surrounded by unit membranes so as to isolates cellular chemical reactions // other organelles are not surrounded by unit membranes

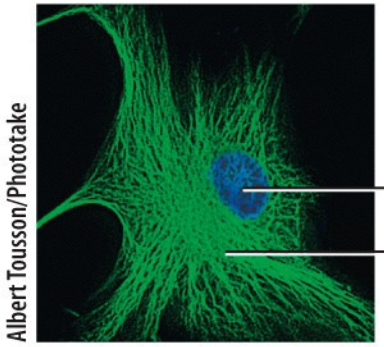
Cytoskeleton

- **Collection of protein filaments and cylinders constructed from protein subunits**
  - **determines shape of cell**
  - **lends structural support**
  - **organizes its contents**
  - **directs movement of substances through the cell // cytoskeleton functions like a highway for transporting vesicles**
  - **contributes to the movements of cell as a whole**
  - **three type: microfilaments, intermediate filaments, and microtubules**

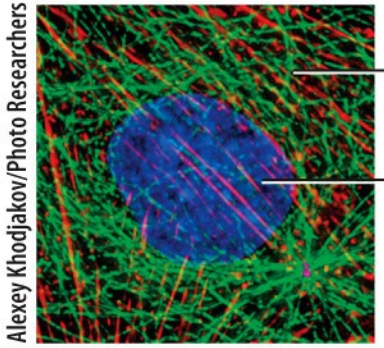




IFM 1500x



IFM 800x



IFM 500x

Cytoskeleton

Microfilaments – made of protein called actin form network on cytoplasmic side of plasma membrane called the terminal web (membrane skeleton)

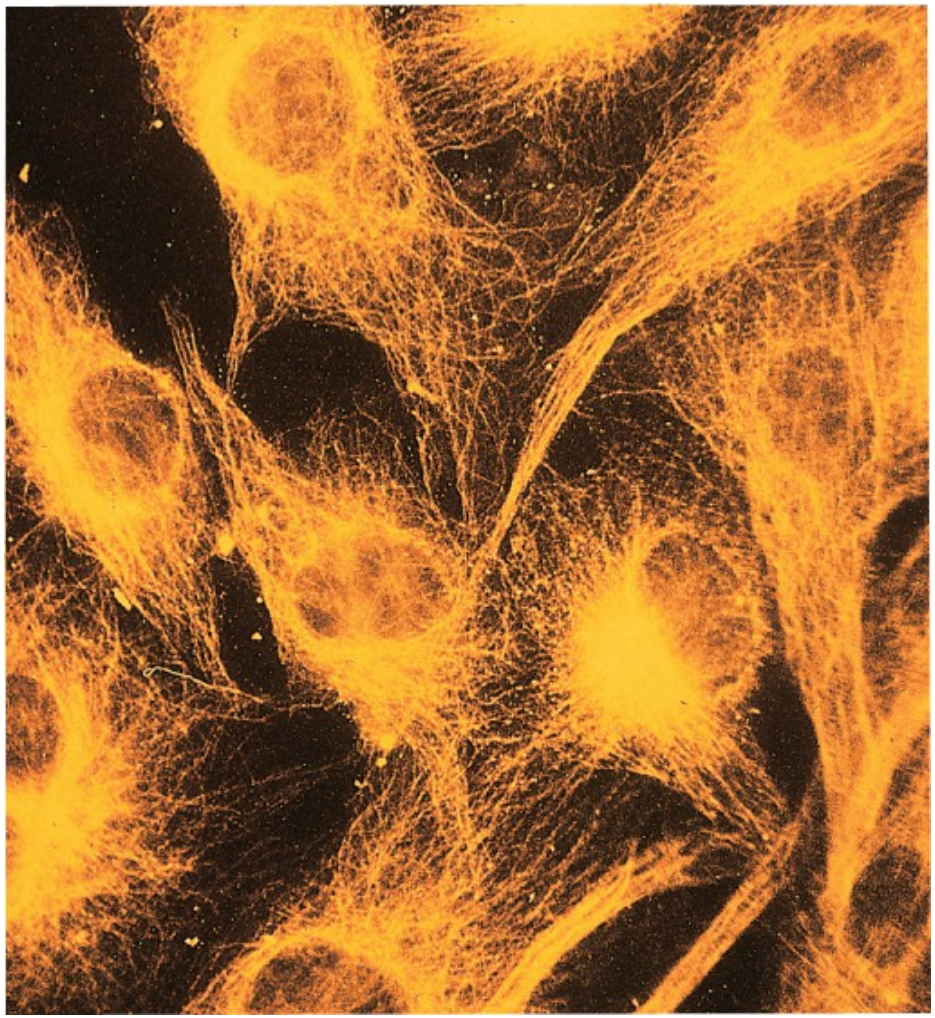
- provides physical support for phosphospholipid bilayer actin
- supports microvilli and produces cell movements

Intermediate fibers – thicker and stiffer than microfilaments resist stresses placed on cell

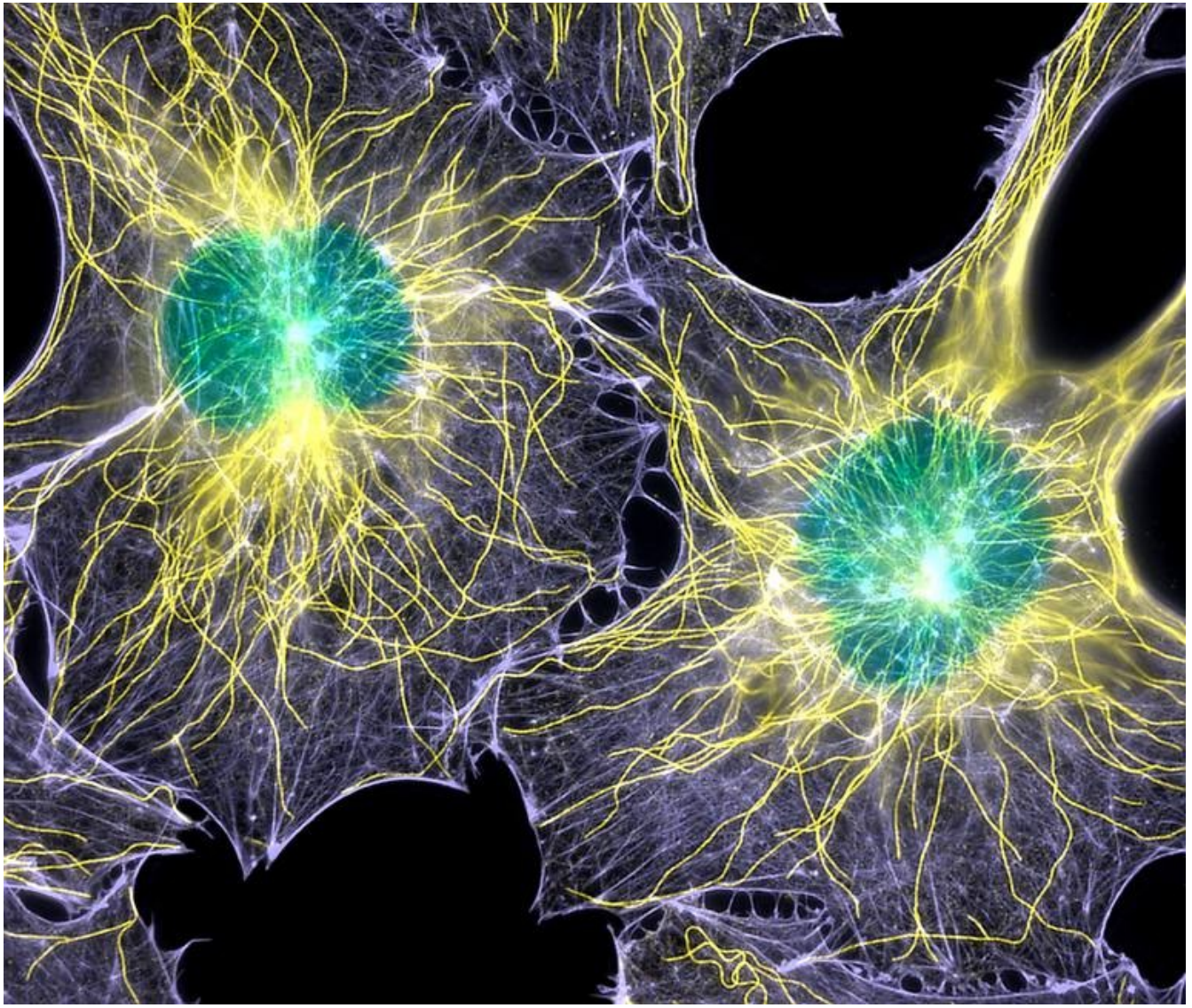
- participate in junctions that attach some cells to their neighbors
- line nuclear envelope and form cage-like nuclear lamina that encloses DNA

Microtubules – cylinders made of 13 parallel strands called protofilaments

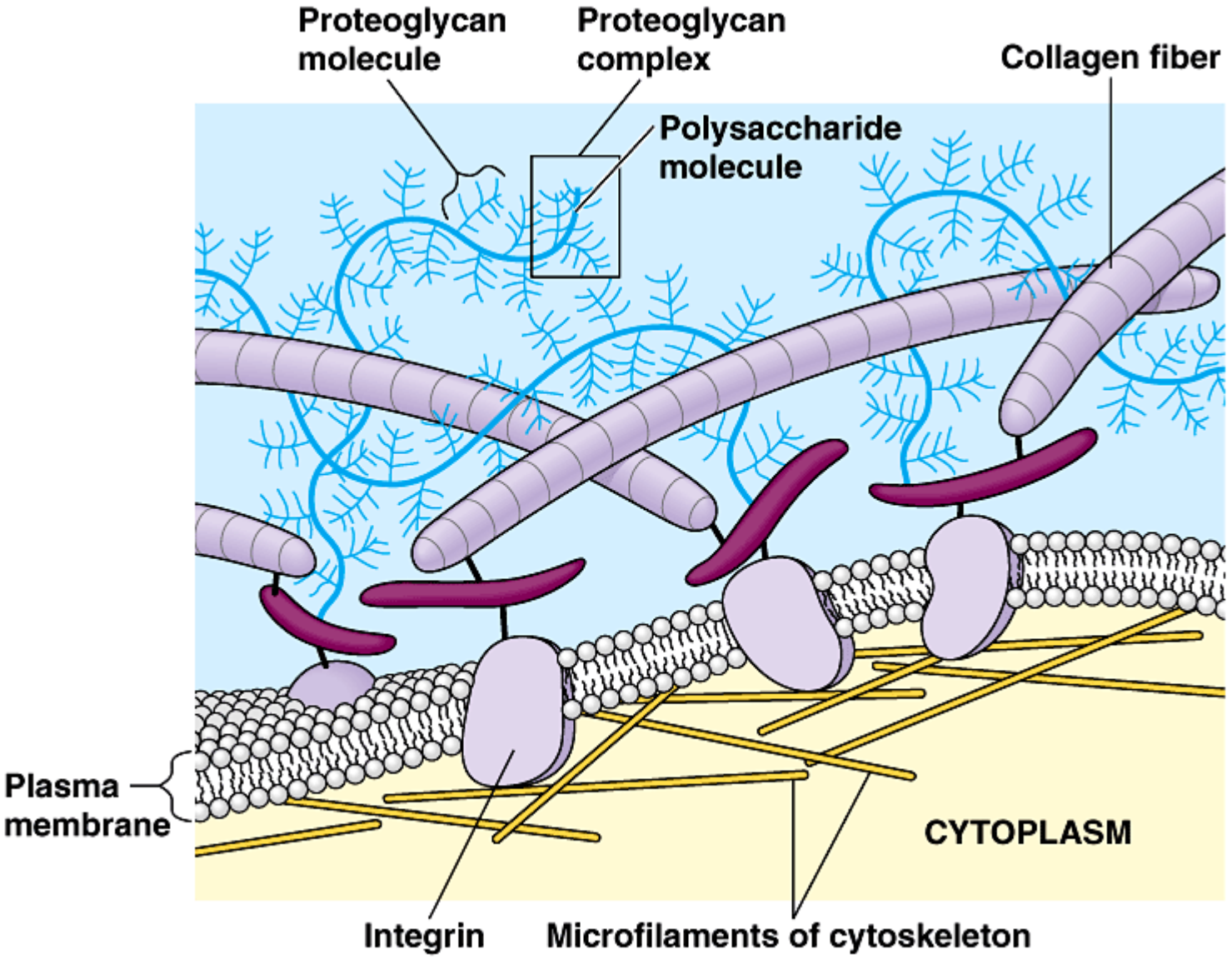
EM and Fluorescent Antibodies Demonstrate Cytoskeleton



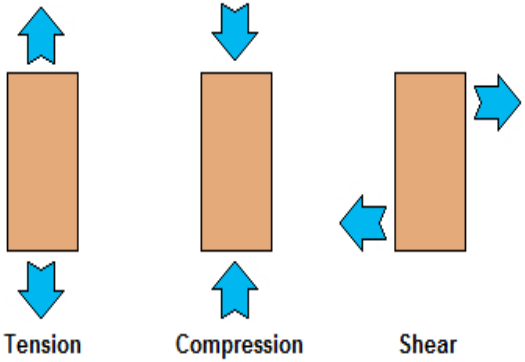
The Cytoskeleton of Two Cells Linked by Extracellular Proteins

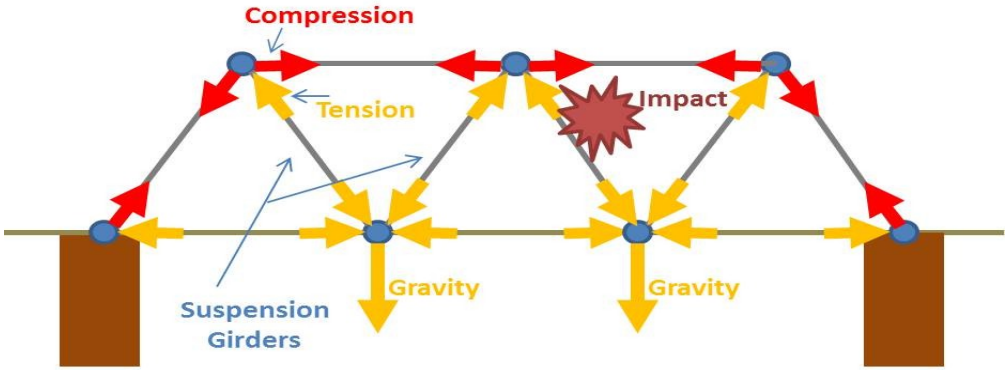


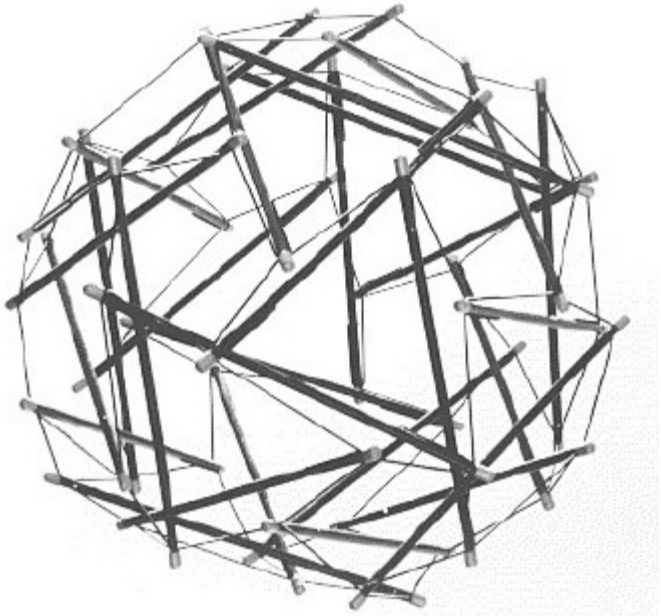
Transmembrane Proteins (integrins) Allows the Cytoskeleton to Connected to Extracellular Structures

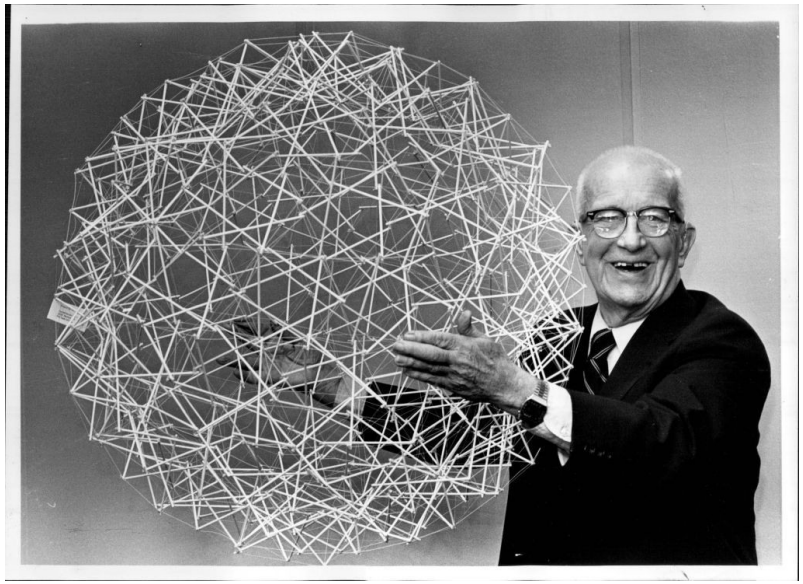


The Physics of Our Cytoskeleton





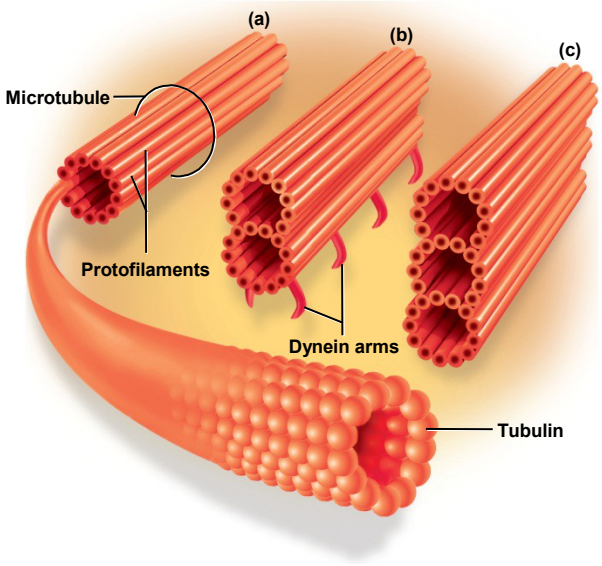




Buckminster Fuller

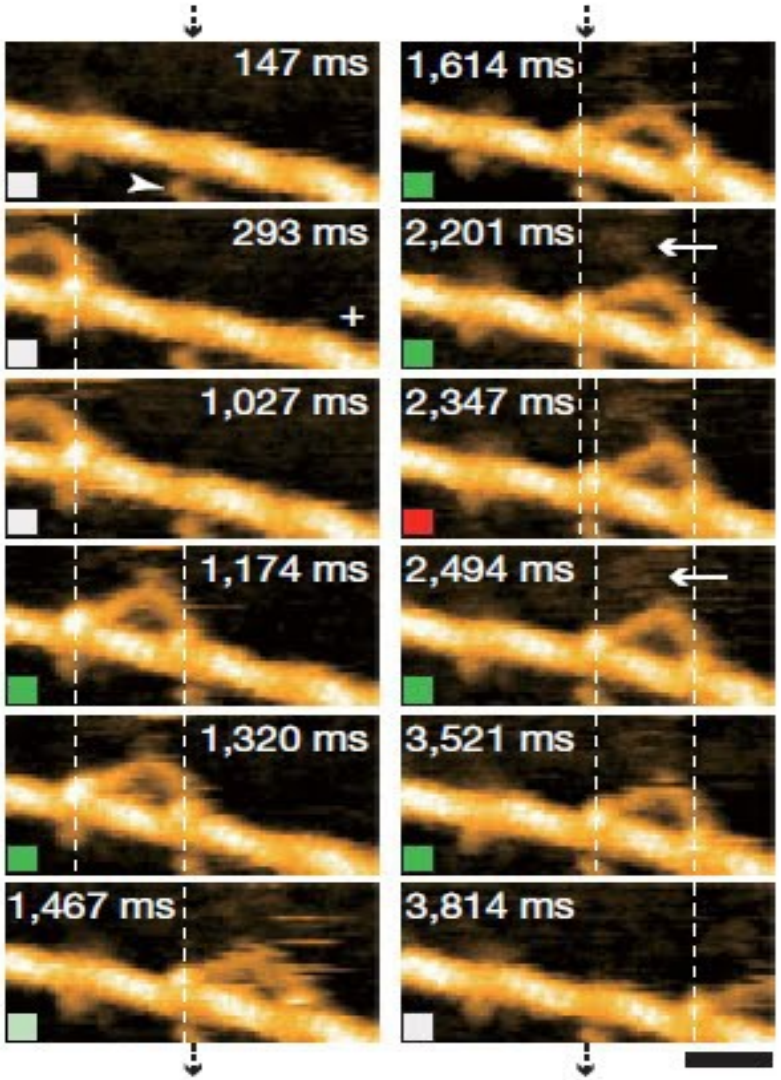
Microtubules

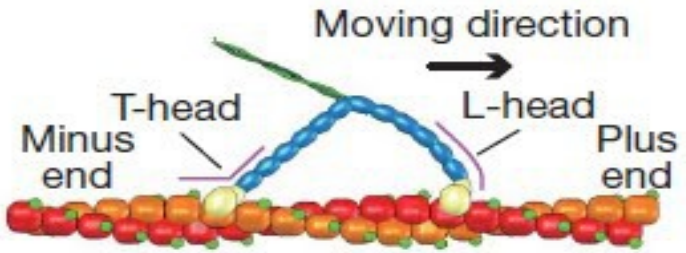
- a microtubule is a cylinder of 13 parallel strands called protofilaments /// each proto-filament is a long chain of globular proteins called tubulin
- microtubules radiate from centrosome and hold organelles in place, form bundles that maintain cell shape and rigidity, and act somewhat like railroad tracks
  - motor proteins 'walk' along these tracks carrying organelles and other macromolecules to specific locations in the cell
- not permanent structures
- tubulin assembles and disassembles
- moment by moment microtubules may change
- this action also allows some cells to "move"

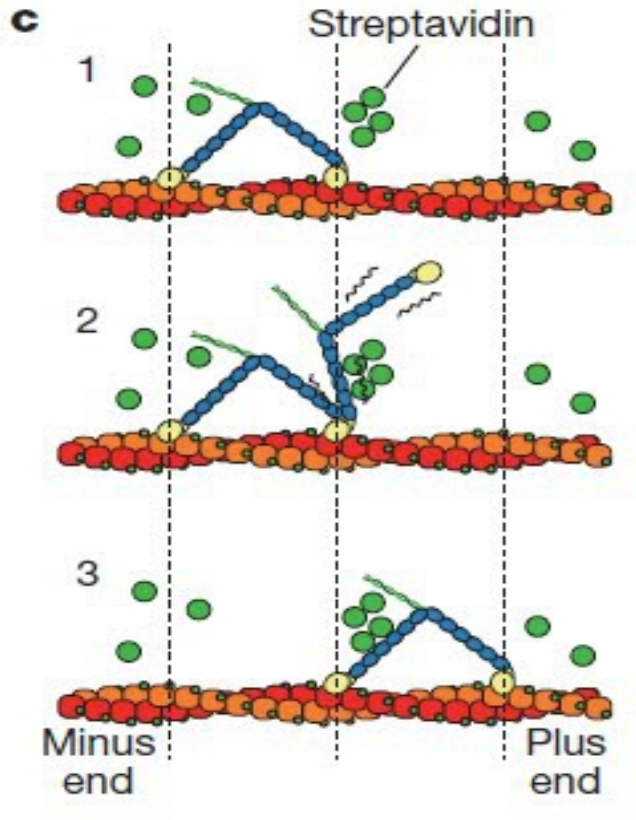


A Nano “Motor” Walks Across Protein Filaments

(Actual Video Taken With Atomic Force Microscope)







Review of the Organelles

- Nucleus
- Centrioles
- Cilia
- Flagella
- Microvilli
- Endoplasmic reticulum
- Golgi complex
- Ribosomes
- Lysosomes
- Peroxisomes
- Proteosomes
- Mitochondria

You will be tested on the structure and function of these organelles.

There are 20 C3 exam questions and 10 of these questions are about organelles!

It is a good idea to make flash cards for these organelles.

Do not overlook the plasma membrane's structure and function.

Nucleus

- Largest organelle (5 μm in diameter) // 40% volume of cell
  - most cells have only one nucleus
  - some cell types are multinucleated (e.g. skeletal muscle)
- Nuclear envelope - two unit membranes surround nucleus
  - perforated by nuclear pores formed by rings of protein
    - regulate molecular traffic through envelope
    - hold two unit membranes together
    - provides points of attachment and organization for chromatin
    - plays role in regulation of the “cell cycle”

Nucleus

Nucleoplasm – the cytoplasm of the nucleus

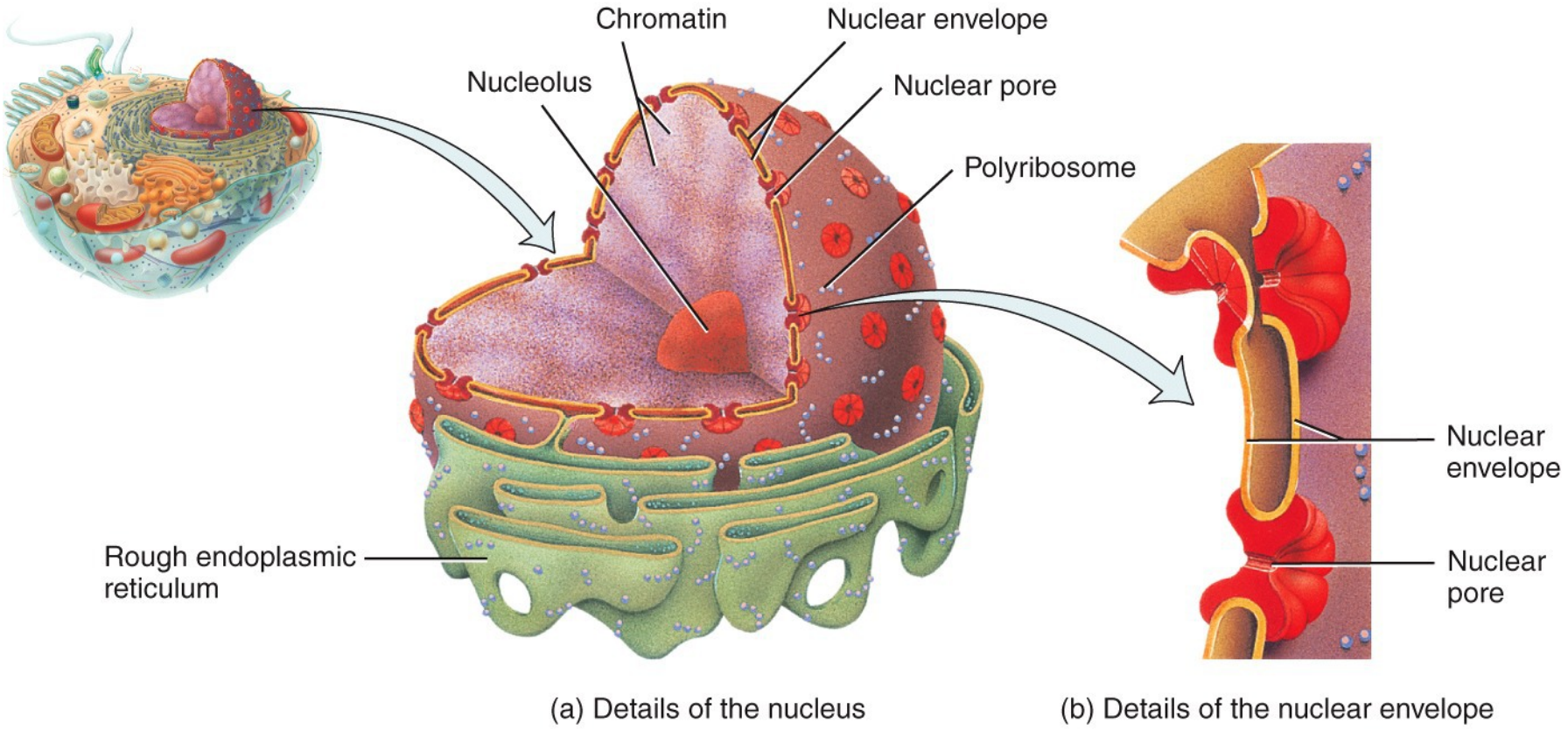
web of protein filaments and DNA

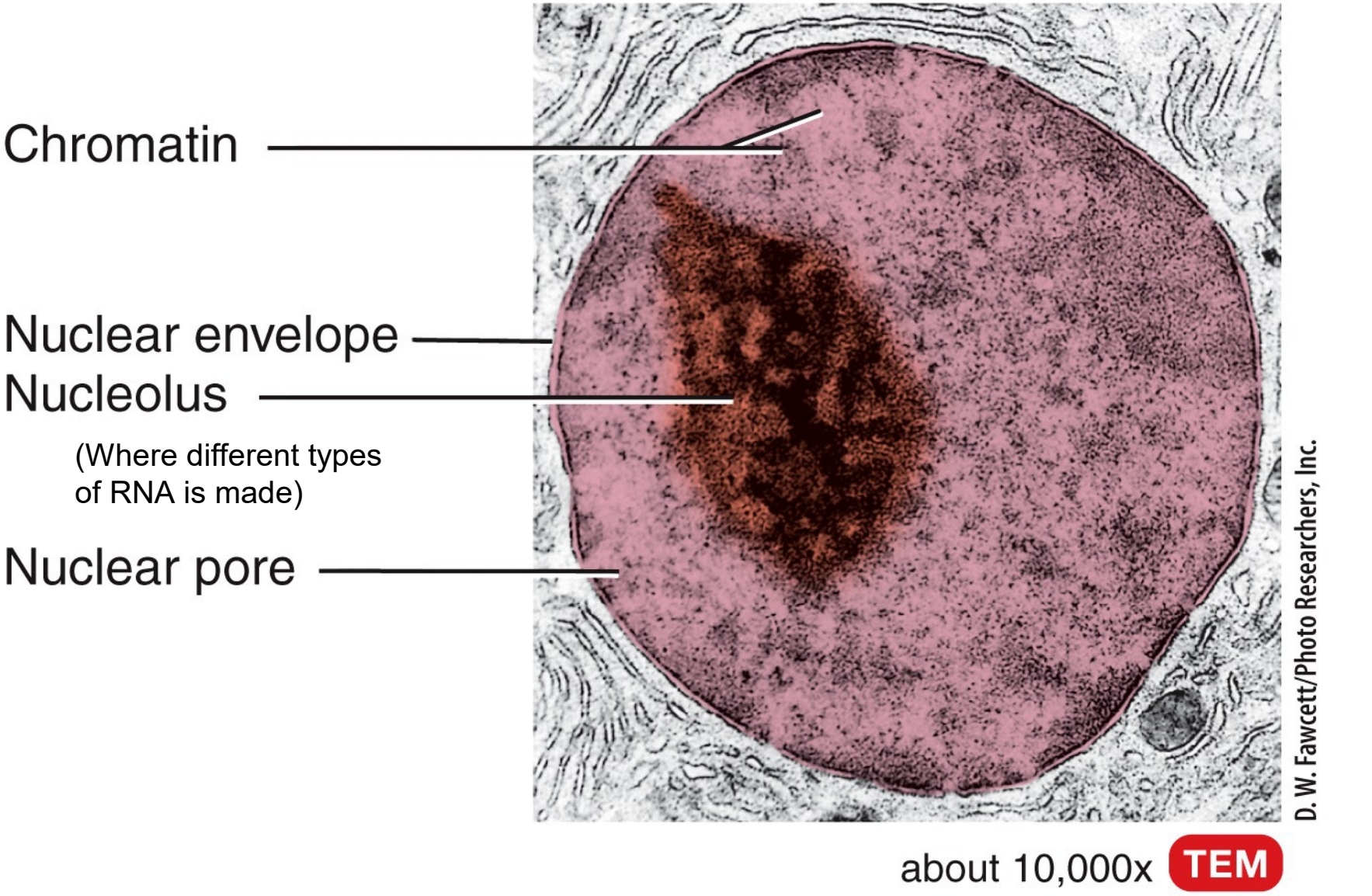
chromatin (thread-like matter) composed of DNA and protein (i.e. at metaphase chromatin = chromosomes)

nucleous = one or more dark masses inside nucleus // genes for making ribosomes are in this area // protein made in cytoplasm migrate back to nucleoli to be assembled as ribosomes

supports nuclear envelope and pores // provides points of attachment and organization for chromatin

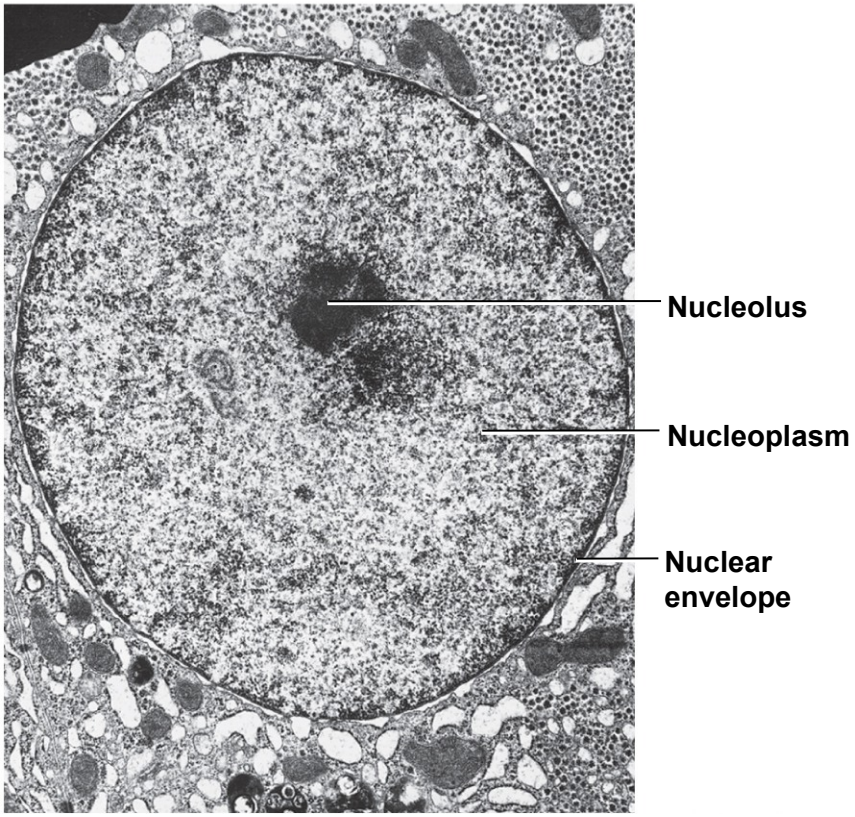
the nucleus is like the “hard drive” of your computer


Chromatin
Nuclear envelope
Nucleolus
Nuclear pore
Polyribosome
Rough endoplasmic reticulum
Nuclear envelope
Nuclear pore
(a) Details of the nucleus
(b) Details of the nuclear envelope

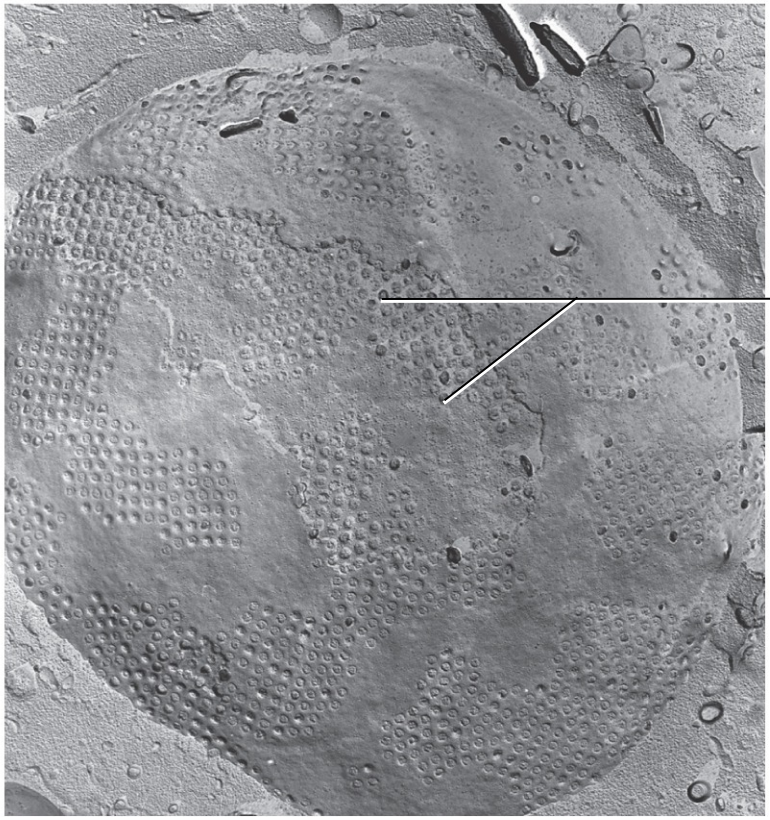


(c) Transverse section of the nucleus

Micrograph of The Nucleus



(a) Interior of nucleus



(b) Surface of nucleus

Centrioles

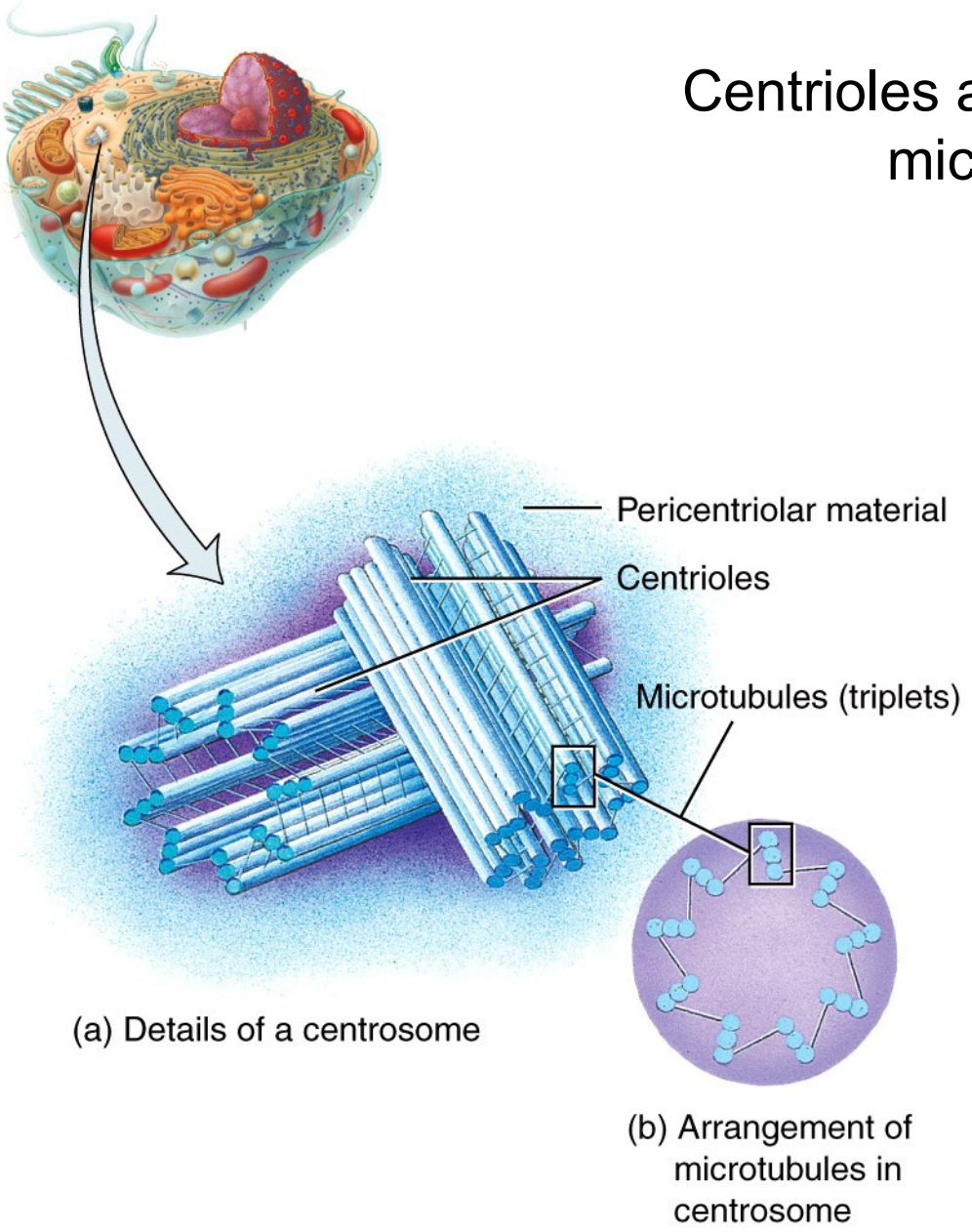
- Centriole – a short cylindrical assembly of microtubules arranged in nine groups of three microtubules each

- Cells have two centrioles located at one pole on the exterior surface of the nucleus in a region called the centresome

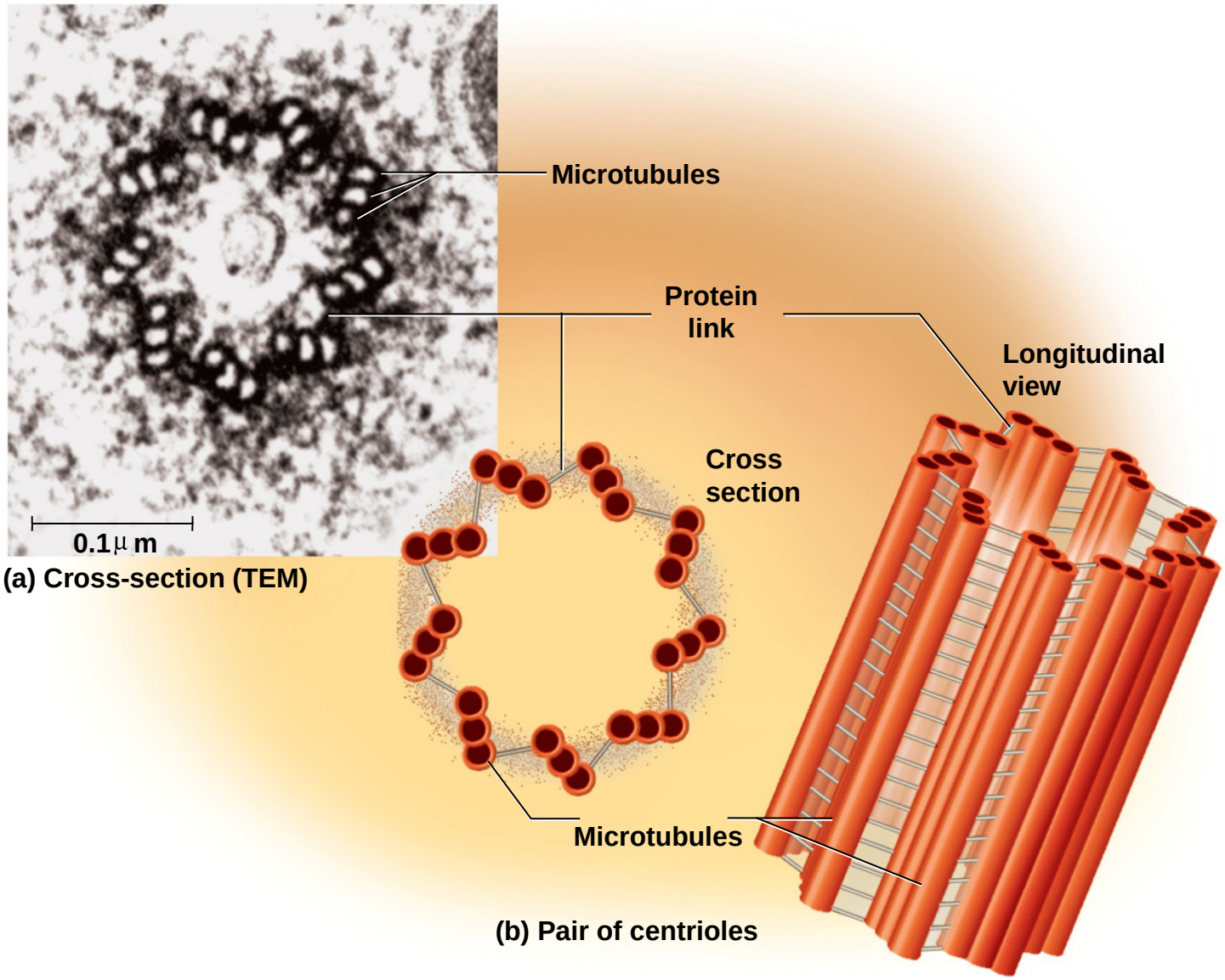
- Centrioles lie perpendicular to each other // one function is to play key role in cell division another function is to produce cytoskeleton's microtubules

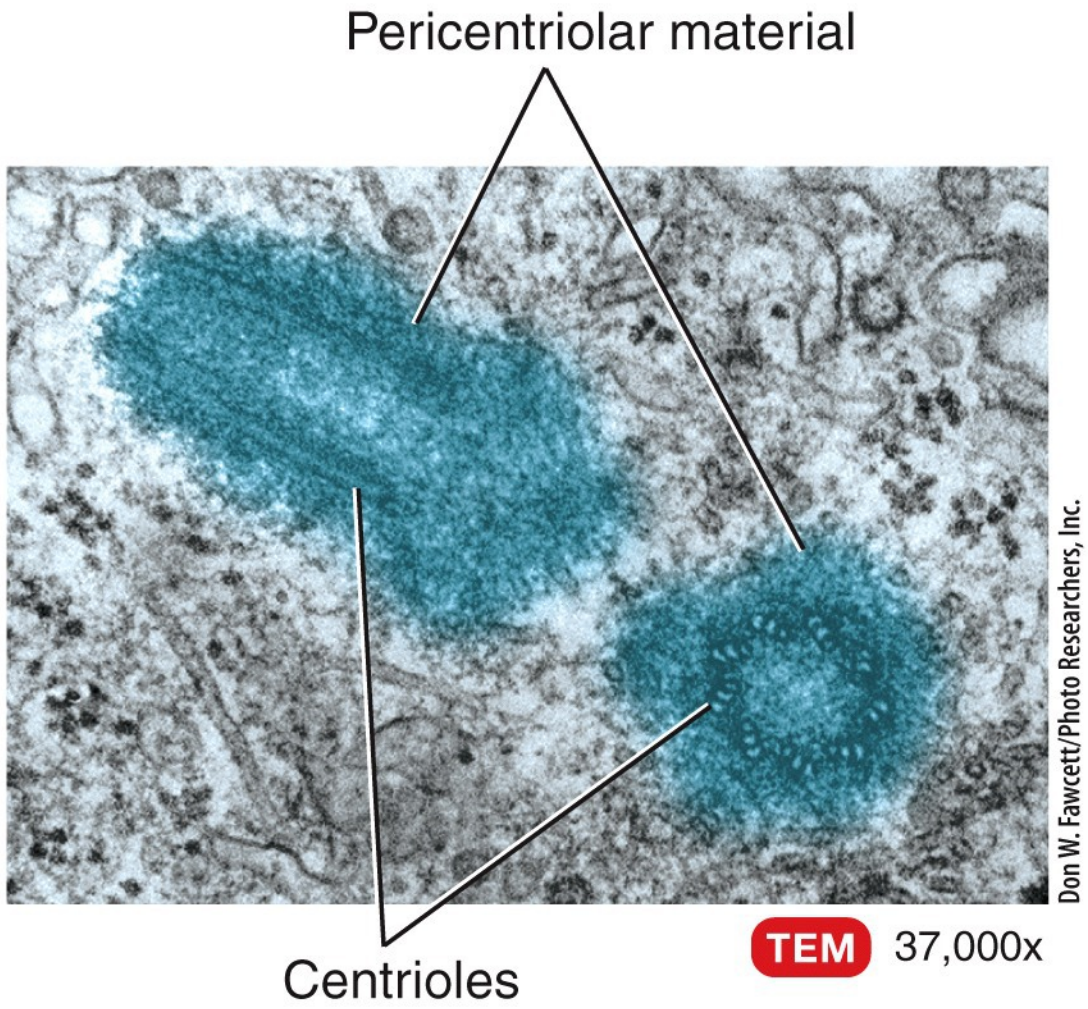
- Centrioles are the “birthing station” for microtubules

Centrioles are where the cytoskeleton's microtubes are formed.



Centrioles

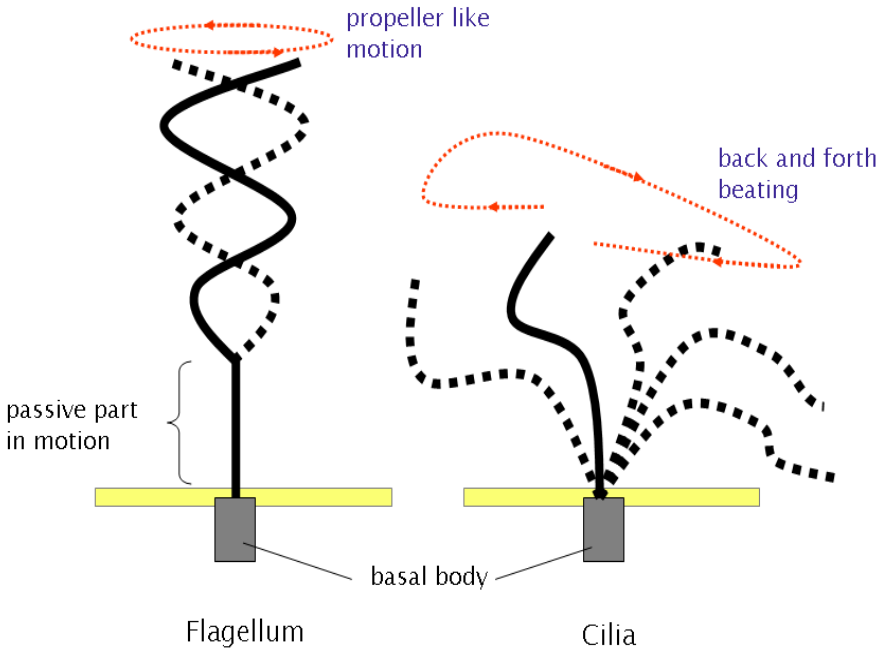

Microtubules
Protein link
Longitudinal view
Cross section
0.1 µ m
Microtubules
(a) Cross-section (TEM)
(b) Pair of centrioles



(c) Centrioles

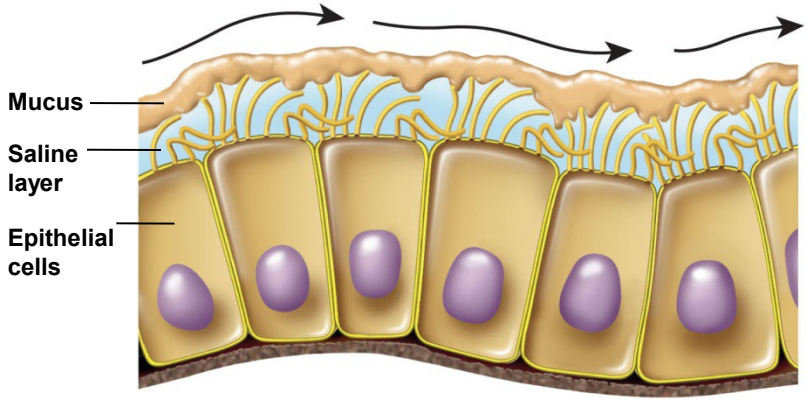
Centrioles Also Form Basal Bodies

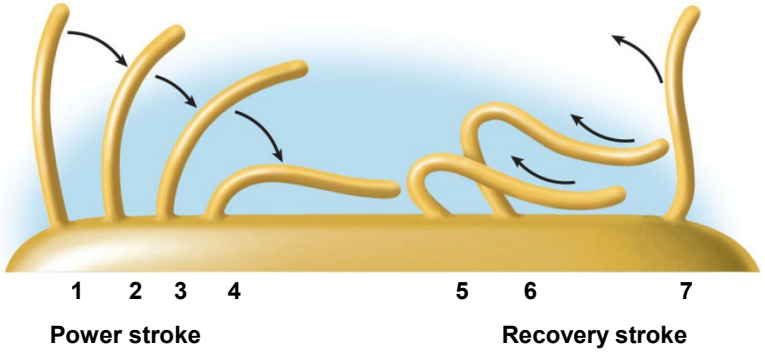
- Single centriole play role in structure and function of both cilia and flagella
- each basal body of a cilium or flagellum is a single centriole oriented perpendicular to plasma membrane
- basal bodies originate in centriolar organizing center // migrates to plasma membrane
- two microtubules of each triplet elongate to form the nine pairs of peripheral microtubules of the axoneme
- cilium reaches full length in less than one hour



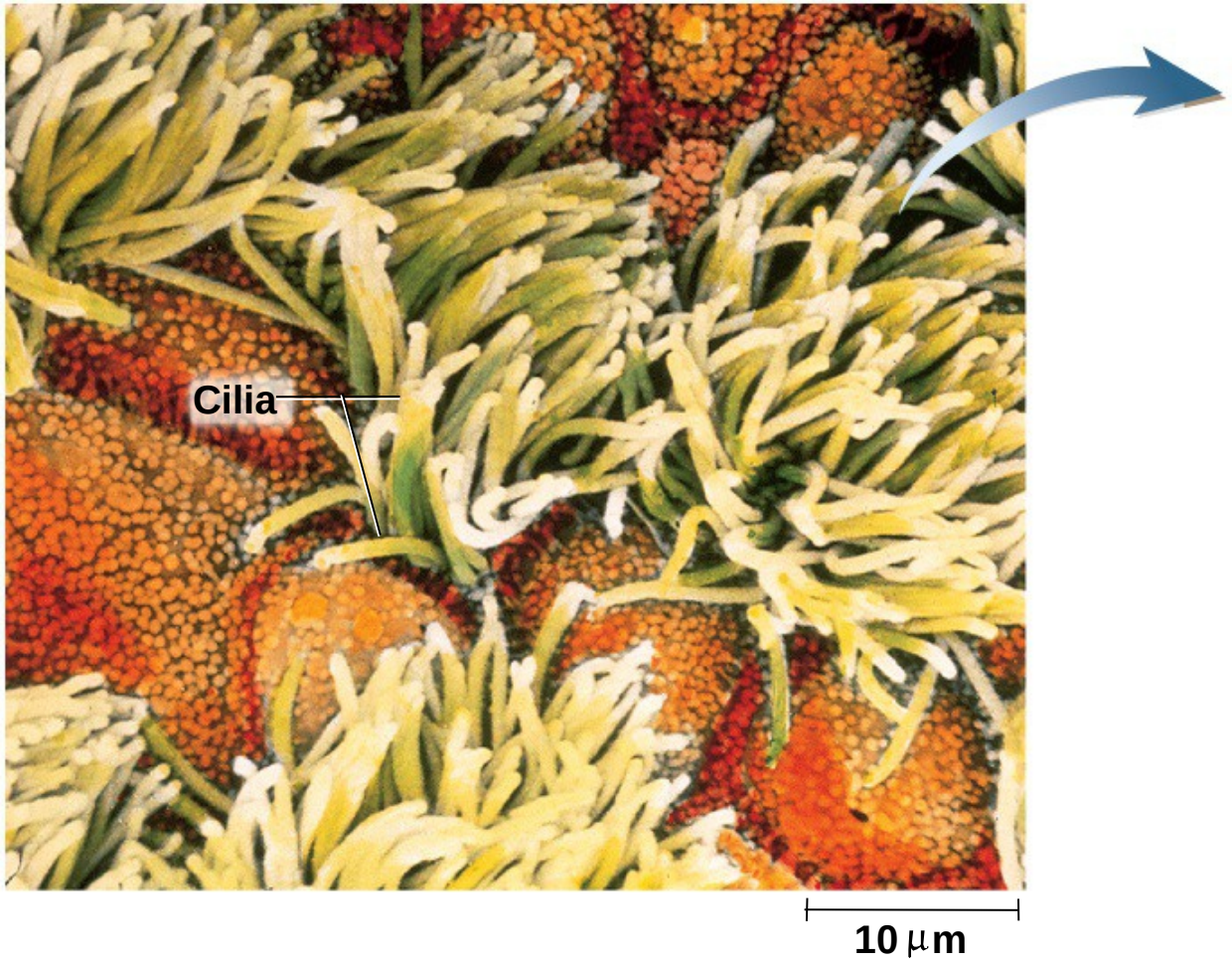
Cilia

- **Hairlike processes 7-10 μm long // one or many per cell**
- **Single non-motile cilia**
  - non-motile “primary cilium”
  - primary cilium found on nearly all cells in the body
  - function as an “antenna’ for monitoring extracellular conditions
  - sensory in inner ear, retina, nasal cavity, and kidney
- **Multiple motile cilia / move fluid across surface of cells**



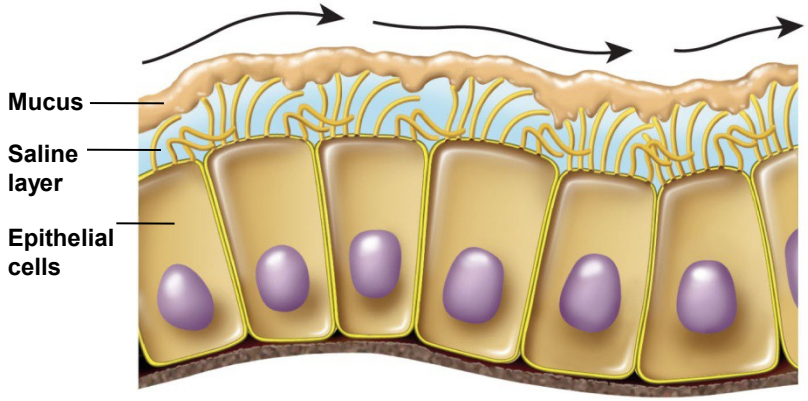


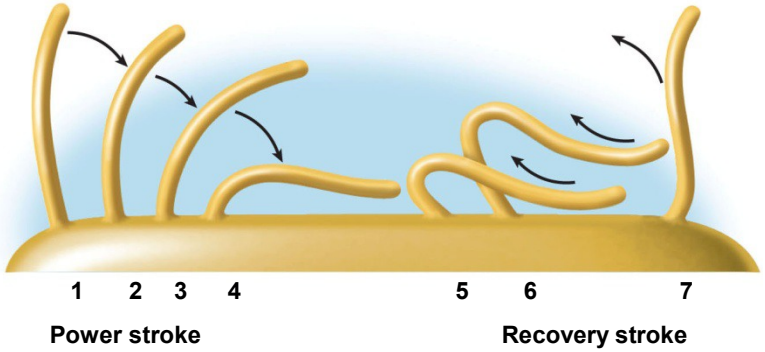
Cilia Lining Trachea

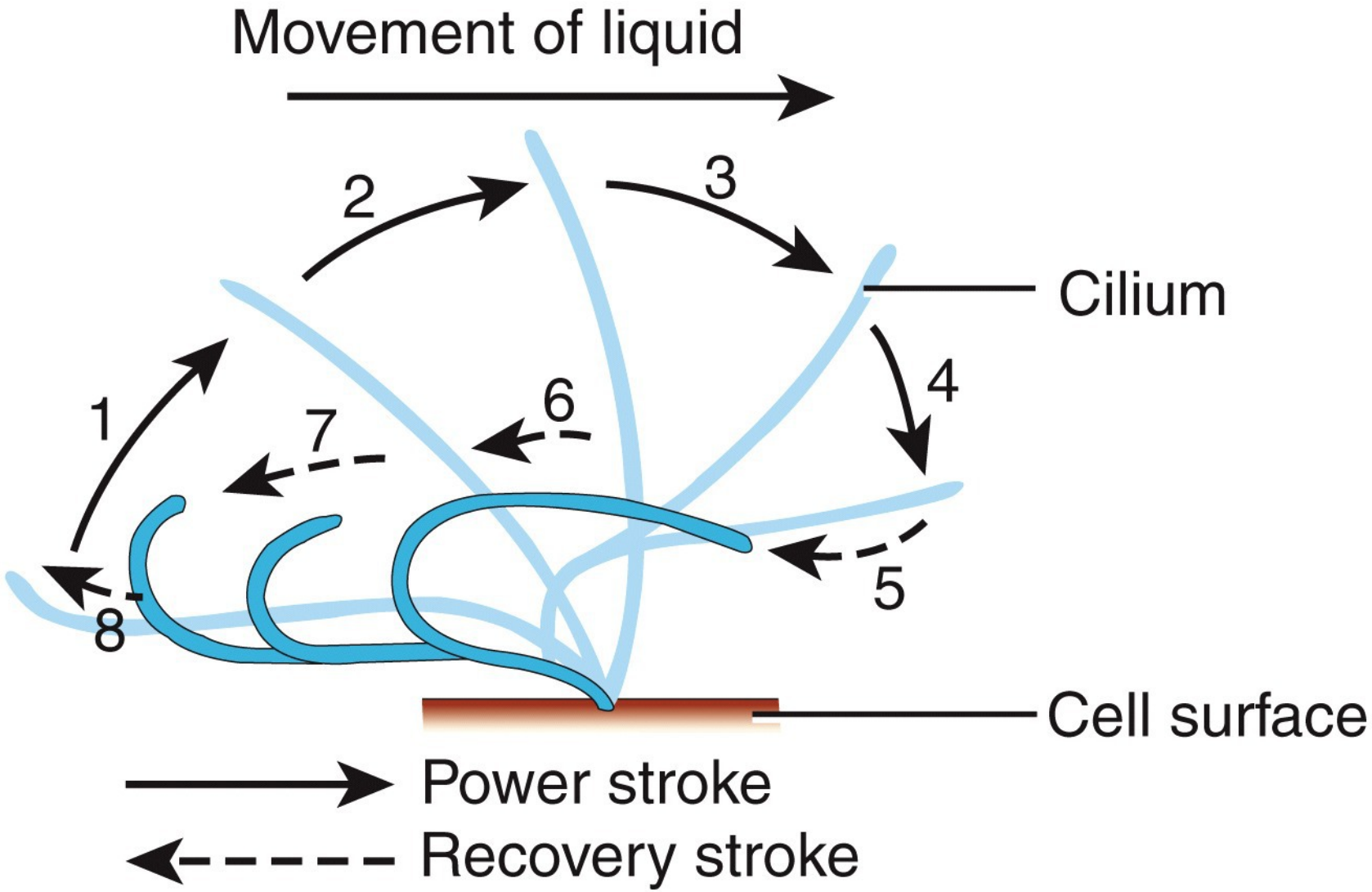


Cilia

- Motile cilia
  - these are motile cilia – respiratory tract, uterine tubes, ventricles of the brain, efferent ductules of testes
  - many per cell
  - beat in waves // sweep substances across surface in same direction
  - power strokes followed by recovery strokes



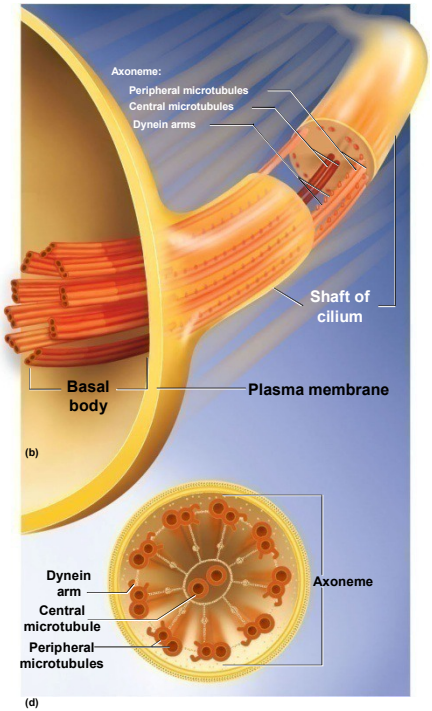


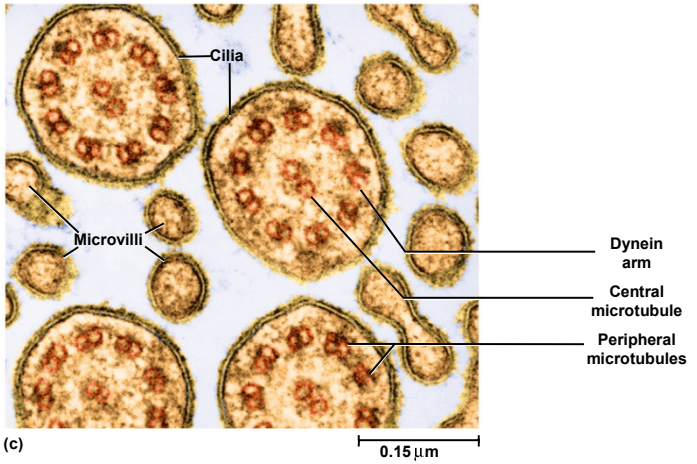


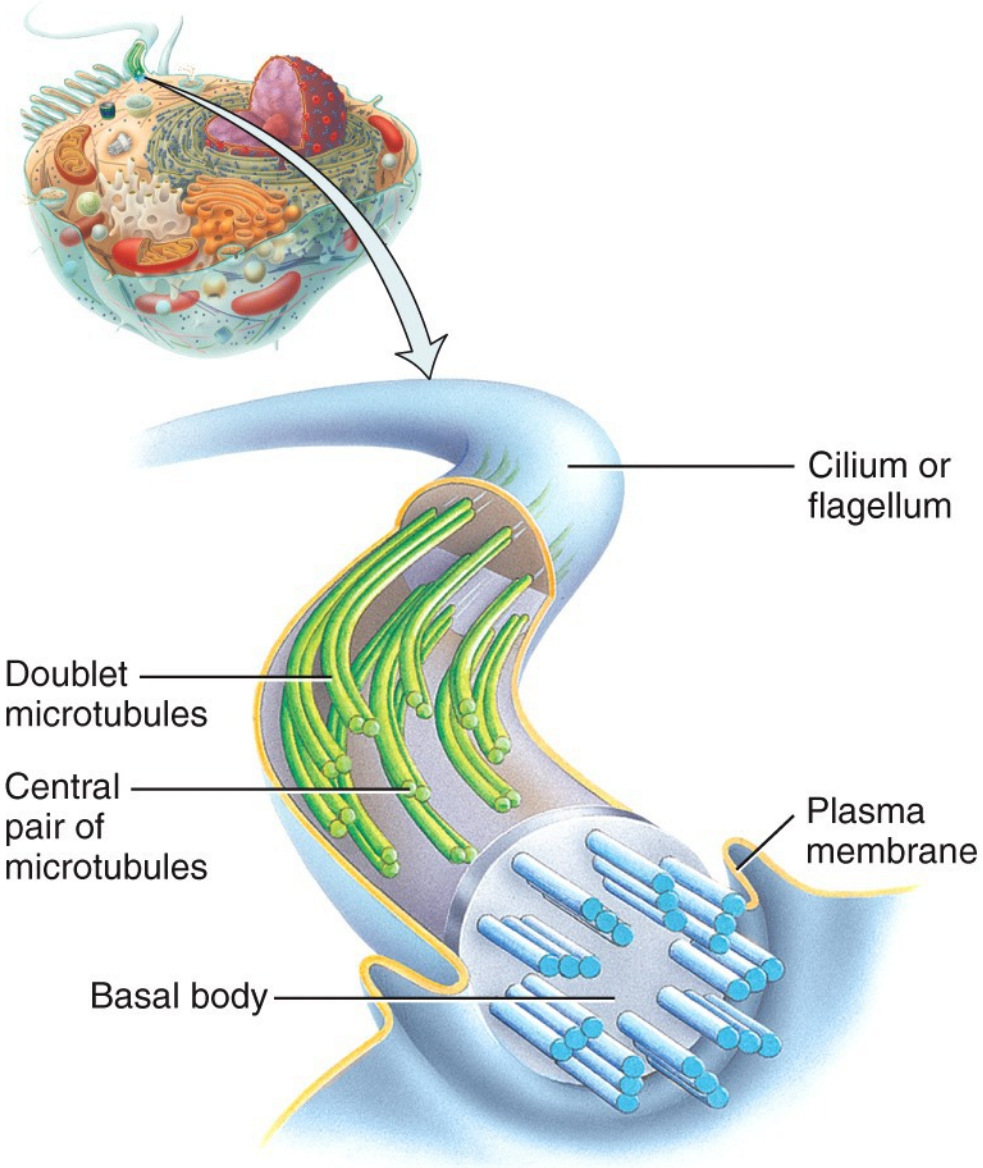
(d) Ciliary movement

Cross Section of a Cilium

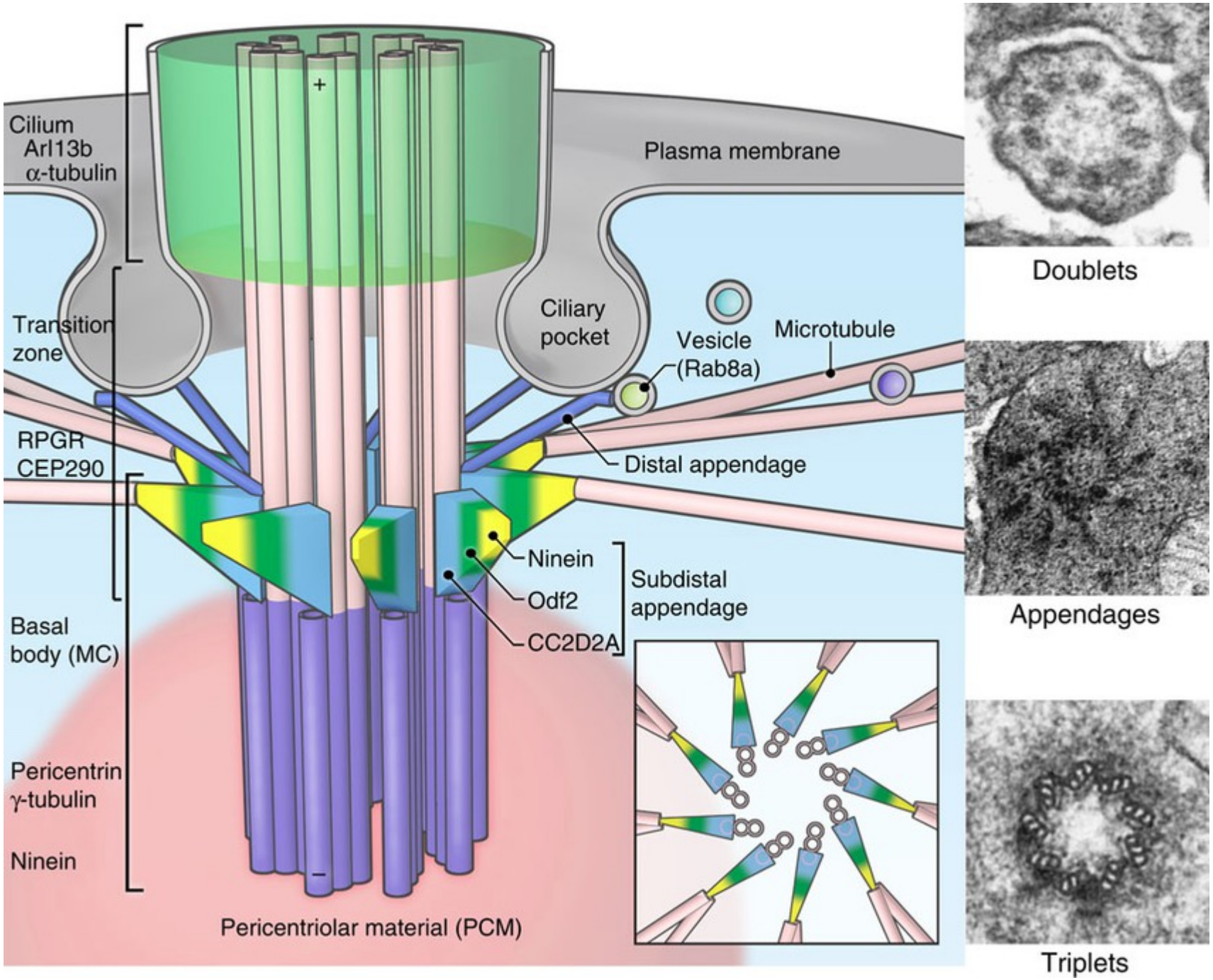
- Axoneme - core of cilia that is the structural basis for ciliary movement
- has 9 + 2 structure of microtubules
  - 9 pairs form basal body inside the cell membrane // anchors cilium
  - dynein arms “crawls” up adjacent microtubule bending the cilia // uses energy from ATP
- Saline Layer
  - chloride pumps pump Cl- into ECF
  - Na+ and H2O follows
  - cilia beat freely in saline layer







(a) Arrangement of microtubules in a cilium or flagellum


Cilium
Arl13b
α-tubulin
Plasma membrane
Transition zone
Ciliary pocket
Vesicle (Rab8a)
Microtubule
RPGR
CEP290
Distal appendage
Ninein
Odf2
CC2D2A
Subdistal appendage
Basal body (MC)
Pericentrin
γ-tubulin
Ninein
Pericentriolar material (PCM)
Doublets
Appendages
Triplets

Cilia & Cystic Fibrosis

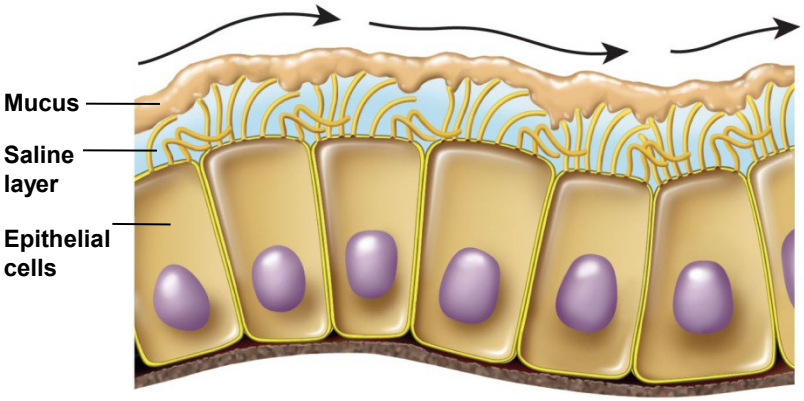
- Saline layer at cell surface due to chloride pumps move Cl- out of cell. Na+ ions and H2O follow

- Cystic fibrosis – hereditary disease in which cells make chloride pumps, but fail to install them in the plasma membrane

  – chloride pumps fail to create adequate saline layer on cell surface

- thick mucus plugs pancreatic ducts and respiratory tract

  – inadequate digestion of nutrients and absorption of oxygen
  – chronic respiratory infections
  – life expectancy of 30



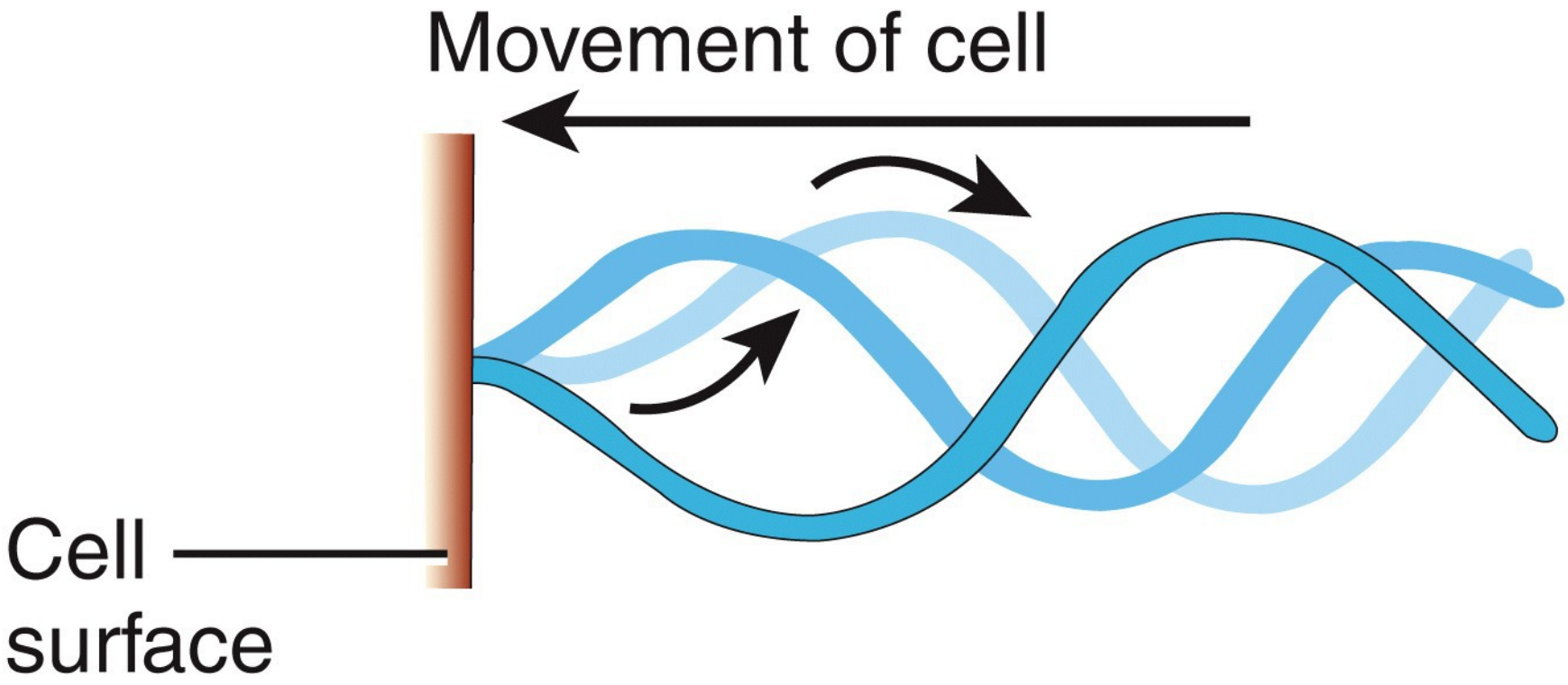
When a mother kisses their newborn, she may discover something tragic. The sweat test measures the amount of chloride in sweat. Kids with cystic fibrosis can have two to five times the normal amount of chloride in their sweat. So if the mother taste chloride in the sweat she knows her child has cystic fibrosis.

(b) Cilia lining the trachea

Flagella

- tail of the male's sperm = only functional flagellum
- whiplike structure with axoneme identical to cilium
  - much longer than cilium
  - stiffened by coarse fibers that supports the tail
- movement is more undulating, snakelike
  - no power stroke or recovery stroke as in cilia

(c) Flagellum of a sperm cell

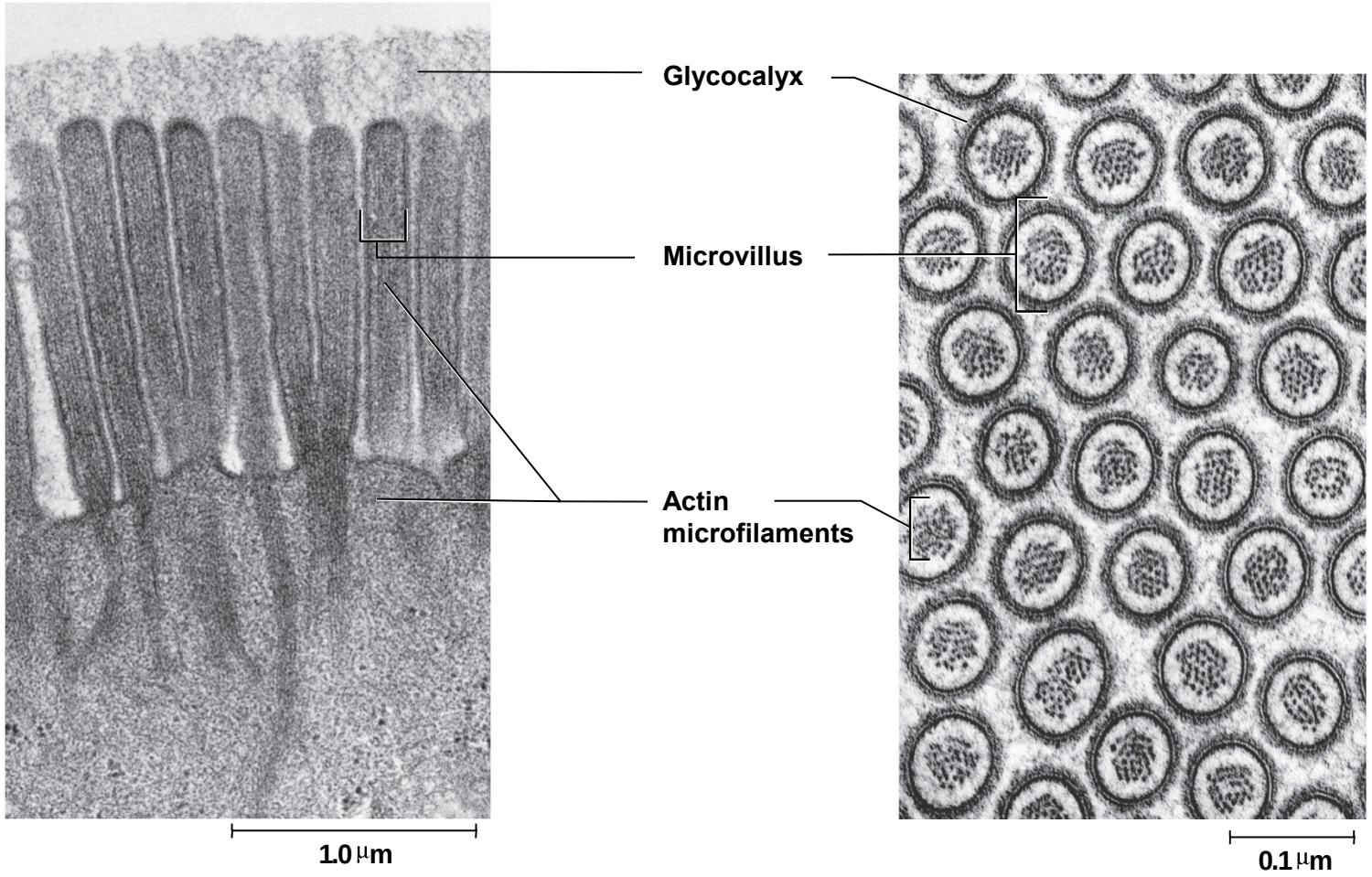


(e) Flagellar movement

Microvilli

- Extensions of plasma membrane (1-2 μm)
  - serves to increase cell's surface area
  - best developed in cells specialized in absorption
  - gives 15 – 40 times more absorptive surface area
  - Microvilli "act like a sponge"
- on some cells they are very dense and appear as a fringe – "brush border"
- milking action of actin // actin filaments shorten microvilli - pushing absorbed contents down into cell

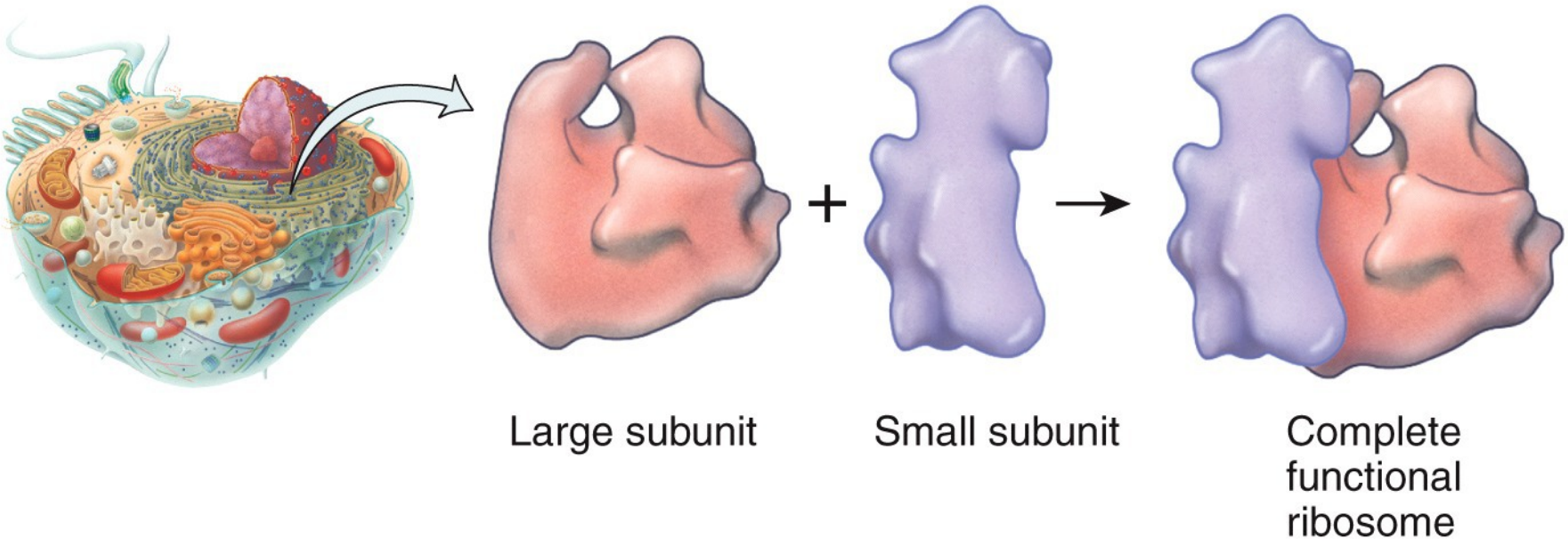
Microvilli



Actin microfilaments are found in center of each microvilli.

Ribosomes

- Ribosomes – complex of small granules of protein and RNA
  - found in nucleoli, in cytosol, on outer surfaces of rough ER, and in nuclear envelope
- they ‘read’ coded genetic messages (messenger RNA) and assemble amino acids into proteins specified by the code
- Commonly called the “protein factories”
- Two type of ribosomes // make protein either for internal use or export outside cell (see discussion on endoplasmic reticulum)

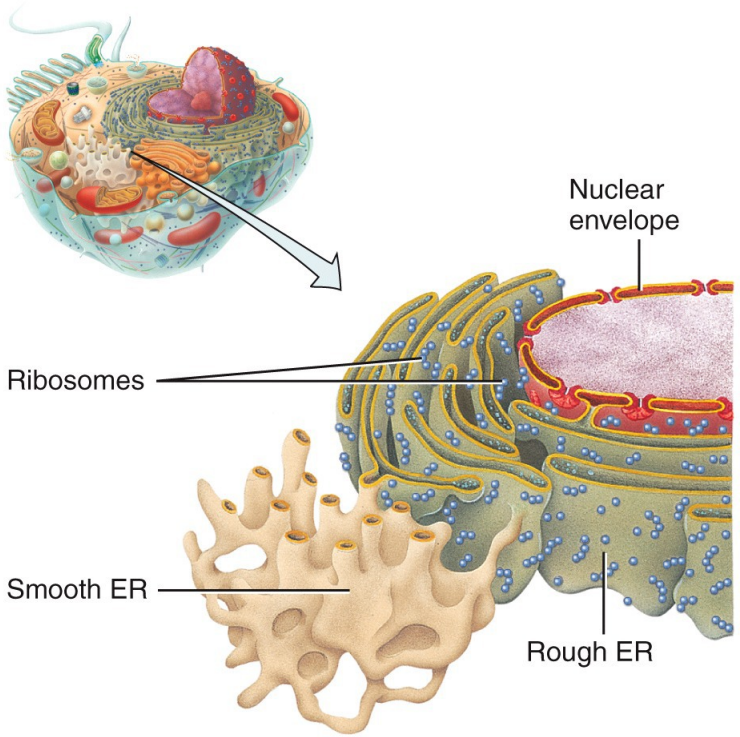


Details of ribosomal subunits

Endoplasmic Reticulum

- **endoplasmic reticulum - system of interconnected channels called cisternae enclosed by unit membrane**

- **Two types: smooth vs rough**



(a) Details

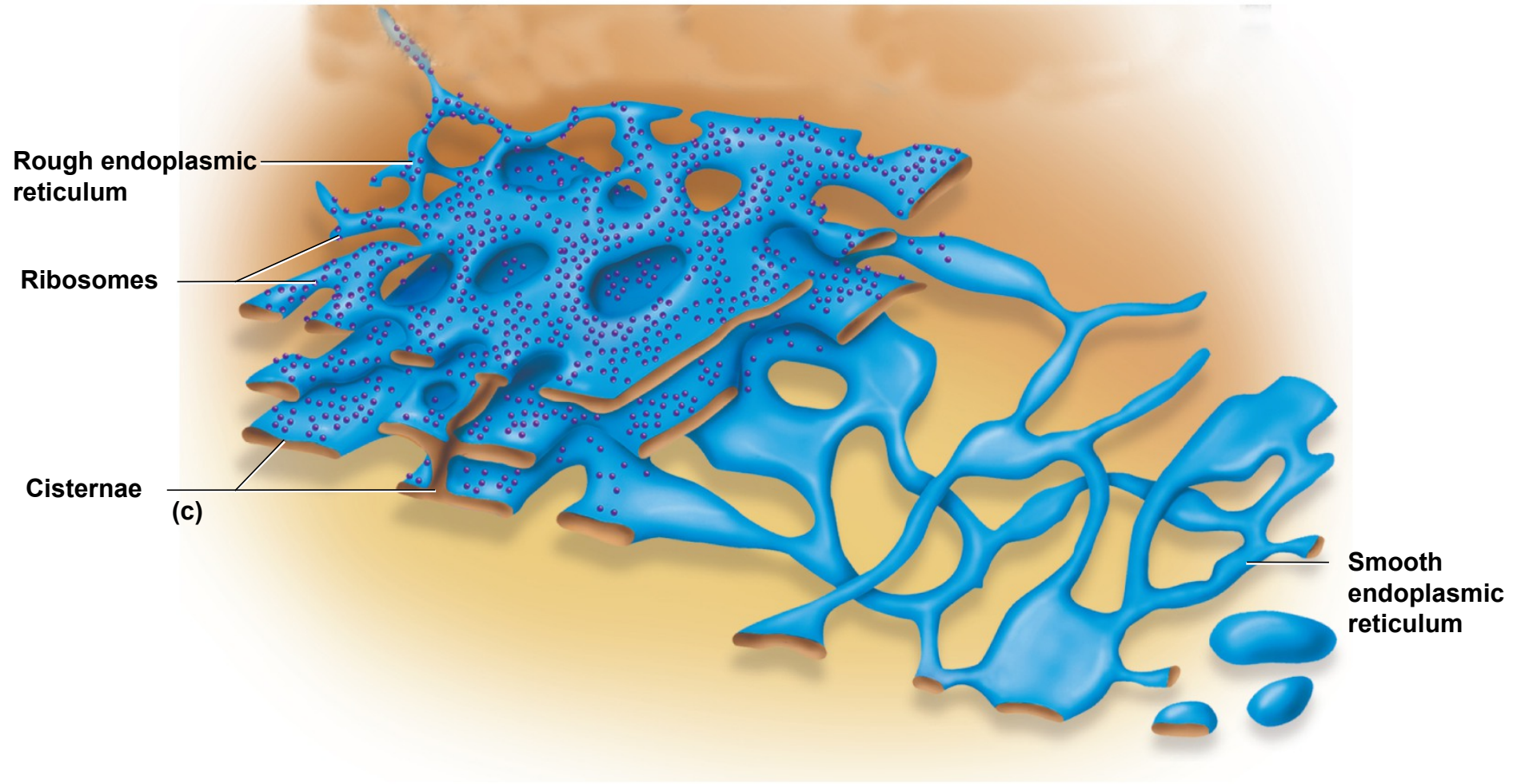
Endoplasmic Reticulum

- **Rough endoplasmic reticulum**
  - **composed of parallel, flattened sacs covered with ribosomes**
  - **continuous with outer membrane of nuclear envelope**
  - **adjacent cisternae are often connected by perpendicular bridges**
  - **produces the phospholipids and proteins of the plasma membrane**
  - **synthesizes proteins that are packaged in other organelles or secreted from cell**

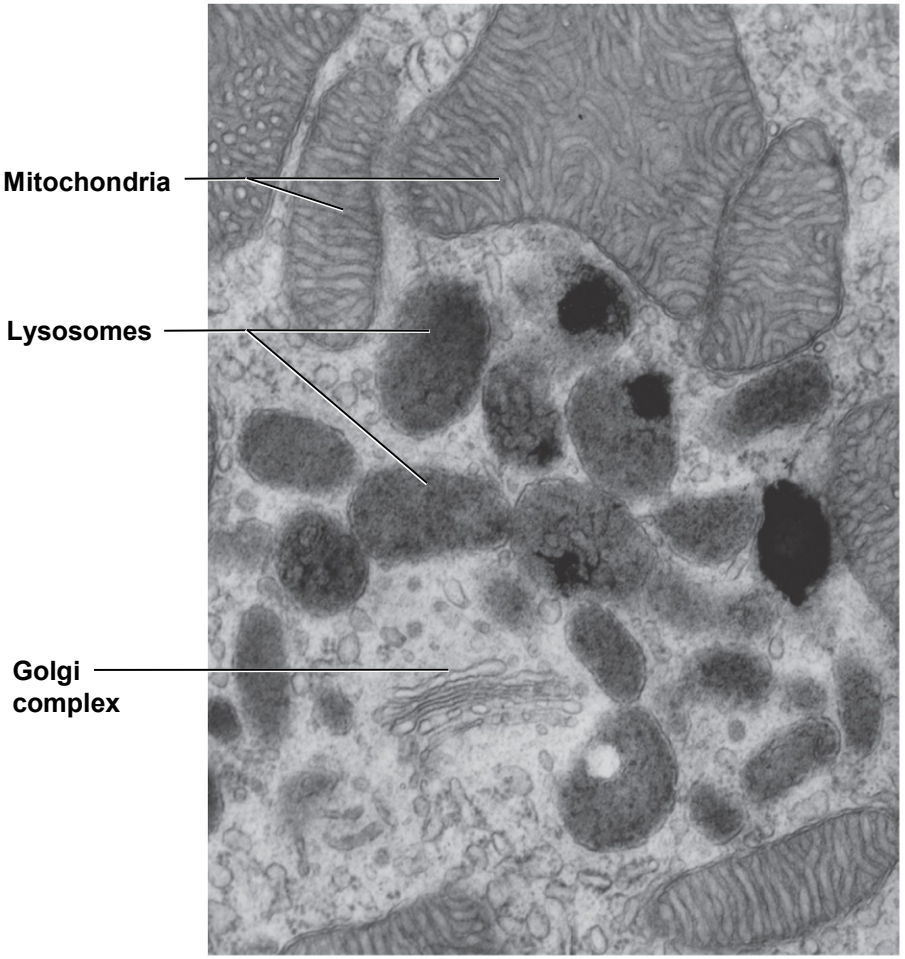
Endoplasmic Reticulum

- Smooth endoplasmic reticulum // lack ribosomes
  - cisternae more tubular and branching
  - cisternae are thought to be continuous with those of rough ER
  - synthesizes steroids and other lipids
  - detoxifies alcohol and other drugs
  - manufactures all membranes of the cell
- *Note: rough and smooth ER are functionally different parts of the same network*

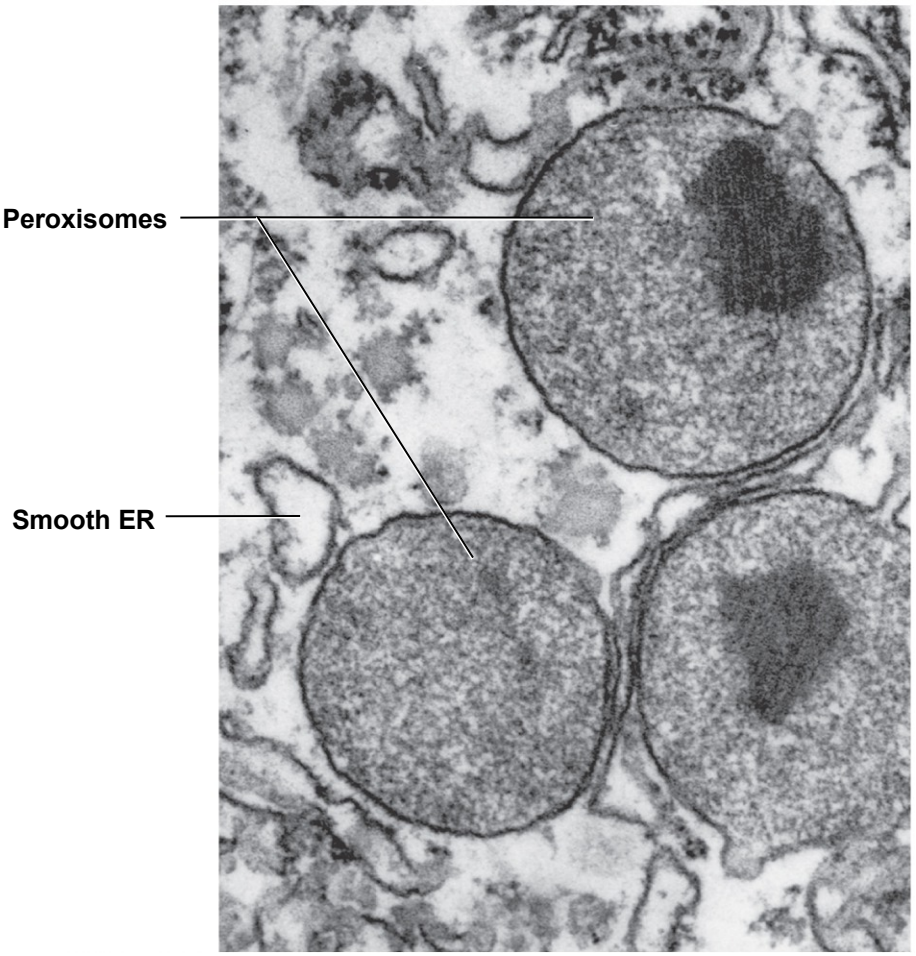
Smooth and Rough ER



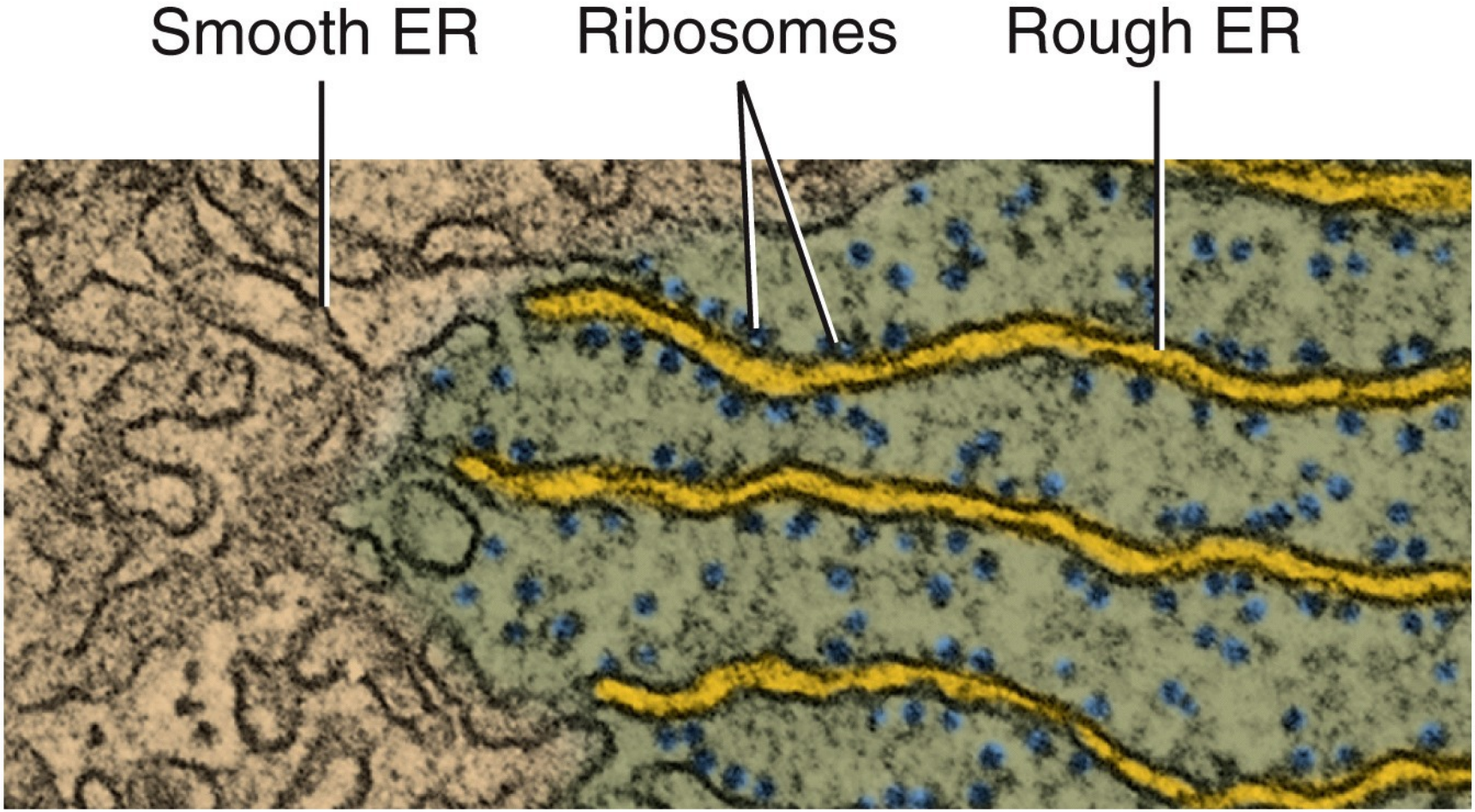
Endoplasmic Reticulum



(a) Lysosomes



(b) Peroxisomes

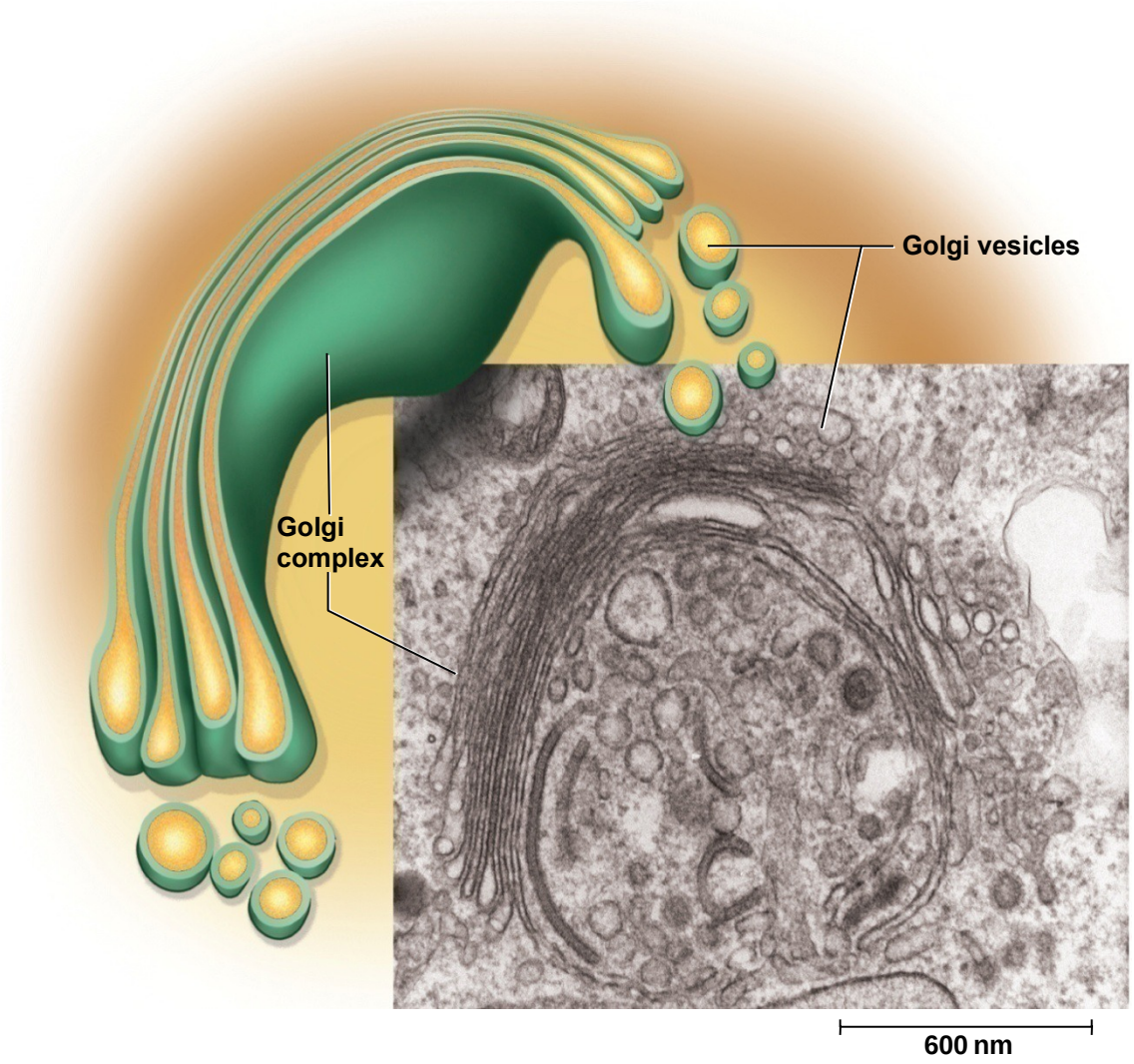


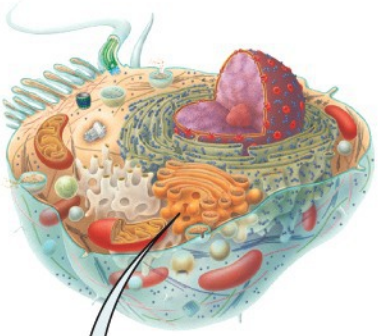
(b) Transverse section

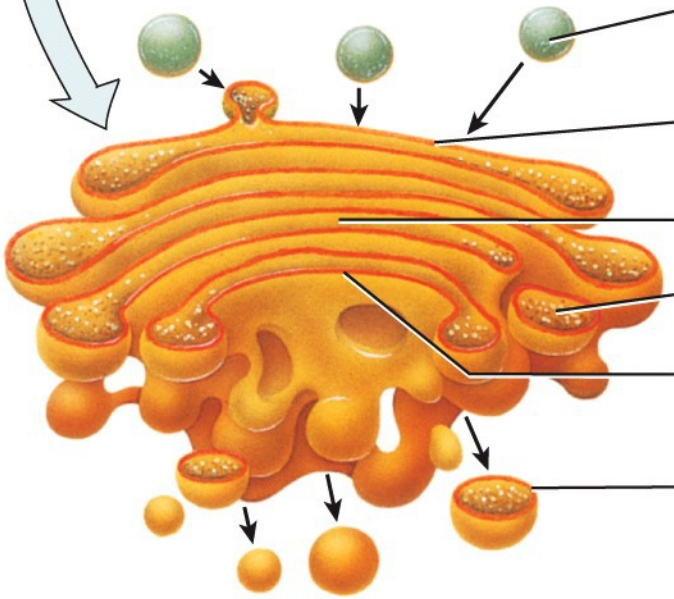
Golgi Complex

- Golgi complex - a small system of cisternae that synthesize carbohydrates and put the finishing touches on protein and glycoprotein synthesis
  - receives newly synthesized proteins from rough ER
  - sorts them, cuts and splices some of them, adds carbohydrate moieties to some, and packages the protein into membrane-bound Golgi vesicles
    - some become lysosomes
    - some migrate to plasma membrane and fuse to it
    - some become secretory vesicles for later release

Golgi Complex







Transport vesicle from rough ER

Entry or *cis* face

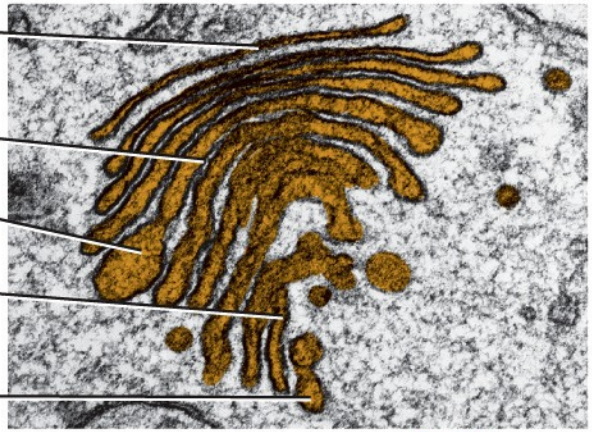
Medial cisterna

Transfer vesicles

Exit or *trans* face

Secretory vesicles

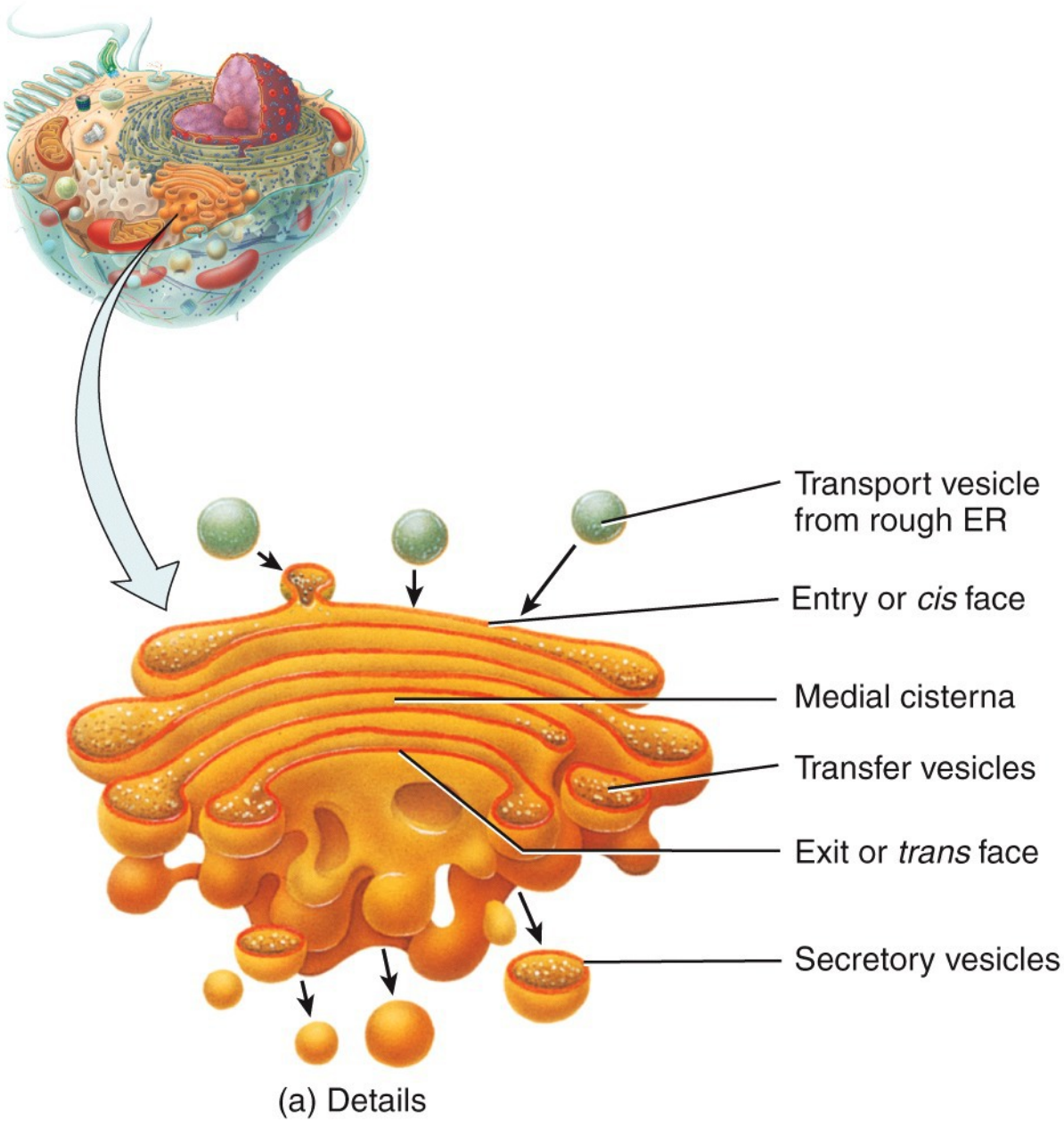
(a) Details



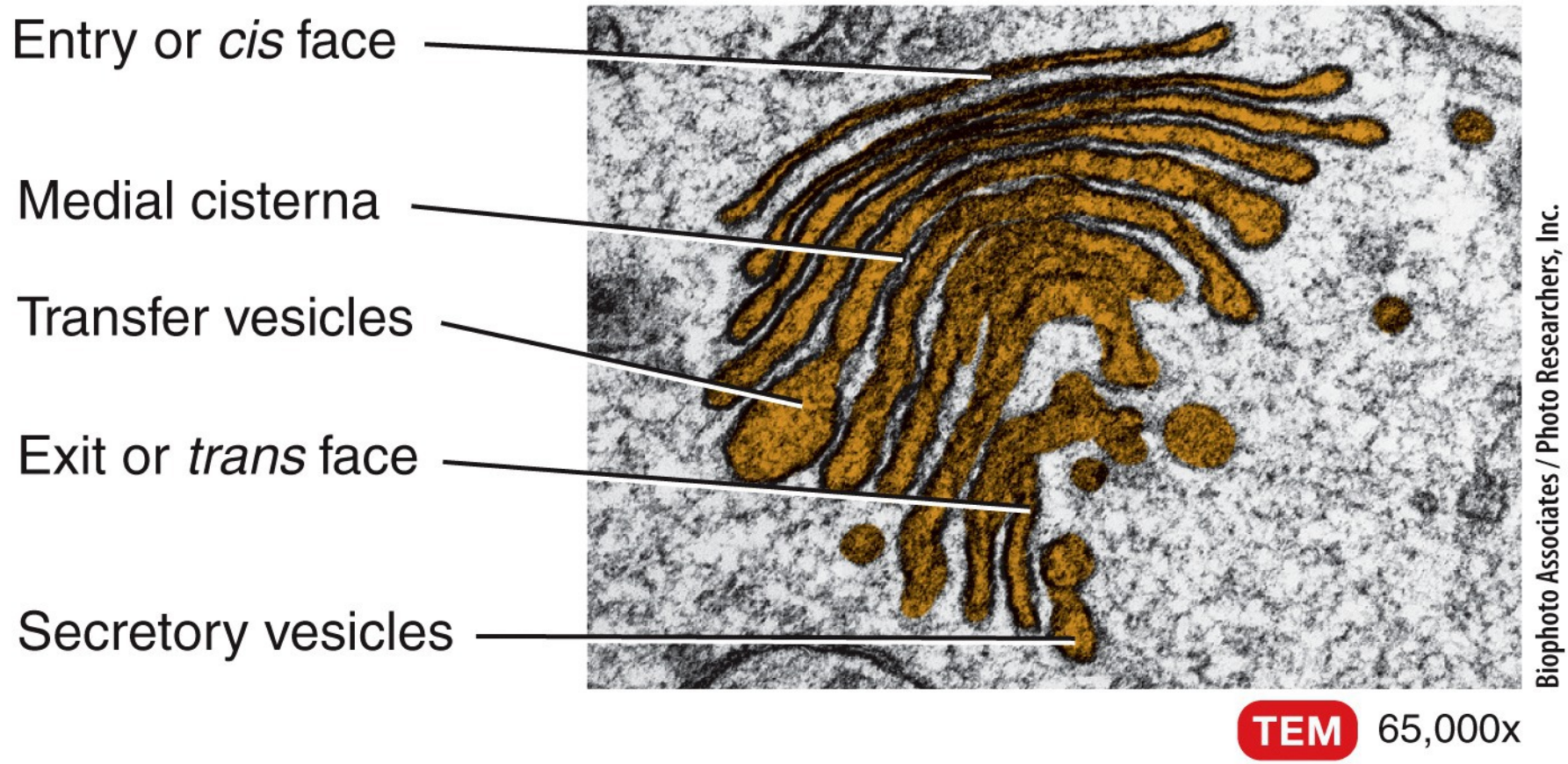
Biophoto Associates / Photo Researchers, Inc.

TEM 65,000x

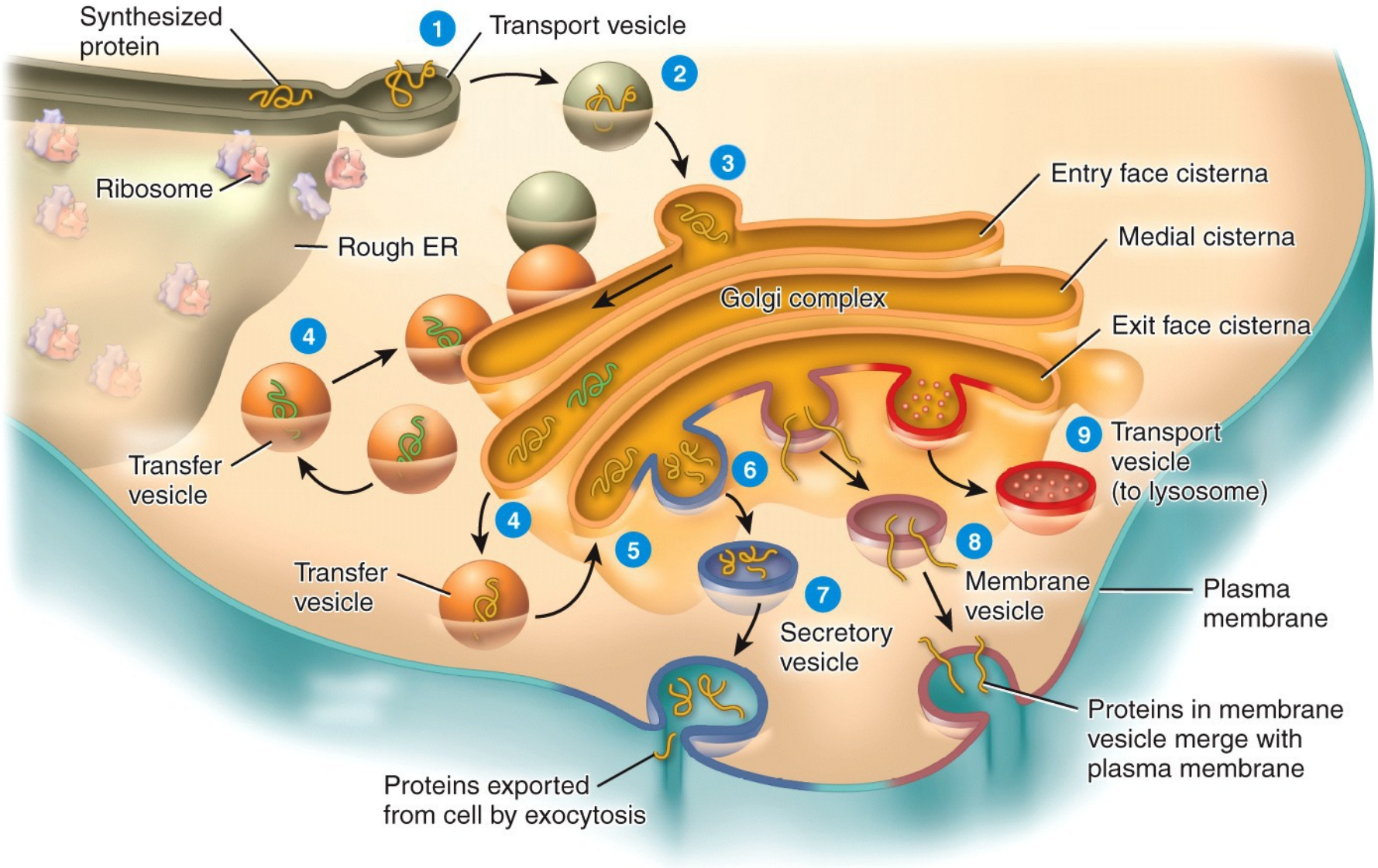
(b) Transverse section


Transport vesicle from rough ER
Entry or *cis* face
Medial cisterna
Transfer vesicles
Exit or *trans* face
Secretory vesicles

(a) Details



(b) Transverse section


Synthesized protein
1
Transport vesicle
2
3
Entry face cisterna
Medial cisterna
Golgi complex
Exit face cisterna
Ribosome
Rough ER
4
Transfer vesicle
4
Transfer vesicle
5
6
7
Secretory vesicle
8
Membrane vesicle
Plasma membrane
9
Transport vesicle (to lysosome)
Proteins in membrane vesicle merge with plasma membrane
Proteins exported from cell by exocytosis

Lysosomes

- Lysosomes - package of enzymes bound by a single unit membrane // extremely variable in shape

- Functions

  - Lysosome fuse with vesicles from endocytosis to form phagosome // Digest content of phagosomes

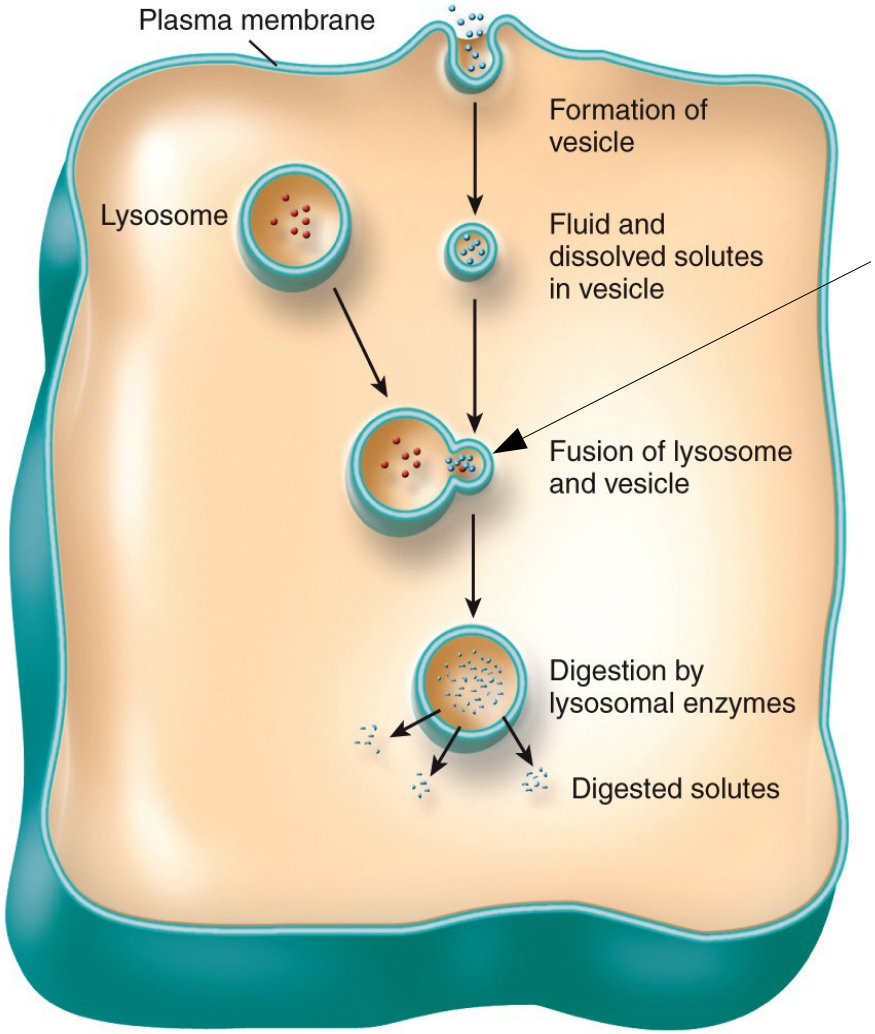
  - Membrane pumps move protons into lysosomes because enzymes work best in acid environment

  - intracellular hydrolytic digestion of proteins, nucleic acids, complex carbohydrates, phospholipids, and other substances

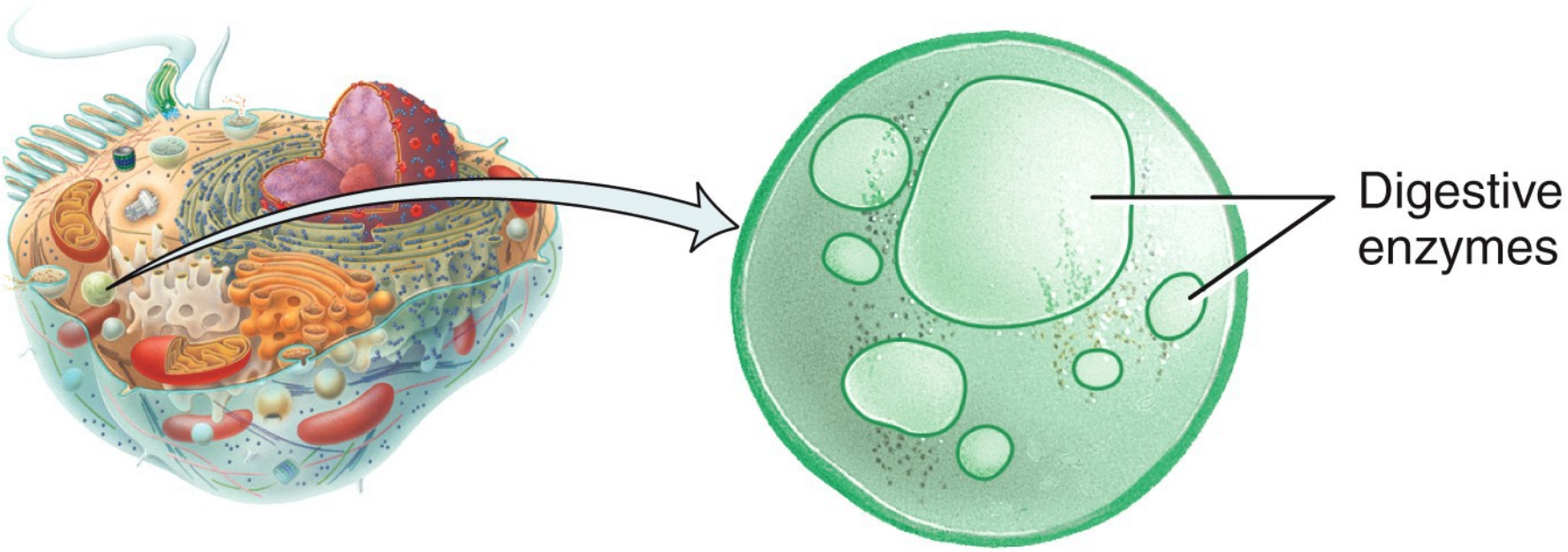
  - autophagy – digest and dispose of worn out mitochondria and other organelles

  - autolysis – ‘cell suicide’ – some cells are meant to do a certain job and then destroy themselves

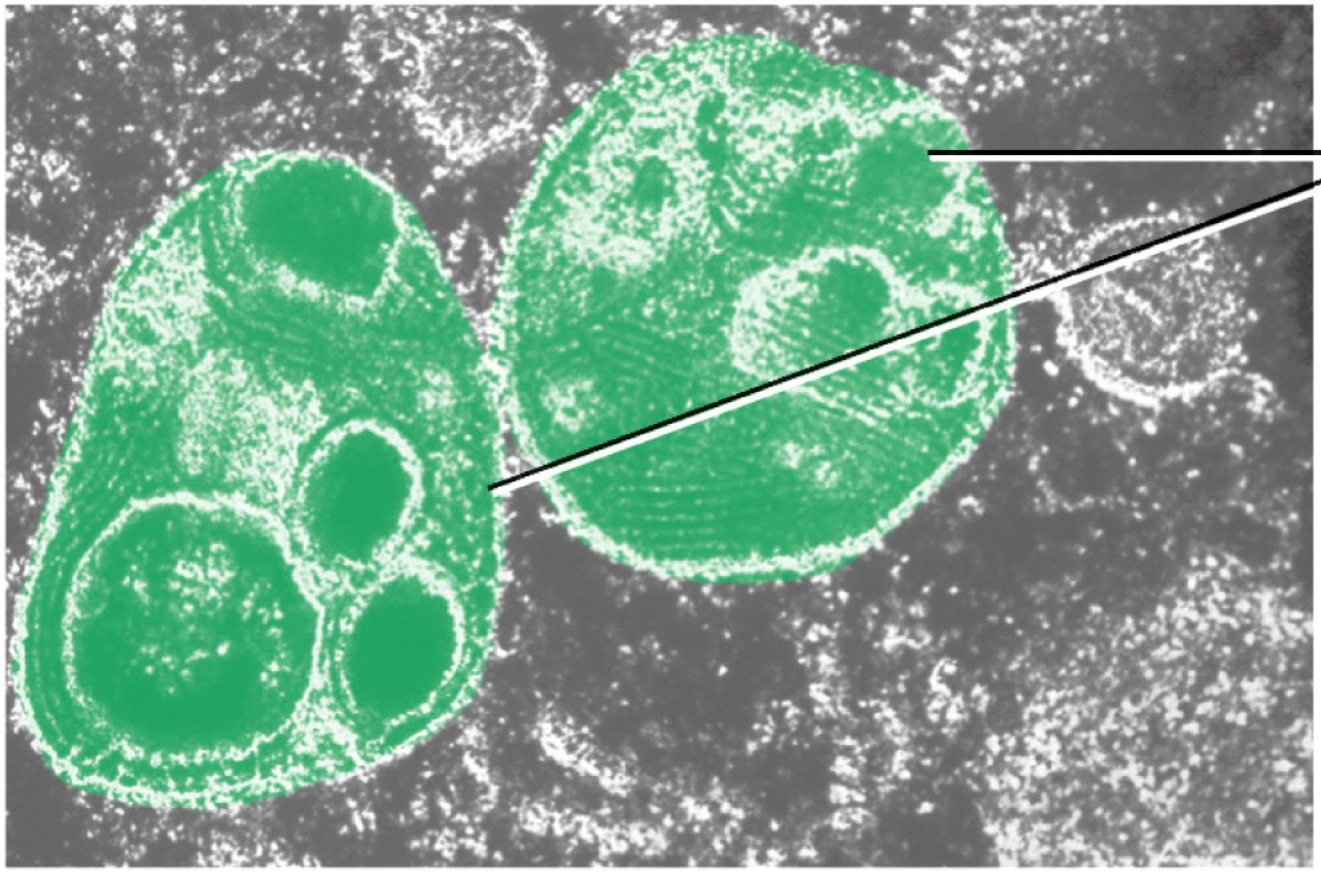
Lysosomes



Digested content in phagosome may also fuse with plasma membrane and release digested content into interstitial space.



(a) Lysosome



(b) Several lysosomes

Peroxisomes

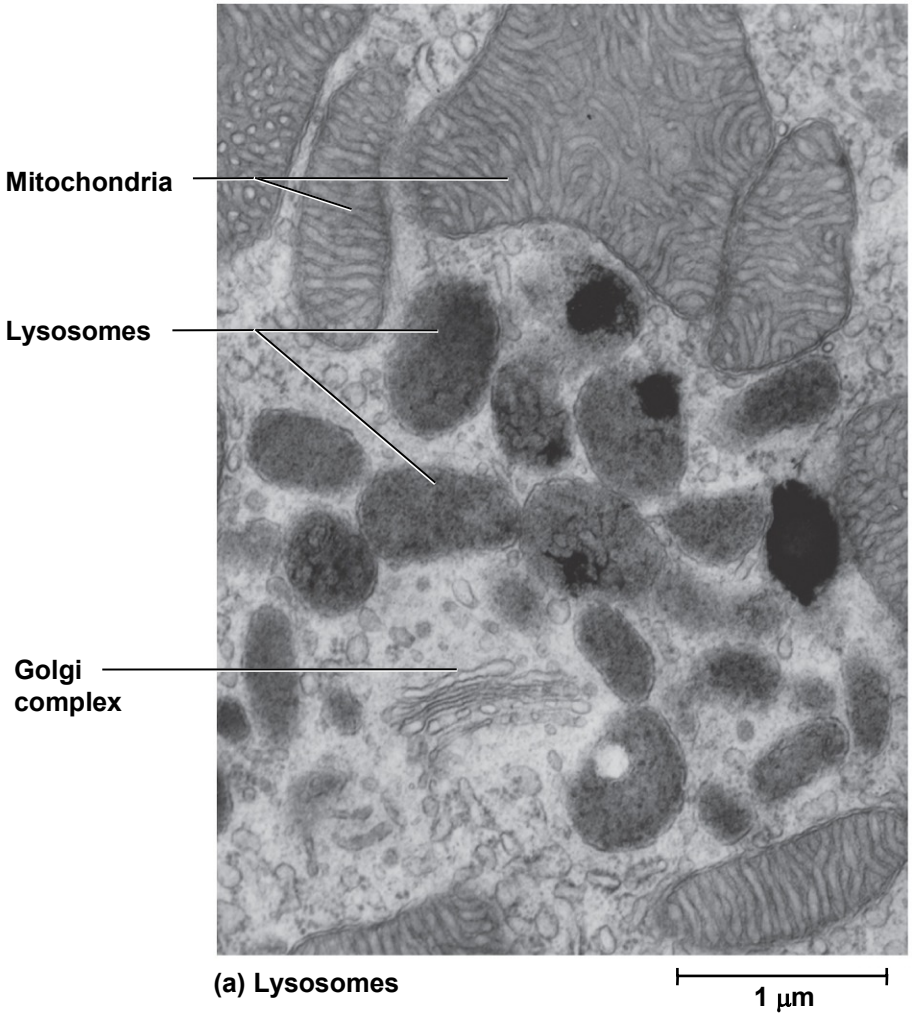
- Peroxisomes - resemble lysosomes but contain different enzymes /// used to destroy toxic molecules

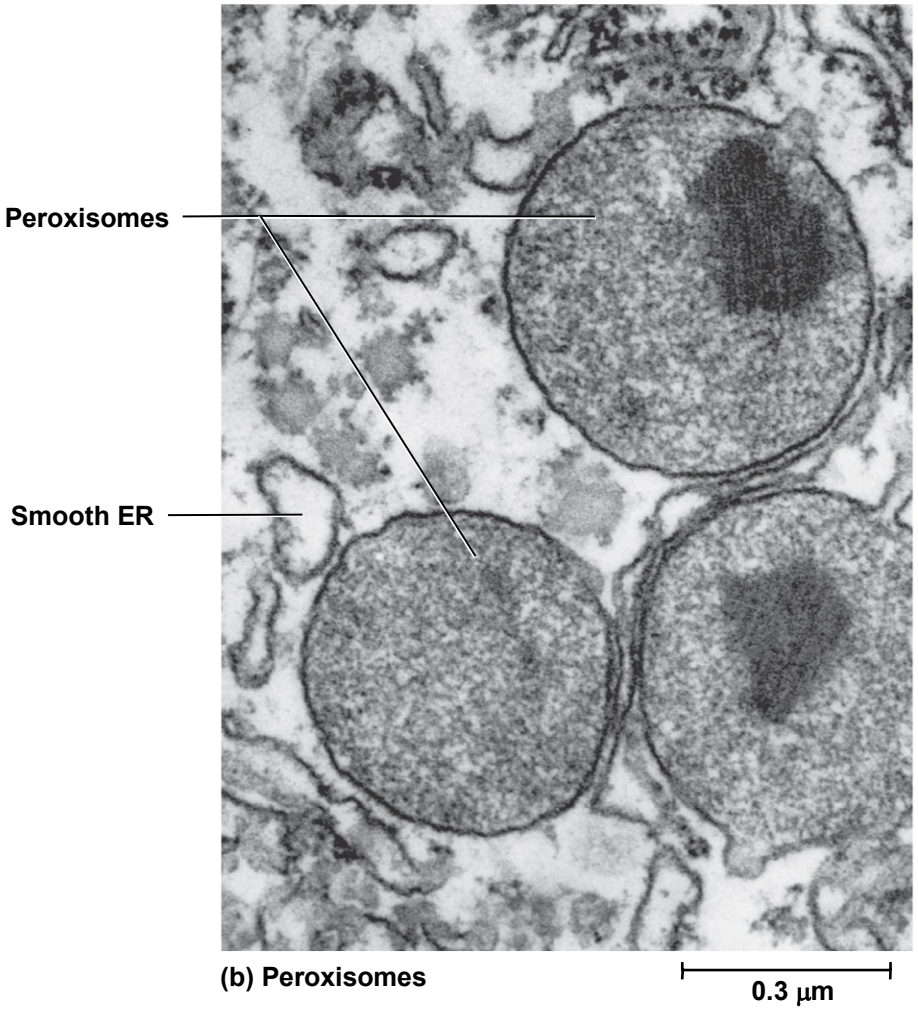
- Use molecular oxygen to oxidize organic molecules – take hydrogen off molecules (creates free radicals like hydrogen peroxide)

  - Contain catalase that breaks down excess hydrogen-peroxide to H2O
  - Also have enzyme that destroys super oxides (O2-)
  - neutralize free radicals, detoxify alcohol, other drugs, and a variety of blood-borne toxins
  - breakdown fatty acids into acetyl groups for mitochondrial use in ATP synthesis

- Present in all cells, but abundant in liver and kidney

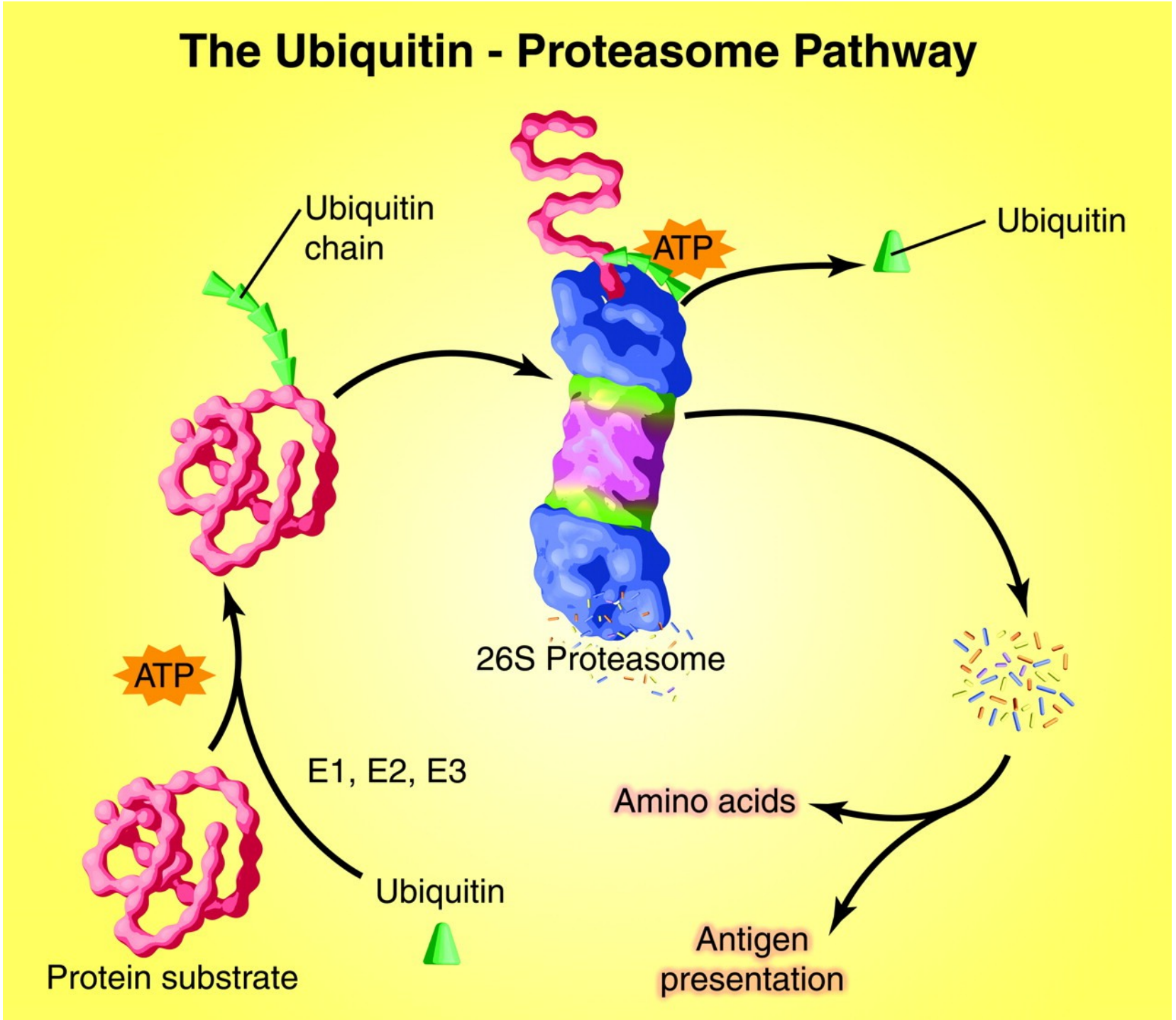
Lysosomes and Peroxisomes





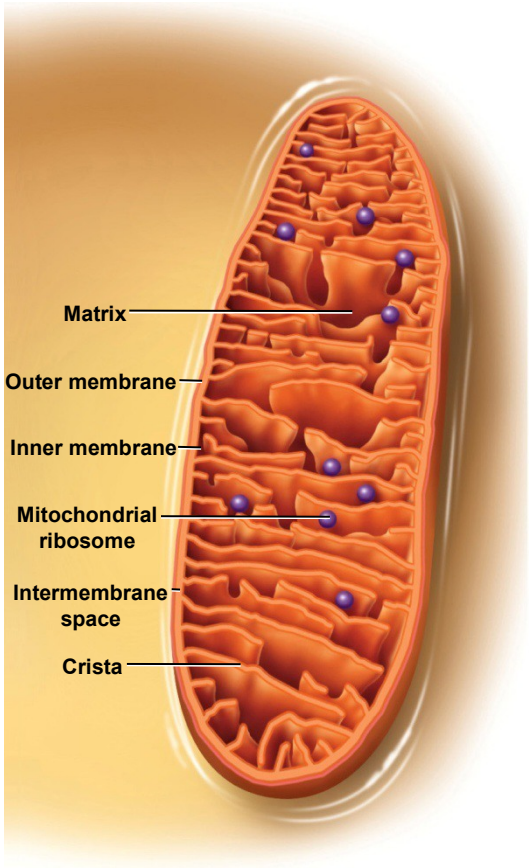
Proteasomes

- Digest old or no longer needed cytoplasmic proteins
- Turn protein into amino acids // a.a. reused to make new protein
- Proteins to be digested by proteasome must be “tagged” by ubiquitin
- Proteasomes are extremely small organelle
- Tubular structure with no unit membranes
- Proteins enter interior of the tubular proteasome and peptide bonds are broken
- Proteasomes are also found in nuleoplasm

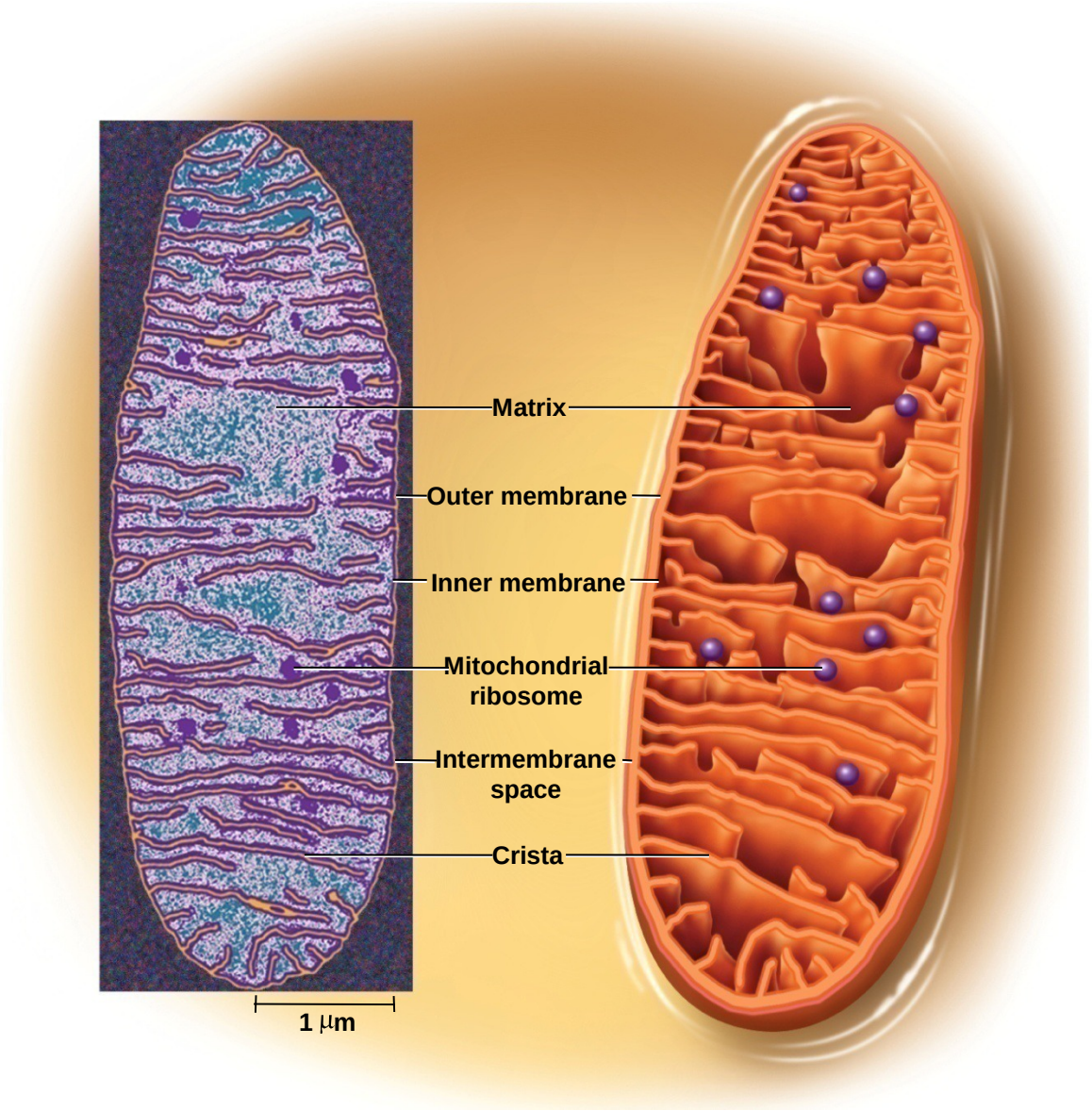

The Ubiquitin - Proteasome Pathway
Ubiquitin chain
ATP
Ubiquitin
26S Proteasome
ATP
E1, E2, E3
Amino acids
Ubiquitin
Protein substrate
Antigen presentation

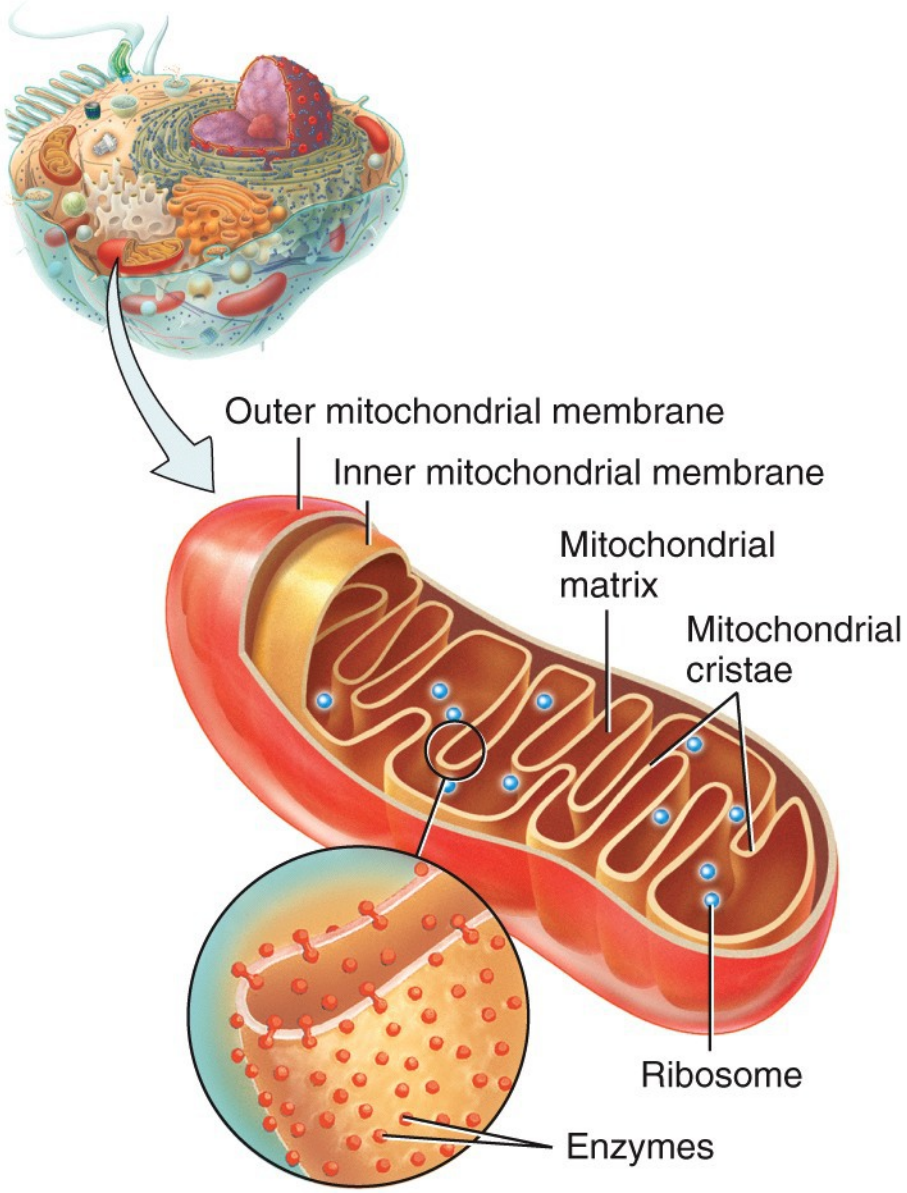
Mitochondrion

- mitochondria – organelles specialized for synthesizing ATP
- variety of shapes – spheroid, rod-shaped, kidney bean-shaped, or threadlike
- surrounded by a double unit membrane
  - inner membrane has folds called cristae
  - spaces between cristae are called matrix
    - matrix contains ribosomes, enzymes used for ATP synthesis, small circular DNA molecule – mitochondrial DNA (mtDNA)
- "Powerhouses" of the cell
  - energy is extracted from organic molecules and transferred to ATP



Mitochondrion

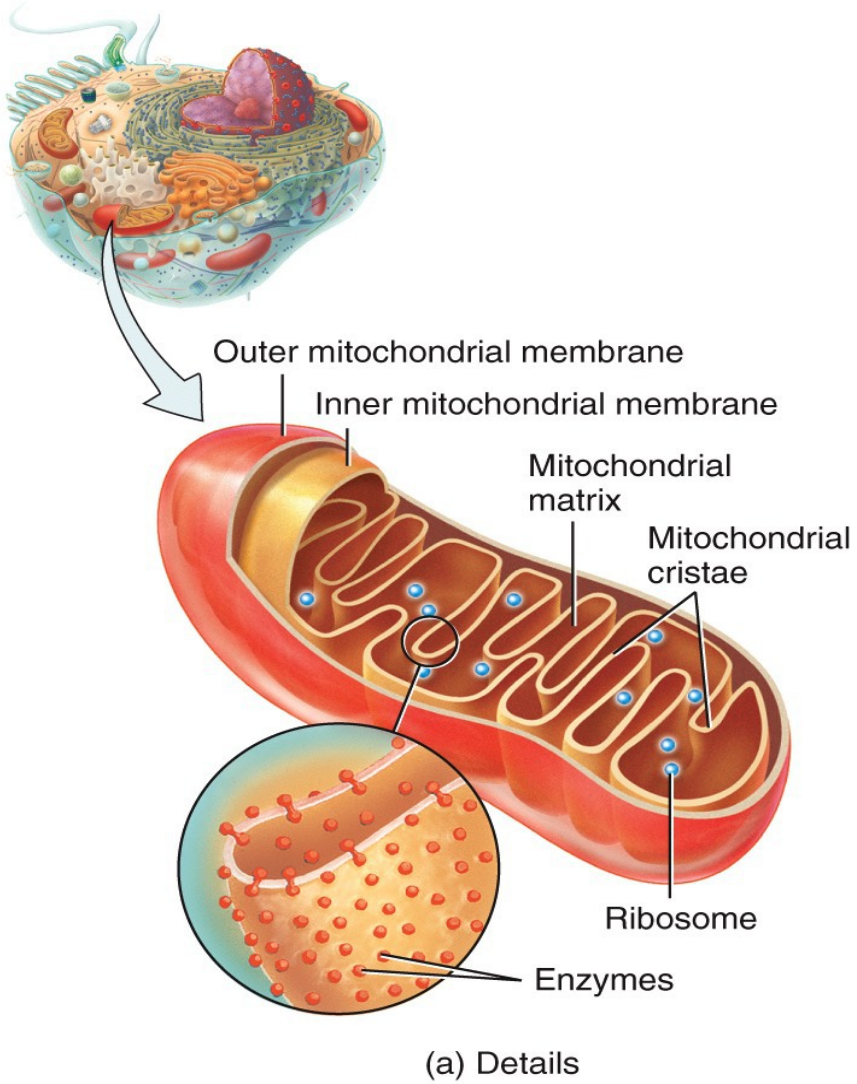



Outer mitochondrial membrane
Inner mitochondrial membrane
Mitochondrial matrix
Mitochondrial cristae
Ribosome
Enzymes

(a) Details

Mitochondria Undergo Mitosis Independent of the Cell's Genome

(What does this suggest? (Endosymbiosis!)

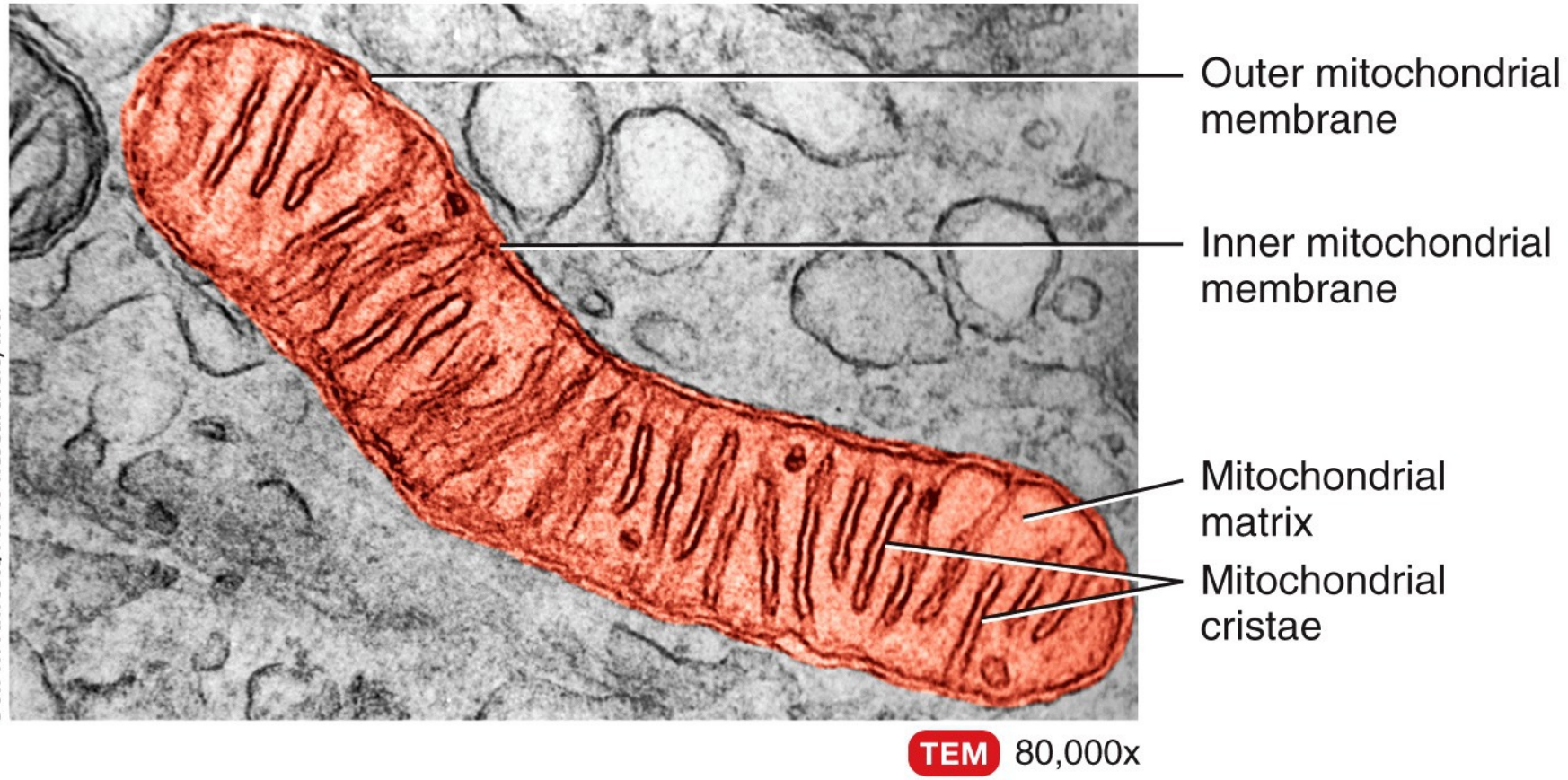


All mitochondria are "maternal" meaning they come from the egg. (sperm do not contribute any mitochondria to the zygote)

Mitochondria have their "own" genetic information.

Mitochondria's DNA is a "circular" chromosome" // prokaryote architecture.

At one time in history mitochondria lived as an independent self sustaining organism. Much like the bacteria of today.



Don W. Fawcett/Photo Researchers, Inc.

(b) Transverse section

Evolution of Mitochondrion

- It is a virtual certainty that mitochondria evolved from bacteria that invaded another primitive cell /// survived in the cytoplasm, and became permanent residents

  - its two unit membranes suggests that the original bacterium provided the inner membrane, and the host cell's phagosome provided the outer membrane
  - mitochondrial ribosomes more like bacterial ribosomes
  - has its own mtDNA // small circular molecule resembling bacterial DNA // replicates independently of nuclear DNA

Evolution of Mitochondrion

- **when a sperm fertilizes the egg, any mitochondria introduced by the sperm are usually destroyed, and only those provided by the egg are passed on to the developing embryo**
  - **mitochondrial DNA is almost exclusively inherited through the mother**
- **mutates more readily than nuclear DNA**
  - **no mechanism for DNA repair**
  - **produces rare hereditary diseases**
  - **mitochondrial myopathy , mitochondrial encephalomyopathy, and others**

TABLE 3.1 Sizes of Biological Structures in Relation to the Resolution of the Eye, Light Microscope, and Transmission Electron Microscope

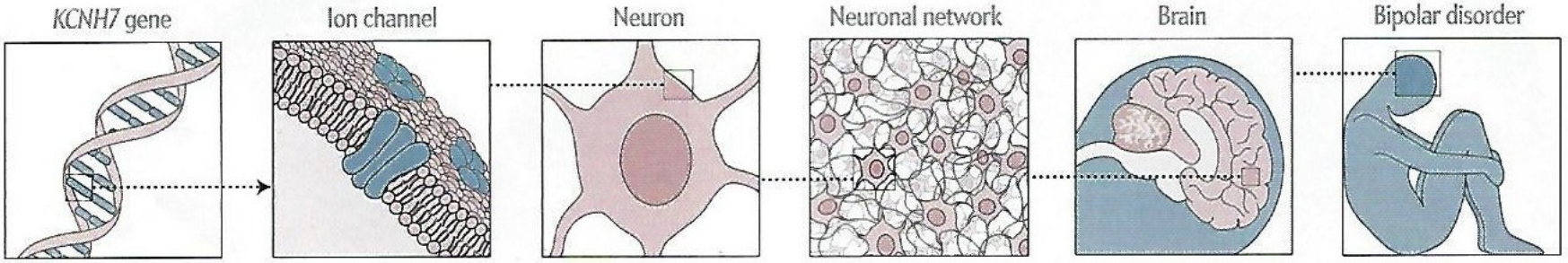
Object	Size
Visible to the Naked Eye (Resolution 70–100 μm)	
Human egg, diameter	100 μm
Visible with the Light Microscope (Resolution 200 nm)	
Most human cells, diameter	10–15 μm
Cilia, length	7–10 μm
Mitochondria, width × length	0.2 × 4 μm
Bacteria *(Escherichia coli)*, length	1–3 μm
Microvilli, length	1–2 μm
Lysosomes, diameter	0.5 μm = 500 nm
Visible with the Transmission Electron Microscope (Resolution 0.5 nm)	
Nuclear pores, diameter	30–100 nm
Centriole, diameter × length	20 × 50 nm
Polio virus, diameter	30 nm
Ribosomes, diameter	15 nm
Globular proteins, diameter	5–10 nm
Plasma membrane, thickness	7.5 nm
DNA molecule, diameter	2.0 nm
Plasma membrane channels, diameter	0.8 nm

TABLE 3.4 Summary of Organelles and Other Cellular Structures

Structure	Appearance to TEM	Function
Plasma membrane (figs. 3.3 and 3.6)	Two dark lines at cell surface, separated by a narrow light space	Prevents escape of cell contents; regulates exchange of materials between cytoplasm and extracellular fluid; involved in intercellular communication
Microvilli (fig. 3.10)	Short, densely spaced, hairlike processes or scattered bumps on cell surface; interior featureless or with bundle of microfilaments	Increase absorptive surface area; widespread sensory roles (hearing, equilibrium, taste)
Cilia (fig. 3.11)	Long hairlike projections of apical cell surface; axoneme with 9 + 2 array of microtubules	Move substances along cell surface; widespread sensory roles (hearing, equilibrium, smell, vision)
Flagellum	Long, single, whiplike process with axoneme	Sperm motility
Nucleus (figs. 3.3 and 3.25)	Largest organelle in most cells, surrounded by double unit membrane with nuclear pores	Genetic control center of cell; directs protein synthesis; shelters the DNA
Rough ER (fig. 3.26a)	Extensive sheets of parallel unit membranes with ribosomes on outer surface	Protein synthesis and manufacture of cellular membranes
Smooth ER (fig. 3.26b)	Branching network of tubules with smooth surface (no ribosomes); usually broken into numerous small segments in TEM photos	Lipid synthesis, detoxification, calcium storage
Ribosomes (fig. 3.26a)	Small dark granules free in cytosol or on surface of rough ER and nuclear envelope	Interpret the genetic code and synthesize polypeptides
Golgi complex (fig. 3.27)	Several closely spaced, parallel cisternae with thick edges, usually near nucleus, often with many Golgi vesicles nearby	Receives and modifies newly synthesized polypeptides, synthesizes carbohydrates, adds carbohydrates to glycoproteins; packages cell products into Golgi vesicles
Golgi vesicles (fig. 3.27)	Round to irregular sacs near Golgi complex, usually with light, featureless contents	Become secretory vesicles and carry cell products to apical surface for exocytosis, or become lysosomes
Lysosomes (fig. 3.28a)	Round to oval sacs with single unit membrane, often a dark featureless interior but sometimes with protein layers or crystals	Contain enzymes for intracellular digestion, autophagy, programmed cell death, and glucose mobilization
Peroxisomes (fig. 3.28b)	Similar to lysosomes; often lighter in color	Contain enzymes for detoxification of free radicals, alcohol, and other drugs; oxidize fatty acids
Mitochondria (fig. 3.29)	Round, rod-shaped, bean-shaped, or threadlike structures with double unit membrane and shelflike infoldings called cristae	ATP synthesis
Centrioles (fig. 3.30)	Short cylindrical bodies, each composed of a circle of nine triplets of microtubules	Form mitotic spindle during cell division; unpaired centrioles form basal bodies of cilia and flagella
Centrosome (fig. 3.5)	Clear area near nucleus containing a pair of centrioles	Organizing center for formation of microtubules of cytoskeleton and mitotic spindle
Basal body (fig. 3.11b)	Unpaired centriole at the base of a cilium or flagellum	Point of origin, growth, and anchorage of a cilium or flagellum; produces axoneme
Microfilaments (figs. 3.10 and 3.31)	Thin protein filaments (6 nm diameter), often in parallel bundles or dense networks in cytoplasm	Support microvilli and plasma membrane; involved in muscle contraction and other cell motility, endocytosis, and cell division
Intermediate filaments (fig. 3.31a)	Thicker protein filaments (8–10 nm diameter) extending throughout cytoplasm or concentrated at cell-to-cell junctions	Give shape and physical support to cell; anchor cells to each other and to extracellular material; compartmentalize cell contents
Microtubules (figs. 3.31 and 3.32)	Hollow protein cylinders (25 nm diameter) radiating from centrosome	Form axonemes of cilia and flagella, centrioles, basal bodies, and mitotic spindles; enable motility of cell parts; form trackways that direct organelles and macromolecules to their destinations within a cell
Inclusions (fig. 3.26b)	Highly variable—fat droplets, glycogen granules, protein crystals, dust, bacteria, viruses; never enclosed in unit membranes	Storage products or other products of cellular metabolism, or foreign matter retained in cytoplasm

How Genetic Mutations Lead to Disease

Gene mutations can disrupt biology at multiple levels (molecules, cells, tissues and organs) to cause disease. Certain mutations are particularly prevalent in Amish and Mennonite populations. For each patient the clinic sees, it applies advanced technologies to identify the individual's genetic variants, understand their causal links to disease, and devise ways to alleviate or prevent the mutations' harmful effects. In related work, the clinic and its collaborators recently identified a gene mutation linked to bipolar disorder among the Amish, and they are now constructing a picture of how it might impair emotional regulation (*below*). This knowledge could lead to a deeper understanding of bipolar disorder in the general population and to new strategies for prevention and treatment.



Gene

A gene consists of a sequence of DNA "letters" that spell out the amino acids needed to make a protein. Proteins are the main workhorses of cells. A mutation in a gene can alter the functioning of the encoded protein. The bipolar study pinpointed a mutation in a gene called *KCNH7*.

Protein

To function properly, proteins must have the right structure, location and abundance in each cell. *KCNH7* encodes a protein that spans the cell membrane, forming a channel that regulates the flow of potassium ions. The mutant is altered at just a single amino acid, but this subtle change affects potassium movement across the membrane.

Cell

All cells contain the same genes, but many genes are expressed (that is, give rise to proteins) only in select cell types. The ion channel encoded by *KCNH7* is used by neurons throughout the brain. Potassium currents critically shape each neuron's electrical behavior, and the mutant alters the cells' firing patterns.

Tissue

Tissues can contain a mixture of cell types. Brain tissue, for instance, includes neurons and supporting cells called glia. The mutant *KCNH7* gene would be expected to disrupt the operation, not only of individual nerve cells, but of whole neuronal circuits, such as those regulating emotions and behavior.

Organ

Nerve cells throughout the brain make the ion channel encoded by the *KCNH7* gene, but the channel is most abundant in brain regions underlying emotions and cognition. Consistent with that finding, mutation of the gene has been tied to mania observed in laboratory animals.

Behavior

Bipolar disorder is marked by a spectrum of behaviors that can include depression, mania and psychosis. New insight into how the *KCNH7* mutation affects each level of biology—from misspelled protein to perturbed brain function—could lead to fresh ideas for interrupting the chain of events underlying the disorder.