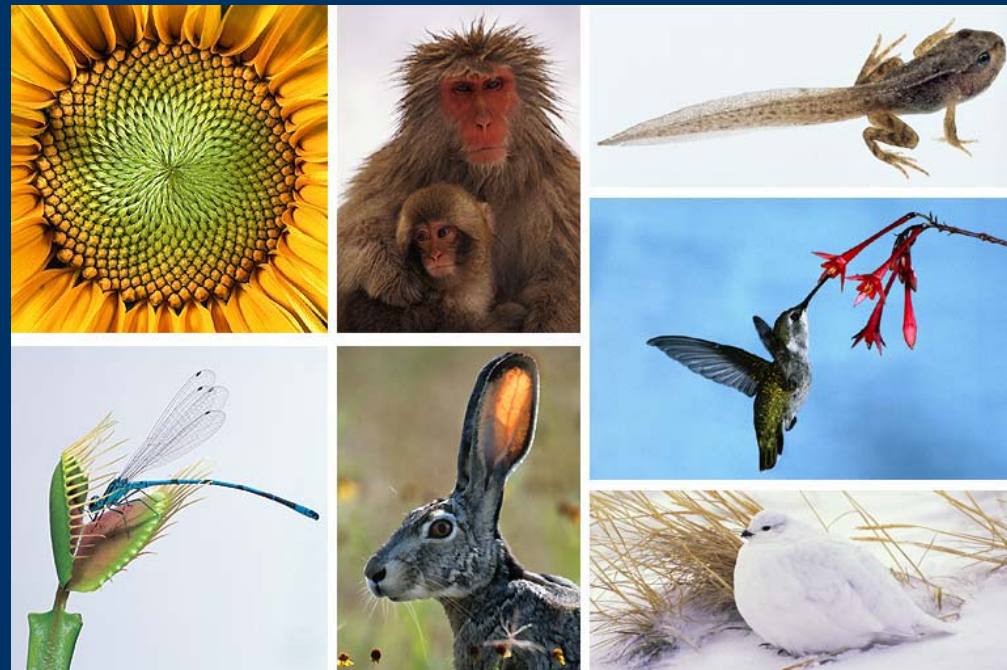


The Cell Structure and Function

The cell is the lowest level of structure capable of performing **all** the activities of life.

The first cells were observed and named by Robert Hooke in 1665 from slice of cork.



The Cell Thoery

Proposed by Matthais Schleiden and Theodor Schwann in 1839:

- All living things are made up of cells.
- Cells are the smallest working unit of all living things.
- All cells come from preexisting cells through cells division.

Some organisms consist of a single cells = **unicellular** organism, others are **multicellular** aggregates of specialized cells.



Bacteria



Archaea



Protista



Plantae



Fungi



Animalia

Whether multicellular or unicellular, **all organisms must accomplish the same functions:**

uptake and processing of nutrients

excretion of wastes

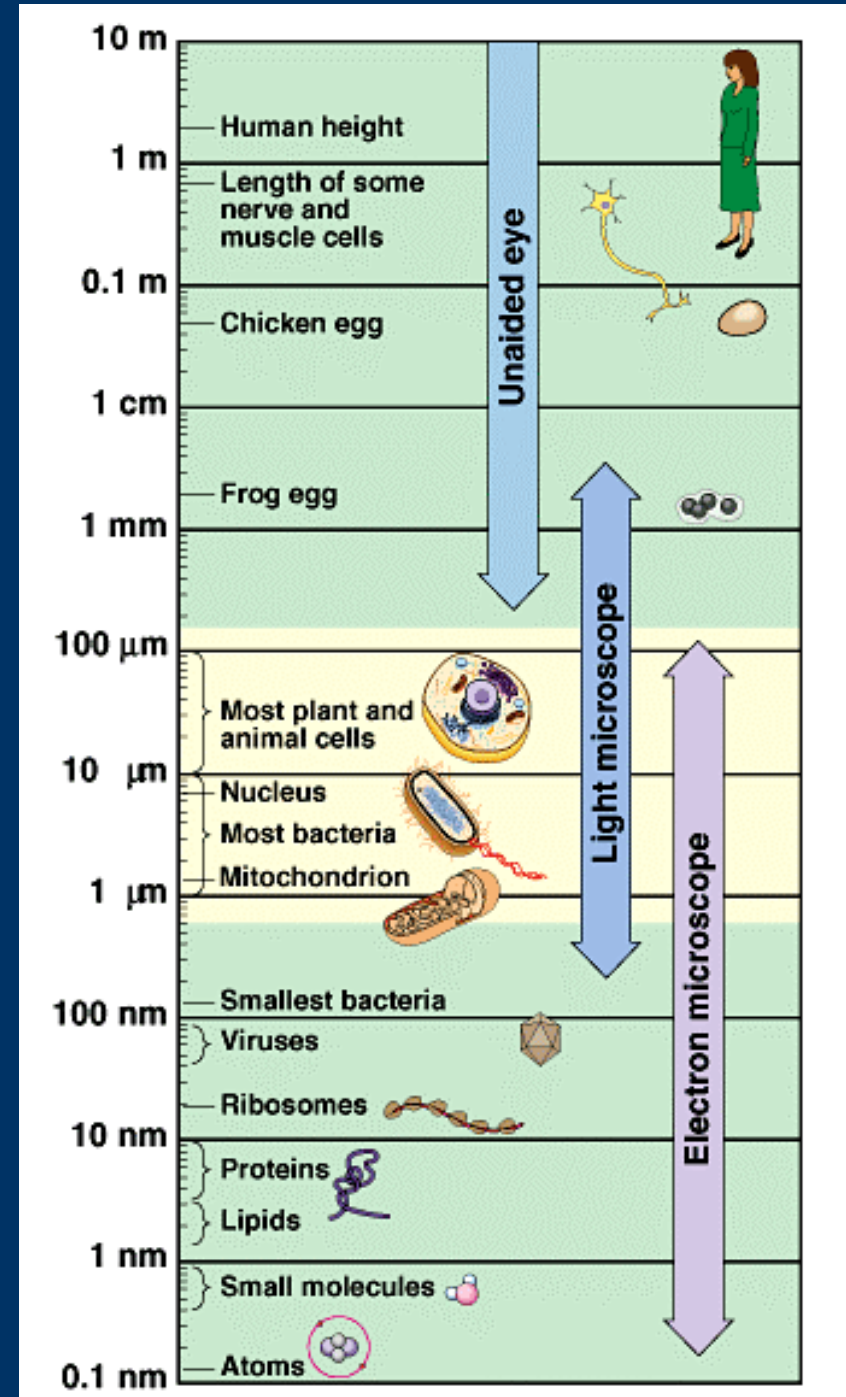
response to environmental stimuli

and reproduction among others.

How We Study Cells?

- microscope
- cell fractionation

Most cells are between 1-100 μm in diameter which can be visualized by light microscope.



Light microscope (LM)

In the LM, visible light is passed through the specimen and then through glass lenses.

The lenses refract light such that the image is magnified into the eyes or the video screen.

magnification and resolving power

Magnification = the ratio of an object's image to its real size.

Magnification of LM \sim X1,000

Resolving power = the measure of the image clarity.

It is the minimum distance two points can be separated and still viewed as two separate points.

Resolution is limited by the shortest wavelength of the light \sim one half of the wavelength used.

The minimum resolution of a light microscope is about 2 microns, the size of a small bacterium.

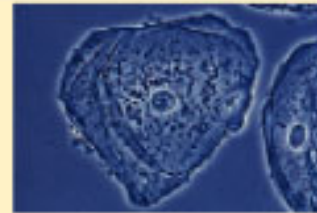
Table 7.1 Different Types of Light Microscopy: A Comparison

Type of Microscopy

Light Micrographs of Human Cheek Epithelial Cells

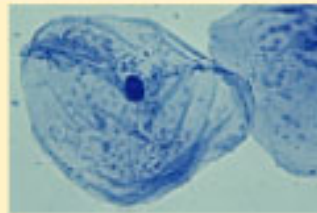
Type of Microscopy

Brightfield (unstained specimen). Passes light directly through specimen; unless cell is naturally pigmented or artificially stained, image has little contrast.



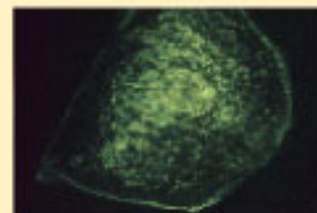
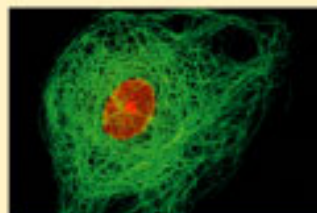
Phase-contrast. Enhances contrast in unstained cells by amplifying variations in density within specimen; especially useful for examining living, unpigmented cells.

Brightfield (stained specimen). Staining with various dyes enhances contrast, but most staining procedures require that cells be fixed (preserved).



Differential-interference-contrast (Nomarski). Like phase-contrast microscopy, it uses optical modifications to exaggerate differences in density.

Fluorescence. Shows the locations of specific molecules in the cell. Fluorescent substances absorb short-wavelength, ultraviolet radiation and emit longer-wavelength, visible light. The fluorescing molecules may occur naturally in the specimen but more often are made by tagging the molecules of interest with fluorescent molecules.



Confocal. Uses lasers and special optics for “optical sectioning.” Only those regions within a narrow depth of focus are imaged. Regions above and below the selected plane of view appear black rather than blurry. This microscope is typically used with fluorescently stained specimens, as in the example here.

Electron microscope (EM)

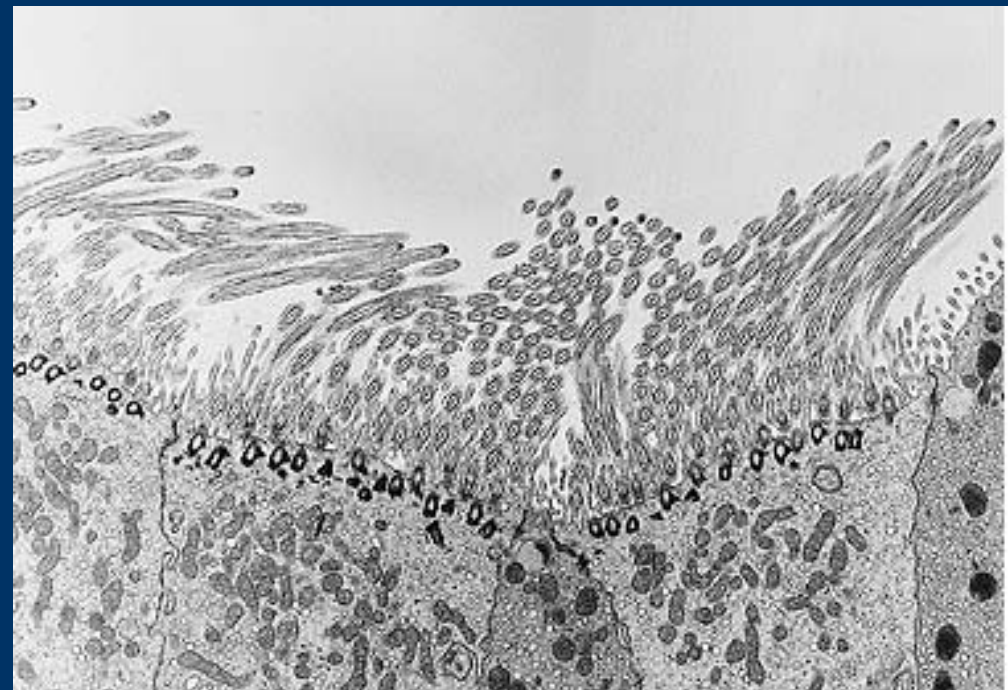
- focuses a **beam of electrons** through the specimen or onto its surface

- theoretically, the resolution of a modern EM could reach 0.1 nanometer (nm), but the practical limit is closer to about 2 nm

- Transmission and Scanning electron microscope

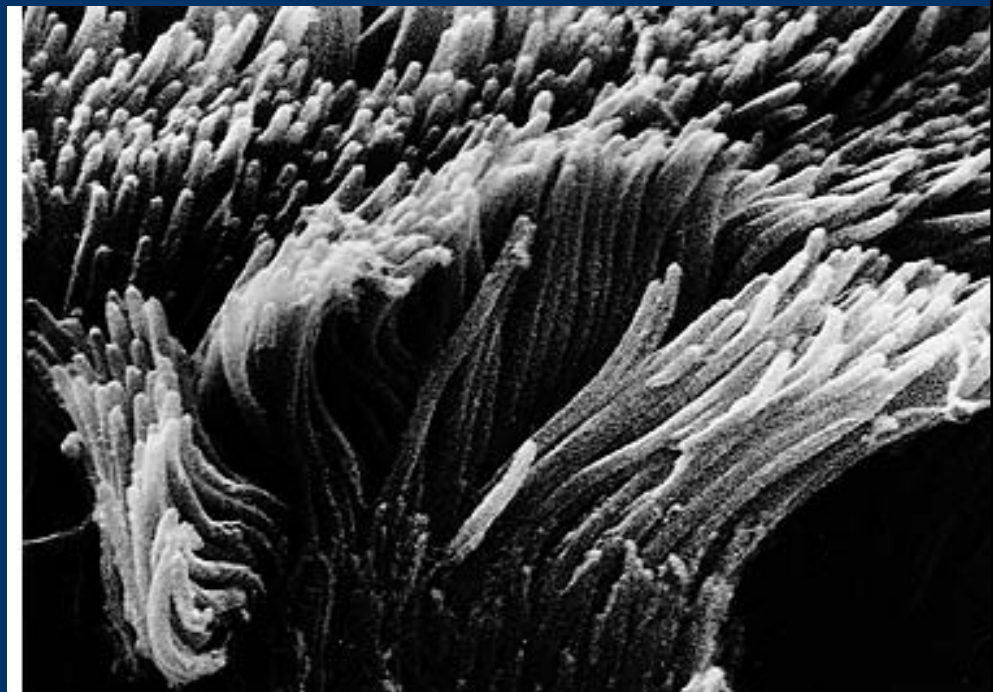
Transmission electron microscope (TEM)

- study **internal ultrastructure** of cells
- electron beam was aimed through the thin section of specimen
- the image was focused and magnified by electromagnet (instead of glass lenses)
- to enhance the image, the thin section of preserved cells are stained with atoms of heavy metals
- the micrograph is **2 dimensional**



Scanning electron microscope (SEM)

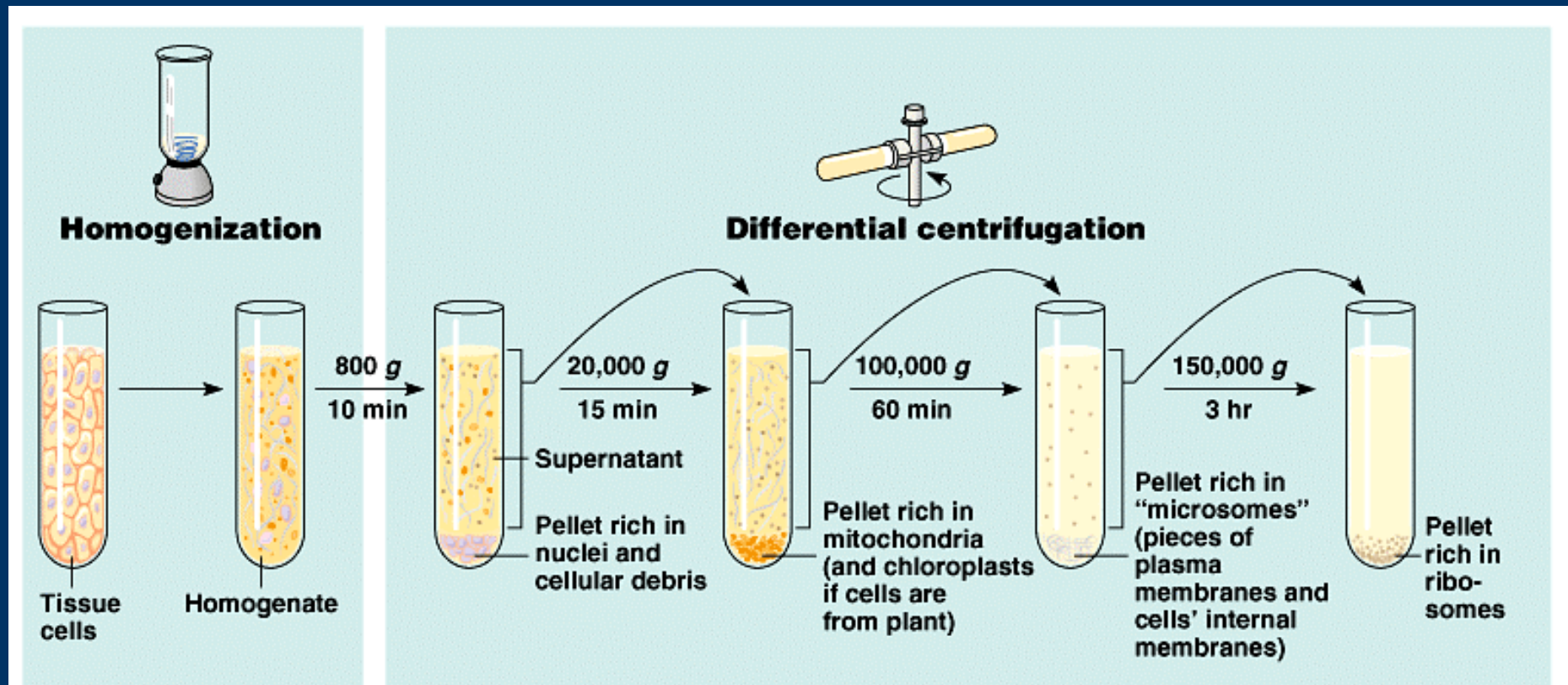
- study the **surface structure of the cells**
- the sample surface is covered with the thin film of gold
- the electron beam excites the electrons on the sample surface
- the secondary electrons are collected and focused on a screen
- the image appeared **3-dimensional**



Cell Fractionation

-to separate the organelles of cells for functional study

-the disrupted cells are centrifuged at different speed and duration to fractionate components of different sizes



Cell fractionation prepares quantities of specific cell components/organelles for functional analysis = biochemical studies.

Microscopes are a major tool in cytology = the study of cell structures.

Cytology coupled with biochemistry, the study of molecules and chemical processes in metabolism, developed modern cell biology.

A Panoramic View of the Cell

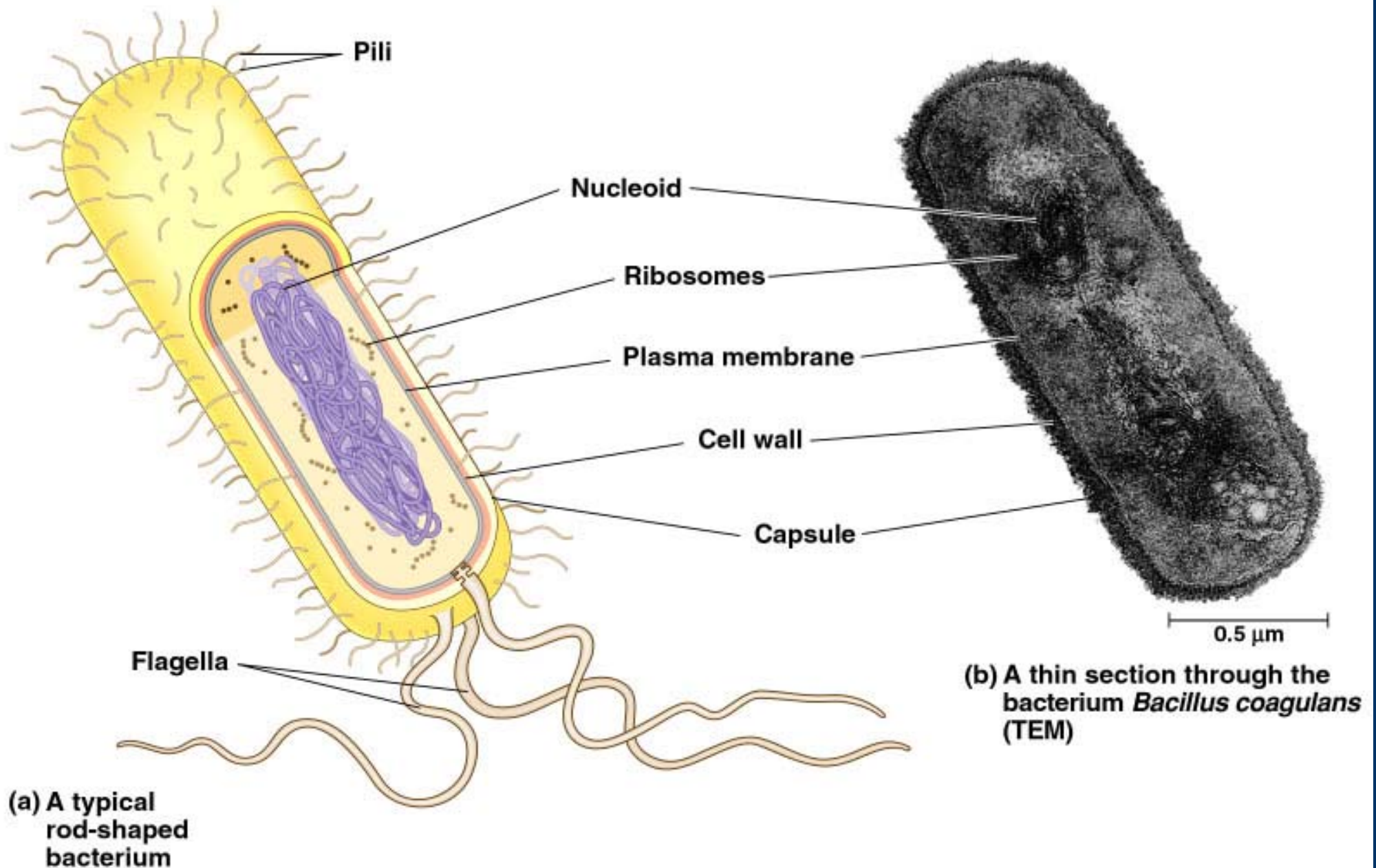
Basic features of cells:

- All cells are bounded by a **plasma membrane**.
- The semifluid substance within the membrane is the **cytosol**, containing the organelles.
- All cells contain chromosomes which carry genes in the form of DNA.
- All cells also have **ribosomes**, tiny organelles that make proteins using the instructions contained in genes.

-A major difference between prokaryotic and eukaryotic cells is the location of chromosomes.

-eukaryotic cell, chromosomes are contained in a membrane-enclosed organelle, the **nucleus**.

-prokaryotic cell, the DNA is concentrated in the **nucleoid** without a membrane separating it from the rest of the cell.



Bacteria: a prokaryotic cell

Problems with Cell Size

In general, eukaryotic cells are much bigger than prokaryotic cells:

Most bacteria are 1-10 microns in diameter.

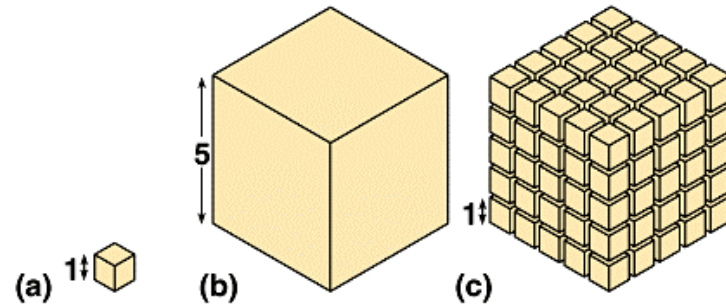
Eukaryotic cells are typically 10-100 microns in diameter.

-A large cell requires "much more" in terms of the cellular components.

-Uptake from the environment is also a problem for large cells: there is less surface area compared to the volume.

-Distribution of nutrients from one portion of a large cell to another is also a problem, simply because of the distance required for the nutrients to travel.

Surface area increases while total volume remains constant



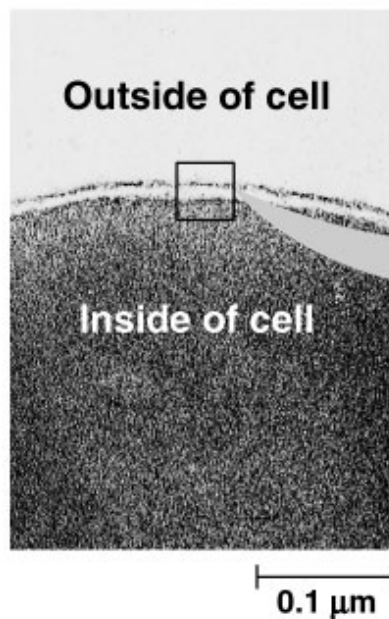
Total surface area (height × width × number of sides × number of boxes)	6	150	750
Total volume (height × width × length × number of boxes)	1	125	125
Surface-to-volume ratio (area ÷ volume)	6	1.2	6

Thus most cells are small: sufficient surface area to accommodate the volume.

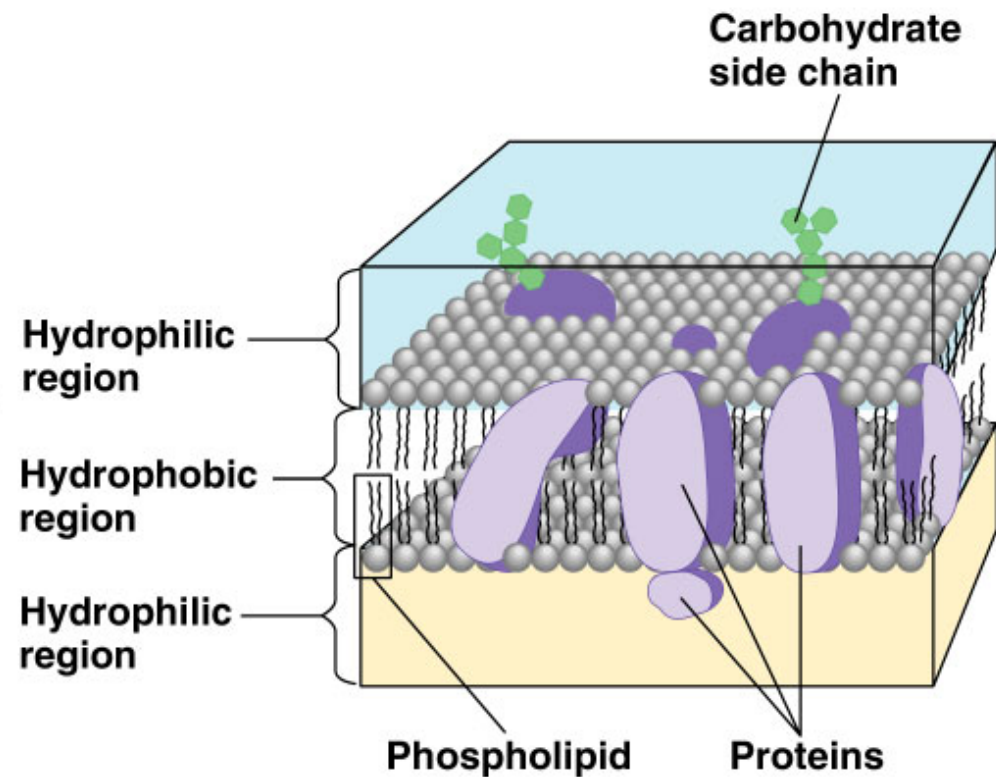
Larger organisms **do not** generally have larger cells than smaller organisms, - just simply **more** cells.

The Plasma Membrane

- double layer of phospholipids
- various proteins are attached to it
- carbohydrate side chains are found only on the outer surface of plasma membrane



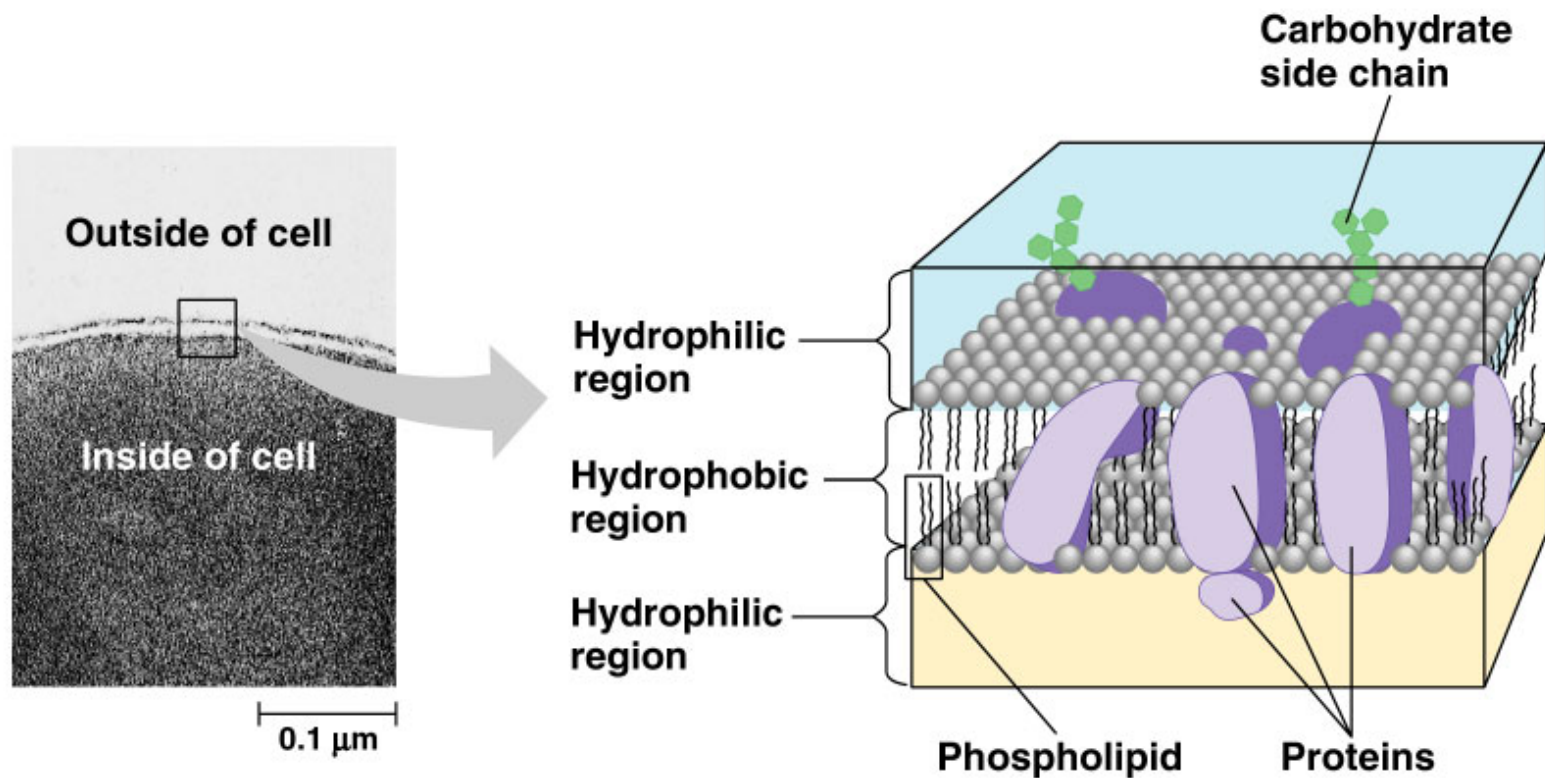
(a) TEM of a red blood cell



(b) Structure of the plasma membrane

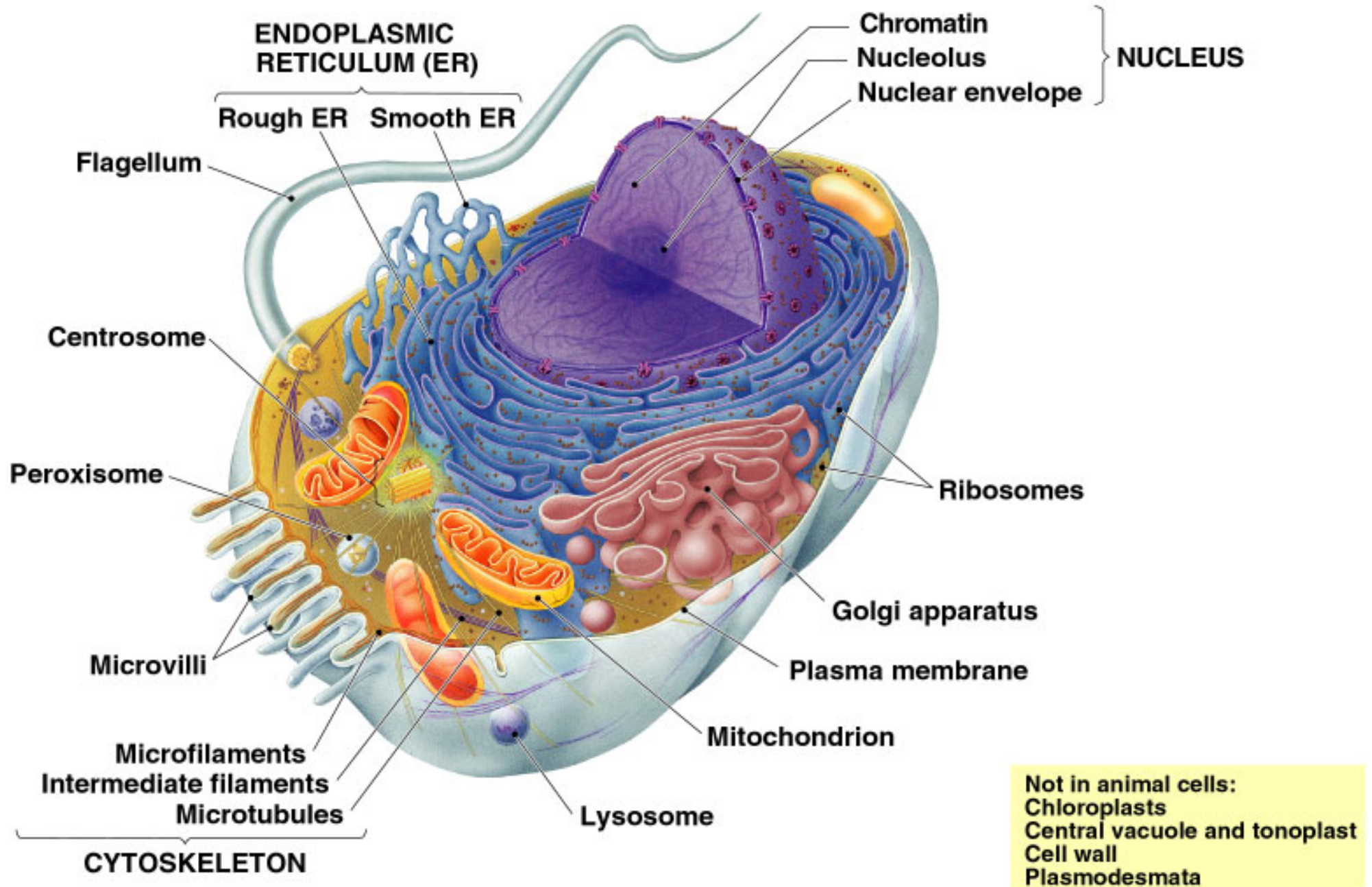
The Plasma Membrane

- function of plasma membrane = selective barrier that allows passage of oxygen, nutrients, and wastes for the whole volume of the cell.

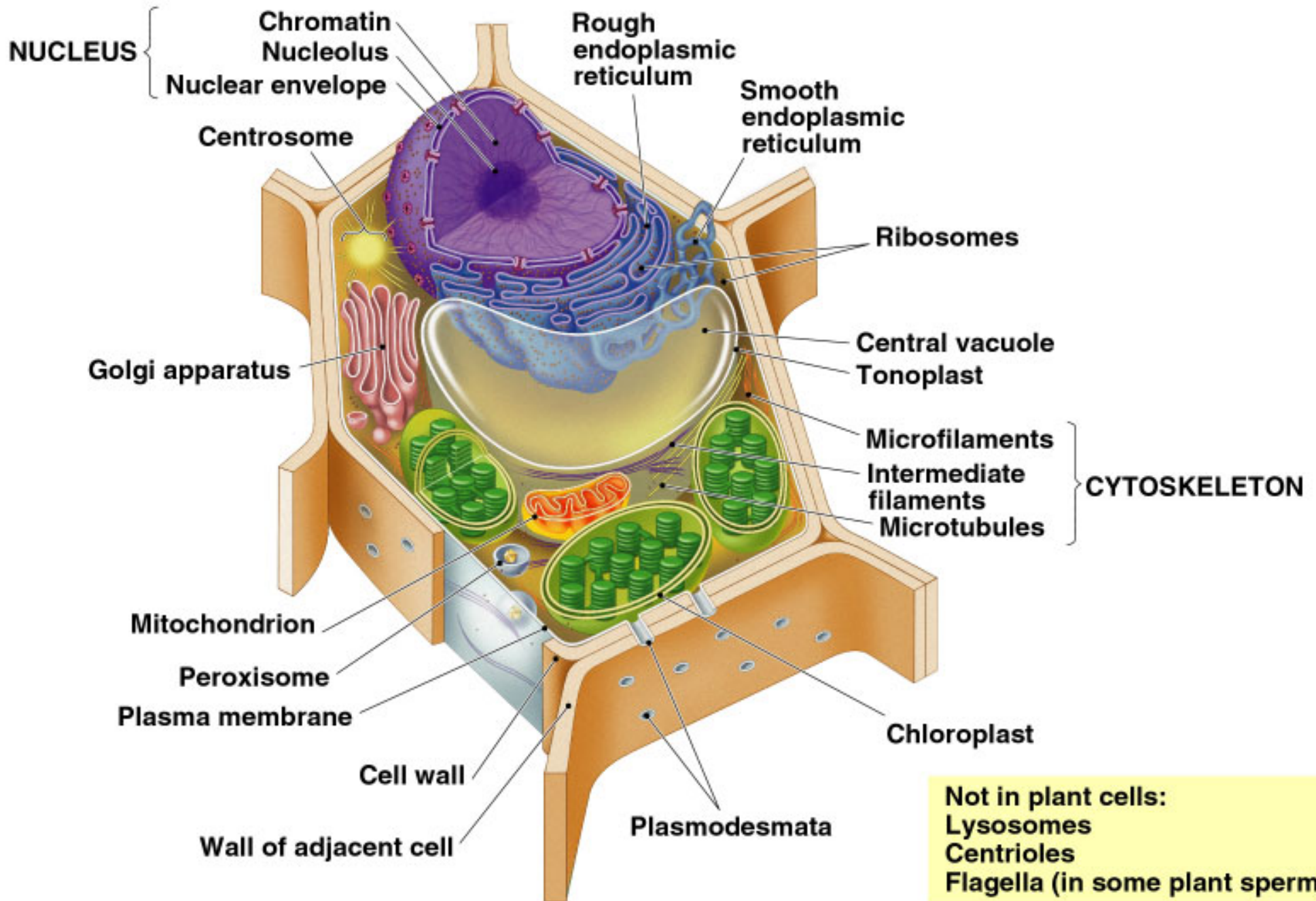


(a) TEM of a red blood cell

(b) Structure of the plasma membrane



Overview of Animal Cell



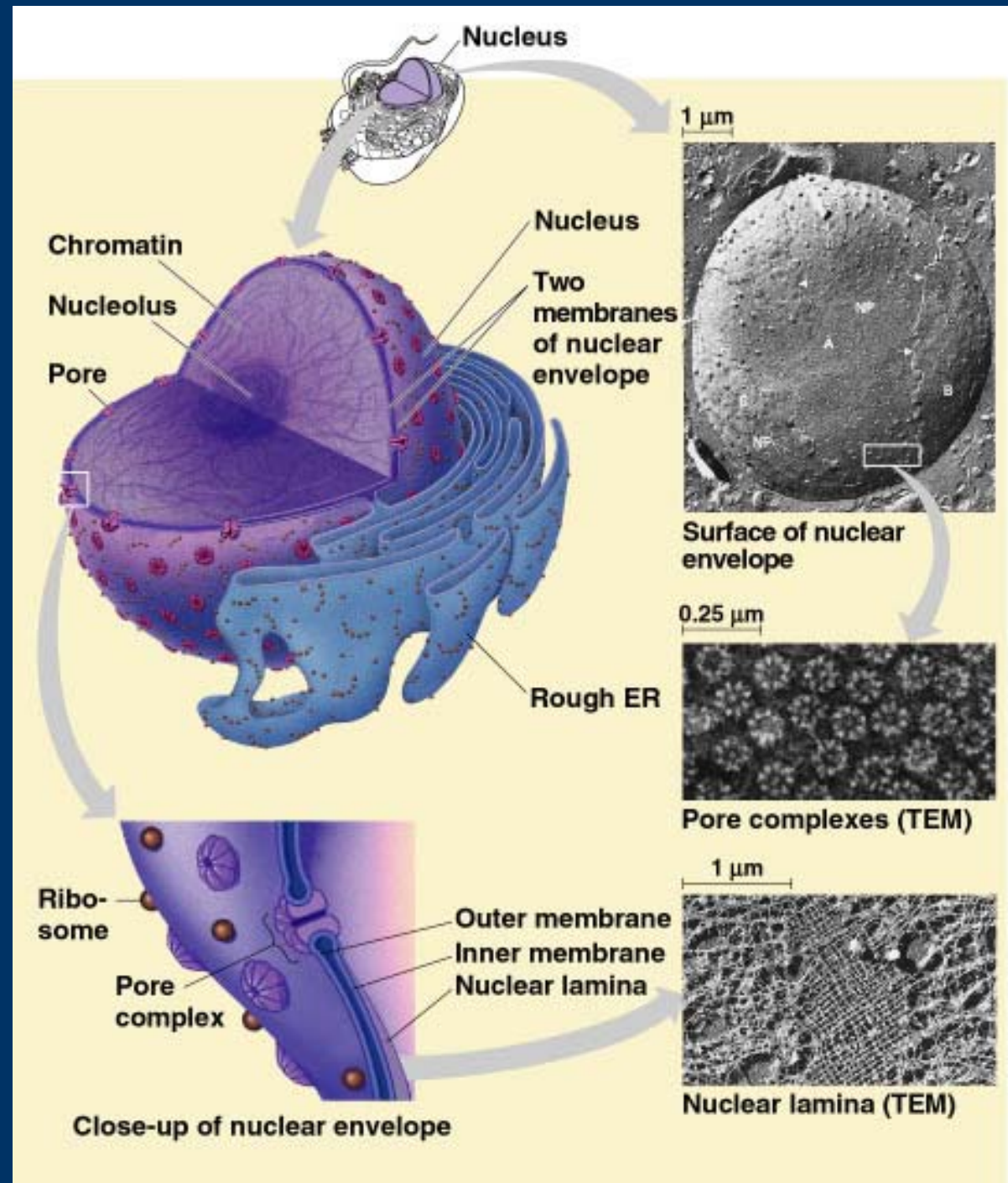
Overview of Plant Cell

The Nucleus and Its Envelope

-The nucleus contains most of the genes in a eukaryotic cell.

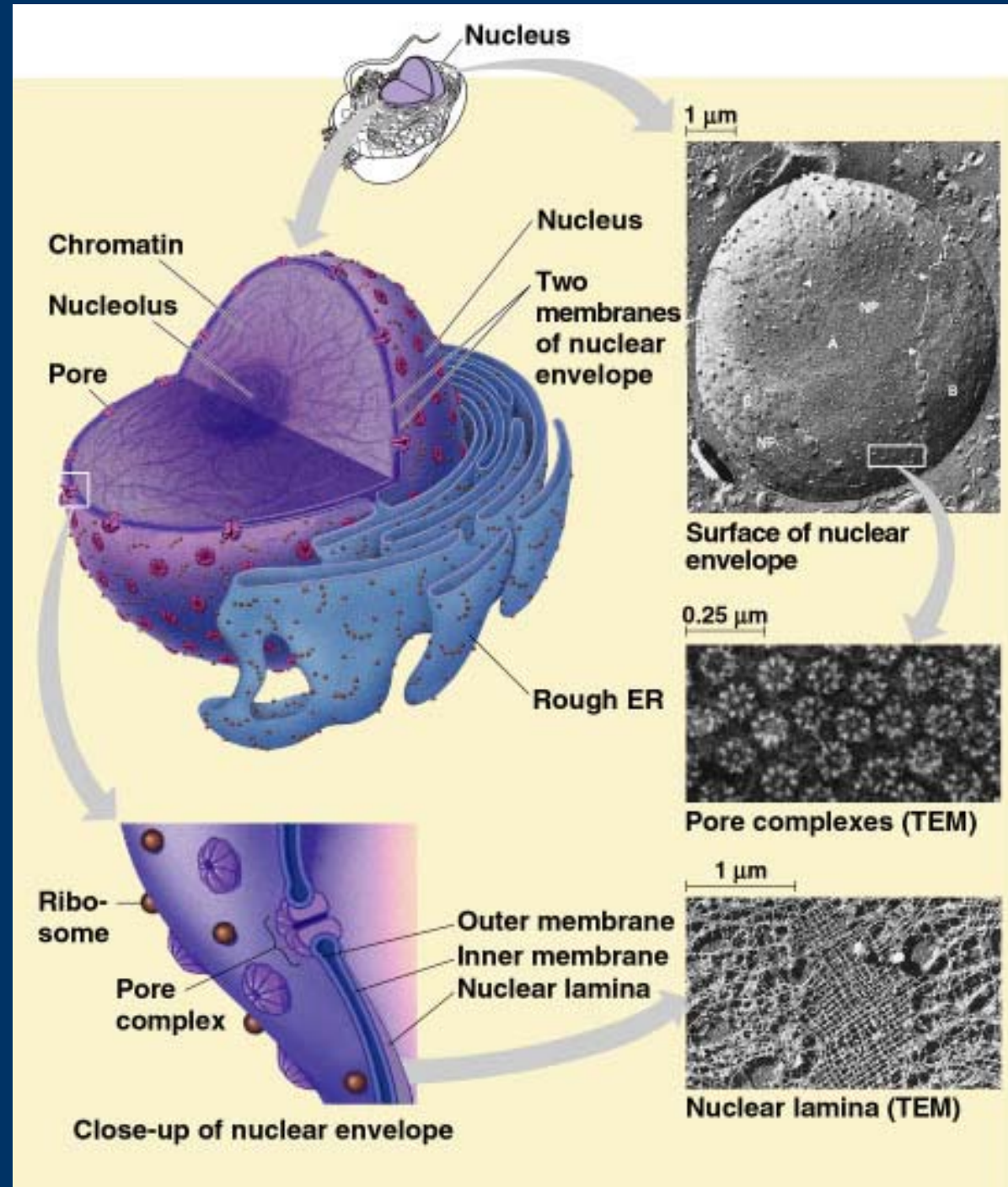
Some genes are located in mitochondria and chloroplast

-The nucleus averages about 5 microns in diameter.

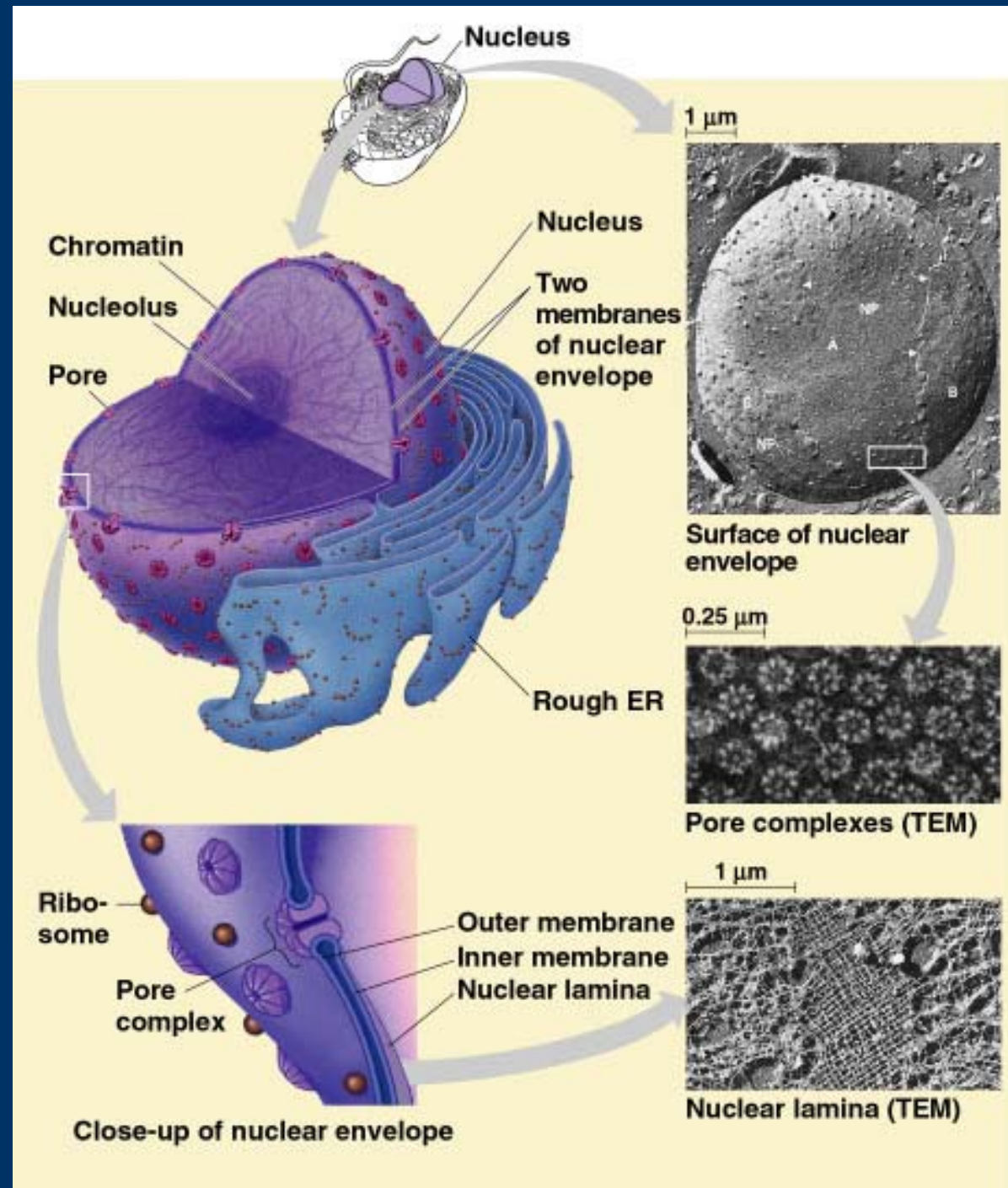


-The nucleus is enclosed by a **nuclear envelope** which is a double membrane of 20 -40 nm apart.

-Where the double membranes are fused, a **nuclear pore complex** allows large macromolecules and particles to pass through.



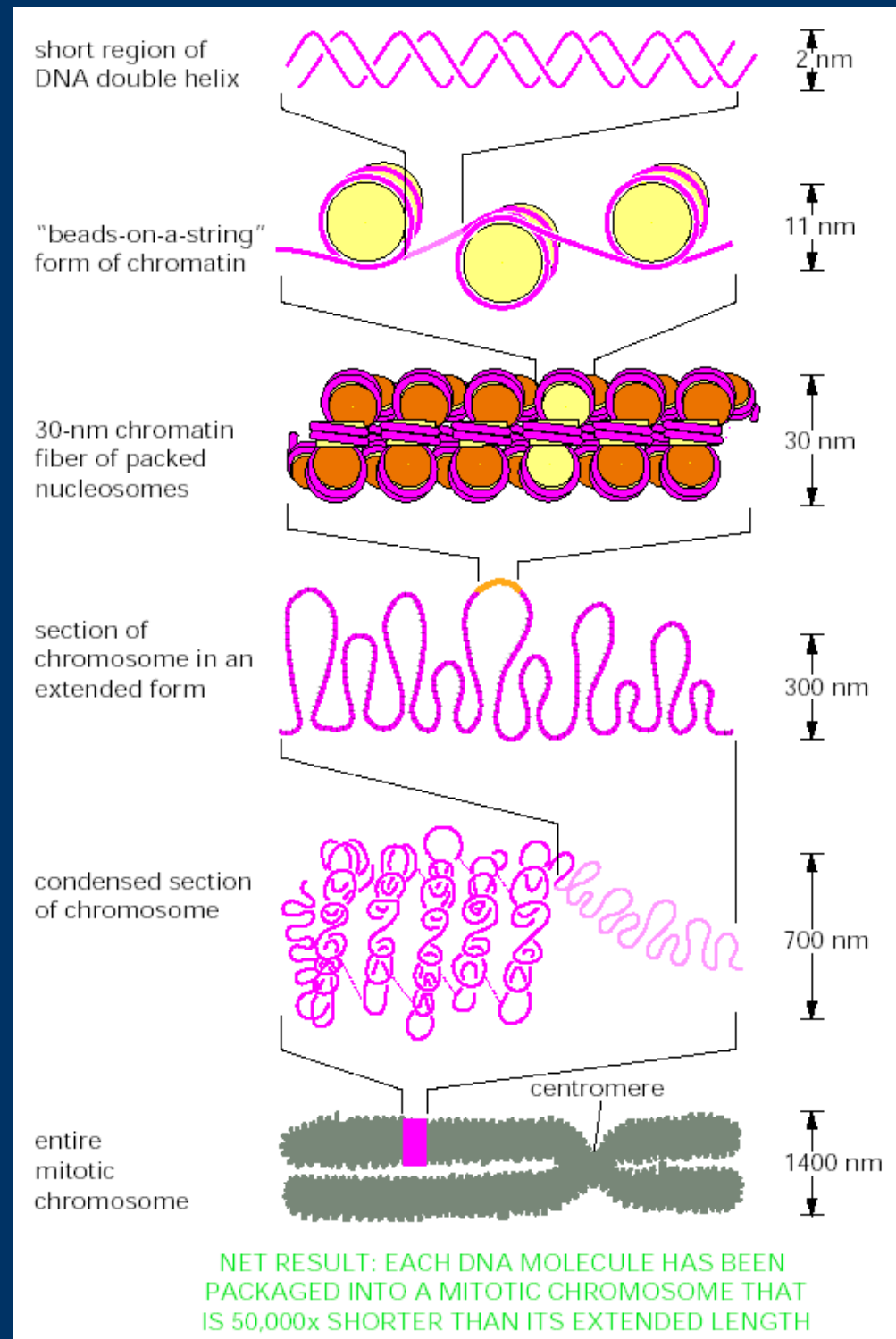
-The nuclear side of the envelope is lined by the **nuclear lamina**, a network of intermediate filaments that maintain the shape of the nucleus.



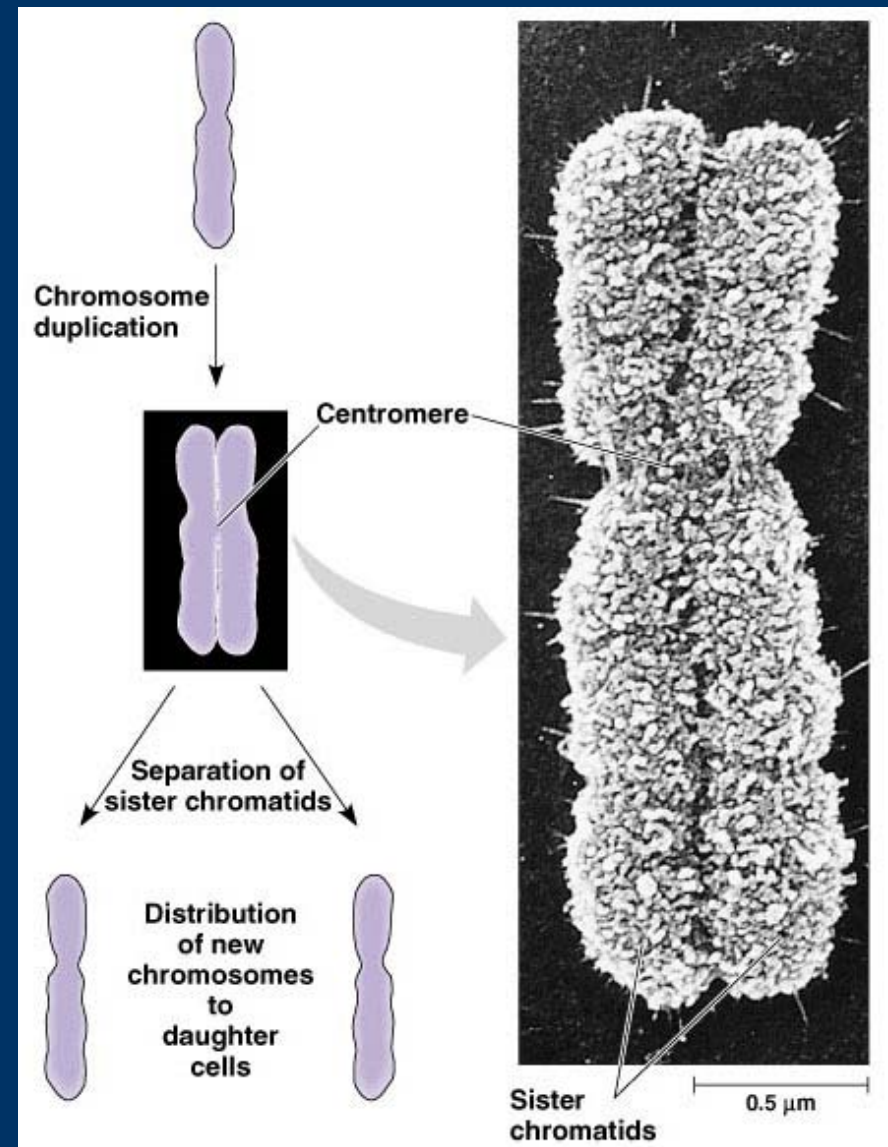
Level of Chromatin Packing

In the nucleus, the DNA and the associated proteins are organised into fibrous material called **chromatin**.

In a normal cell they appear as diffuse mass.



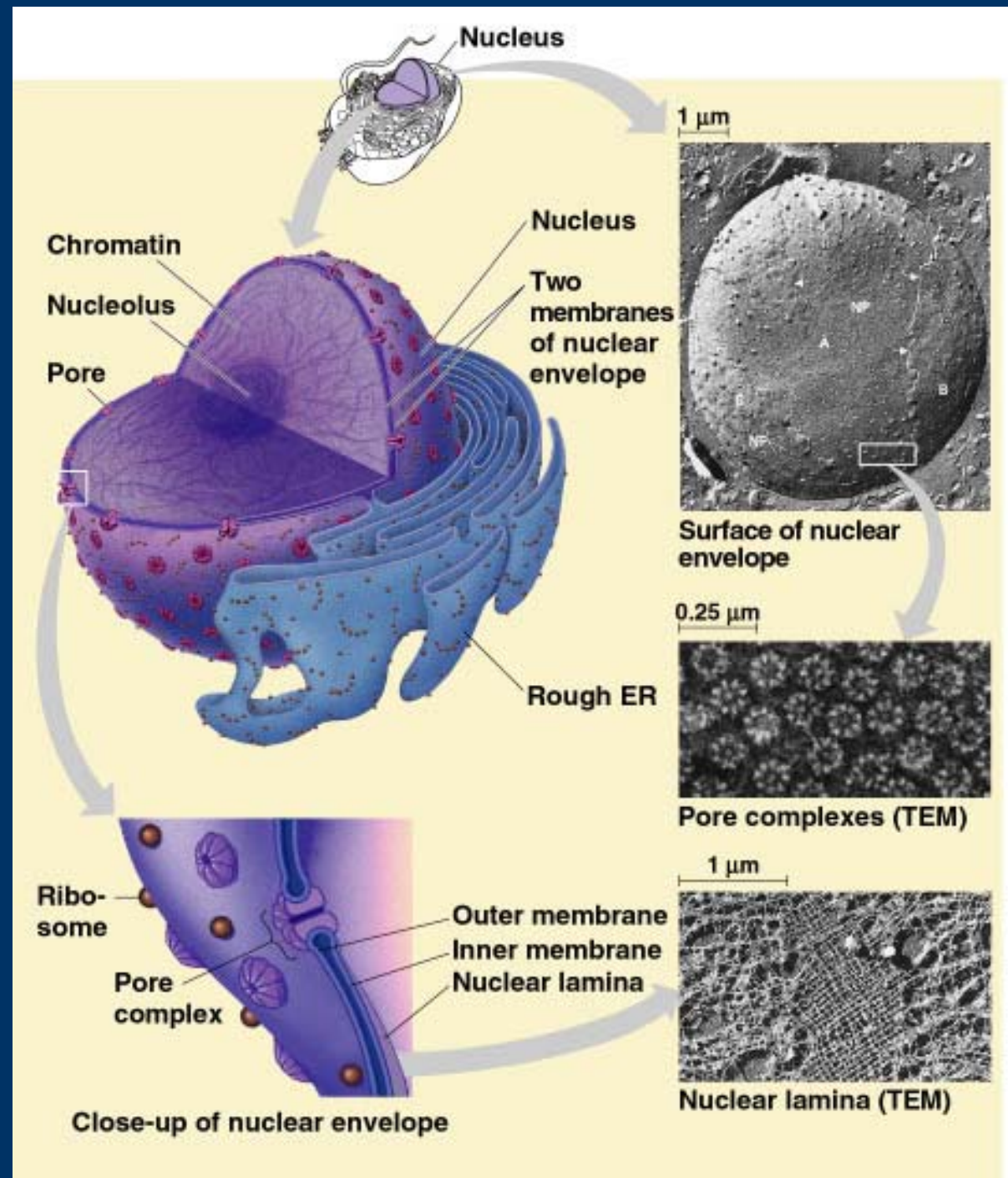
However, when the cell prepares to divide, the chromatin fibers coil up to be seen as separate structures, **chromosomes**.



Nucleolus = a region (in the nucleus) of densely stained fibers and granules adjoining chromatin.

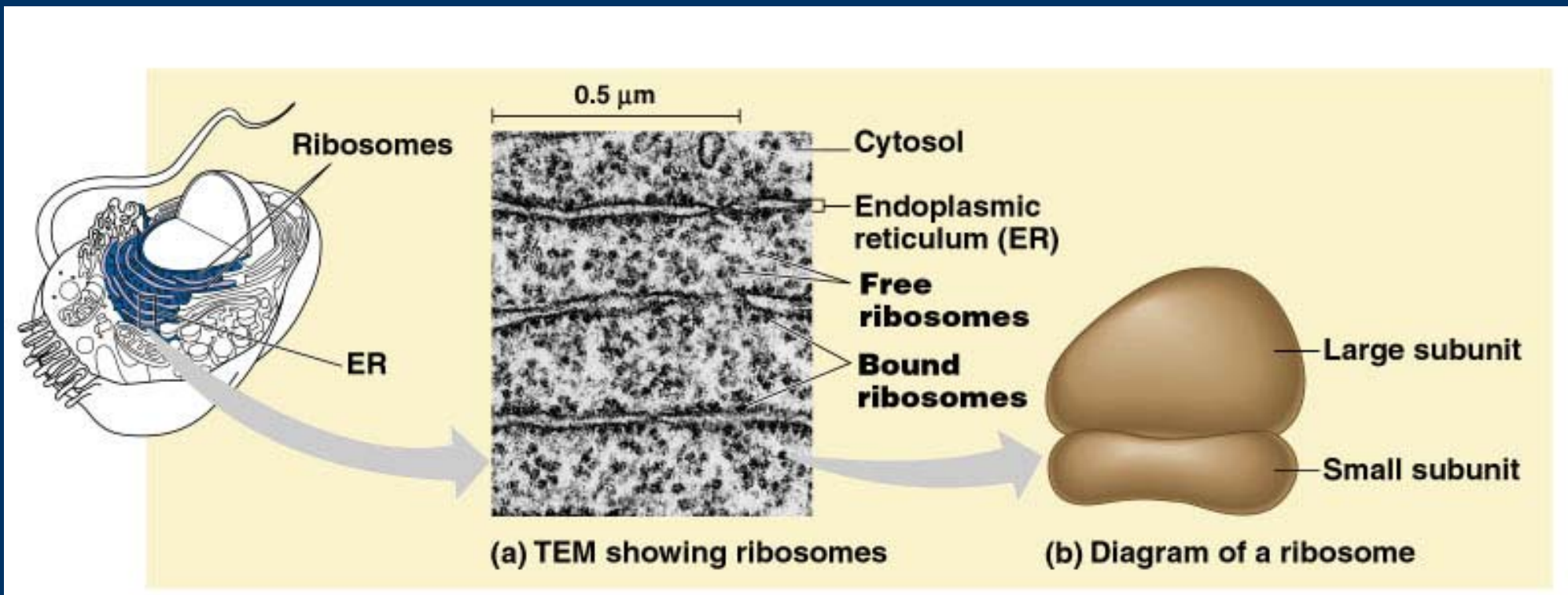
In the nucleolus, rRNA is synthesized and assembled with proteins from the cytoplasm to form ribosomal subunits.

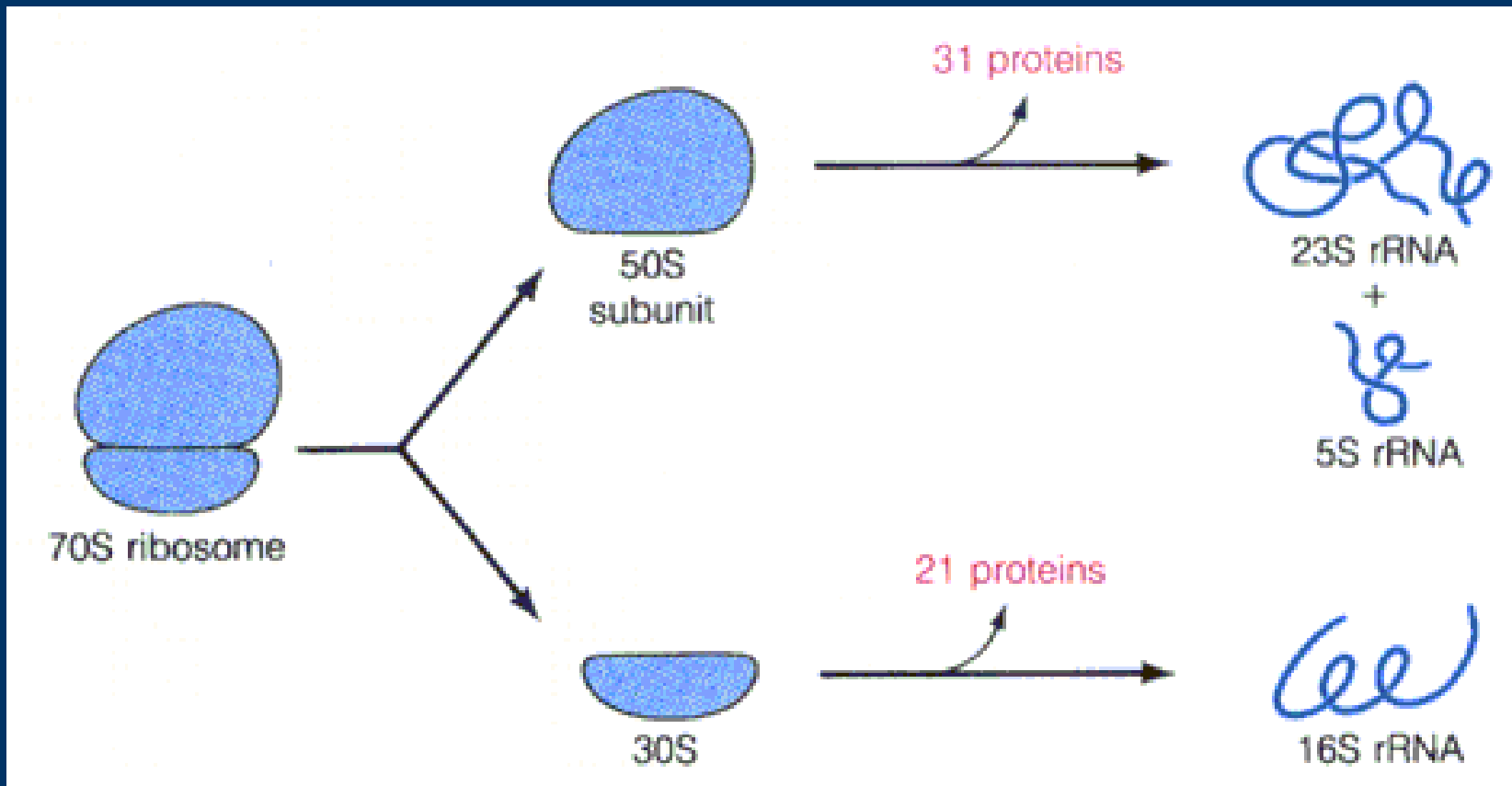
The subunits pass from the nuclear pores to the cytoplasm where they combine to form ribosomes.



Ribosomes

- particles consisted of proteins and ribosomal RNA (rRNA)
- function = protein synthesis
- prokaryotes = 70S eukaryotes = 80S





Eukaryotes (80S ribosome):

large subunit = 60S

45 proteins

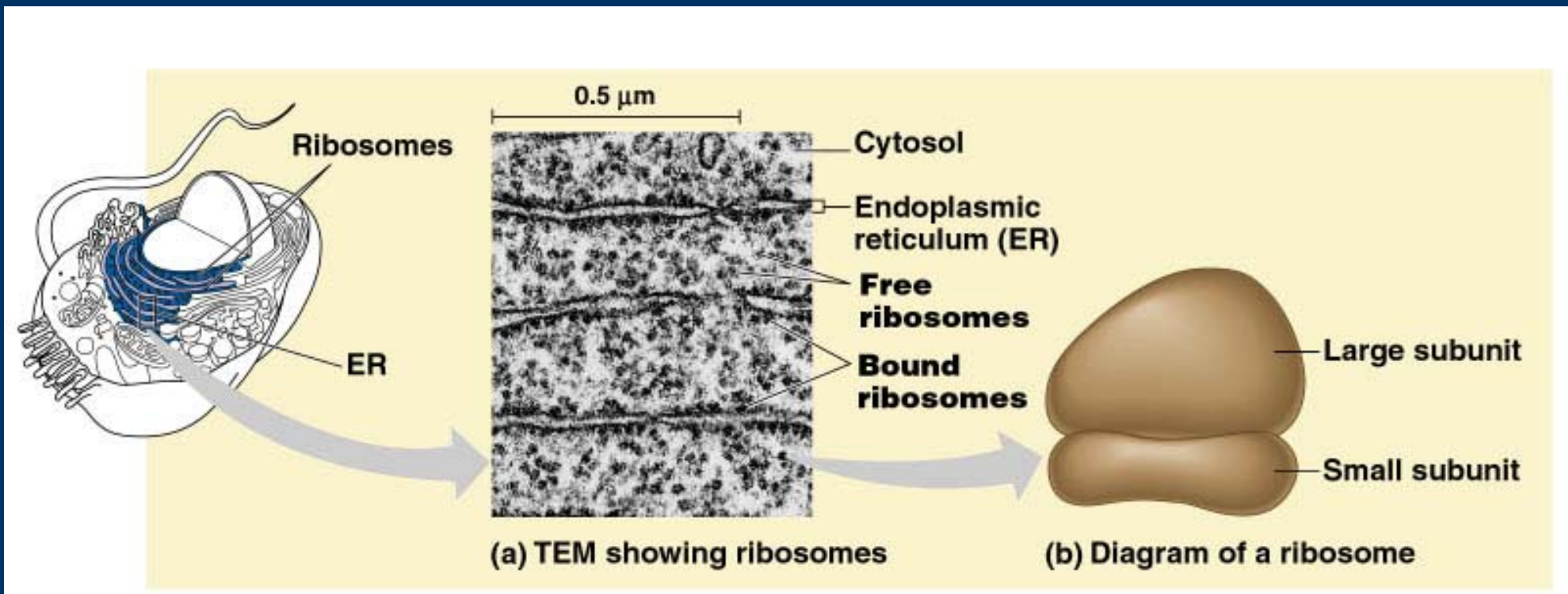
rRNA = 28S, 8S and 5S

small subunit = 40S

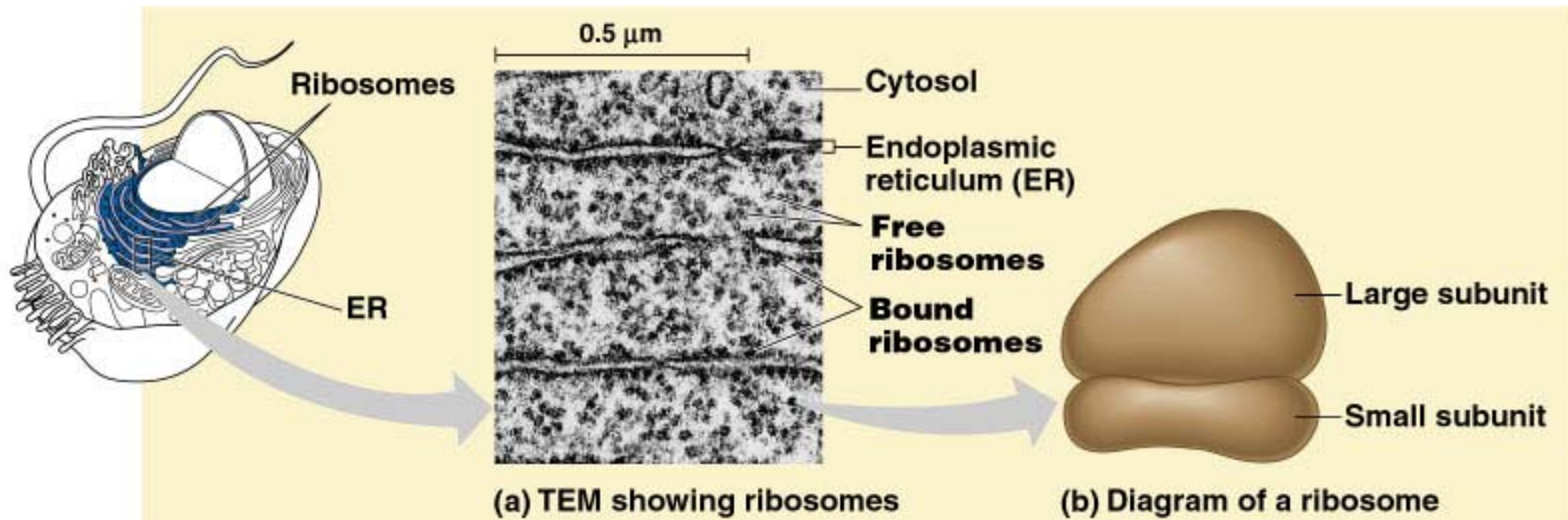
30 proteins

rRNA = 18S

- free ribosomes in cytosol synthesize proteins that function within cytosol
- bound ribosomes are attached to the outside of the endoplasmic reticulum or nuclear envelope: membrane protein, organelle proteins or secretory protein



Bound and free ribosomes are structurally identical and can alternate between the two roles.



The Endomembrane System

The collection of membranes inside and around a eukaryotic cell.

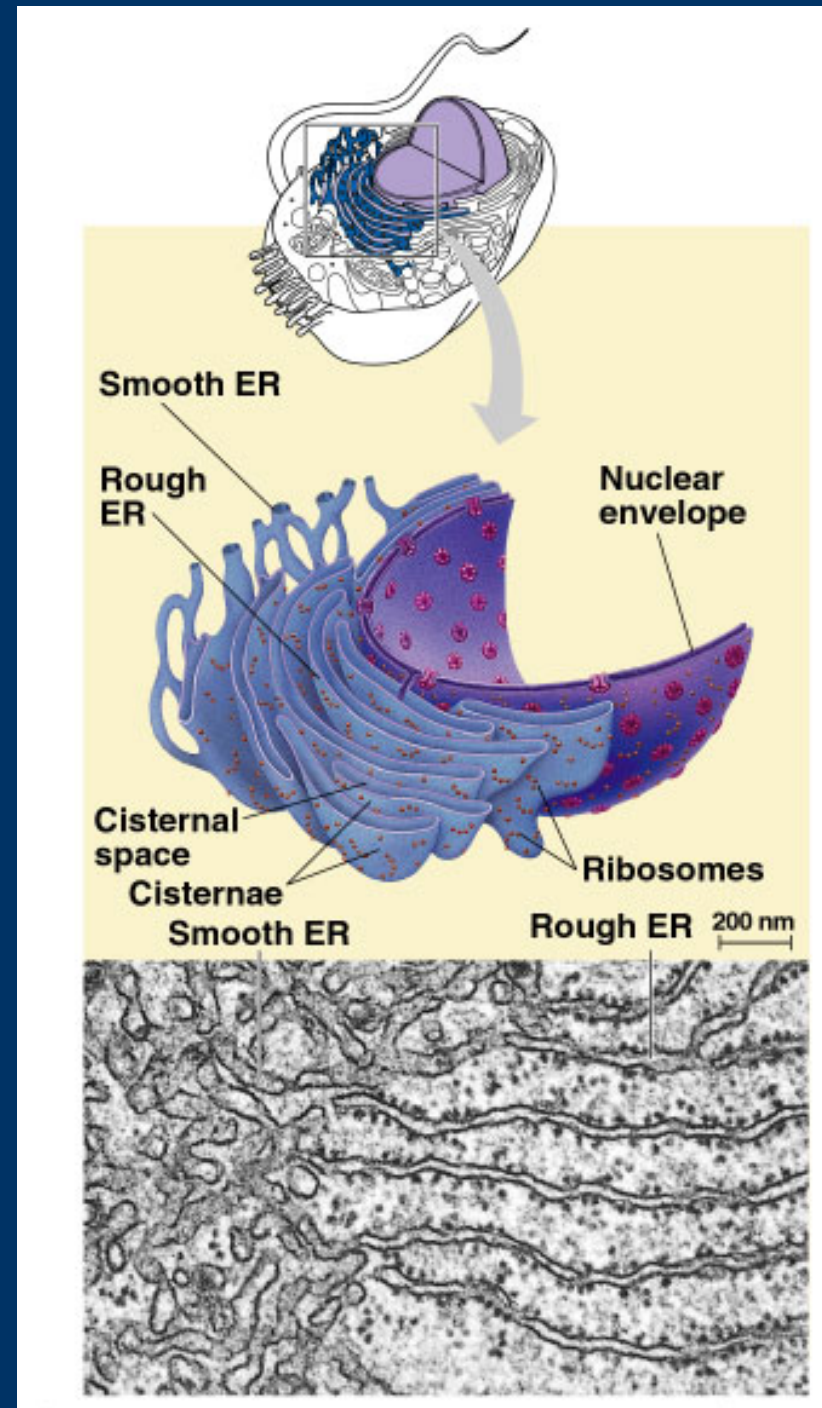
These membranes are related either through direct physical contact or by transfer of vesicles (sac of membrane).

In spite of these links, these membranes have diverse functions and structures:

nuclear envelope, endoplasmic reticulum, Golgi apparatus, lysosomes, vacuoles, and the plasma membrane.

Endoplasmic reticulum (ER)

- ER consists of a network of membranous tubules and sacs called cisternae. (*cisterna* = a reservoir for a liquid)
- the network are interconnected
- The ER membrane is continuous with the nuclear envelope and the cisternal space of the ER is continuous with the space between the two membranes of the nuclear envelope.



-smooth and rough ER (with & without ribosomes)

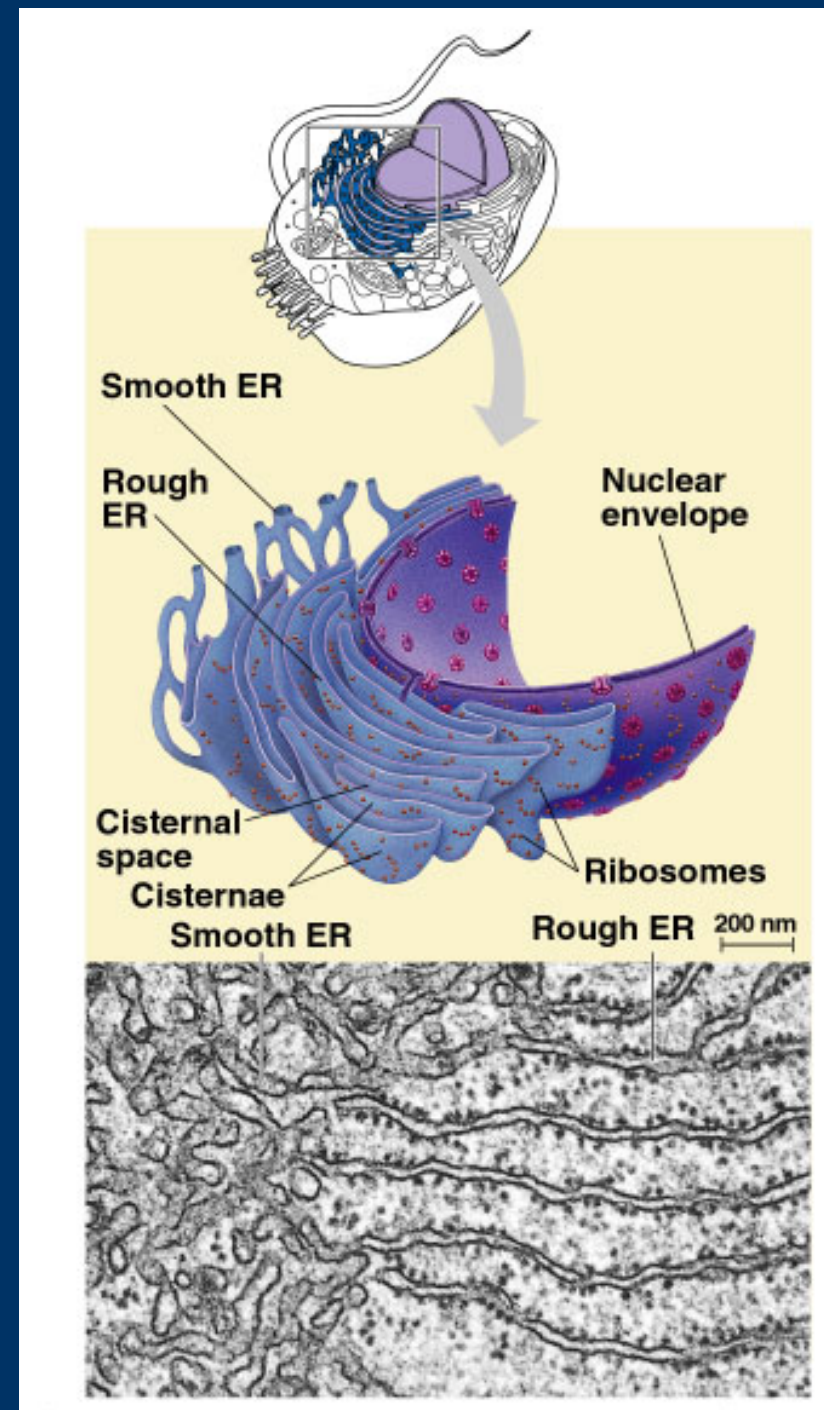
-Smooth ER:

 synthesis of lipid (oils,
 phospholipids, and steroids)

 glycogen metabolism in
the liver cells

 detoxification of drugs
and poisons

 store calcium for muscle
contraction



Rough ER: ribosomes are attached to the outside

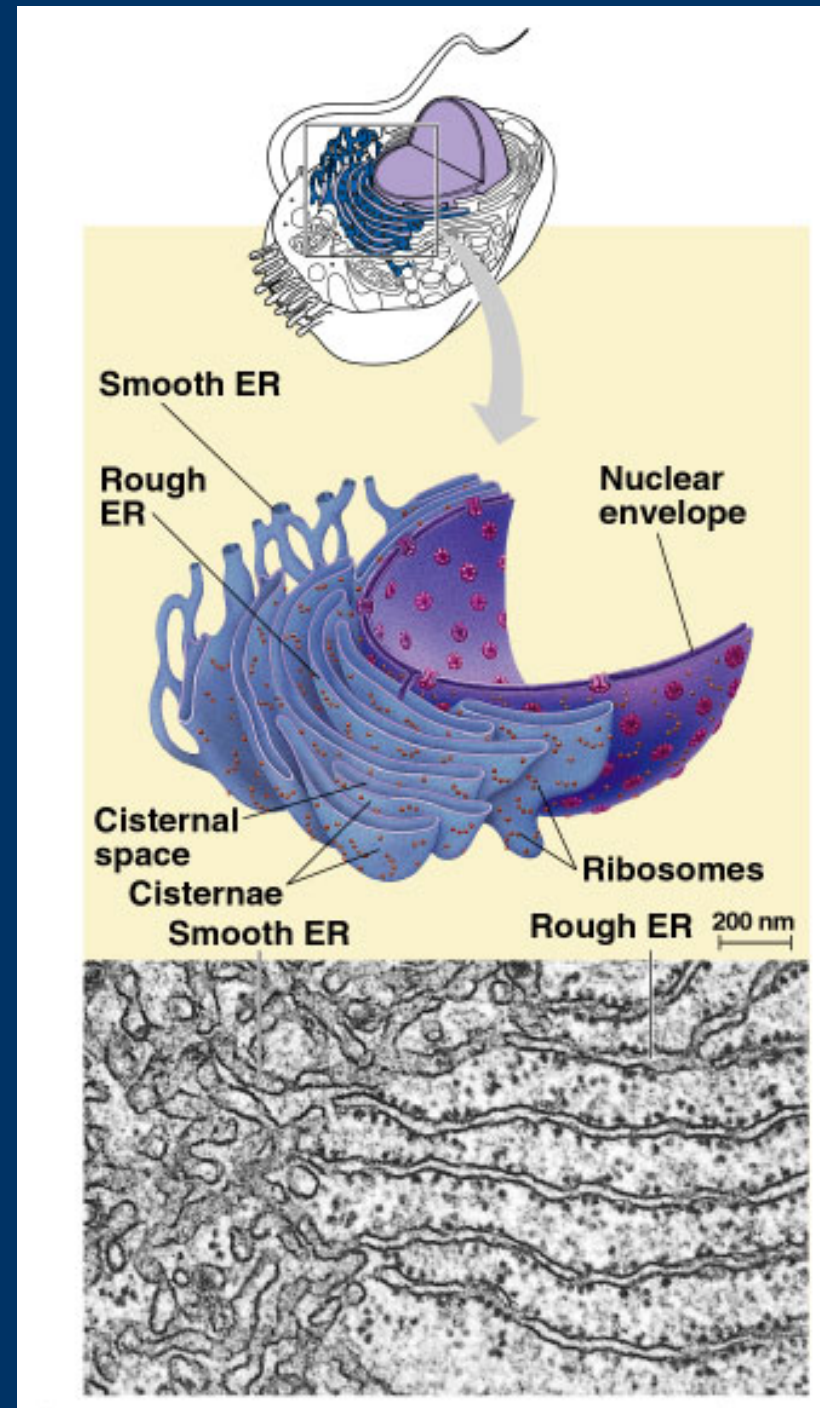
-is abundant in cells that secrete protein

-synthesis secretory proteins, cell membrane protein and organelle protein

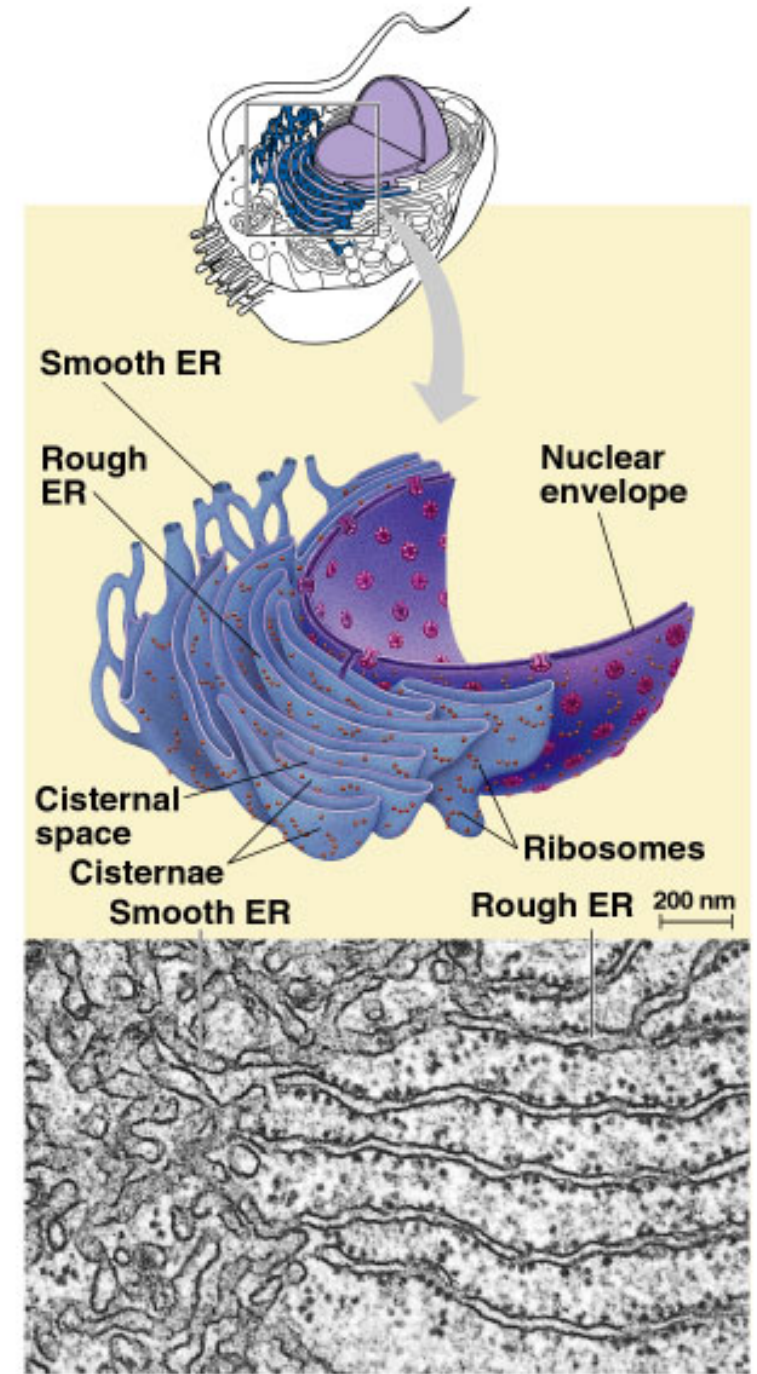
(proteins are targeted to determined location according to the sorting signals.

Sorting signals are encoded in a.a sequences or in the attached oligosaccharides)

-synthesis of phospholipids and ER associated protein

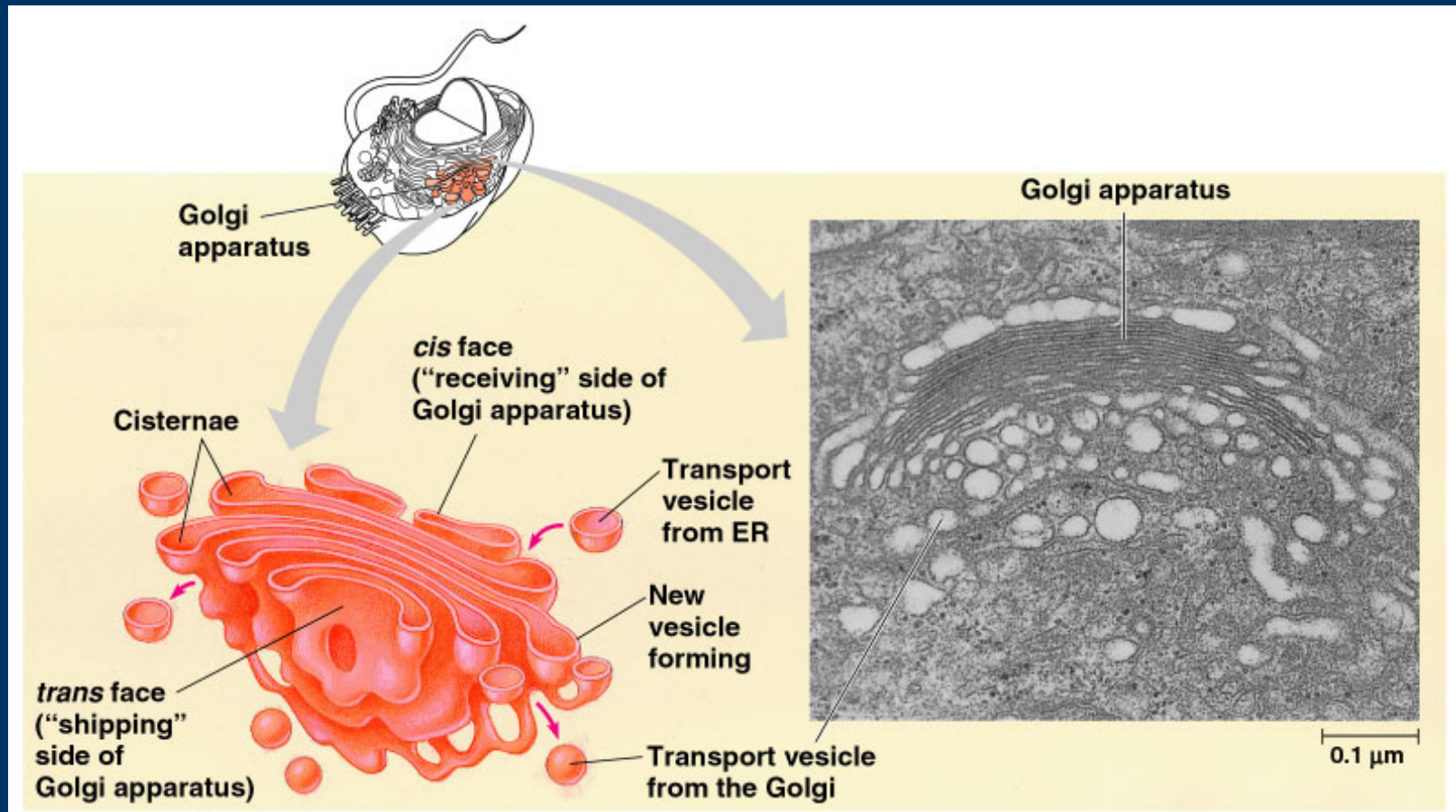


- proteins are synthesized from the bound ribosomes
- threaded into the cisternal space through a pore formed by a protein in the ER membrane
- protein folds into its native conformation
- an oligosaccharide is attached to the protein = **glycosylation**
- those proteins are wrapped in the **transport vesicles** that **bud** from the ER

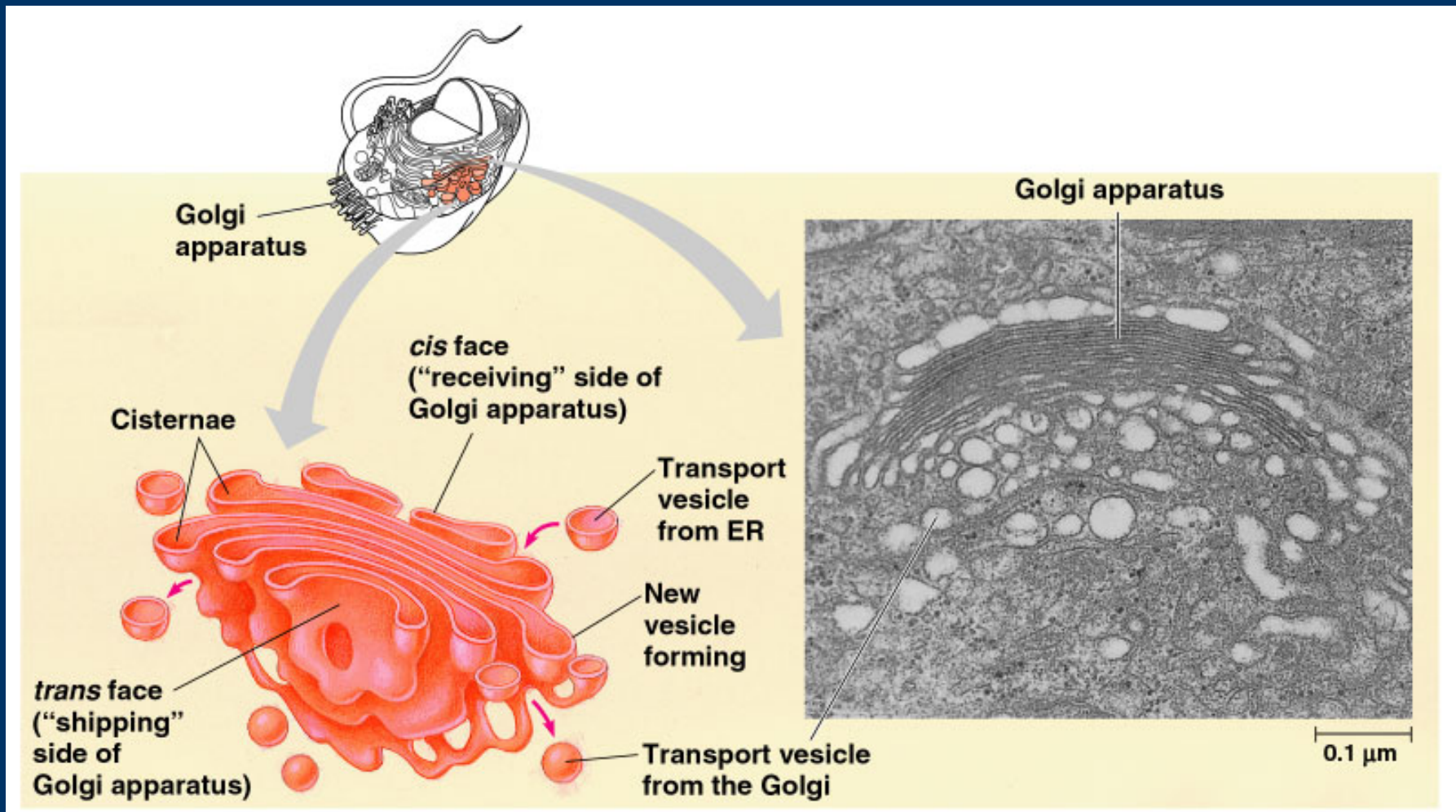


The Golgi apparatus:

- major sites for carbohydrate synthesis
- sorting and dispatching station for the products of the ER
- consists of flattened membranous sacs, cisternae
- unlike ER cisternae, the Golgi cisternae are not physically connected.



-a Golgi stacks has polarity: *cis* face (the receiving side) and *trans* face (the shipping side)



-transport vesicle from ER fuses to the *cis* face to transfer the material to the Golgi

-proteins and lipids are altered; **glycosylation and phosphorylation** (tagging the sorting signal)

-**oligosaccharides portion of the glycoproteins are modified:**

Golgi removes some sugar monomers and substitutes others

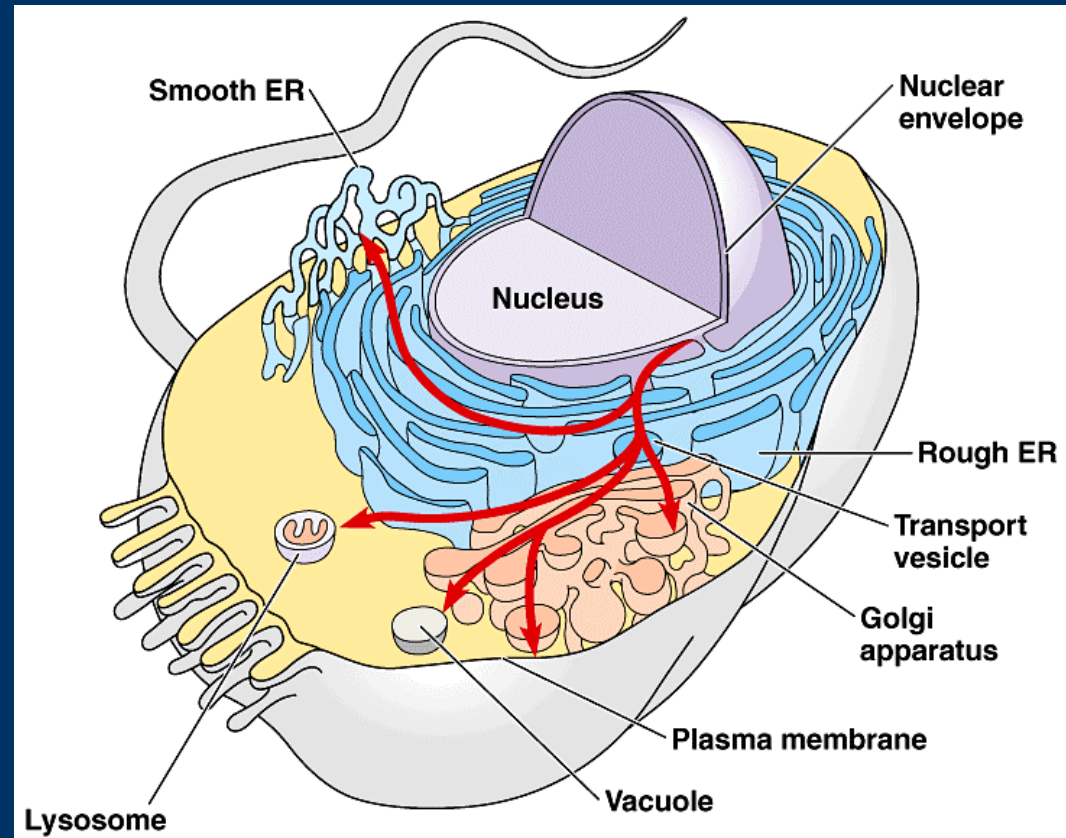
-some **polysaccharides** are **synthesized** in the Golgi e.g pectin and cellulose of the plant cell wall and most of the glycosaminoglycans of animal extracellular matrix

-Golgi products (that will be secreted) depart from the *trans* face of the Golgi by transport vesicle for the correct docking.

Relationships among Organelles of the Endomembrane System

-secretory proteins, lysosomes, vacuoles and membrane are synthesized by the rough ER, then transported through the Golgi as a vesicle.

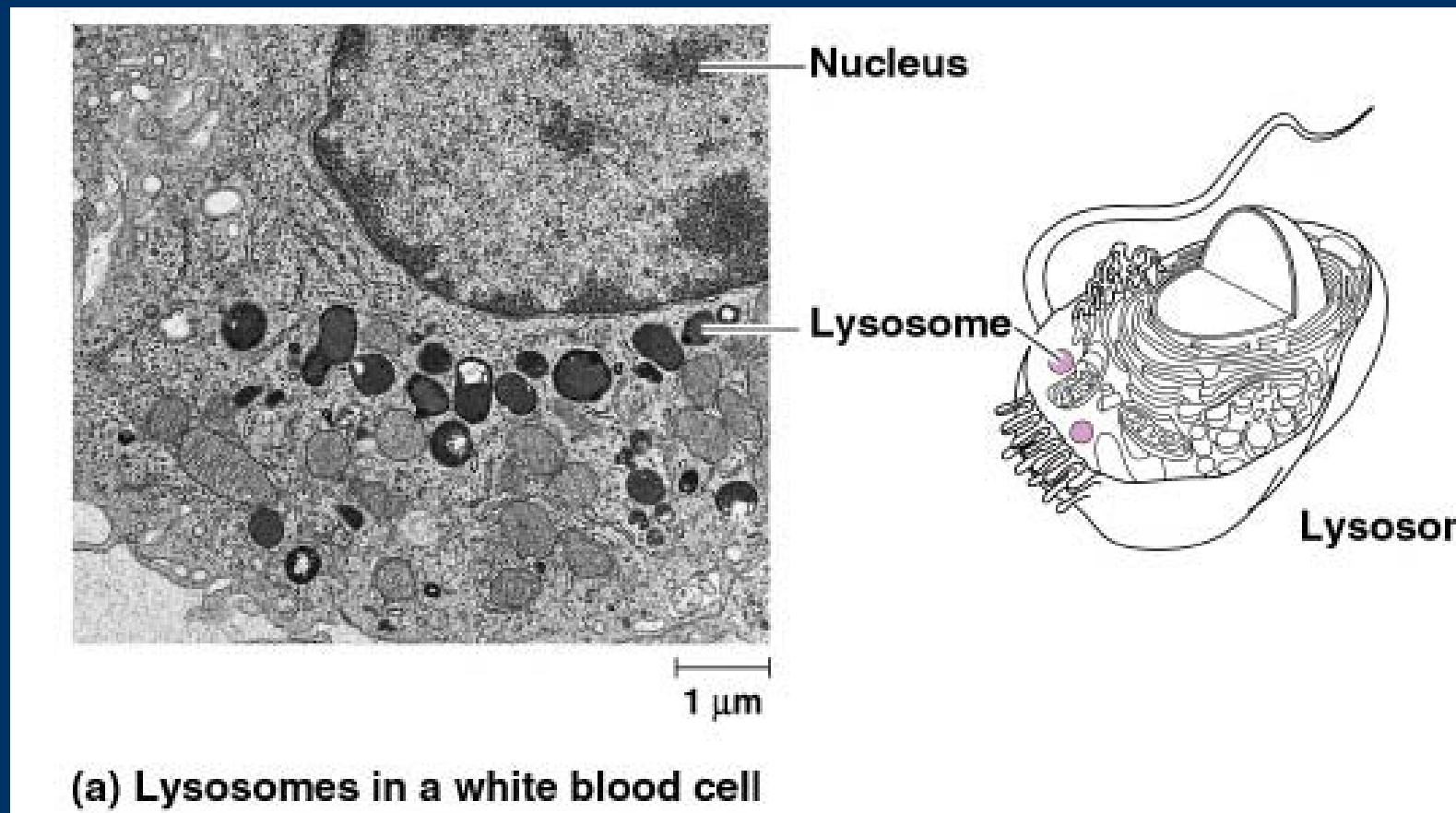
-during this process, their molecular compositions and metabolic functions are modified.



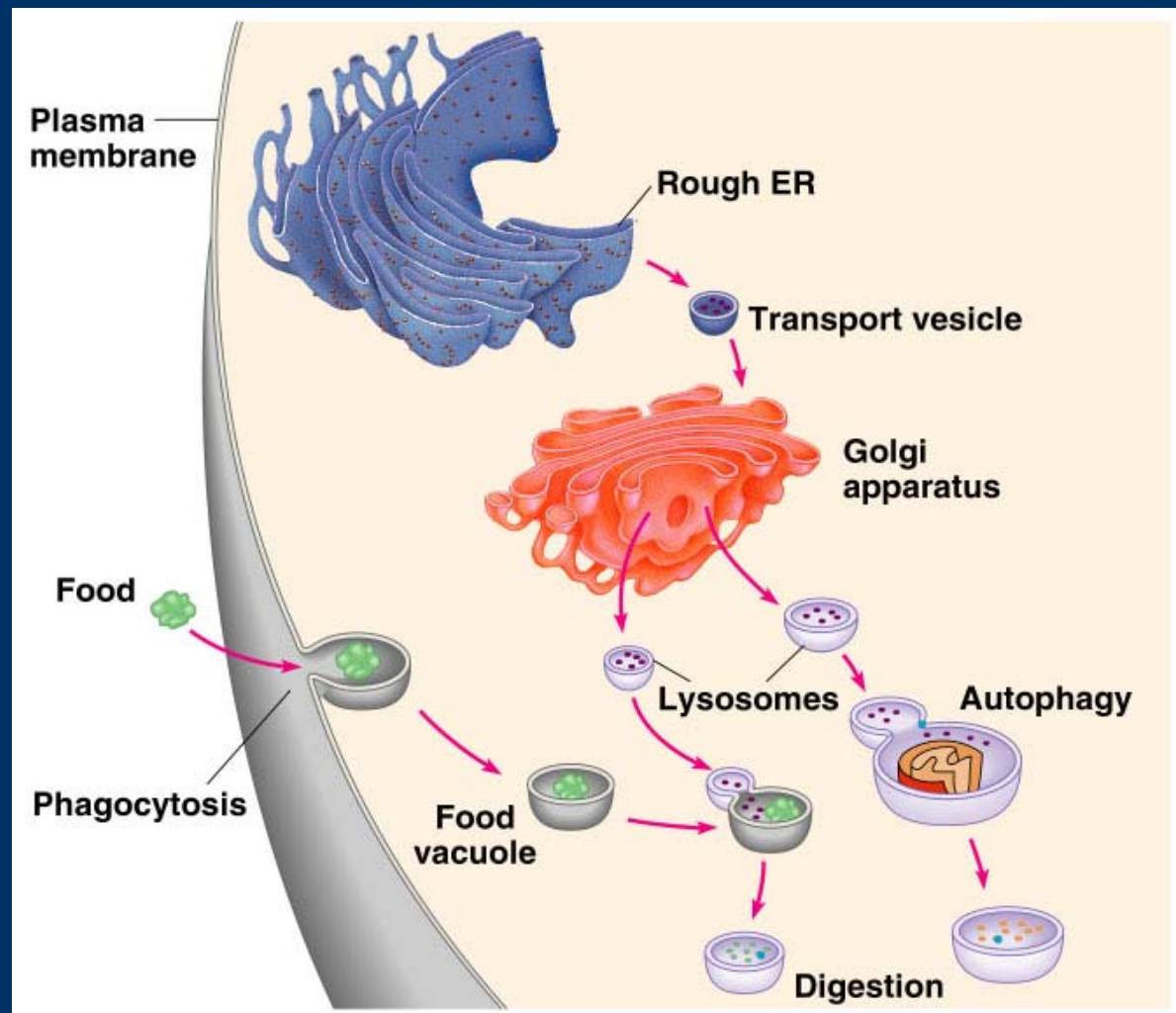
Lysosomes: principal sites of intracellular digestion

-contain hydrolytic enzymes (required acidic pH) to digest proteins, polysaccharides, fats and nucleic acids

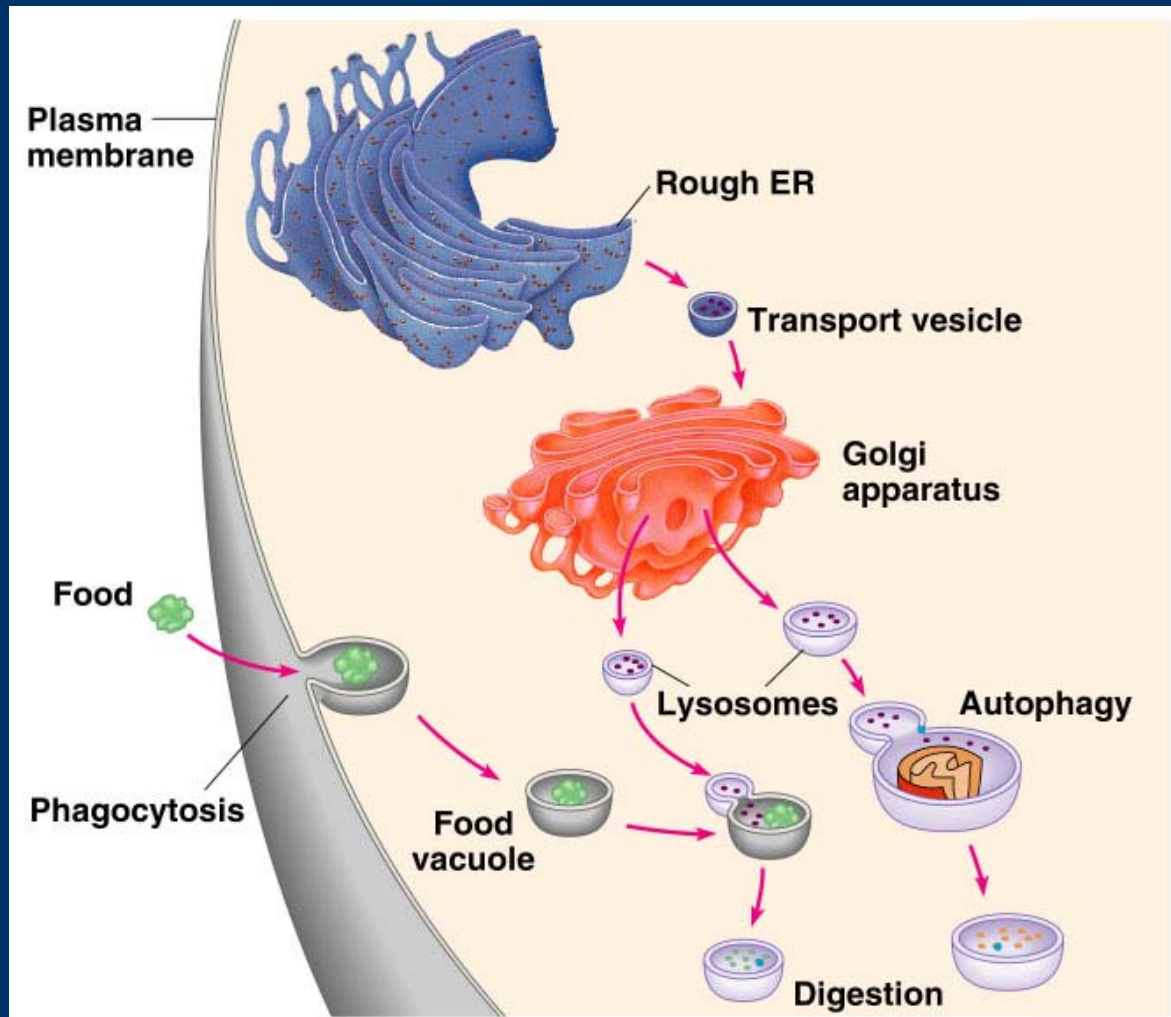
(if those hydrolases leak out of the lysosomes, they are not likely to do damage unless the cells become acidic)



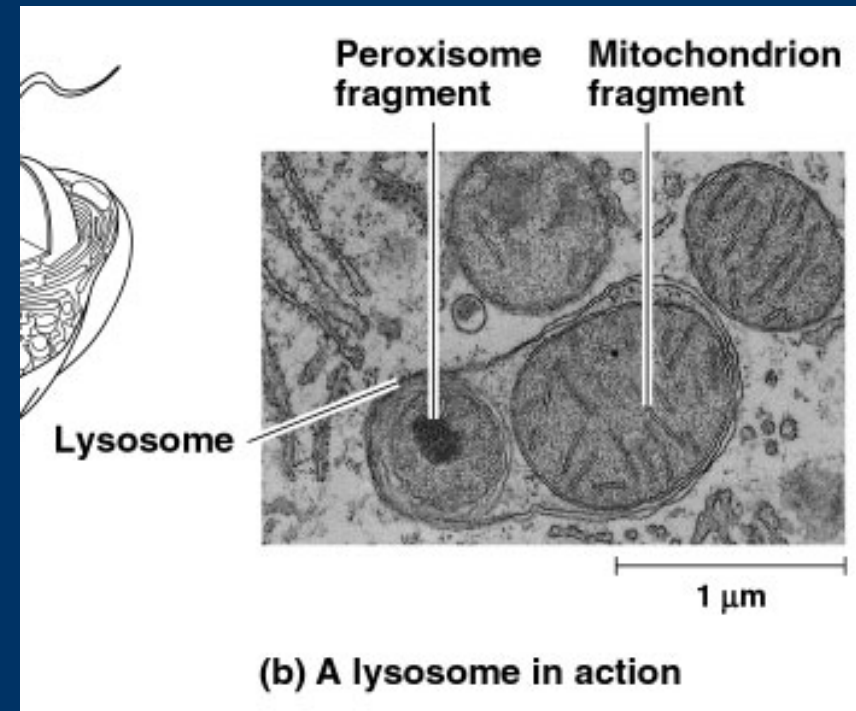
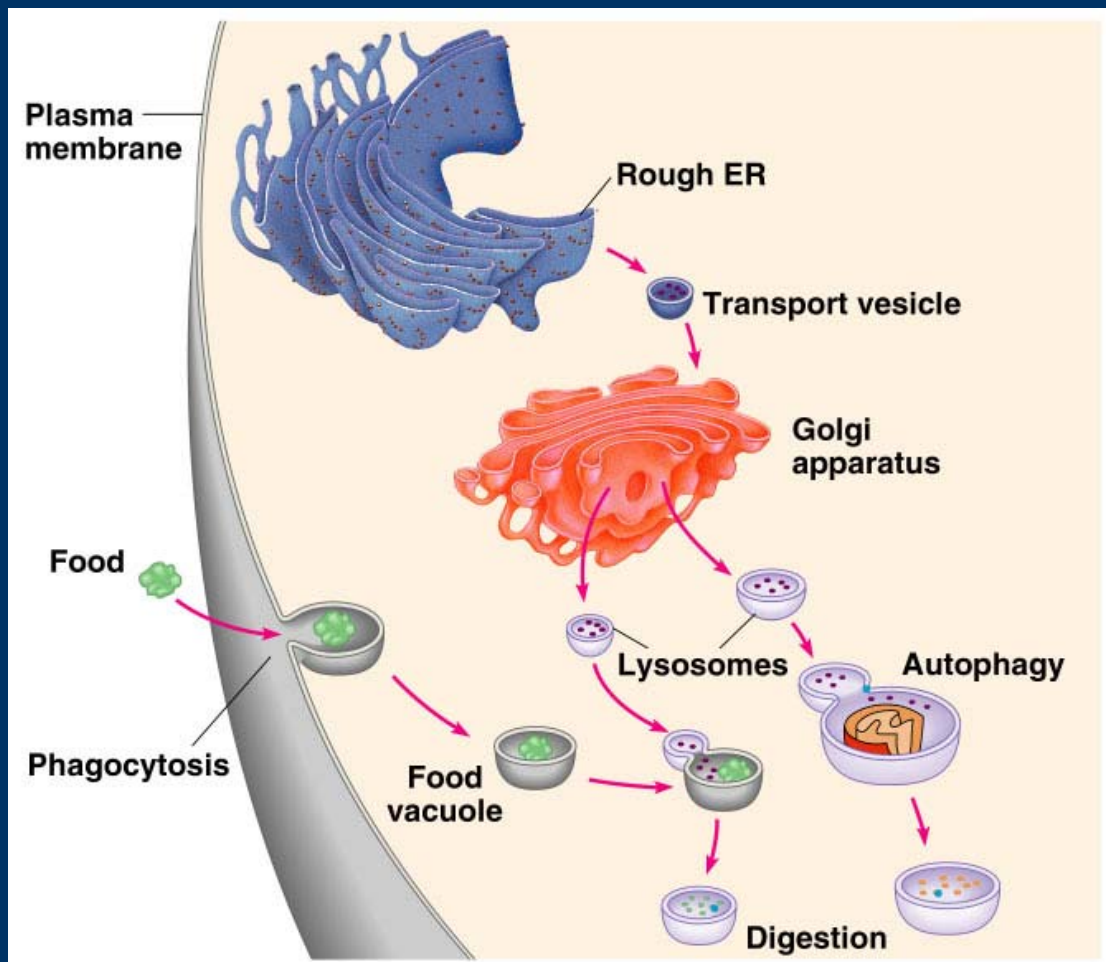
- lysosomal enzymes and membranes are made by rough ER and transferred to the Golgi for processing
- lysosomal membranes are highly glycosylated to protect them from lysosomal proteases



- Food particles engulfed as a food vacuole (phagocytosis) or an endosome (product of receptor-mediated endocytosis) is fused with the lysosome.
- The digestion products are passed to cytosol and become nutrient for the cell.



- autophagy = process which cells recycle its own organic material
- the organelles are fused with a lysosome
- after digestion, the organic monomers are returned to the cytosol for reuse



Vacuoles:

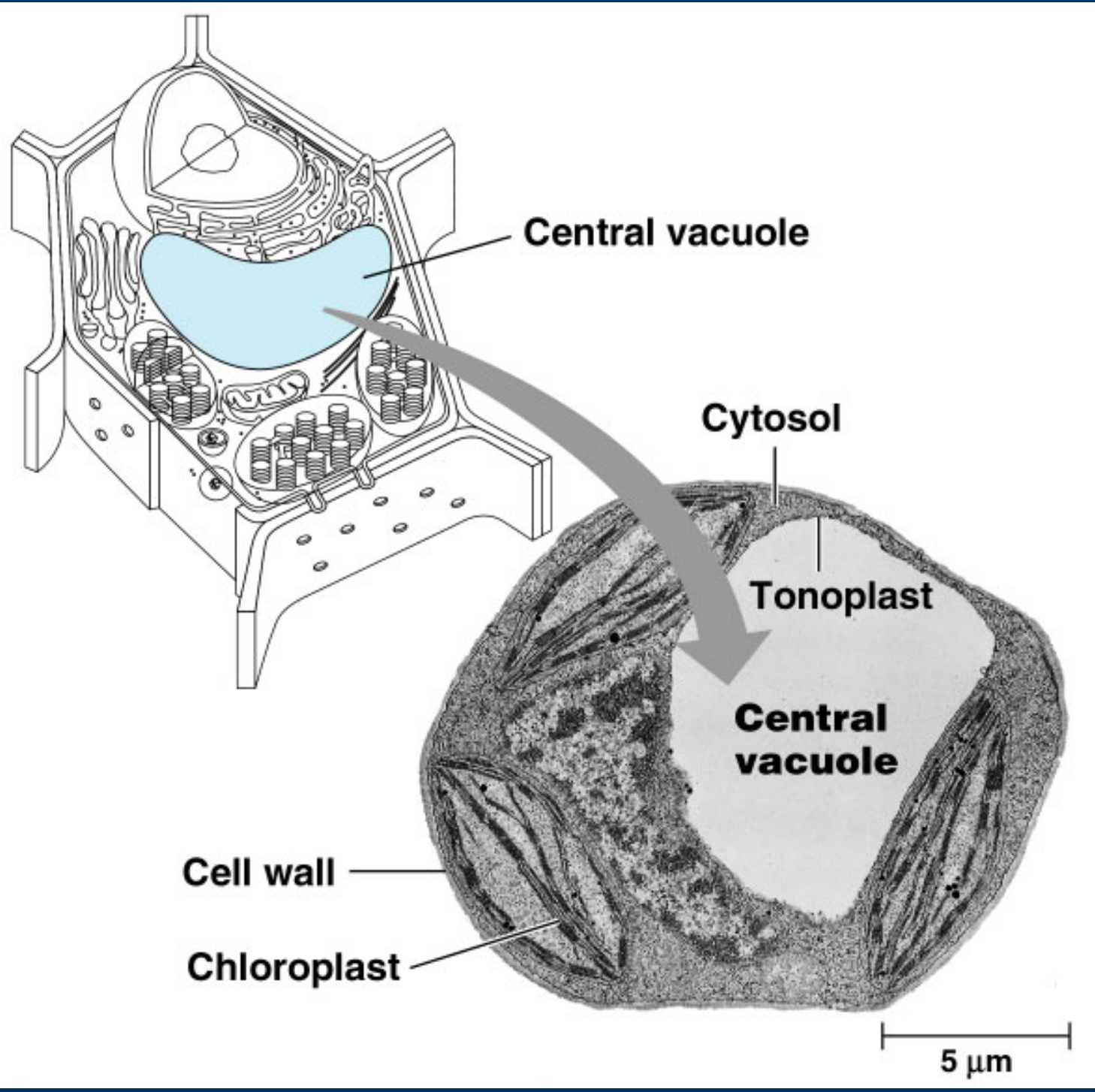
- membrane-bound sacs

- diverse functions in cell maintenance

 - food vacuoles formed by phagocytosis and digested by lysosomes

 - contractile vacuoles (in protists) pump excess water out of the cells

 - central vacuole (a versatile compartment in plants) stores protein and metabolic by-products, reservoir of inorganic ions, pigments

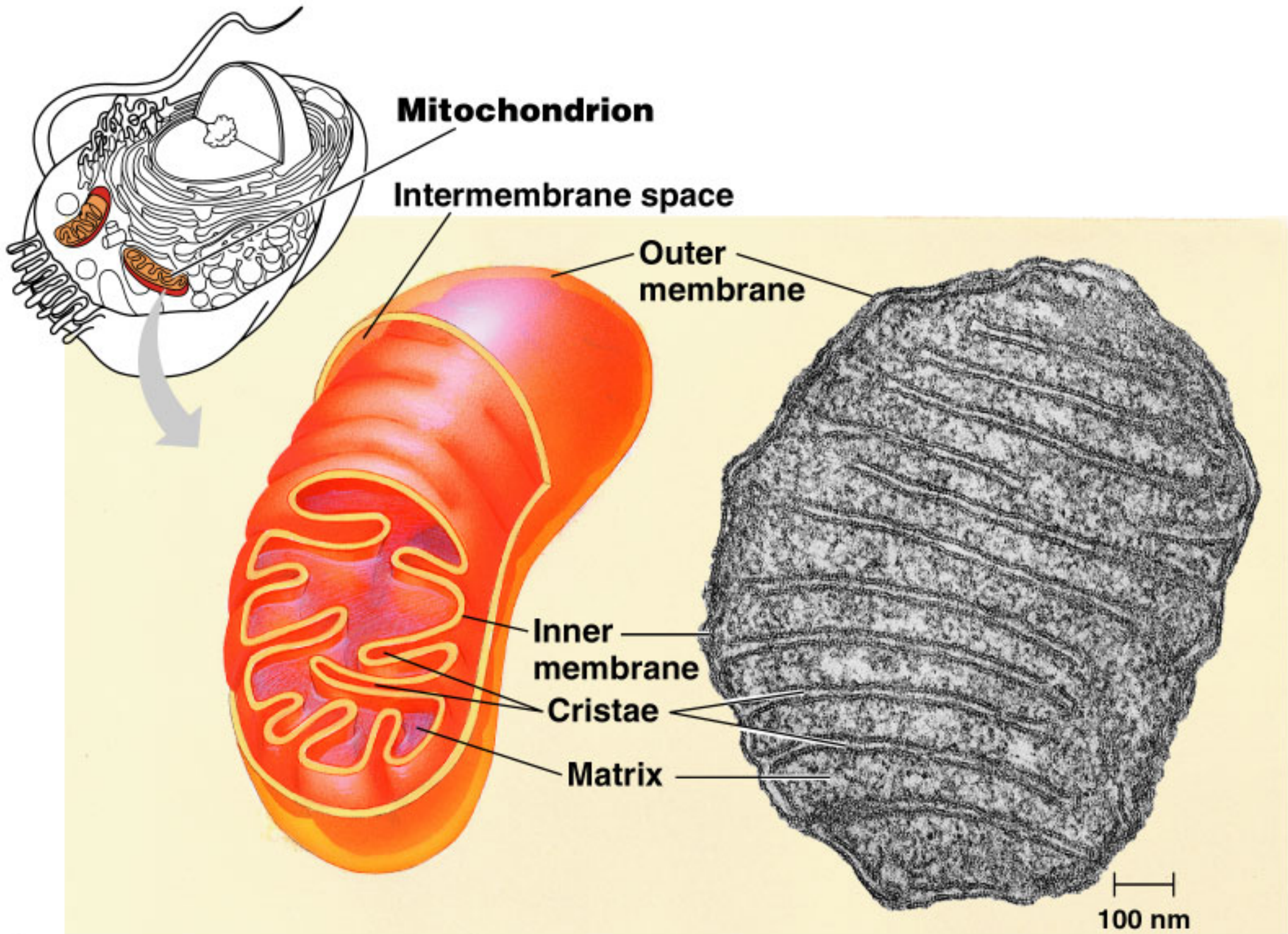


Mitochondria and Chloroplast

- both are energy transformers of cells
 - mitochondria = cellular respiration
 - chloroplast = photosynthesis
- both **are not** part of the endomembrane system
- most of their proteins are synthesized by the free ribosomes in the cytosol
- a few of the proteins are synthesized from their own ribosomes

-both organelles contain small quantity of DNA that direct the synthesis of polypeptides produced by the internal ribosomes

-both organelles grow and reproduce as semiautonomous organelles



Mitochondria

- 1-10 μm long
- some cells contain a single large mitochondrion but most cells contain several mitochondria
- enclosed by two membrane: outer and inner membrane with different permeability
- cristae = fold innermembrane to increase the surface area
- matrix and intermembrane space

-matrix contains:

- ds circular DNA

- prokaryote like ribosome (70S)

- enzymes in TCA cycle

- enzymes for β -oxidation of fatty acid

Glucose and fatty acids are catabolized in the matrix of mitochondria.

-innermembrane of mitochondria contains:

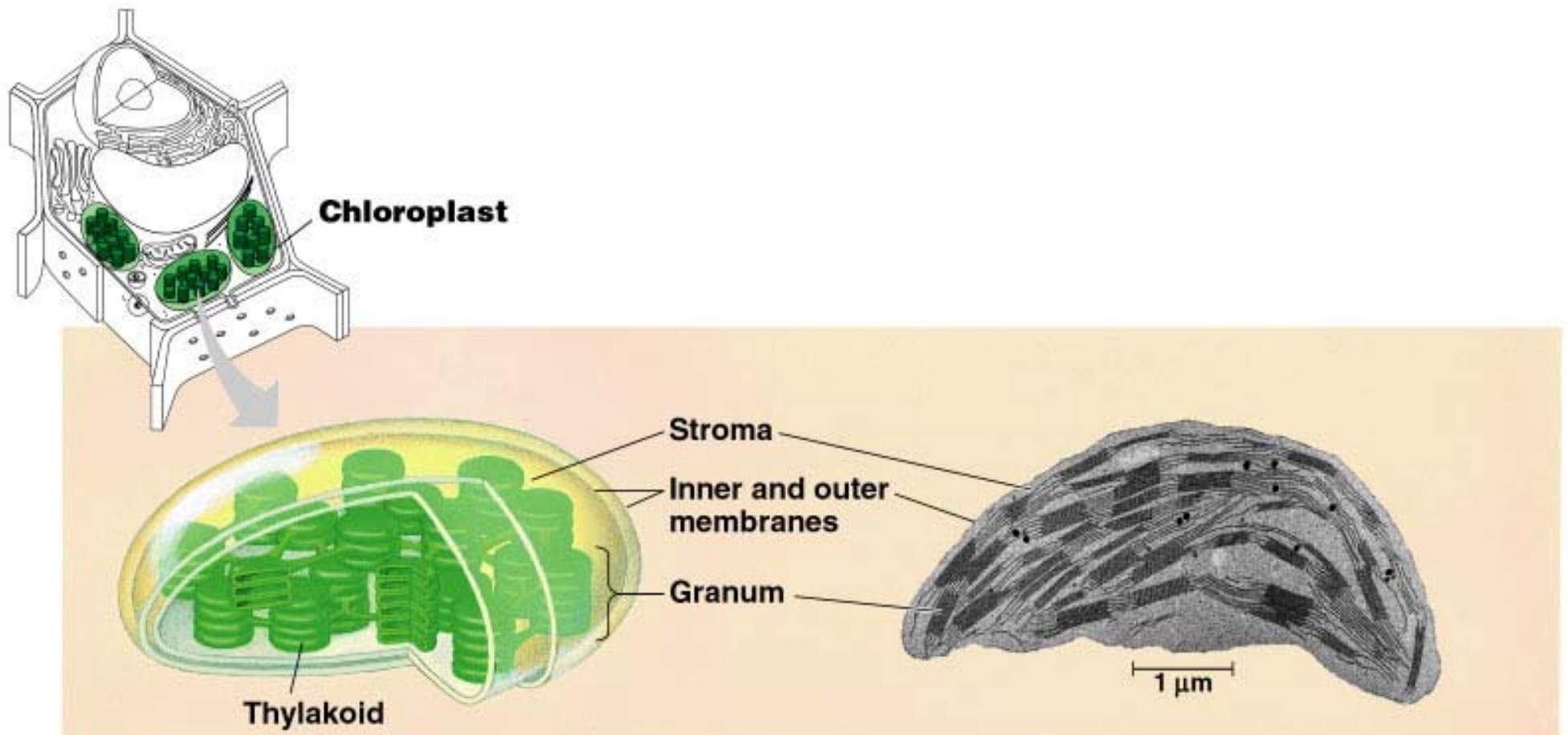
- electron transport chain

- ATP synthase

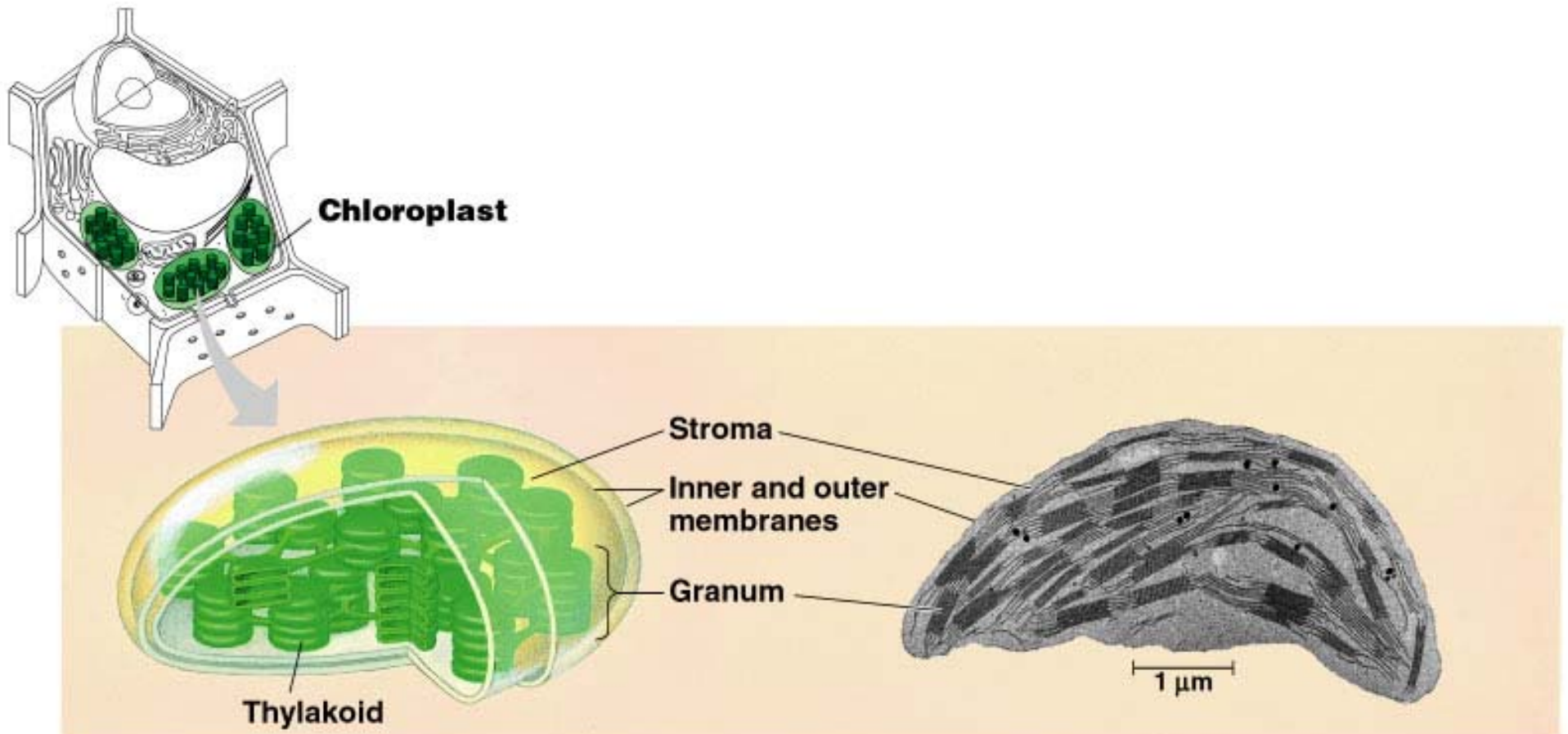
The energy from catabolism in the matrix is converted into ATP.

Chloroplast

- is one of the generalized plant structure called plastids
- found in mesophyll cells of the leaves and in algae
- 2-4 μm wide and 5-10 μm long



- 2 membranes: inner and outer membrane
- stroma ~ matrix of mitochondria
 - *ds circular DNA
 - *70S ribosomes
 - *enzyme for carbohydrate biosynthesis

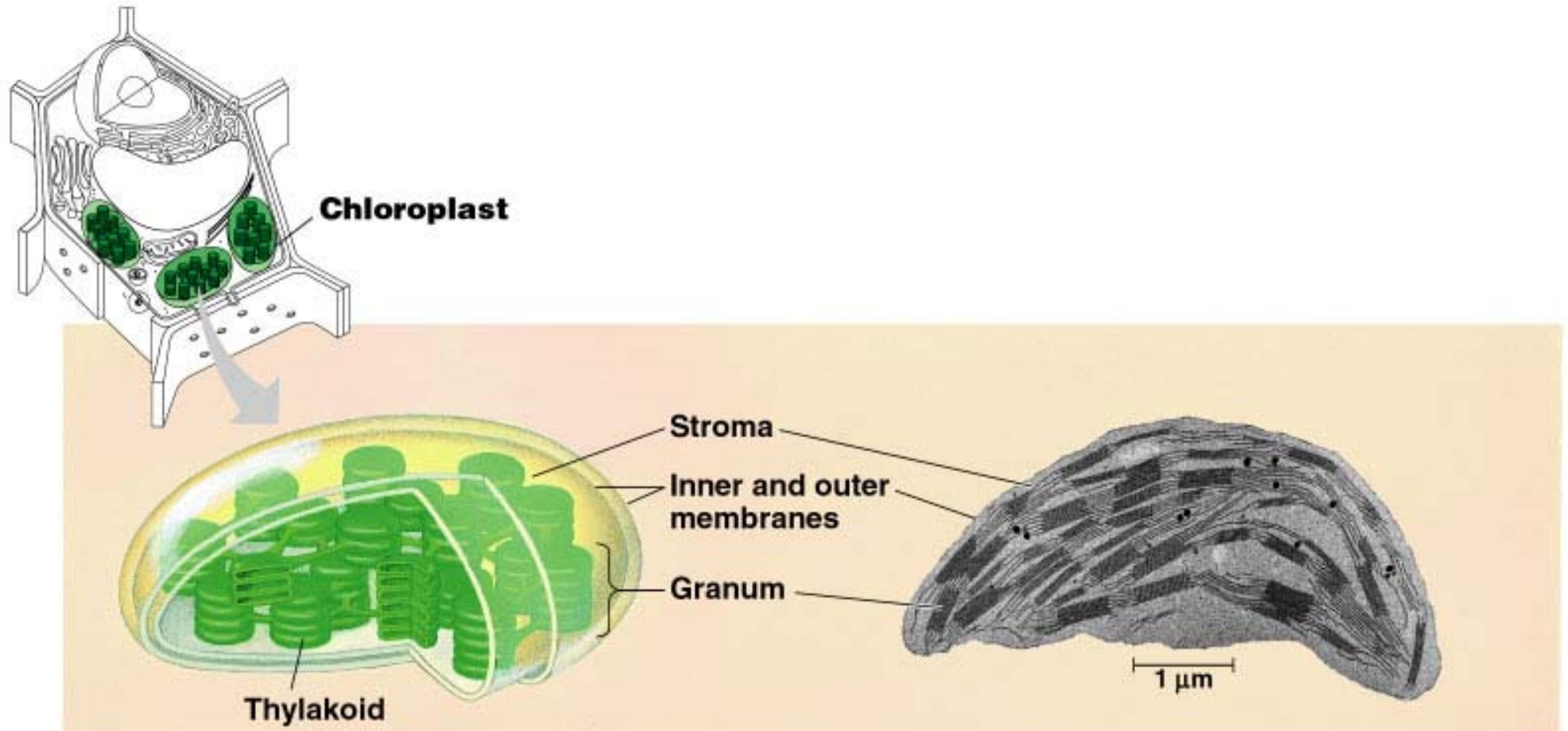


-thylakoids contain photosynthetic machinery of the chloroplast:

- *light absorbing pigment

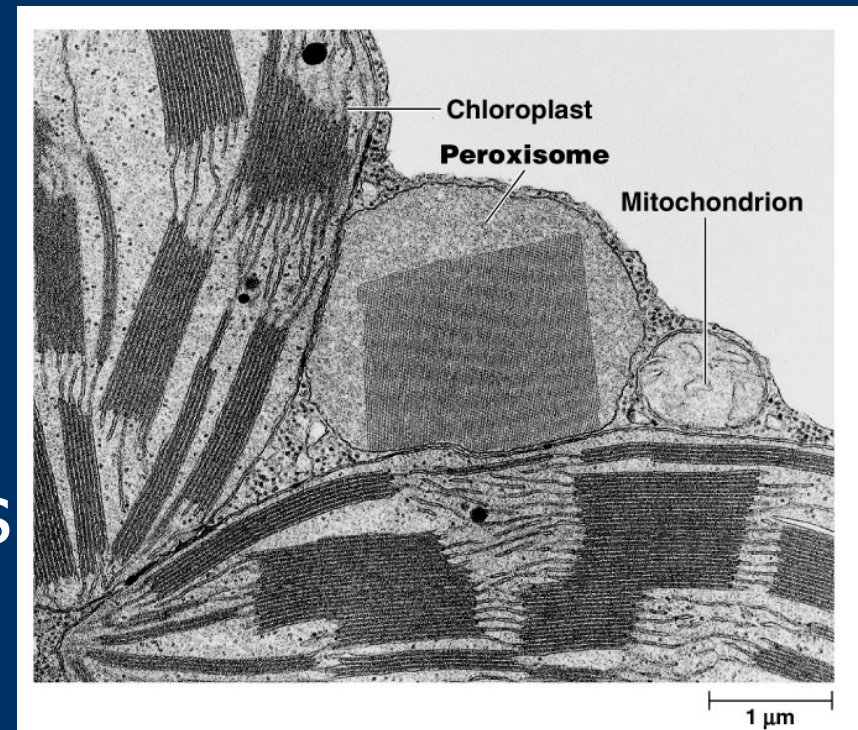
- *electron carriers

- *ATP synthesizing apparatus



Microbodies

- electron-dense cytoplasmic particles bound by a single membrane
- contain oxidative enzymes: D-amino acid oxidase, ureate oxidase and catalase
- they are not formed in the Golgi complex
- they are self replicating, like the mitochondria
- e.g. peroxisomes, glyoxisomes

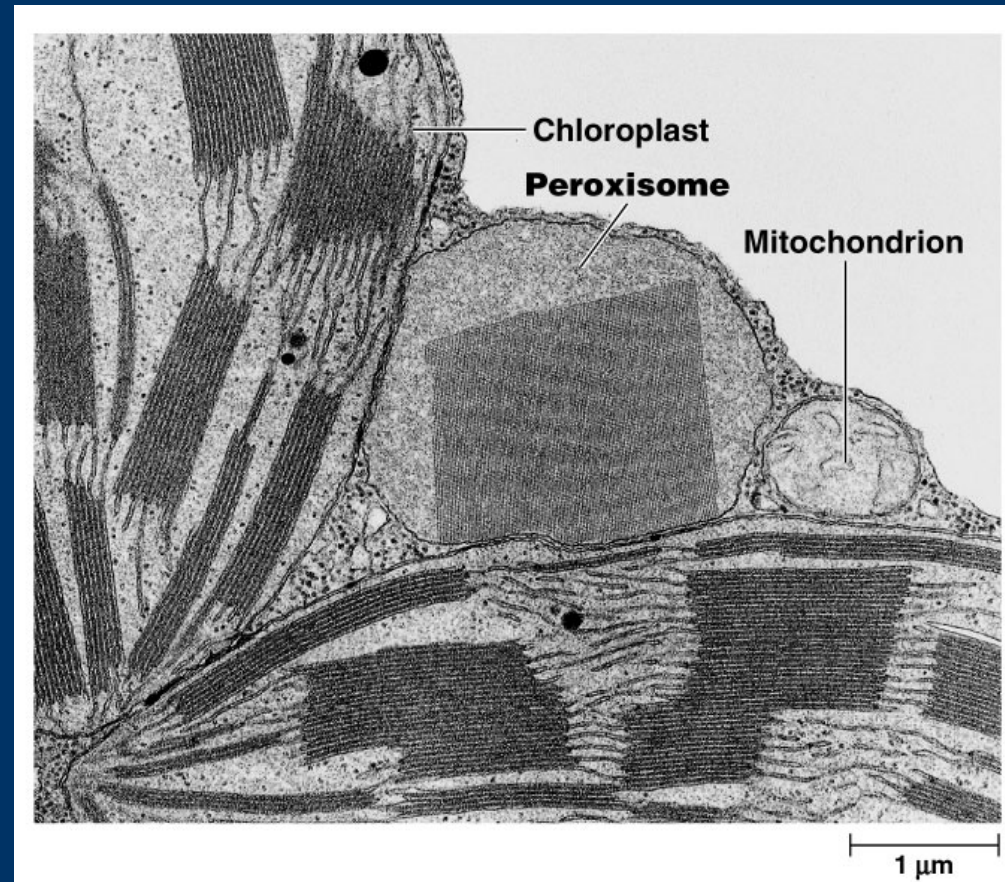


Peroxisomes

- single membrane
- contain enzymes that transfer hydrogen from various substrate to oxygen and produce H_2O_2 as intermediate product
- but peroxisomes contain another enzyme that convert H_2O_2 to H_2O

-some peroxisomes break down fatty acids to smaller molecules that are transported to mitochondria for fuel

Glyoxysomes = specialized peroxisomes (found in fat storing tissues of plant seeds) convert fatty acid to sugar which can be used as energy for seedling.



The Cytoskeleton

-a network of fibers extending throughout the cytoplasm

-function:

provide mechanical strength to the cell

establish cell shape

locomotion (several types of cell motility)

intracellular transport of organelles

-3 main types of fiber:

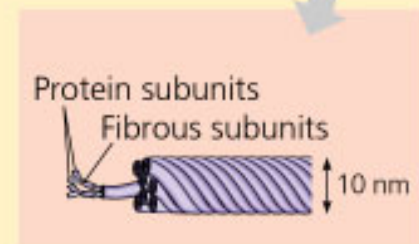
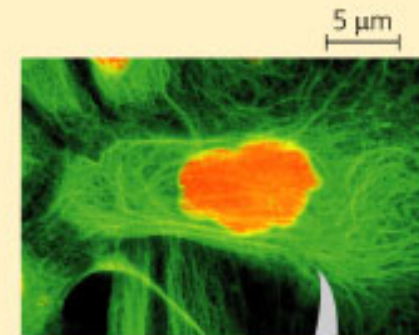
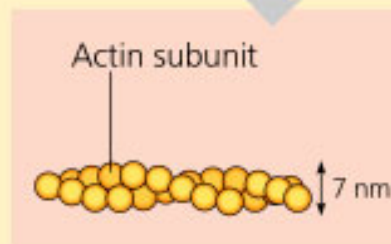
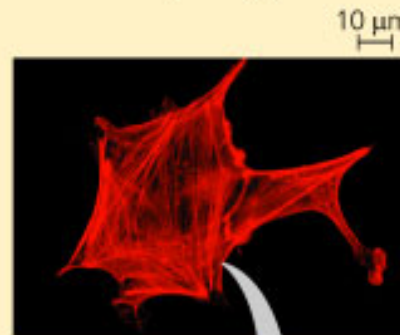
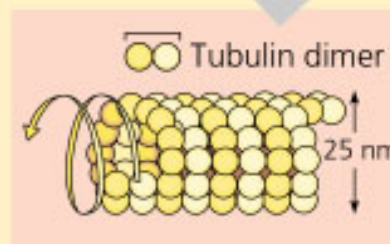
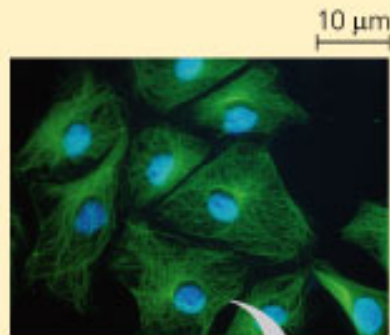
1.microtubules: determine the positions of membrane-enclosed organelles and intracellular transport

2.microfilament: determine the shape of the cell and necessary for the whole cell locomotion

3.intermediate filament: provide mechanical strength and resistance to shear stress

Table 7.2 The Structure and Function of the Cytoskeleton

Property	Microtubules	Microfilaments (Actin Filaments)	Intermediate Filaments
Structure	Hollow tubes; wall consists of 13 columns of tubulin molecules	Two intertwined strands of actin	Fibrous proteins supercoiled into thicker cables
Diameter	25 nm with 15-nm lumen	7 nm	8–12 nm
Protein subunits	Tubulin, consisting of α -tubulin and β -tubulin	Actin	One of several different proteins of the keratin family, depending on cell type
Main functions	Maintenance of cell shape (compression-resisting “girders”) Cell motility (as in cilia or flagella) Chromosome movements in cell division Organelle movements	Maintenance of cell shape (tension-bearing elements) Changes in cell shape Muscle contraction Cytoplasmic streaming Cell motility (as in pseudopodia) Cell division (cleavage furrow formation)	Maintenance of cell shape (tension-bearing elements) Anchorage of nucleus and certain other organelles Formation of nuclear lamina

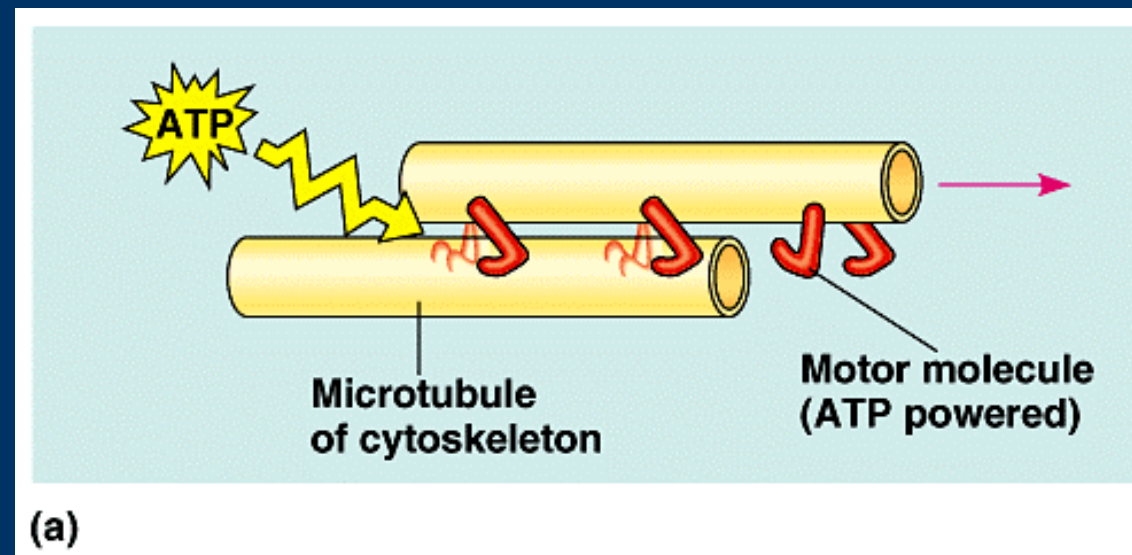


SOURCE: Adapted from W. M. Becker, L. J. Kleinsmith, and J. Hardin, *The World of the Cell*, 4th ed. (San Francisco, CA: Benjamin Cummings, 2000), p. 753.

Cytoskeleton and Cell Motility

Cell motility requires interaction of cytoskeleton with proteins called **motor molecules** in ATP dependent manner.

Sliding of neighboring microtubules moves cilia and flagella.

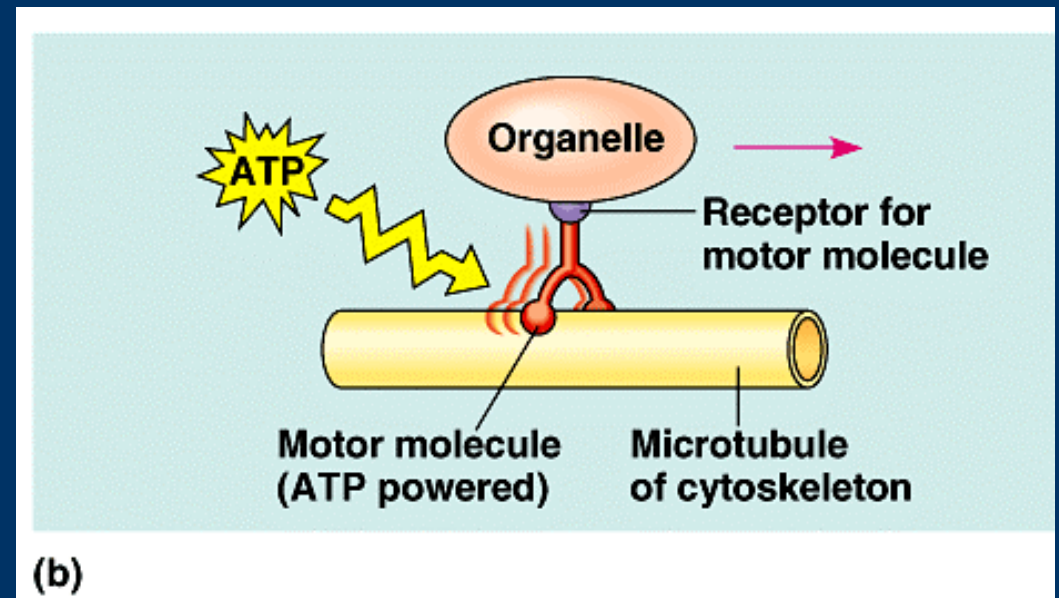


In muscle contraction, motor molecules slide microfilaments.

Walking of organelles along microtubules

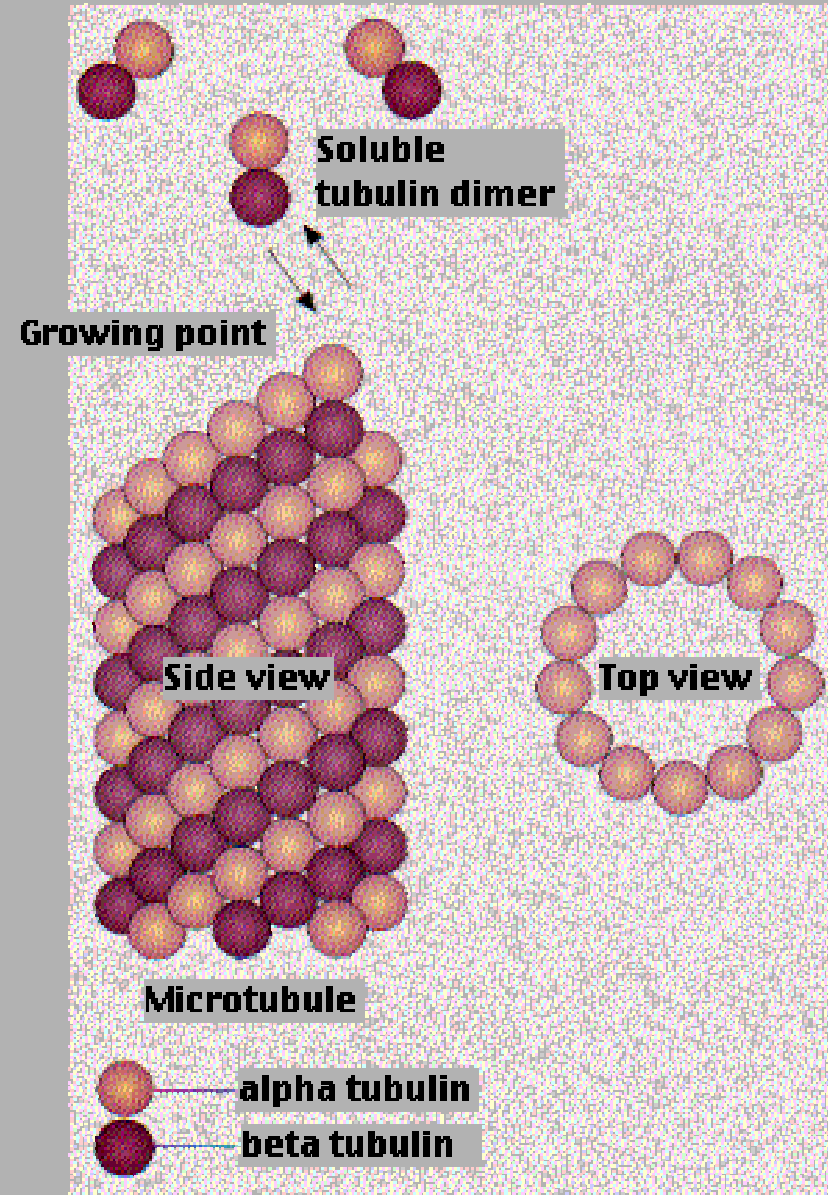
Motor molecule attached to receptor on organelles can “walk” the organelles along microtubules or microfilaments.

e.g. migration of neurotransmitters containing vesicles to the tips of nerve cell axon.



Microtubules

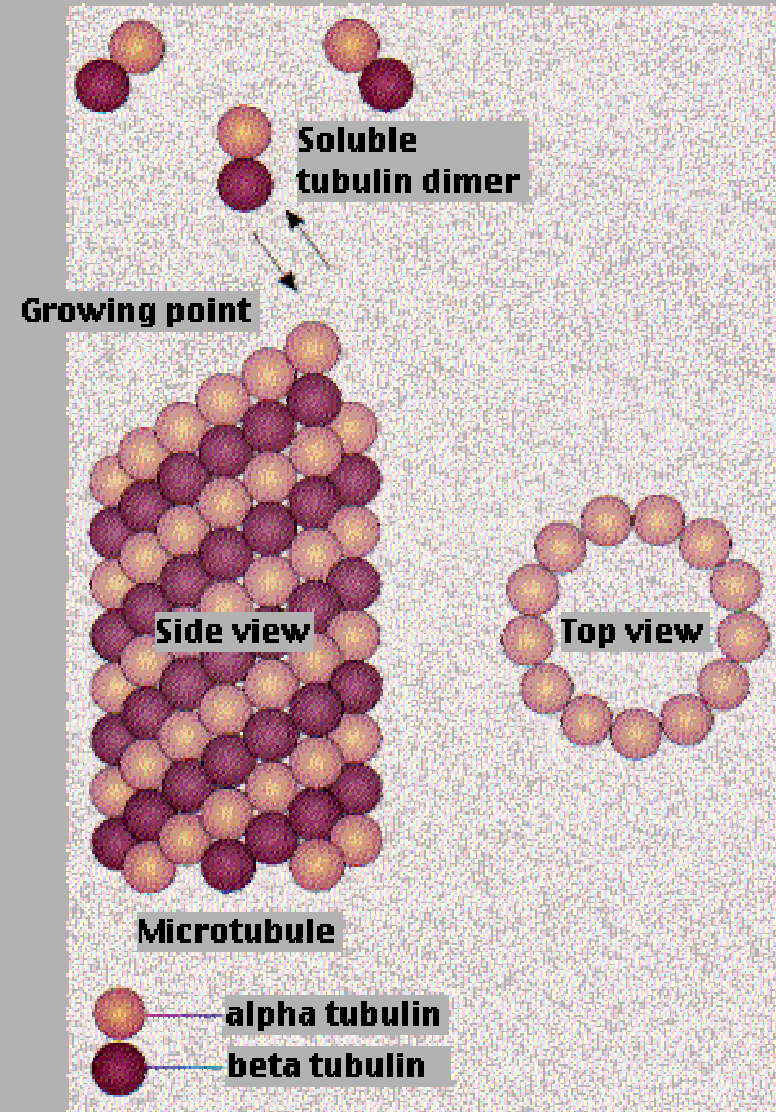
- are straight, hollow cylinders
- have a diameter of about 25 nm
- are variable in length but can grow 1000 times as long as they are thick
- are built by the assembly of dimers of **alpha tubulin** and **beta tubulin**.
- are found in both animal and plant cells



-grow at each end by the polymerization of tubulin dimers (powered by the hydrolysis of **GTP**)

-shrink at each end by the release of tubulin dimers (depolymerization)

-participate in a wide variety of cell activities. Most involve motion. The motion is provided by protein "motors" that use the energy of **ATP** to move along the microtubule.



Microtubule motors

There are two major groups of microtubule motors: **kinesins** (most of these move toward the plus end of the microtubules) and **dyneins** (which move toward the minus end).

Examples:

The rapid transport of organelles, like vesicles and mitochondria, along the axons of neurons takes place along microtubules with their plus ends pointed toward the end of the axon. The motors are kinesins.

The migration of chromosomes in mitosis and meiosis takes place on microtubules that make up the spindle fibers. Both kinesins and dyneins are used as motors

-function of microtubules:

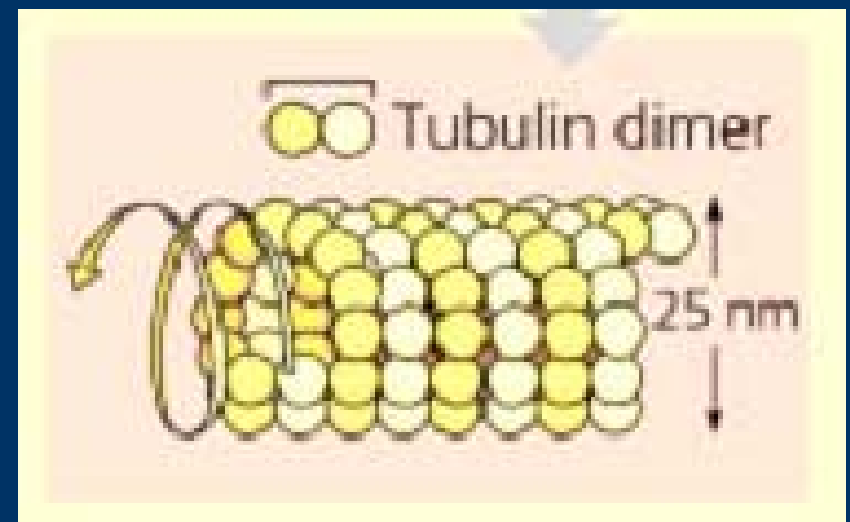
- *shape and support the cell

- *resist compression

- *serve as track along which organelle can move via motor molecule

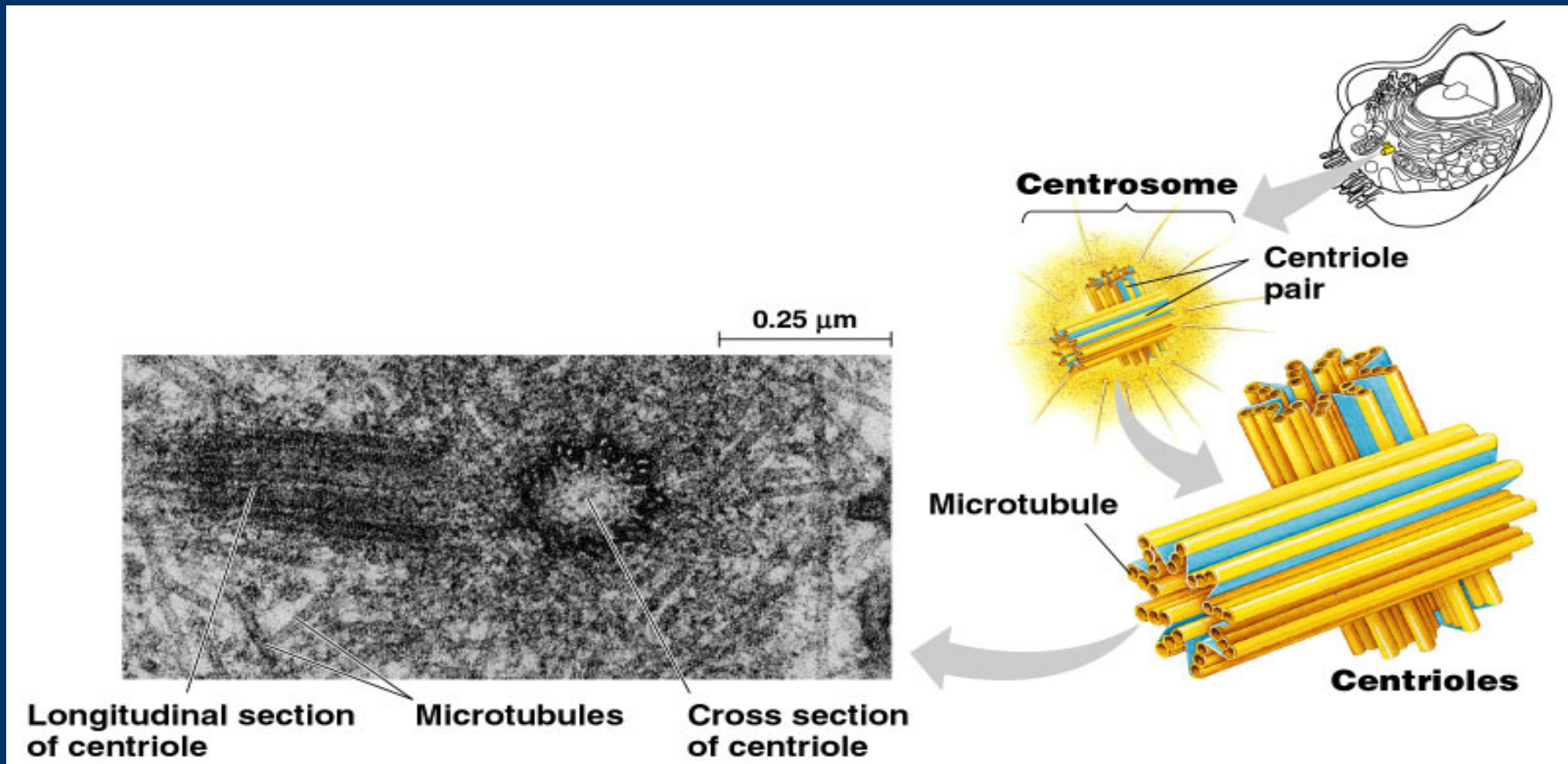
- *responsible for separation of chromosome during cell division

- *component of centrosome, centrioles, cilia and flagella



Centrosomes and Centrioles

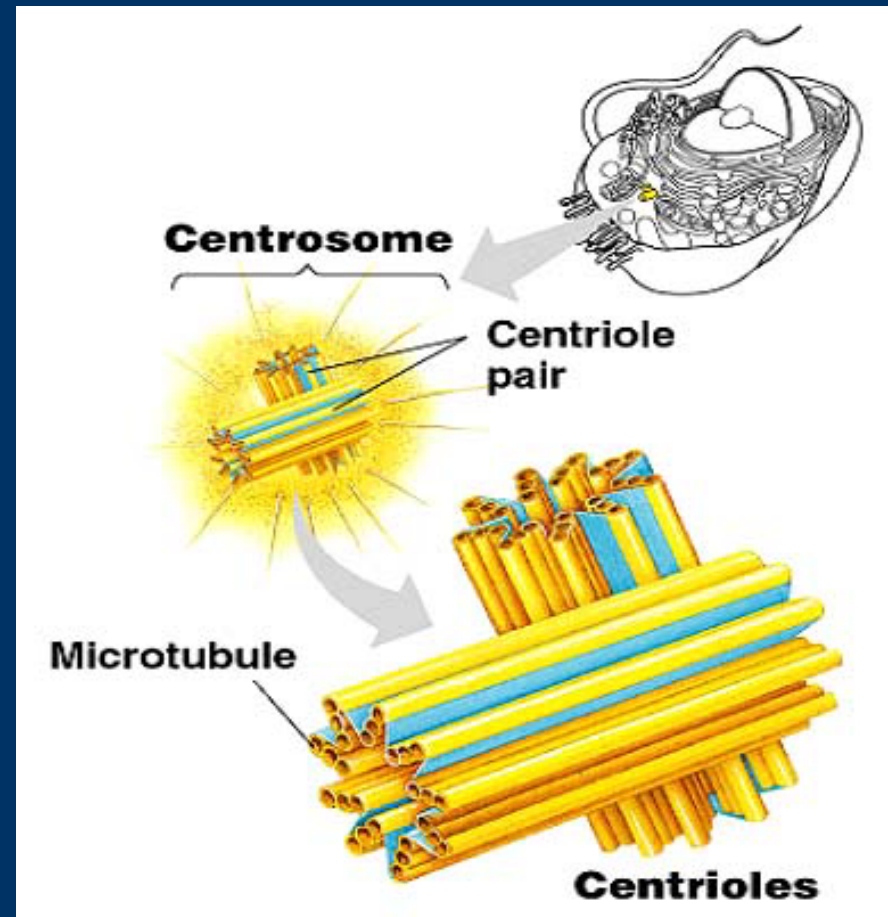
Centrosomes (microtubule-organizing center) = a region near the nucleus from which microtubules sprout.



Centrioles

- each centrosomes contain a pair of centrioles
- found in animal cells
- composed of 9 sets of triplet microtubules arranged in a ring
- centrioles replicate before cell division
- may help organize microtubule assembly

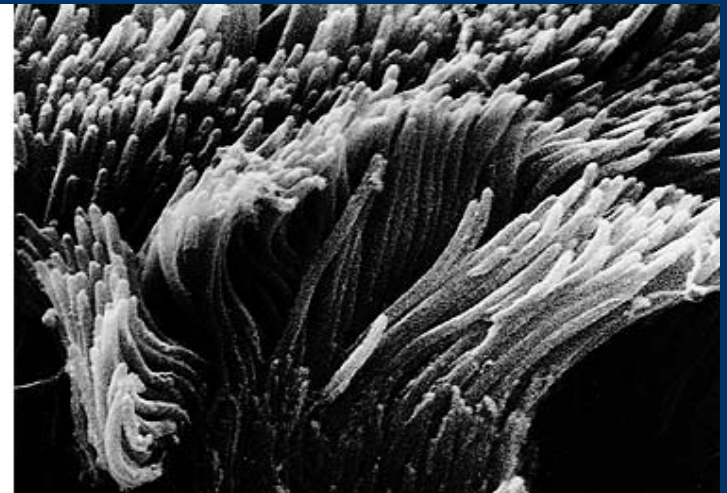
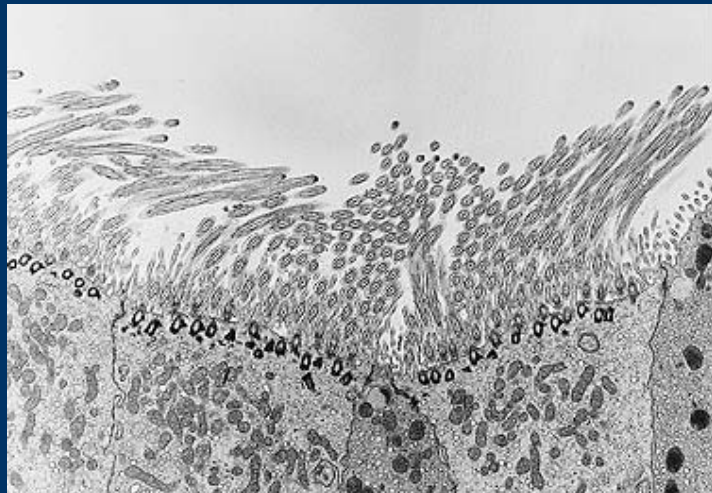
but centrioles are not essential for this function:
centrosomes of most plants lack centrioles.



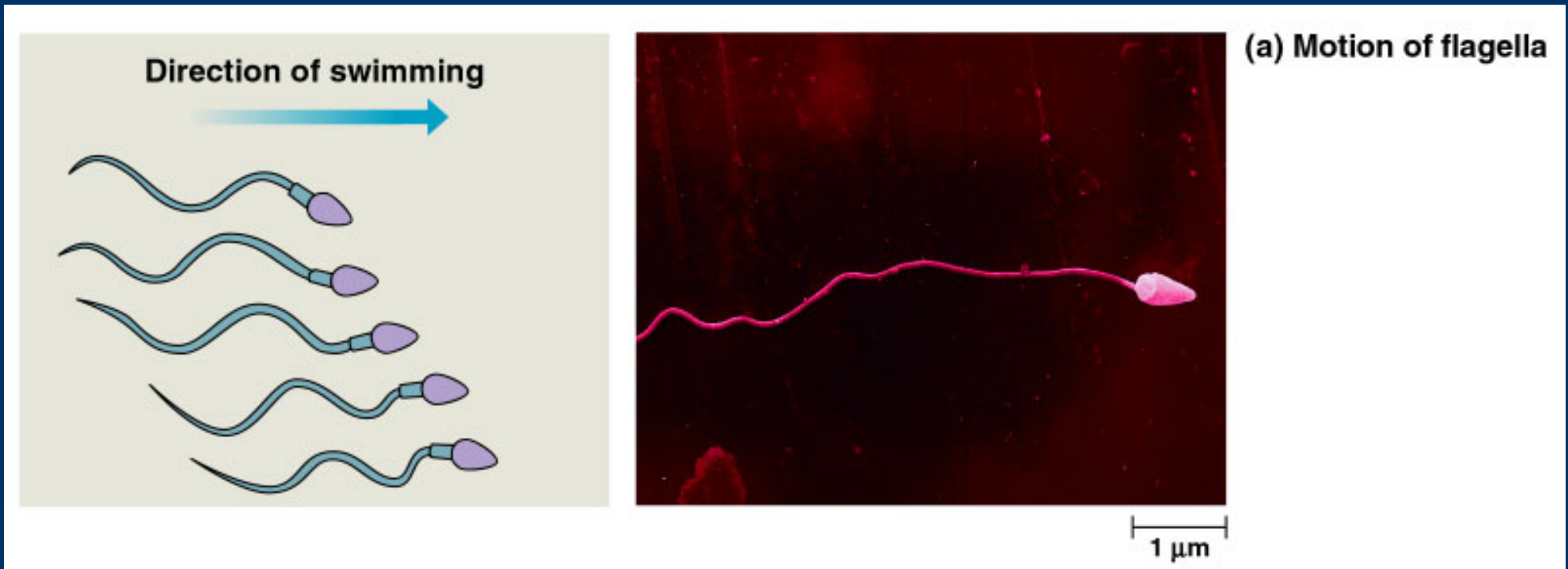
Cilia and Flagella

- both cilia and flagella are constructed from microtubules
- both provide either locomotion for the cell or move fluid pass the cell
- found in prokaryotes and eukaryotes
- cilia and flagella differ in their beating pattern

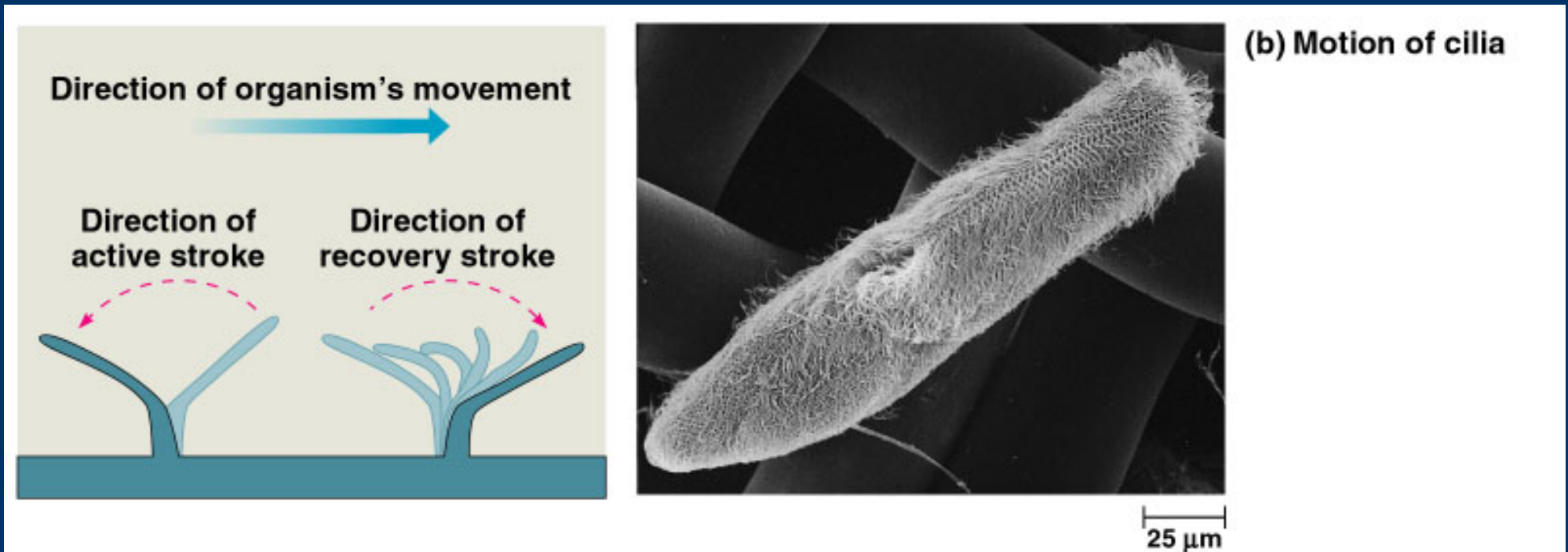
cilia sweep
mucus carrying
trapped debris
from the lungs.



A flagellum has an undulating motion that generates force in the same direction as the flagellum's axis.



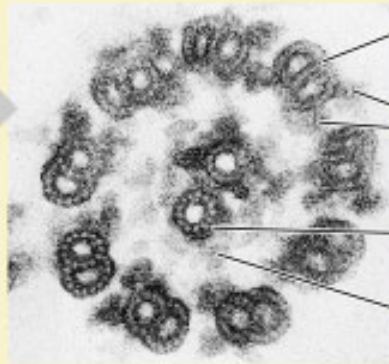
Cilia works like oars. The alternating power and recovery strokes generating force in a direction perpendicular to the cilium's axis.





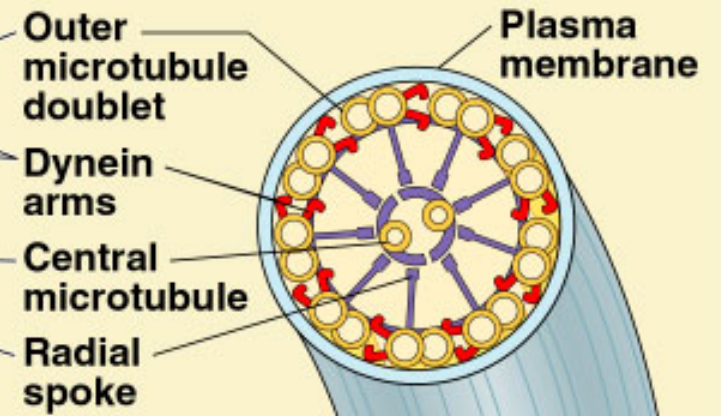
(a)

0.5 μm

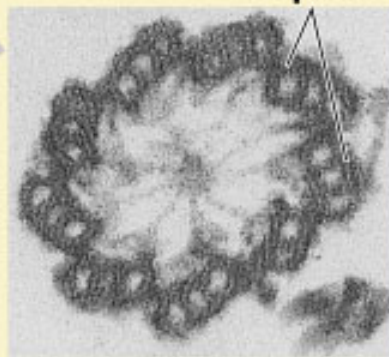


(b)

0.1 μm



(c)



(d)

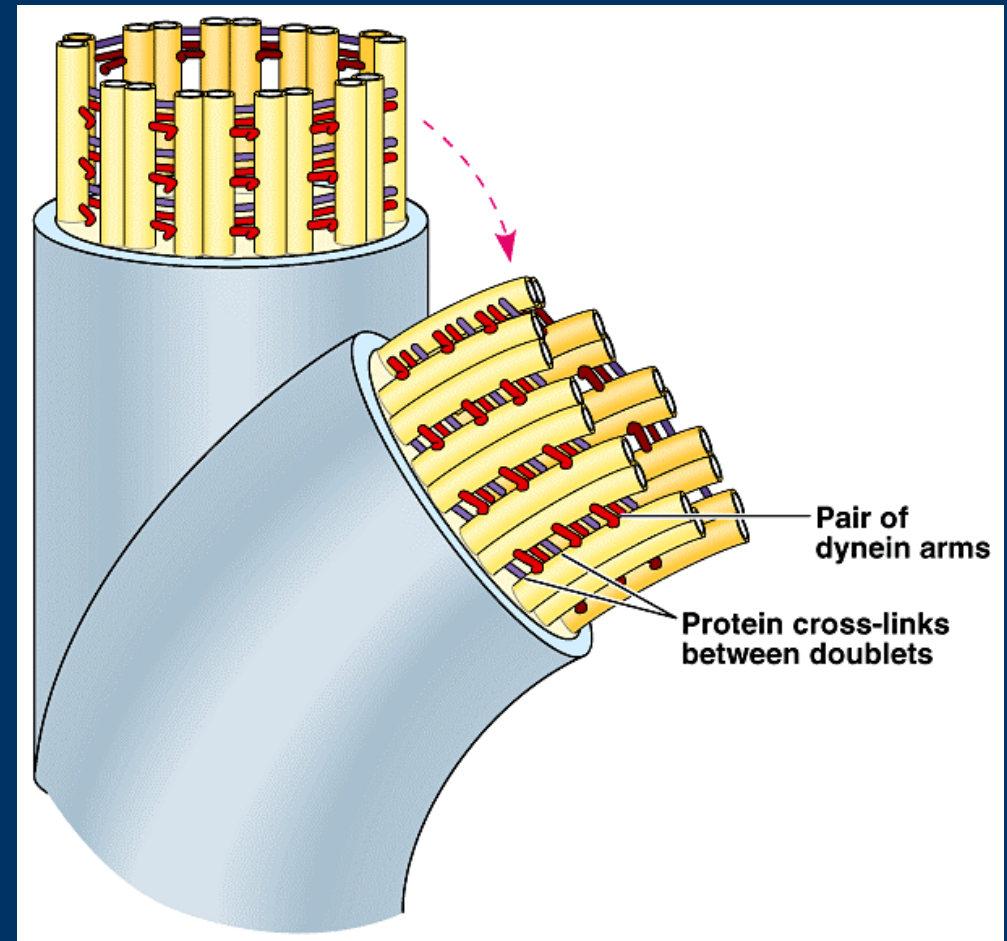
0.1 μm

-celia and flagella have the same ultrastructure =
microtubules core sheathed in an extension of
plasma membrane

-“9+2” arrangement of microtubules (9 doublets +
2 single)

-both are anchored in the cell by a basal body,
whose structure is identical to a centriole

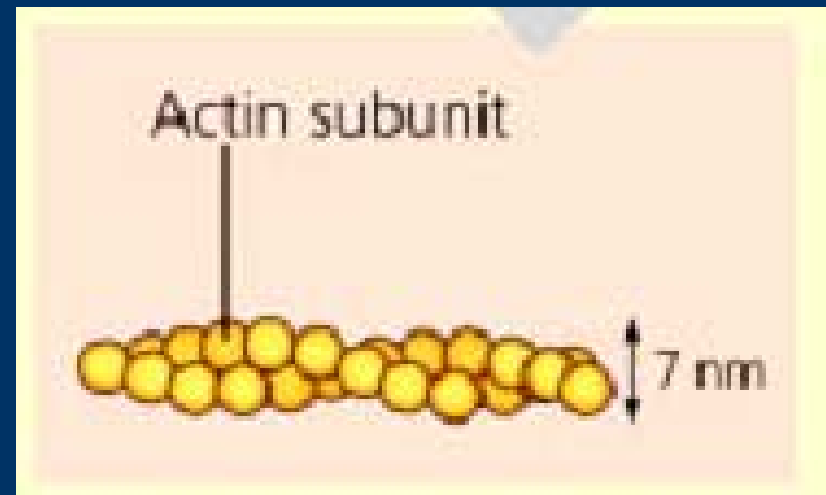
- each microtubule connects to the next by a motor molecule dynein
- dynein is responsible for the bending of cilia and flagella



- addition of phosphate group from ATP to dynein causes conformational change in this protein which result in grabbing, moving and releasing of the outer microtubule

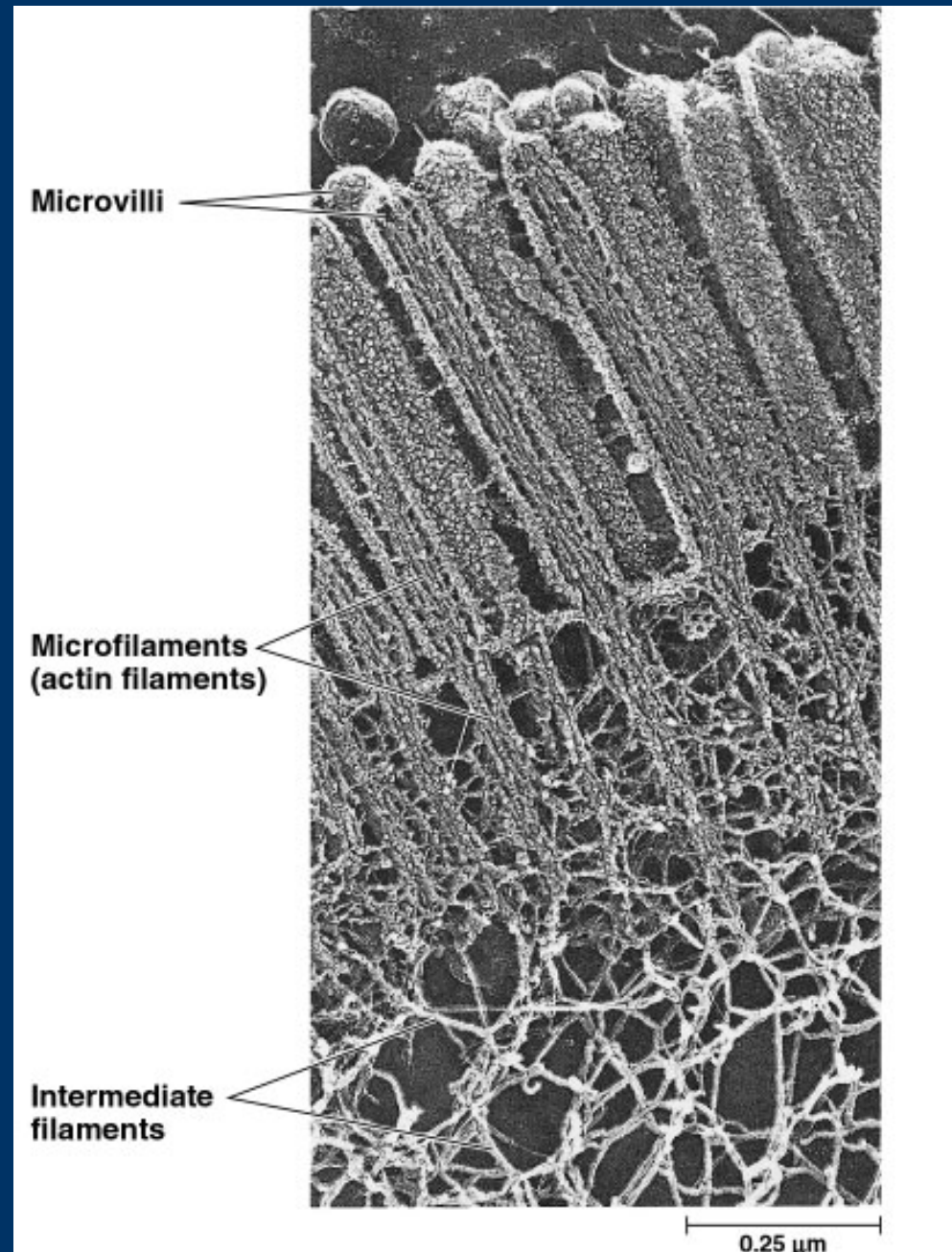
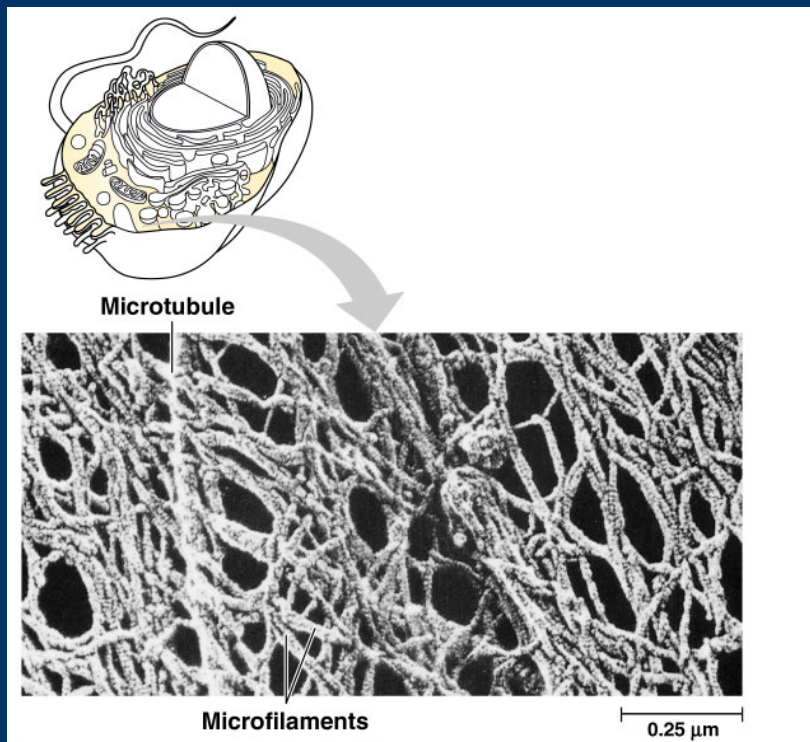
Microfilament or Actin Filament

- a twisted double chain of actin subunits of 7 nm diameter
- bear tension (pulling force)
- found in all eukaryotic cells



- combine with other protein to form a three-dimensional network beneath the plasma membrane

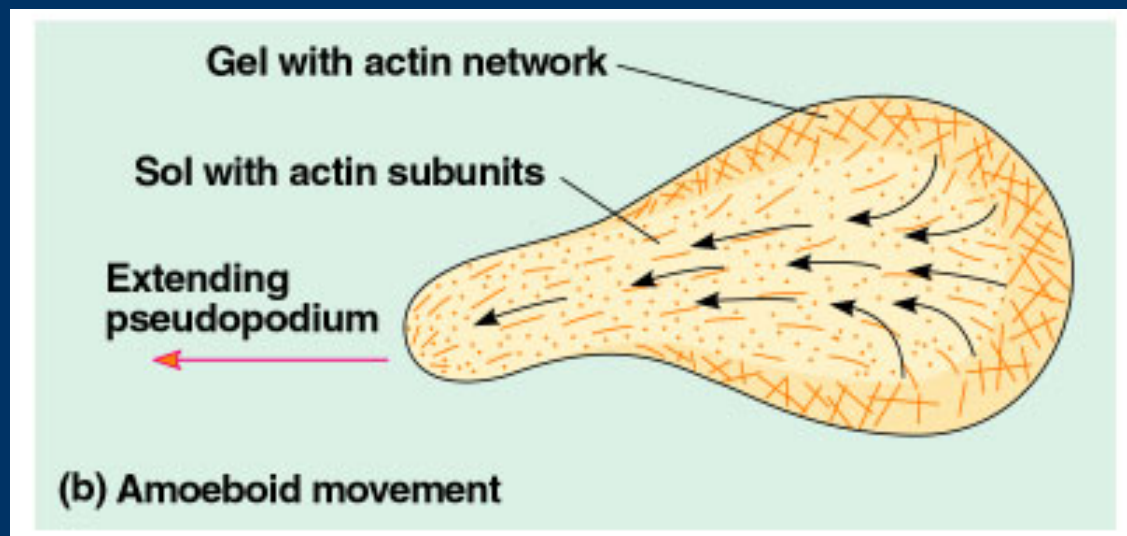
-Bundles of microfilament make up core of microvilli (to increase cell surface area) of the animal cells specialized in transport materials across plasma membrane.



-this network make the semisolid consistency of the cortex = **gel state** in the outer cytoplasmic layer

-the interior cytoplasm is the more **fluid state** (sol)

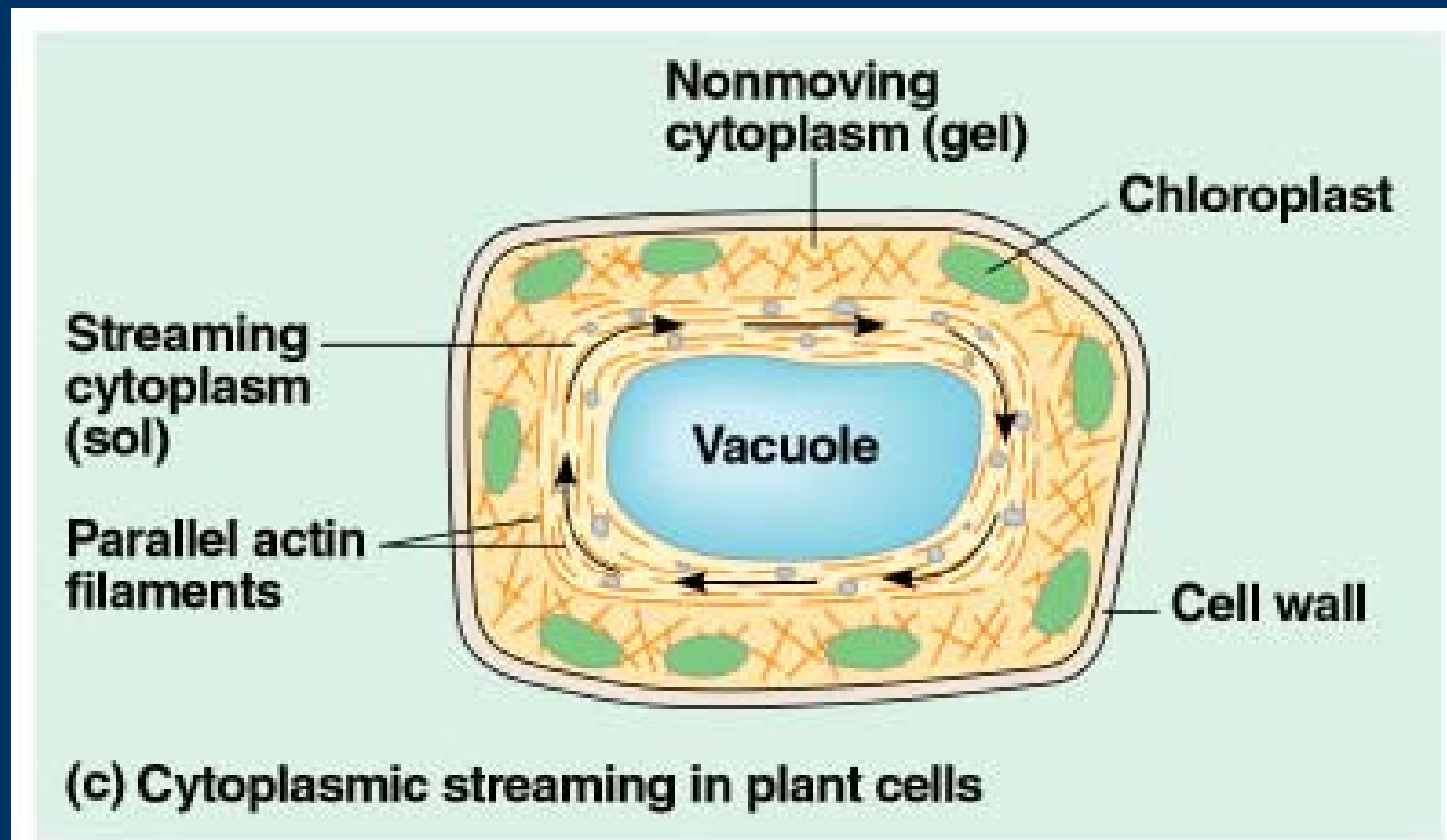
-cytoplasm can be converted between gel-sol due to the reversible assembly of microfilaments into the networks



Amoeboid movement
:Amoeba, white blood cells

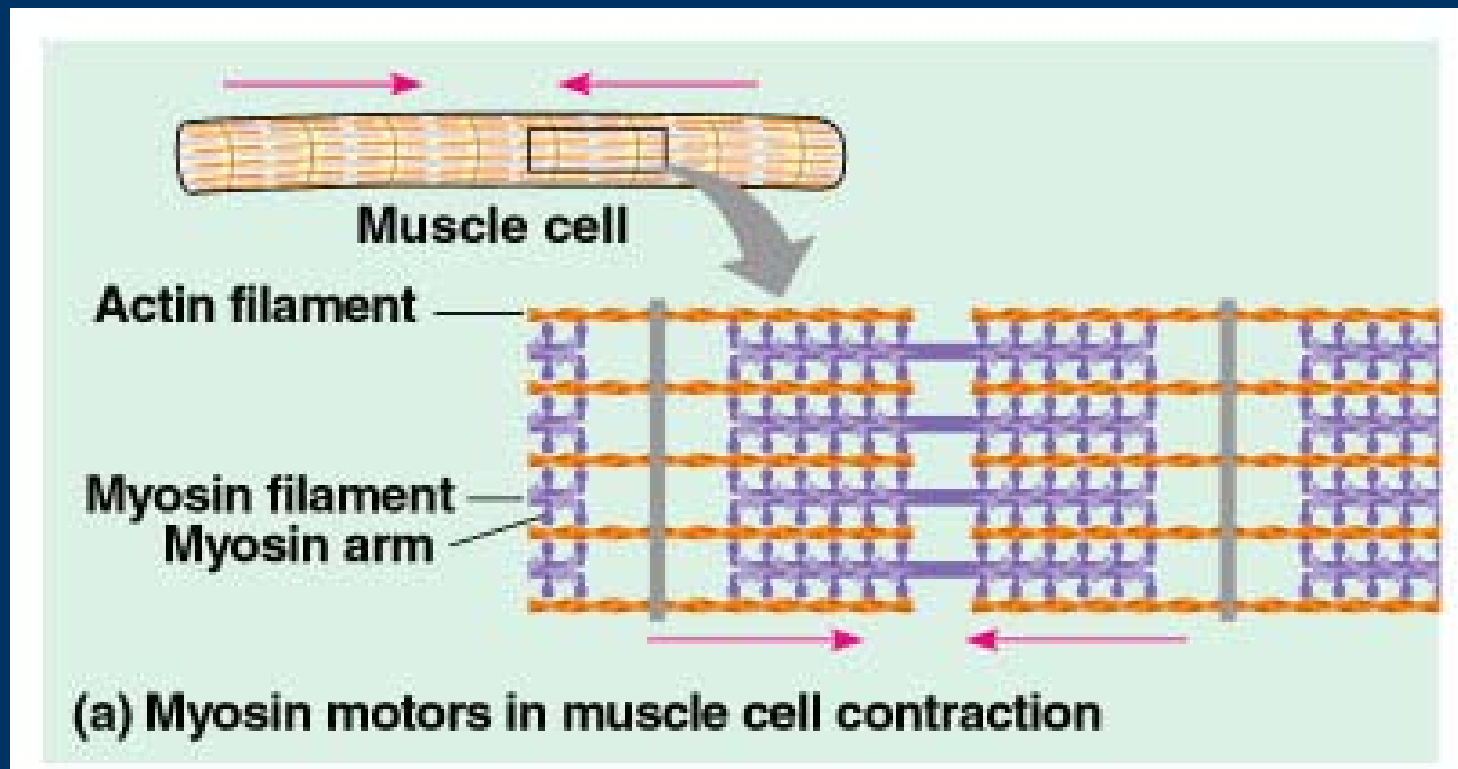
Cytoplasmic streaming: plant cells

- a circular flow of cytoplasm within cells
- this movement is a result of actin-myosin interactions and sol-gel transformations
- speed the distribution of materials within the cells



Muscle fiber

- made of actin filaments arranged parallel to one another along the length of a muscle cell
- a motor molecule myosin is interdigitated with actin filament
- muscle contraction** results from the **sliding** of actin and myosin



Intermediate filament

-cytoplasmic ropelike fibers with average 10 nm in diameter (and thus are "intermediate" in size between actin filaments (8 nm) and microtubules (25 nm))

-There are several types of intermediate filament, each constructed from one or more proteins characteristic of it.

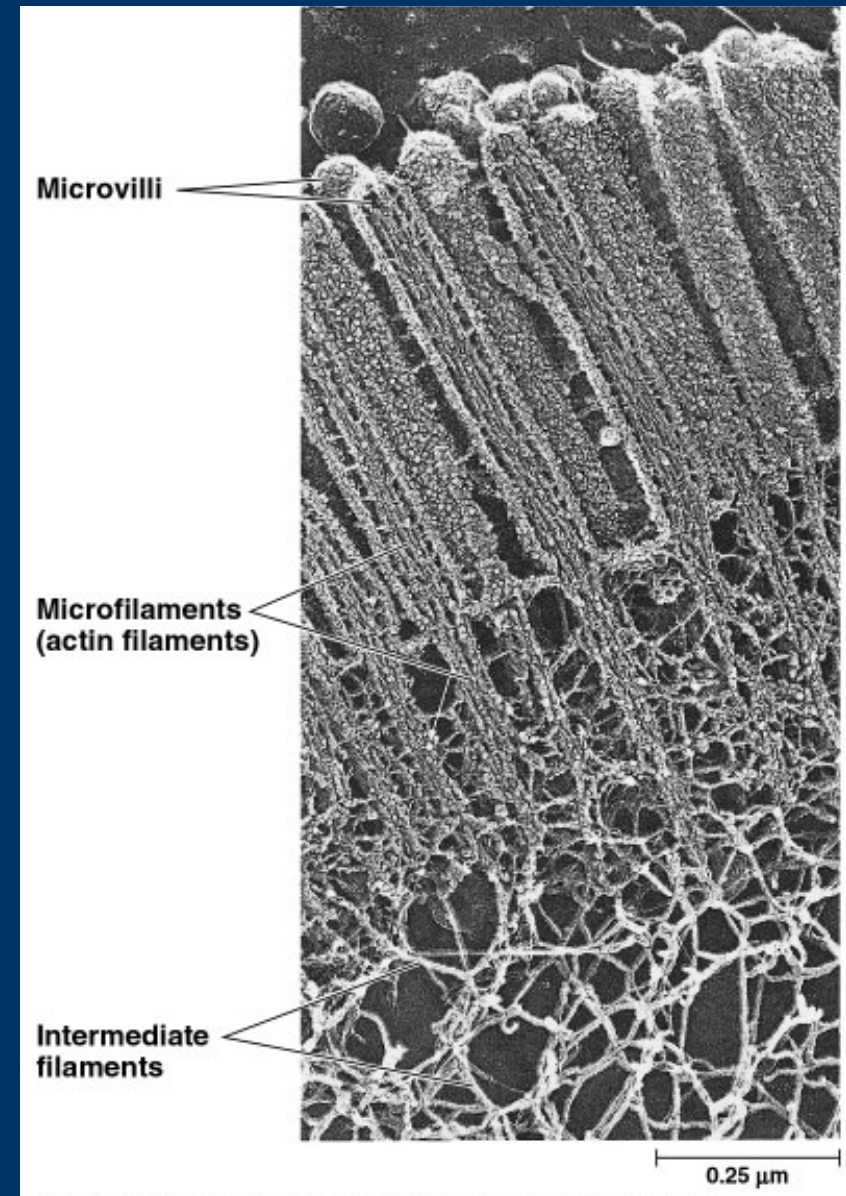
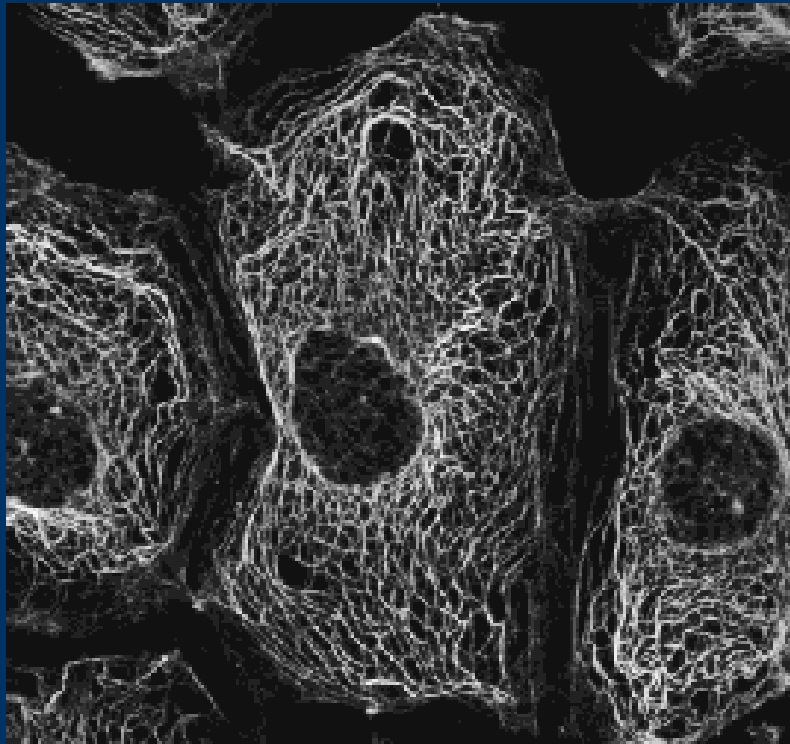
keratins are found in epithelial cells and also form hair and nails (over 20 different kinds of keratins have been found)

nuclear **lamins** form a meshwork that stabilizes the inner membrane of the nuclear envelope

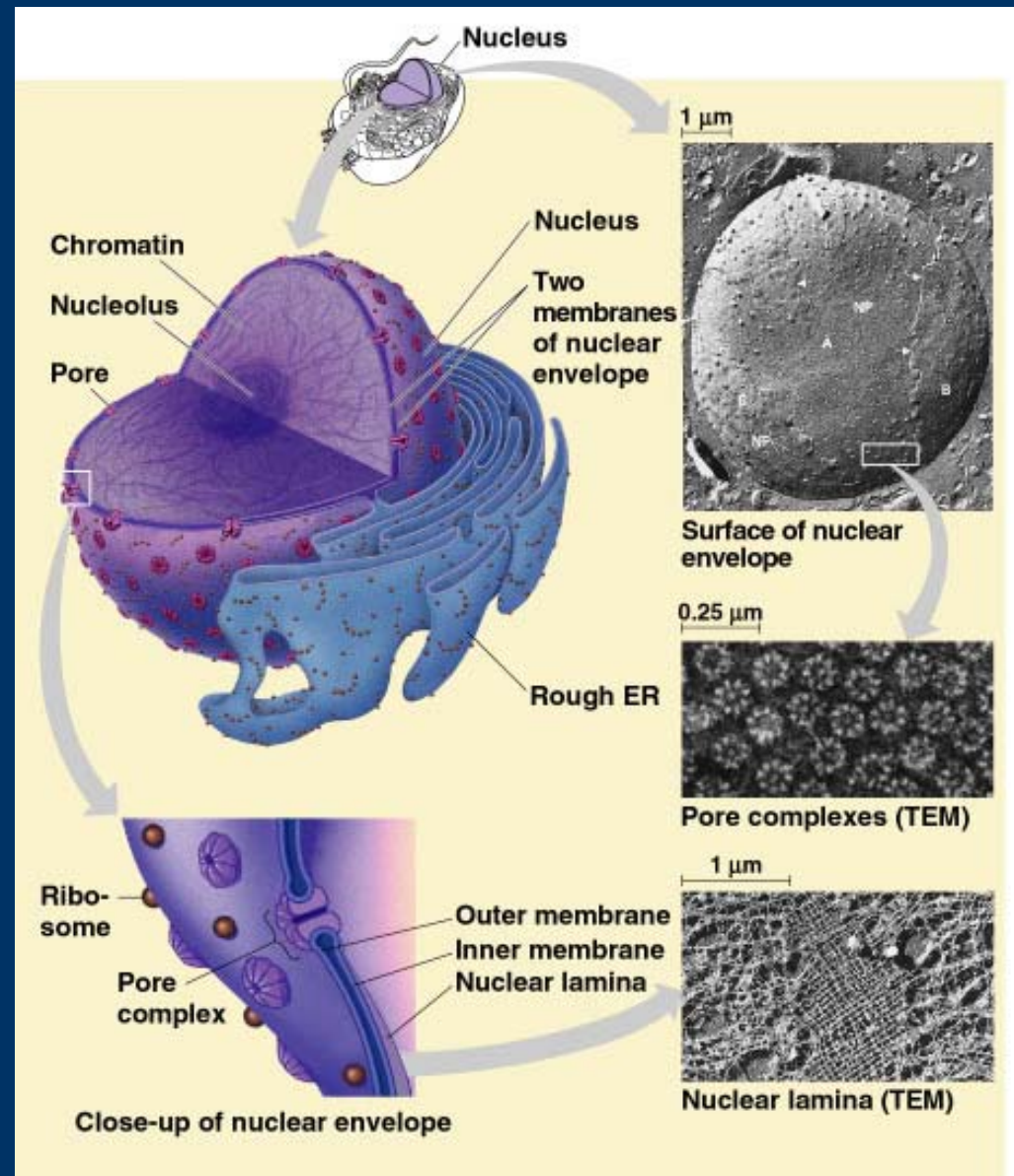
neurofilaments strengthen the long axons of neurons;

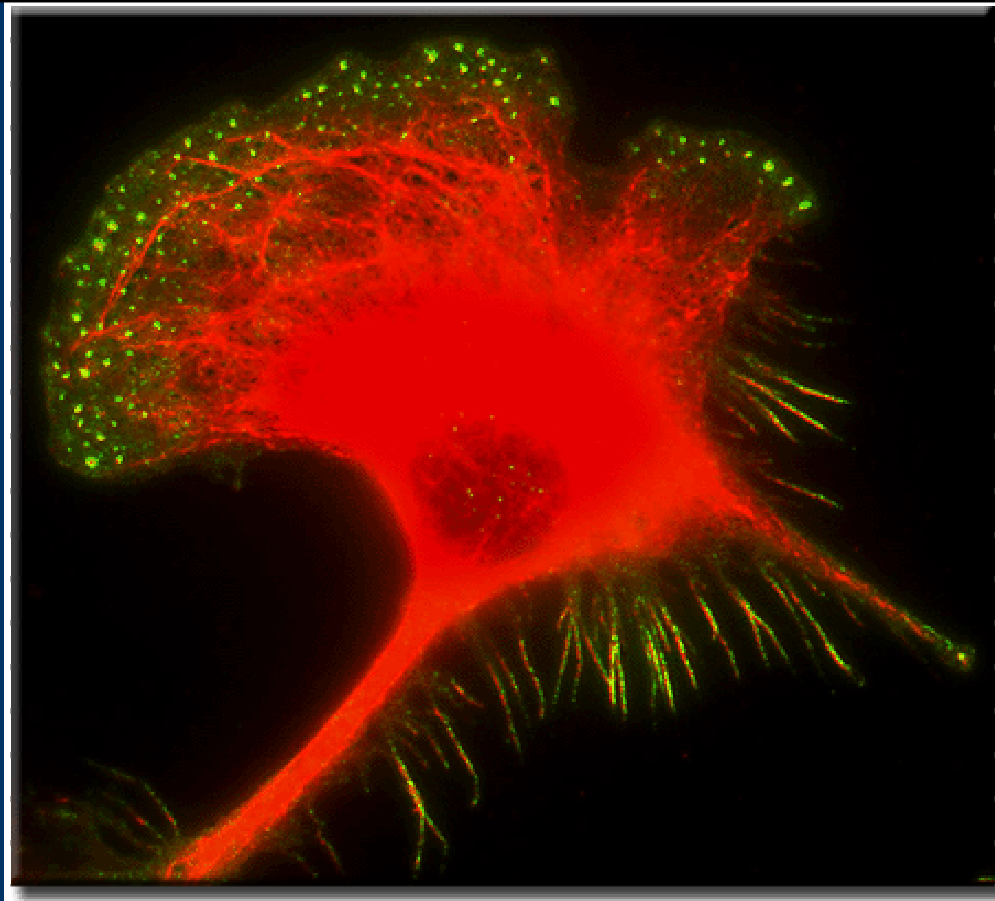
vimentins provide mechanical strength to muscle (and other) cells.

Despite their chemical diversity, intermediate filaments play similar roles in the cells: providing a supporting framework within the cells



-other intermediate filaments make up the nuclear lamina that lines the interior of the nuclear envelope





The vimentin intermediate filament network (red) extends into the lamella where tetramers colocalize with the actin-bundling protein, fimbrin (green). These fluorescent foci are specialized focal adhesions found in **osteoclasts** and macrophages called podosomes

-intermediate filaments strengthen the long extension (axon) of nerve cells that transmit impulse

