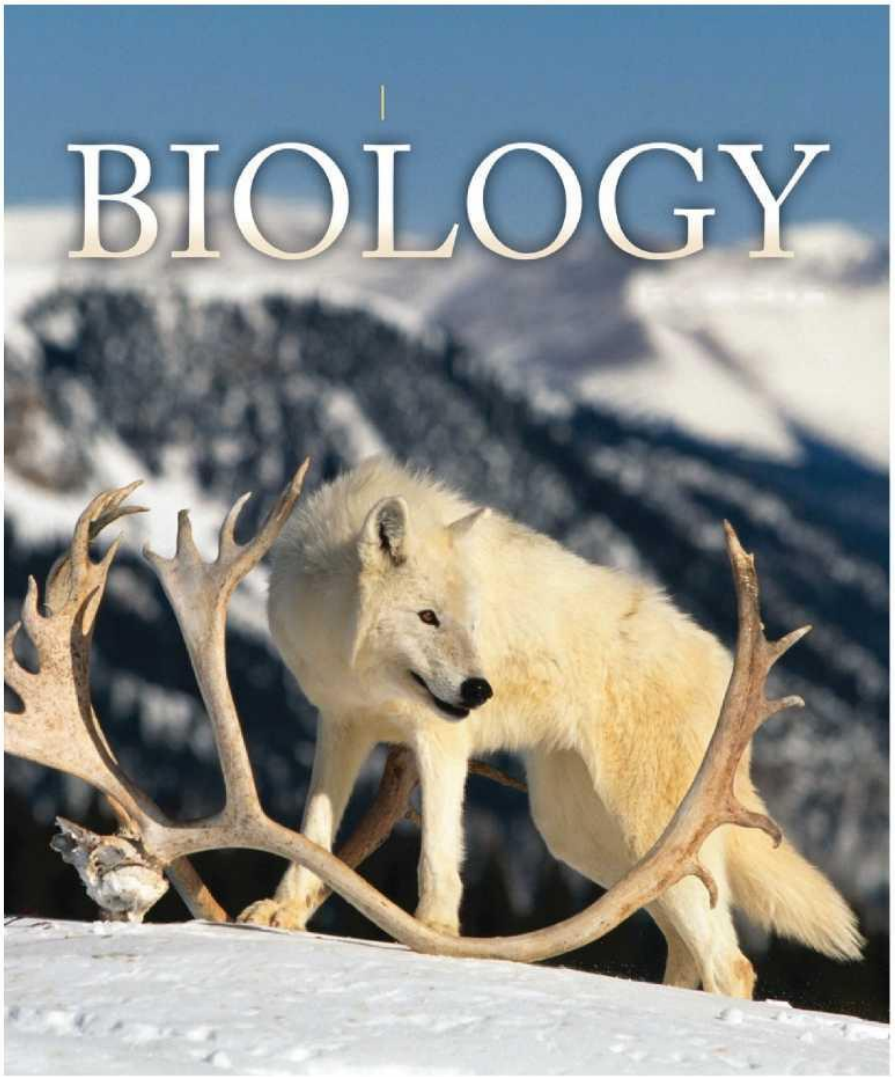
NATIONAL UNIVERSITY OF PHARMACY

DEPARTMENT OF VETERINARY MEDICINE AND PHARMACY



Lecture on Biology and genetics principles specialty 226 Pharmacy

Cell Structure and Functions

Lecturer: associate professor Department of Veterinary medicine and pharmacy Ph.D. Dotsenko Roman Valeryevich

LECTURE PLAN

- Cellular Level of Organization
- Introducing Eukaryotic Cells
- The Nucleus and Ribosomes
- The Endomembrane System
- Other Vesicles and Vacuoles
- Energy-Related Organelles
- The Cytoskeleton

Recommended literature

Maloshtan L.M., Filiptsova O.V. 2011. Biology and genetics principles, Publisher house of NUPh, Kharkiv, pp. 4-18,56-68.

https://www.britannica.com/list/6-cell-organelles

Craig, Nancy (2014). Molecular Biology, Principles of Genome Function. ISBN 978-0-19-965857-2.

Darwin, Charles (1859). *On the Origin of Species*, John Murray.

"biology, n". Oxford English Dictionary online version. Oxford University Press. September 2011. Retrieved 1 November 2011.

Microbiology: A Guide to Laboratory Lessons. Study a manual for students of higher educational institutions / IL Wild, I.I. Sidorchuk, I.Yu. Kholupiak, N.E. Sheveleva, MM Great, N.A. Volkova, L.F. Silayeva, O.P. Strilec, O.G. Heyderich, V.E. Litarov - Kh.: Publishing house of NfaU; Golden Pages, 2002. 444 p.

Properties of life

- Reproduction :
  - sexual : genetic variation, fertilization
  - asexual : genetically identical, e.g. sporulation, budding, regeneration, binary fission
- Metabolism : anabolism Vs. catabolism
- Growth and Development
- Response to environment
- Homeostasis : regulated via organ system
- Organization : Cell, tissue, organ, organ system, organism
  - acellular
  - unicellular : bacteria, yeast
  - multicellular : plant, animal

Cell Theory

- All organisms are composed of cells
- All cells come only from preexisting cells (Rudolf Virchow)
- Cells are the smallest structural and functional unit of organisms
- Cells carry genetic information in the form of DNA

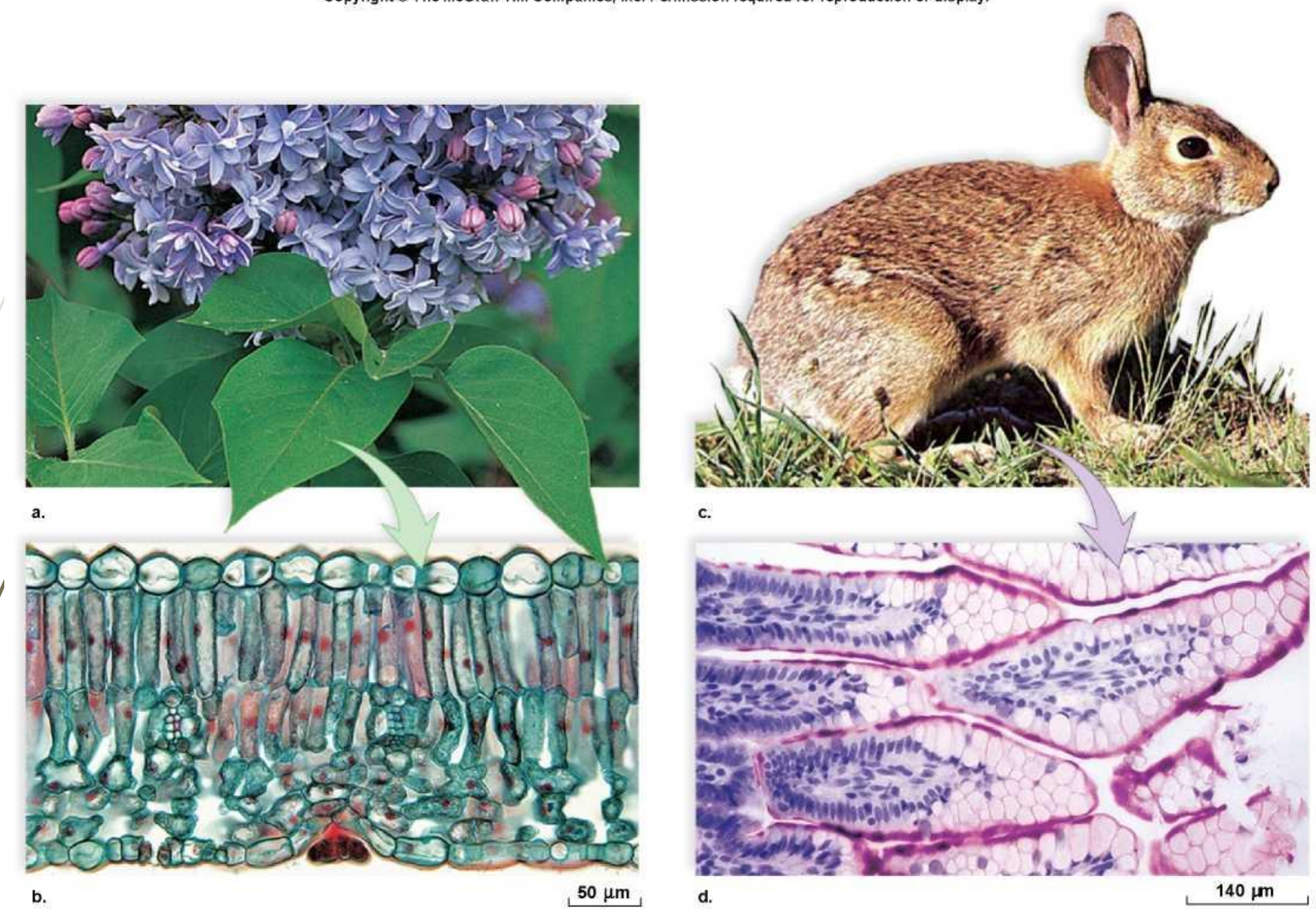
Robert Hooke (1665)

Antony van Leeuwenhoek (1673)

Matthias Jacob Schleiden (1838) plant

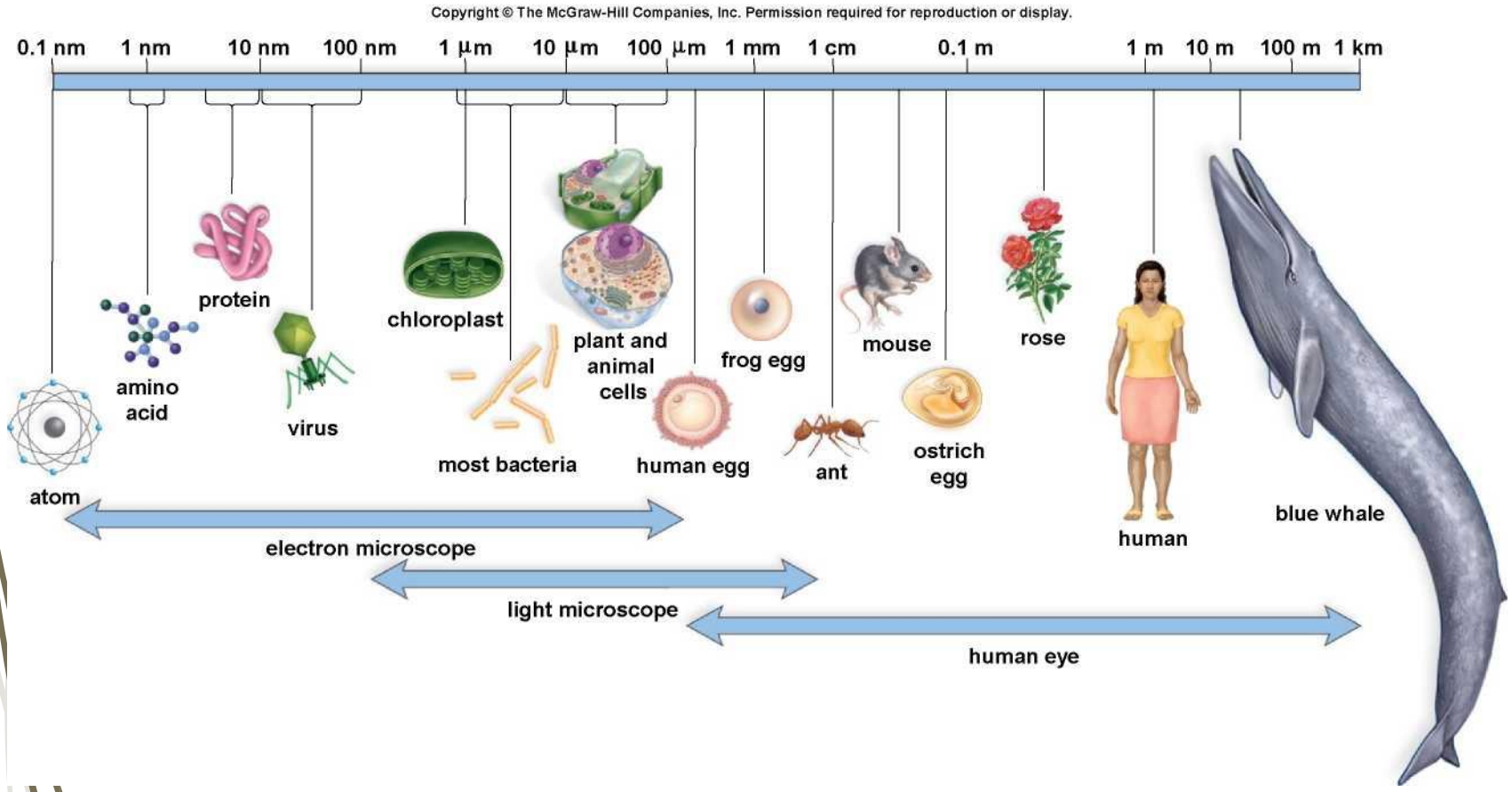
Theodor Schwann (1839) animal

Organisms and Cells



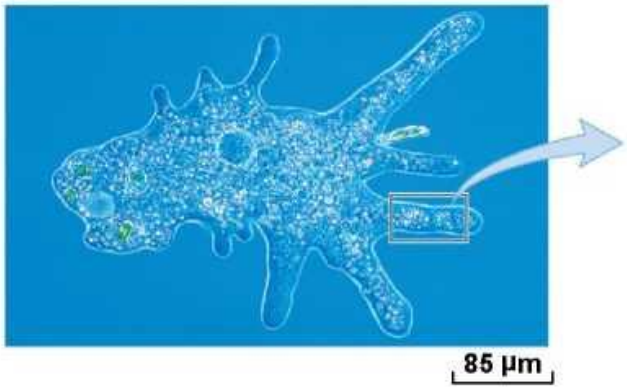
a: © Geoff Bryant/Photo Researchers, Inc.; b: Courtesy Ray F. Evert/University of Wisconsin Madison;
c: © Barbara J. Miller/Biological Photo Service; d: Courtesy O. Sabatakou and E. Xylouri-Frangiadak

Sizes of Living Things

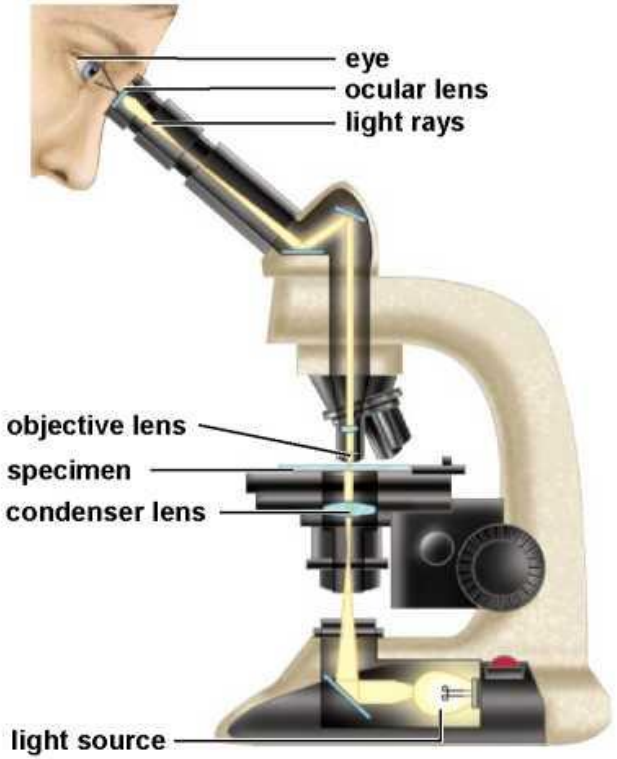


Microscopy Today: Compound Light Microscope

- Light passed through specimen
- Focused by glass lenses
- Image formed on human retina
- Max magnification about 1000X
- Resolves objects separated by 0.2 mm, 500X better than human eye



amoeba, light micrograph

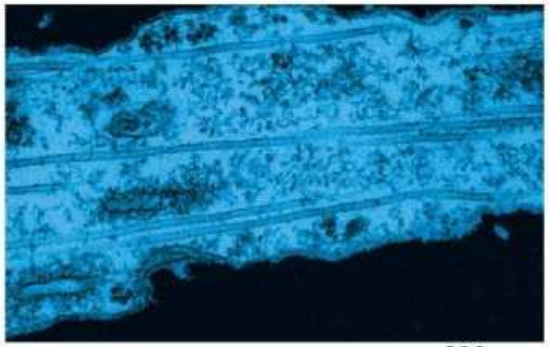


a. Compound light microscope

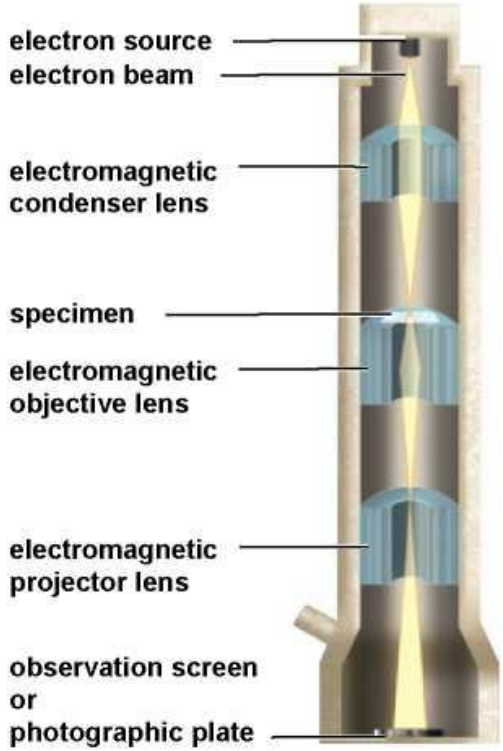
Compound Light Microscope

Electron Microscope

- Electrons passed through specimen
- Focused by magnetic lenses
- Image formed on fluorescent screen
  - Similar to TV screen
  - Image is then photographed
- Greater magnification than Compound Light Microscope
- Resolves objects separated by 0.0002 mm, 100,000X better than human eye [1]



pseudopod segment, transmission electron micrograph

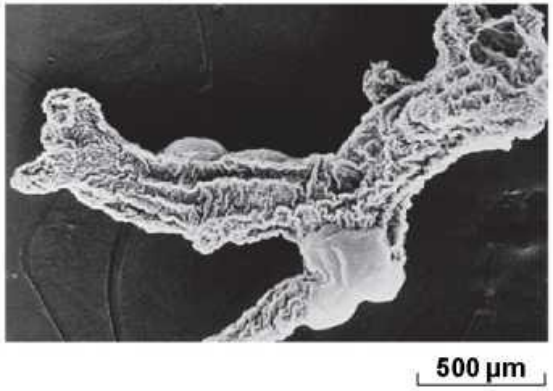


b. Transmission electron microscope

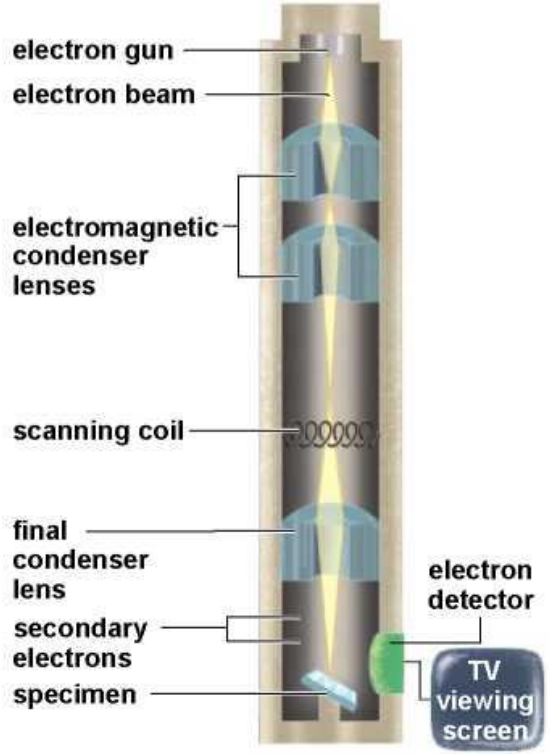
Transmission Electron Microscope

Scanning Electron Microscope

- Abbreviated S.E.M.
- Specimen sprayed with thin coat of metal
  - Electron beam scanned across surface of specimen
  - Metal emits secondary electrons
- Emitted electrons focused by magnetic lenses
- Image formed on fluorescent screen
  - Similar to TV screen
  - Image is then photographed



amoeba, scanning electron micrograph



c. Scanning electron microscope

Scanning Electron Microscope

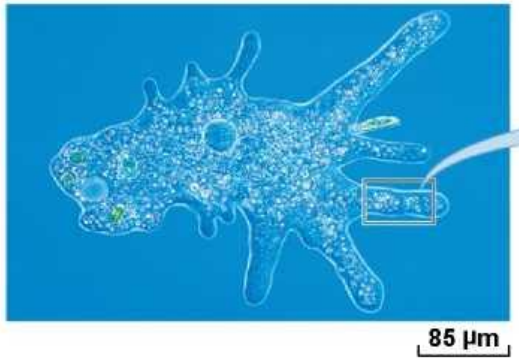
Immunofluorescence Light Microscope

- Antibodies developed against a specific protein
  - Fluorescent dye molecule attached to antibody molecules
  - Specimen exposed to fluorescent antibodies
- Ultra-violet light (black light) passed through specimen
  - Fluorescent dye glows in color where antigen is located
  - Emitted light is focused by glass lenses onto human retina
- Allows mapping distribution of a specific protein in cell

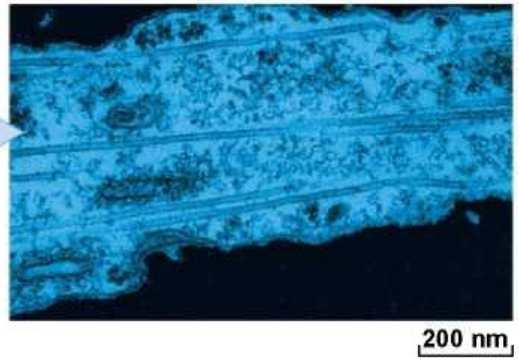
Confocal Microscopy

- Narrow laser beam scanned across transparent specimen
- Beam is focused at a very thin plane
- Allows microscopist to optically section a specimen
  - Sections made at different levels
  - Allows assembly of three-dimensional image on computer screen that can be rotated

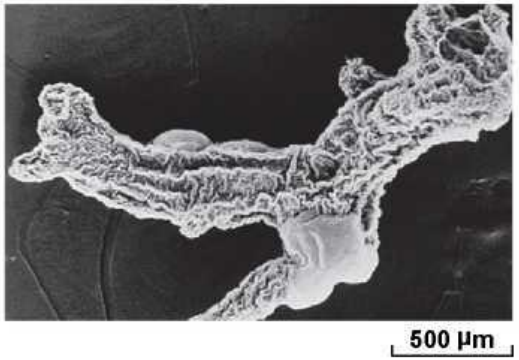
Microscopy *Amoeba proteus*



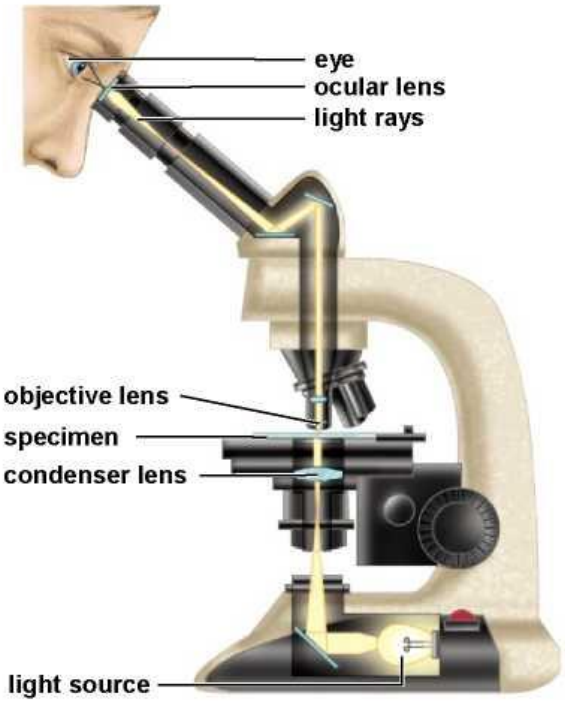
amoeba, light micrograph



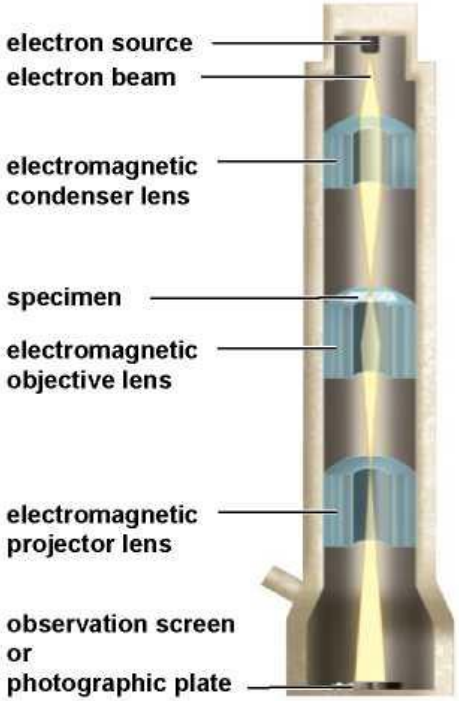
pseudopod segment, transmission electron micrograph



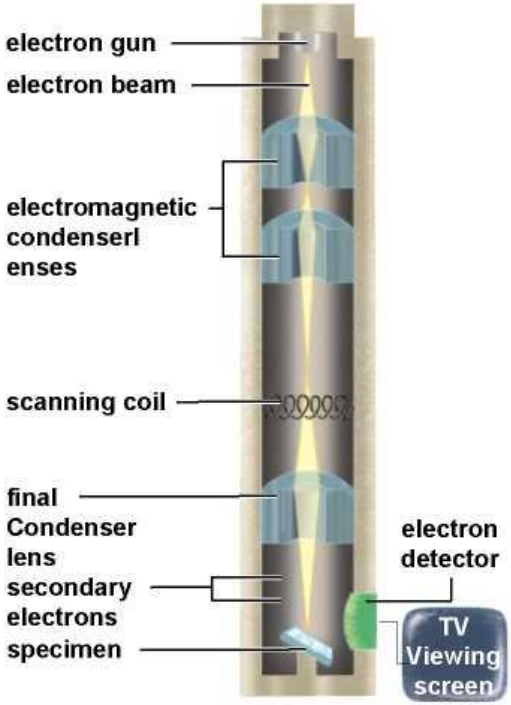
amoeba, scanning electron micrograph



a. Compound light microscope

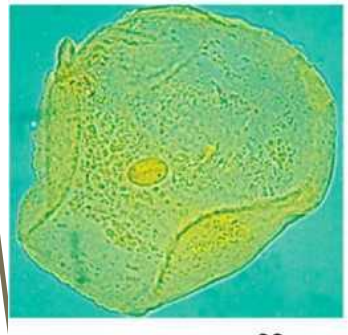


b. Transmission electron microscope

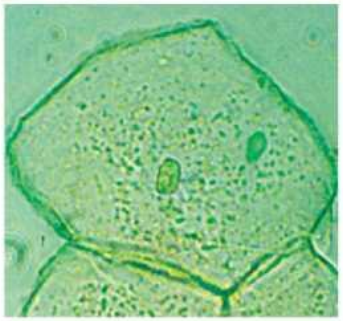


c. Scanning electron microscope

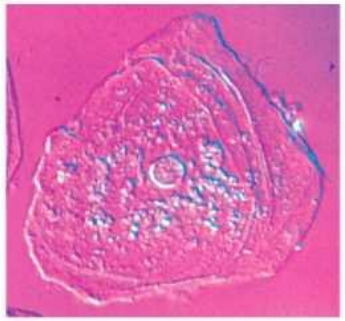
Microscopy and Cheek Cells



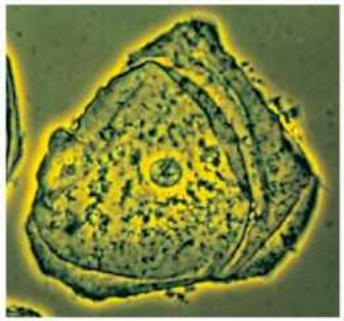
Bright-field. Light passing through the specimen is brought directly into focus. Usually, the low level of contrast within the specimen interferes with viewing but its largest component



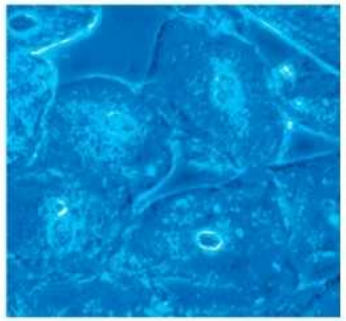
Bright-field (stained). dyes are used to stain the specimen. Certain components take up the dye more than other components, and therefore contrast is enhanced.



Differential interference contrast. Optical methods are used to enhance density differences within the specimen so that certain regions appear brighter than others. This technique is used to view living cells, chromosomes, and organelle masses.

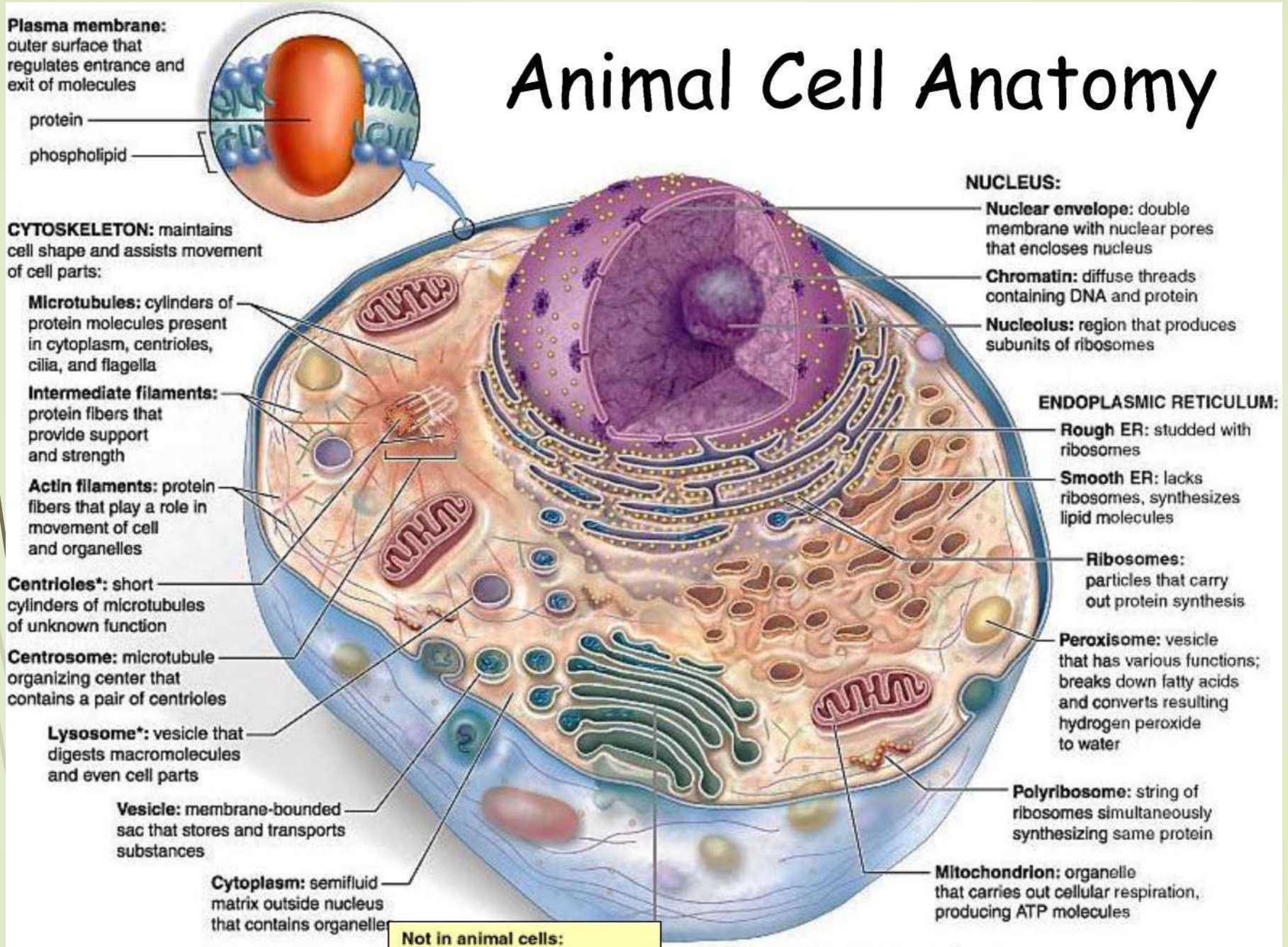


Phase contrast. Density differences in the specimen cause light rays to come out of "phase." The microscope enhances these phase differences so that some regions of the specimen appear brighter or darker than others. The technique is widely used to observe living cells and organelles.



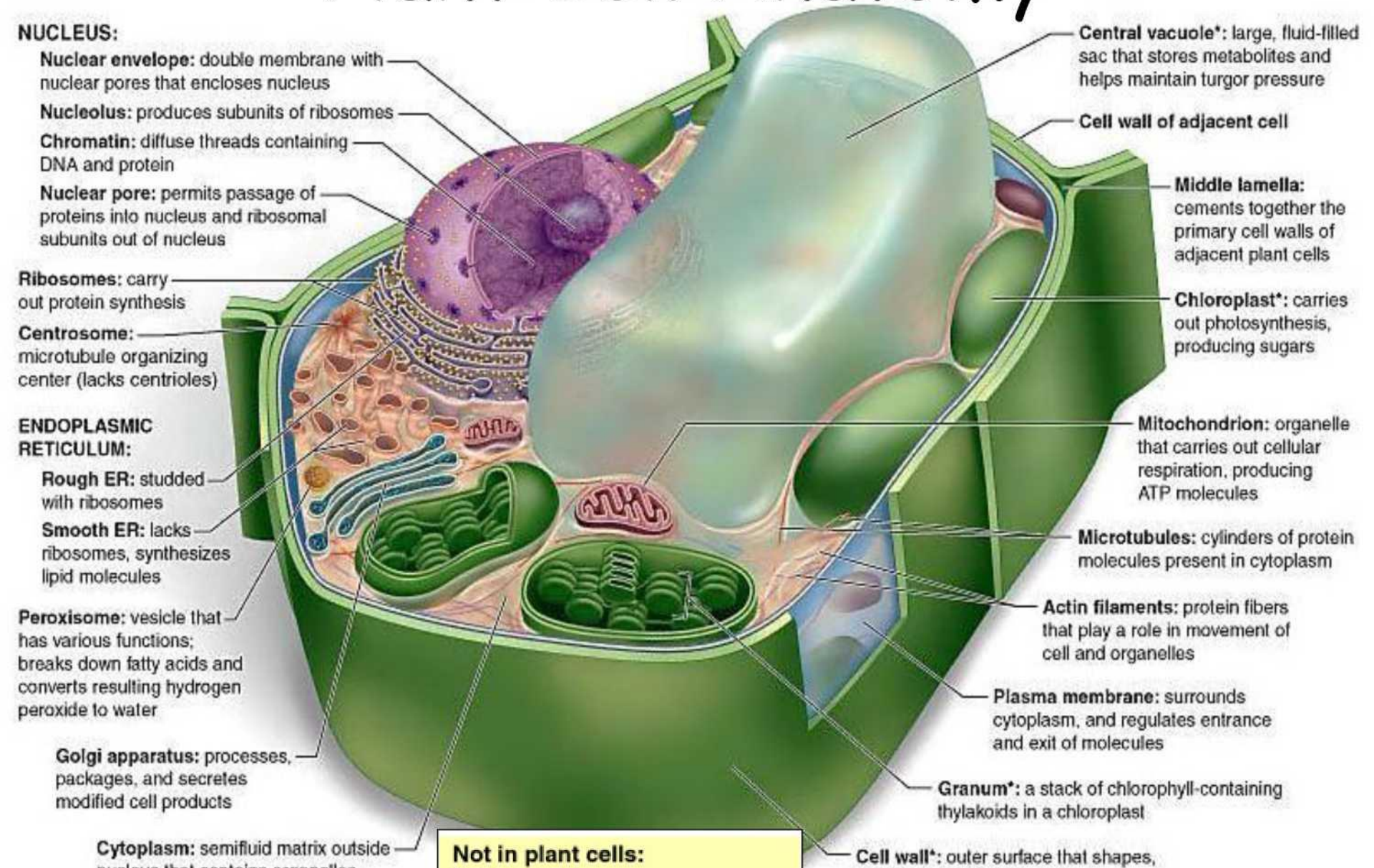
Dark-field. Light is passed through the specimen at an oblique angle so that the objective lens receives only light diffracted and scattered by the object. This technique is used to view organelles, which appear quite bright against a dark field.

Animal Cell Anatomy



http://traddude.blogspot.com/2008/06/cells-compendium-1.html

Plant Cell Anatomy

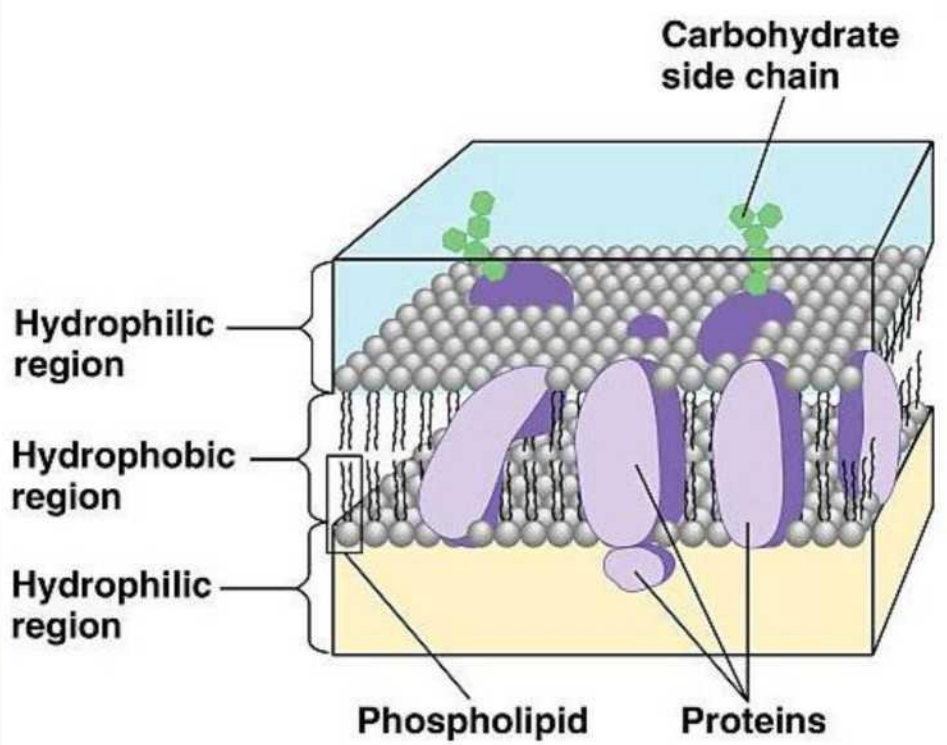


Not in plant cells:
Lysosomes
Centrioles
Flagella (in some plant sperm)

http://minhalogia.blogspot.com/2013_03_01_archive.html

Plasma membrane

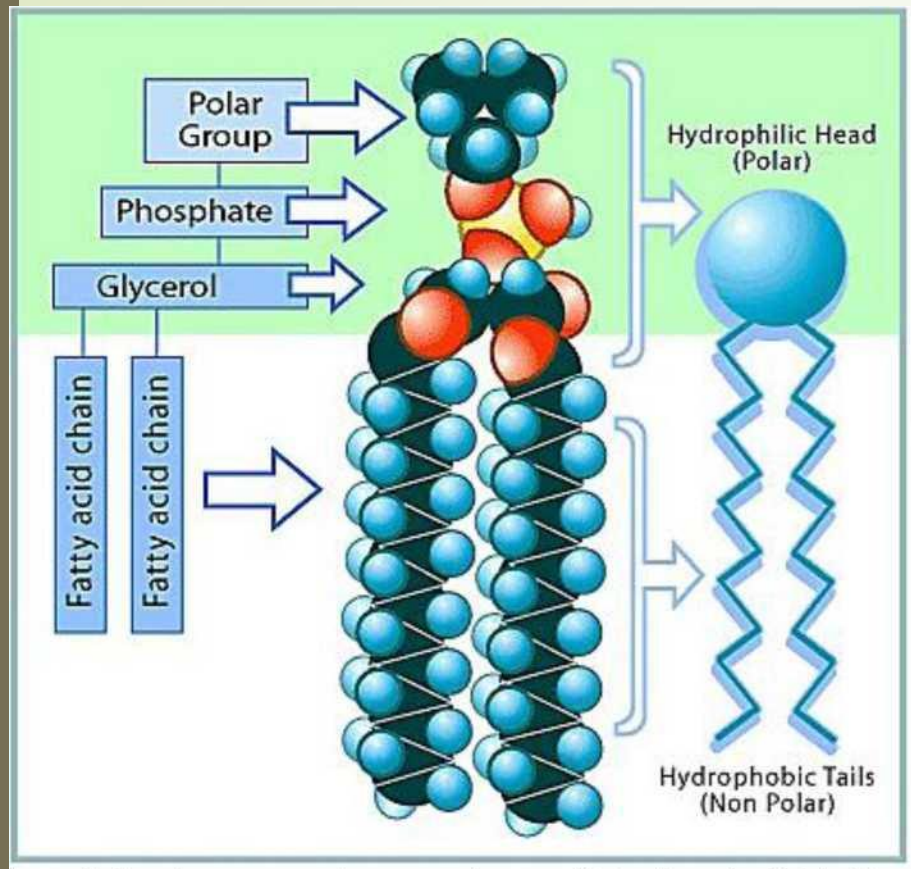
- Fluid mosaic model
  - Phospholipid bilayer acts more like a fluid than a liquid
- Contains integral and peripheral proteins
- Semi permeable membrane
- Like a city border they surround the cell and are able to regulate entrance and exit



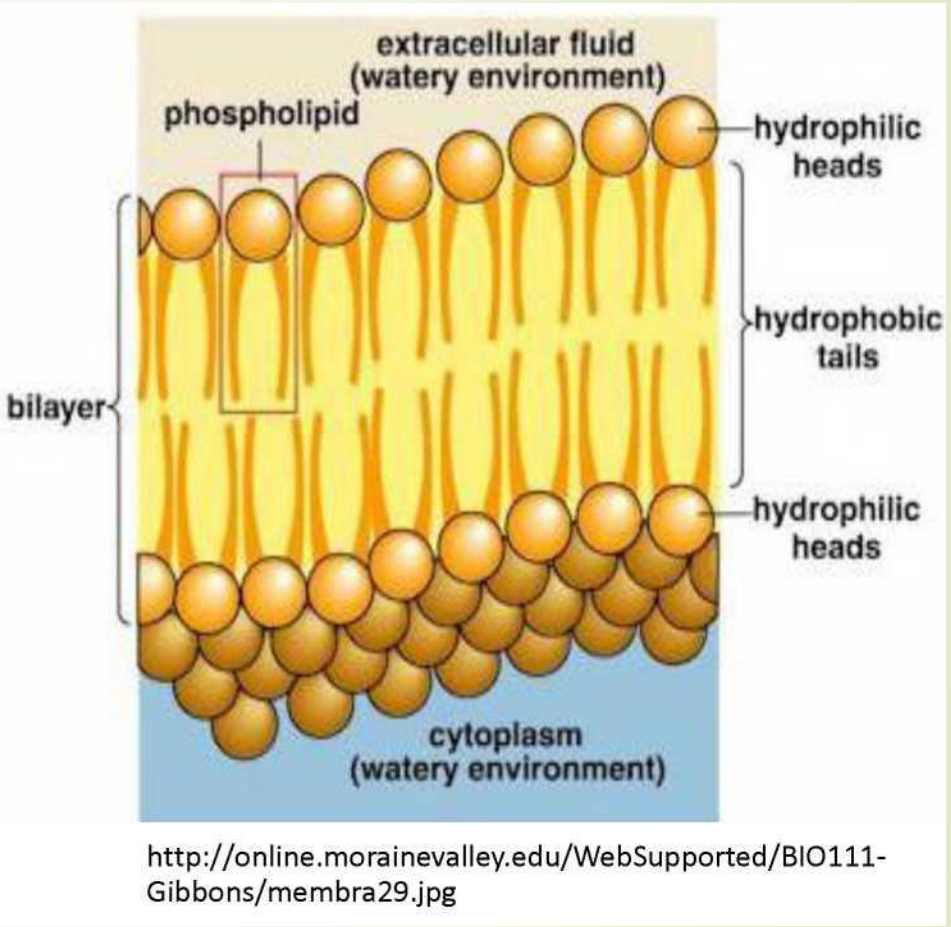
(b) Structure of the plasma membrane

Campbell *et al*, Biology; 2009.

Phospholipid bilayer

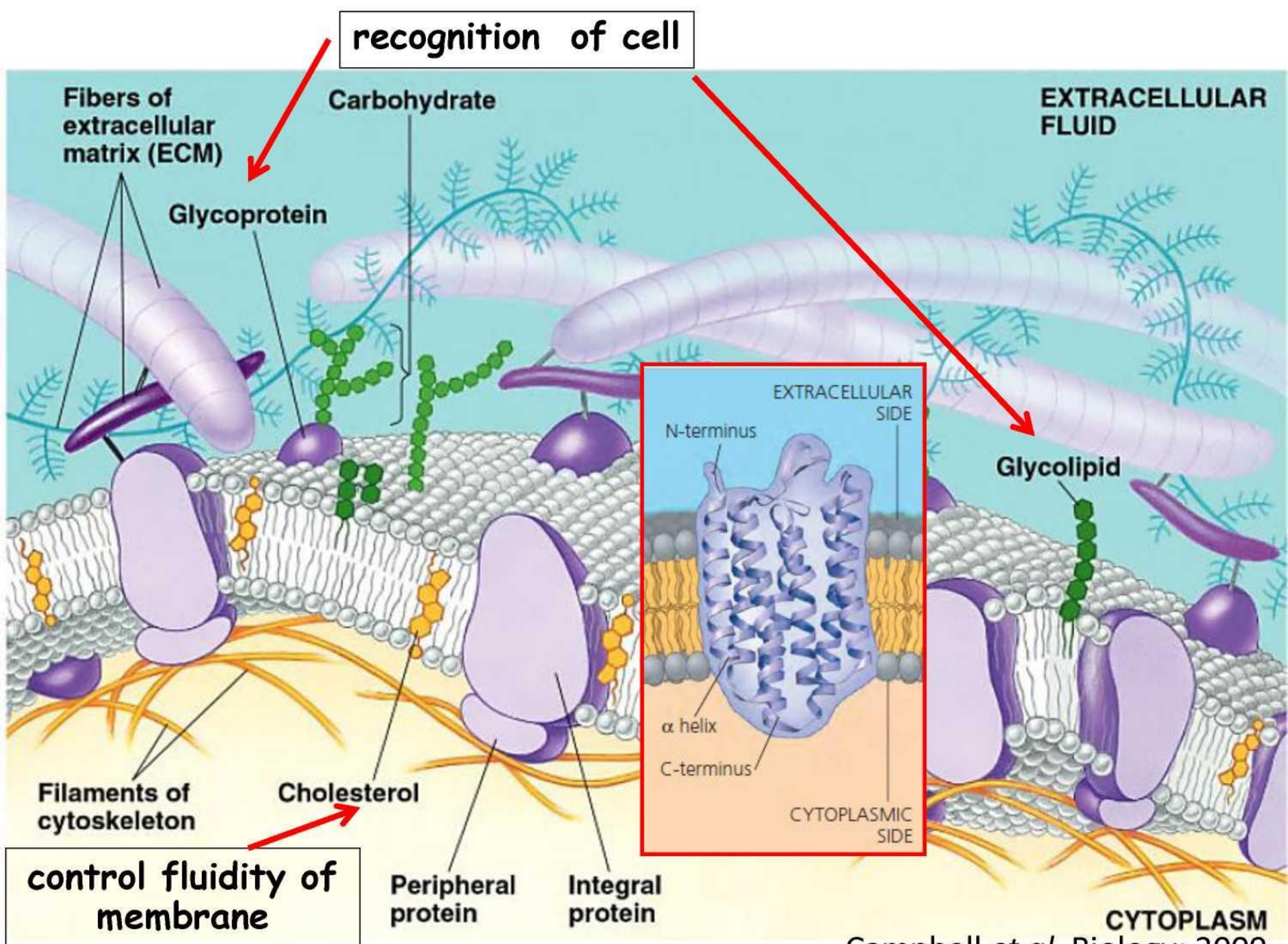


http://alevelnotes.com/content_images/i38_phospholipid.gif



http://online.morainevalley.edu/WebSupported/BIO111-Gibbons/membra29.jpg

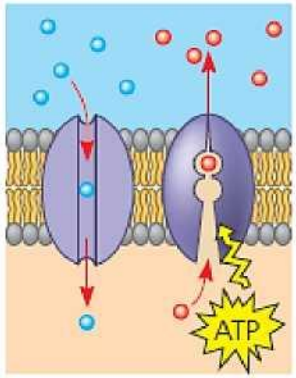
- **polar heads face outward towards the watery environments both inside and outside the cell**
- **non polar tails face inward away from the watery environment**



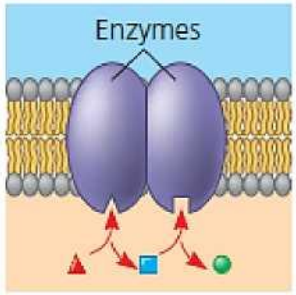
Campbell *et al*, Biology; 2009.

Function of membrane protein

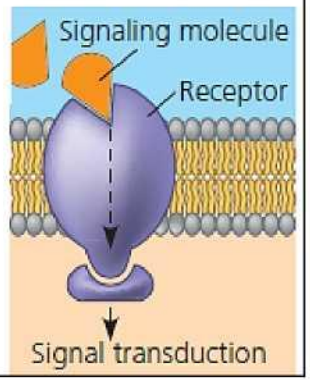
(a) **Transport.** *Left:* A protein that spans the membrane may provide a hydrophilic channel across the membrane that is selective for a particular solute. *Right:* Other transport proteins shuttle a substance from one side to the other by changing shape (see Figure 7.17). Some of these proteins hydrolyze ATP as an energy source to actively pump substances across the membrane.



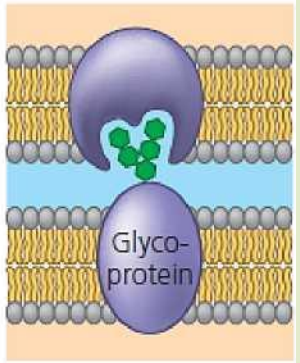
(b) **Enzymatic activity.** A protein built into the membrane may be an enzyme with its active site exposed to substances in the adjacent solution. In some cases, several enzymes in a membrane are organized as a team that carries out sequential steps of a metabolic pathway.



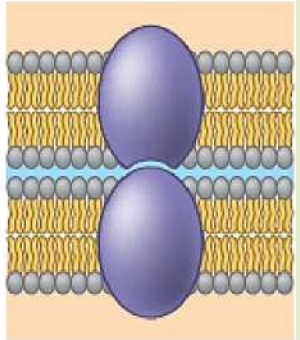
(c) **Signal transduction.** A membrane protein (receptor) may have a binding site with a specific shape that fits the shape of a chemical messenger, such as a hormone. The external messenger (signaling molecule) may cause the protein to change shape, allowing it to relay the message to the inside of the cell, usually by binding to a cytoplasmic protein (see Figure 11.6).



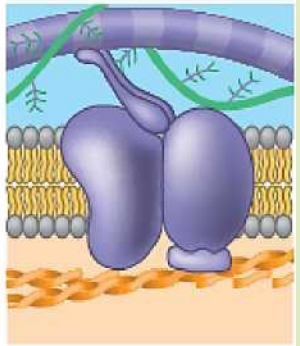
(d) **Cell-cell recognition.** Some glycoproteins serve as identification tags that are specifically recognized by membrane proteins of other cells. This type of cell-cell binding is usually short-lived compared to that shown in (e).



(e) **Intercellular joining.** Membrane proteins of adjacent cells may hook together in various kinds of junctions, such as gap junctions or tight junctions (see Figure 6.32). This type of binding is more long-lasting than that shown in (d).

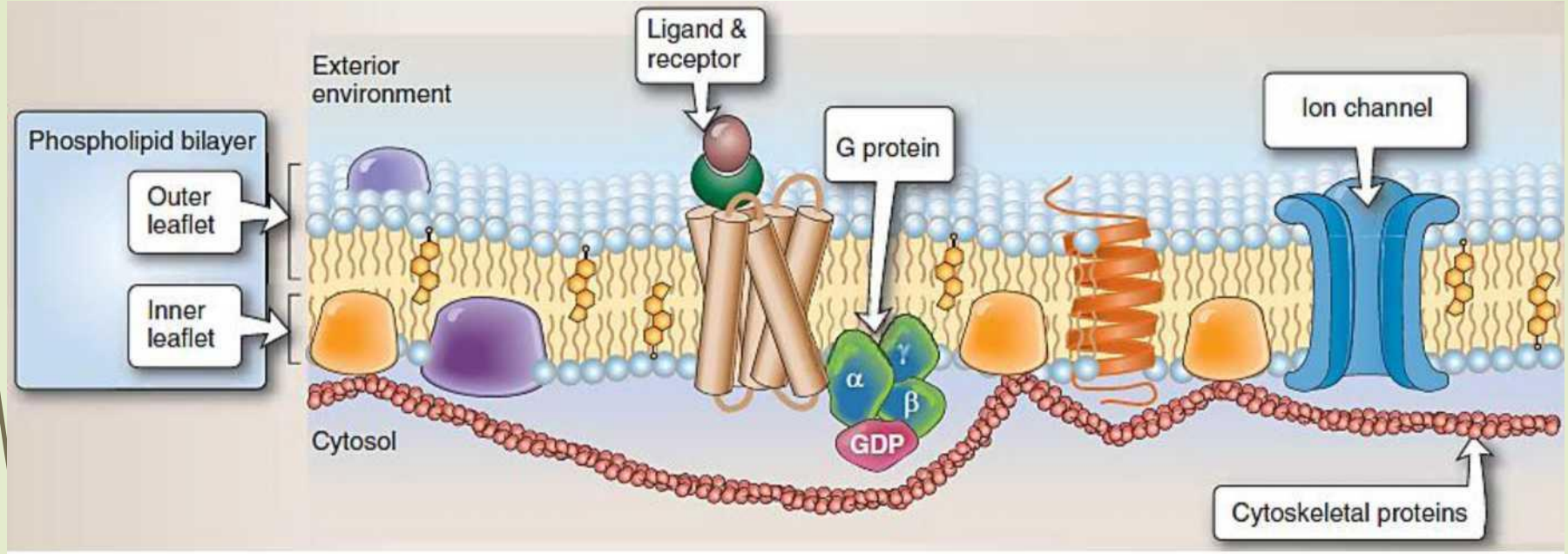


(f) **Attachment to the cytoskeleton and extracellular matrix (ECM).** Microfilaments or other elements of the cytoskeleton may be noncovalently bound to membrane proteins, a function that helps maintain cell shape and stabilizes the location of certain membrane proteins. Proteins that can bind to ECM molecules can coordinate extracellular and intracellular changes (see Figure 6.30).



Campbell *et al*, Biology; 2009.

Function of membrane protein



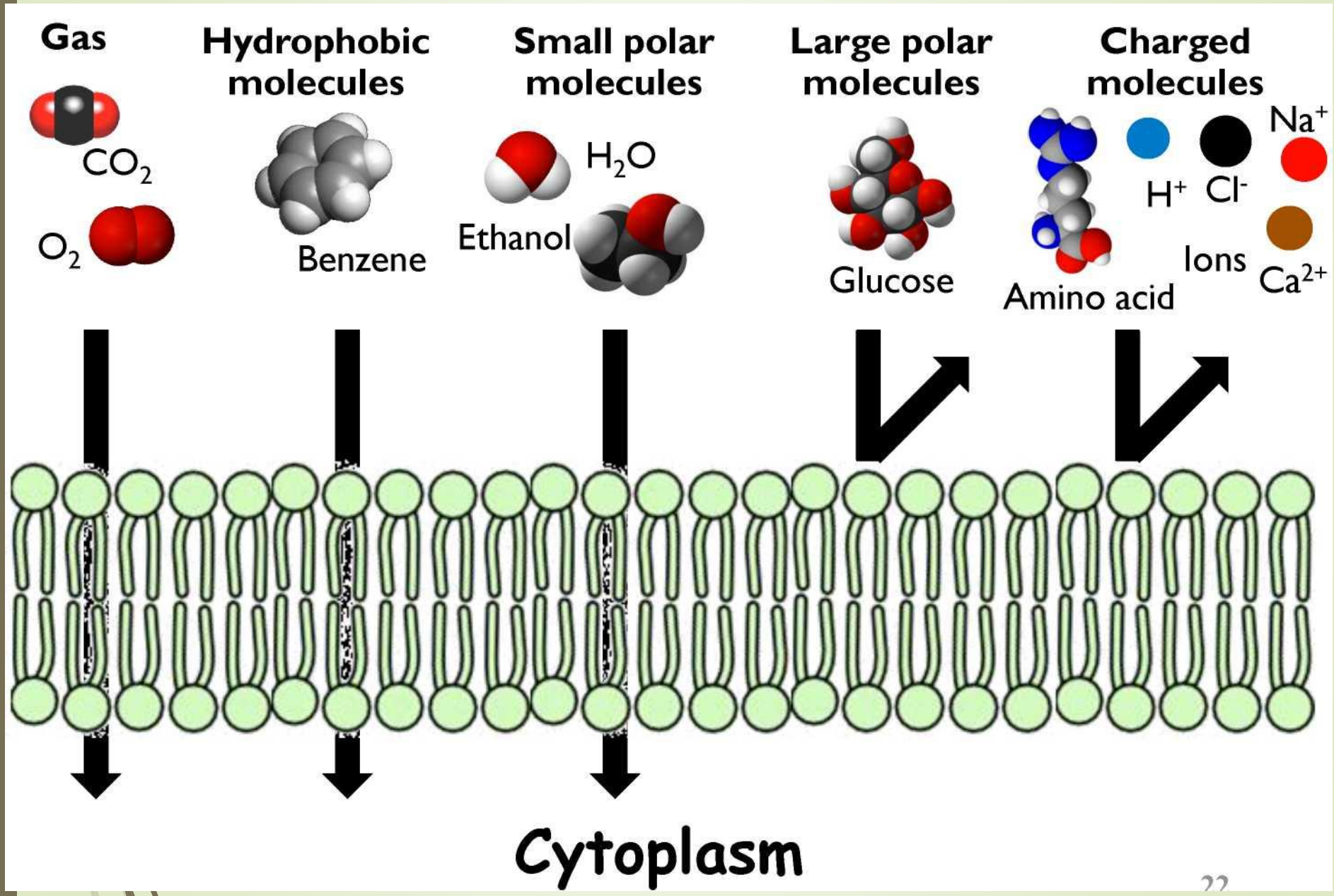
Chandar *et al*, Lippincott's Illustrated Reviews: Cell and Molecular Biology; 2010.

- Enzyme
- Mediate the passage of ions and most biological molecule
- Selective traffic of molecule
- Control the interactions between cells of multicellular organisms
- Serve as sensor (e.g. receptors, signal transductions)

Transport through membrane

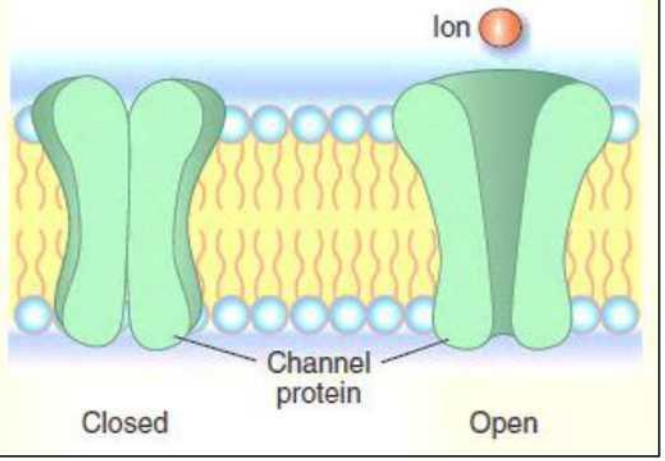
- **Passive transport: need no energy, downhill**
  - **simple diffusion**
  - **facilitated diffusion: channel protein, carrier protein**
- **Active transport: need energy, uphill**
  - **primary active : direct hydrolysis of ATP** o **secondary active : symporters, antiporters**
- **Vesicle transport**
  - **endocytosis: receptor mediated, phagocytosis, pinocytosis**
  - **exocytosis**

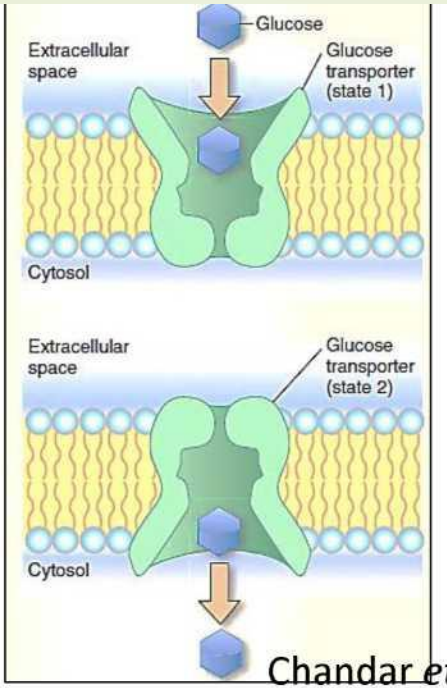
External environment



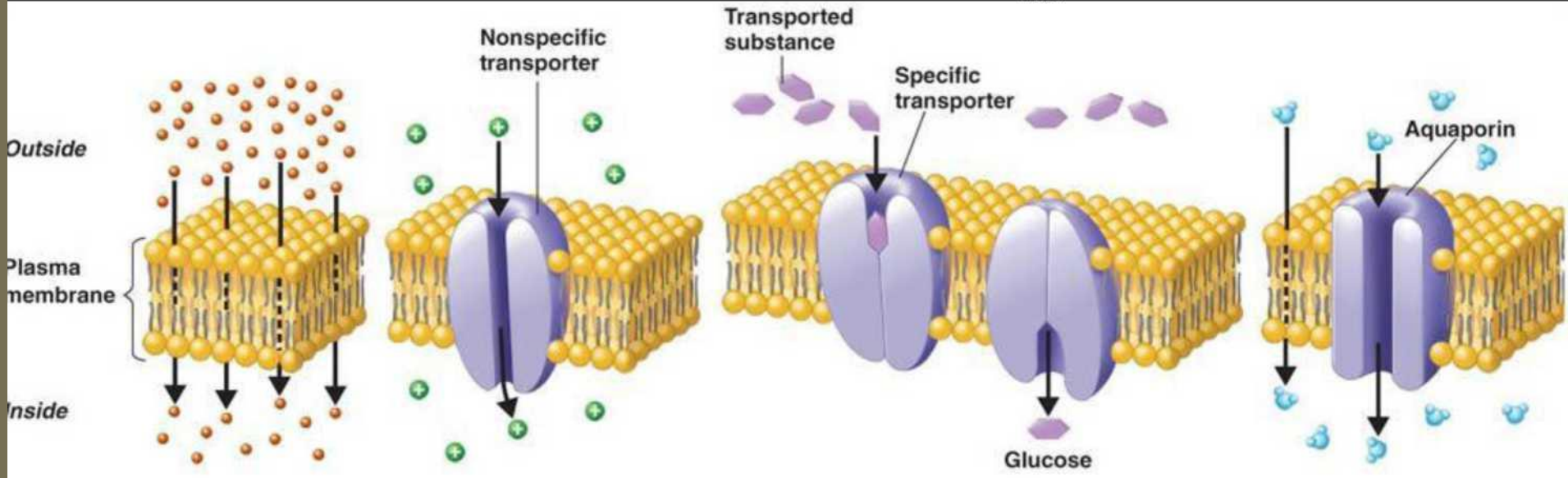
Passive transport

The channel protein is inserted into the membrane such that hydrophilic amino acid residues of its structure form a path for the ion to enter the cell protected from the hydrophobic core of the phospholipids.

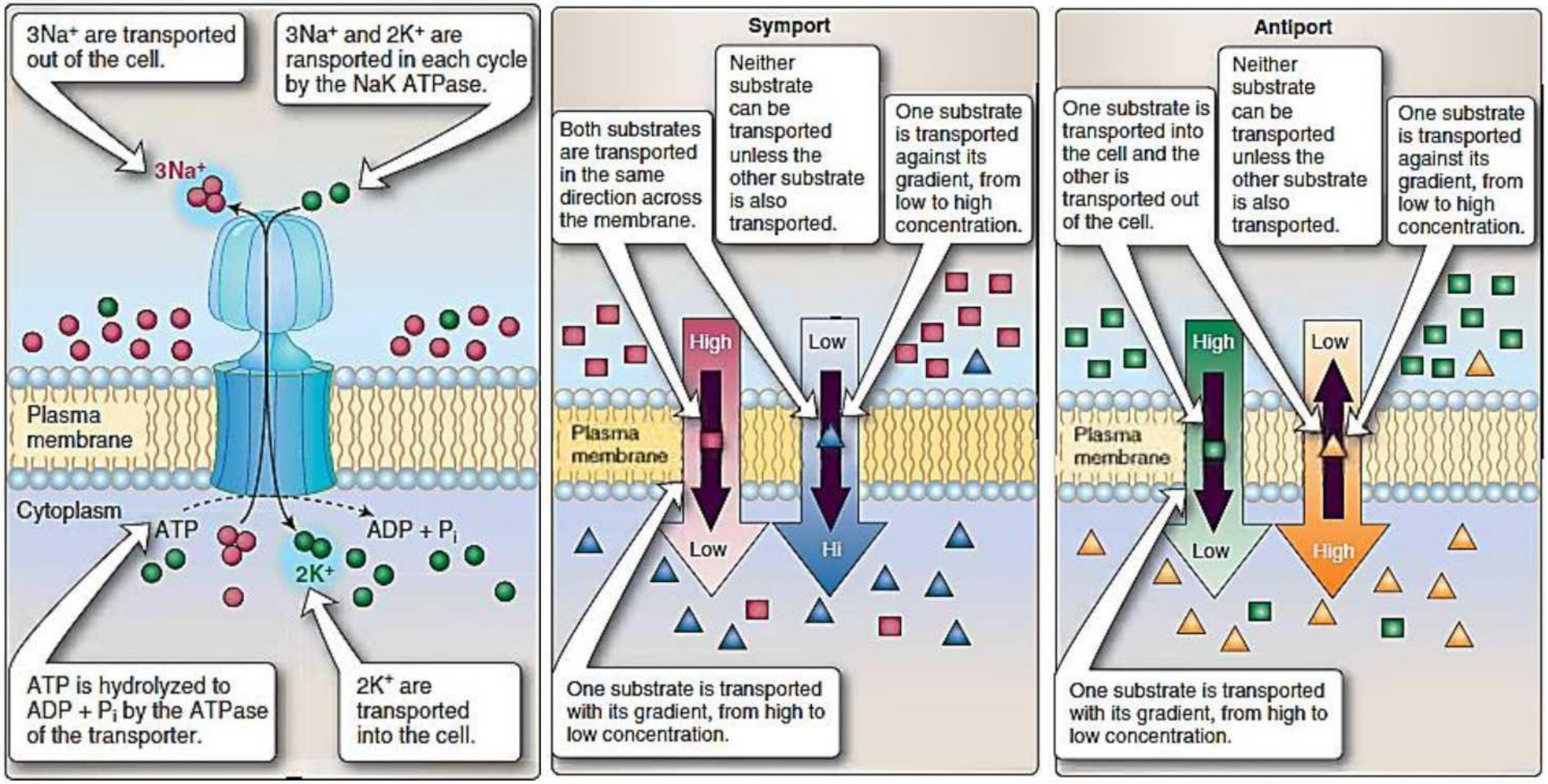




Chandar *et al*, Lippincott's Illustrated Reviews: Cell and Molecular Biology; 2010.



Active transport

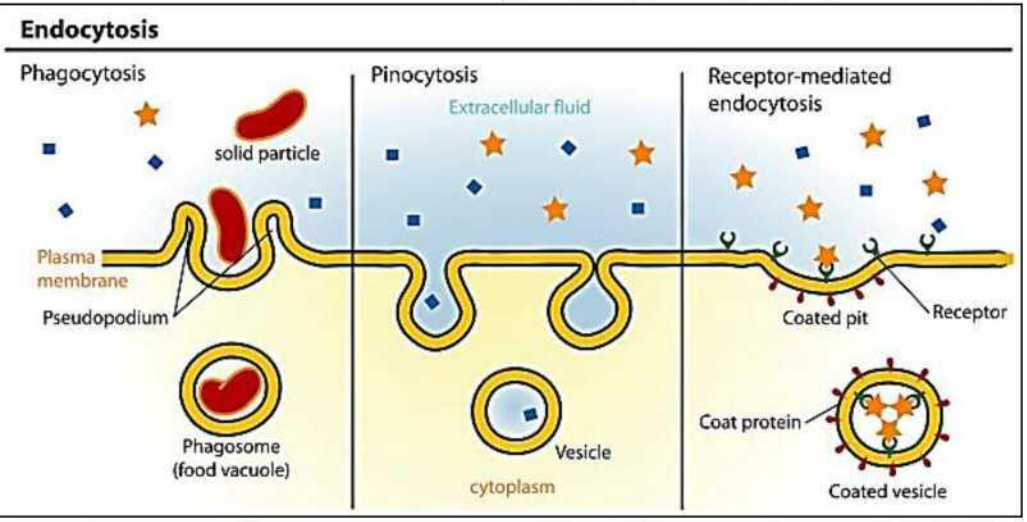


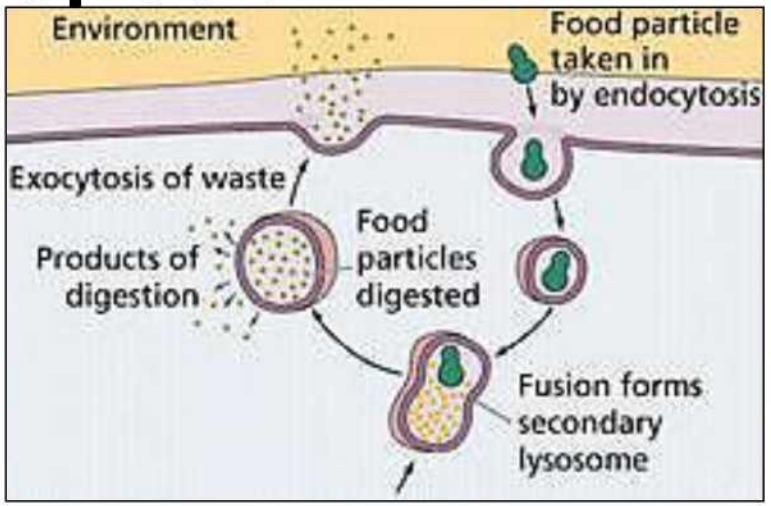
Na^+-glucose transporter in intestinal epithelial cell

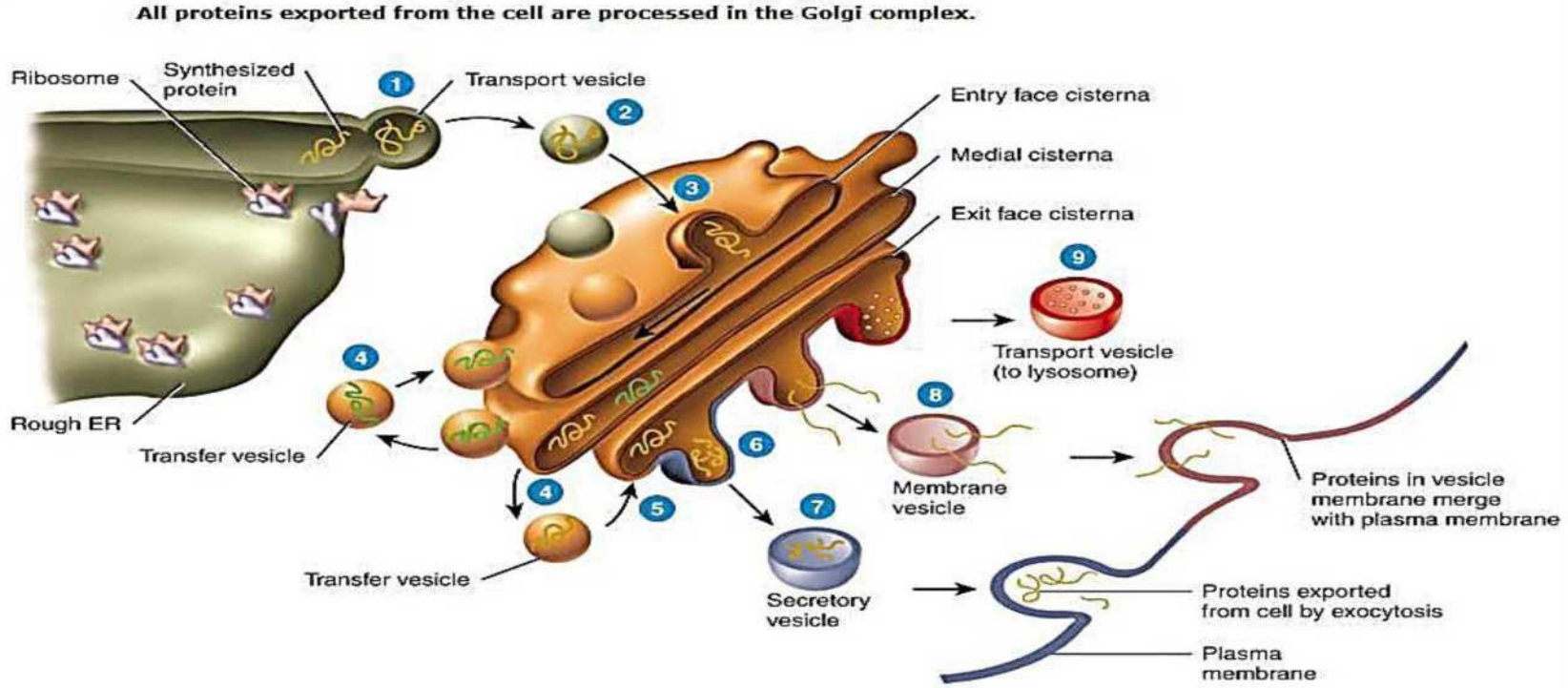
Na^+-Ca^{2+}antiporter in cardiac muscle

Chandar *et al*, Lippincott's Illustrated Reviews: Cell and Molecular Biology; 2010.

Vesicle Transport

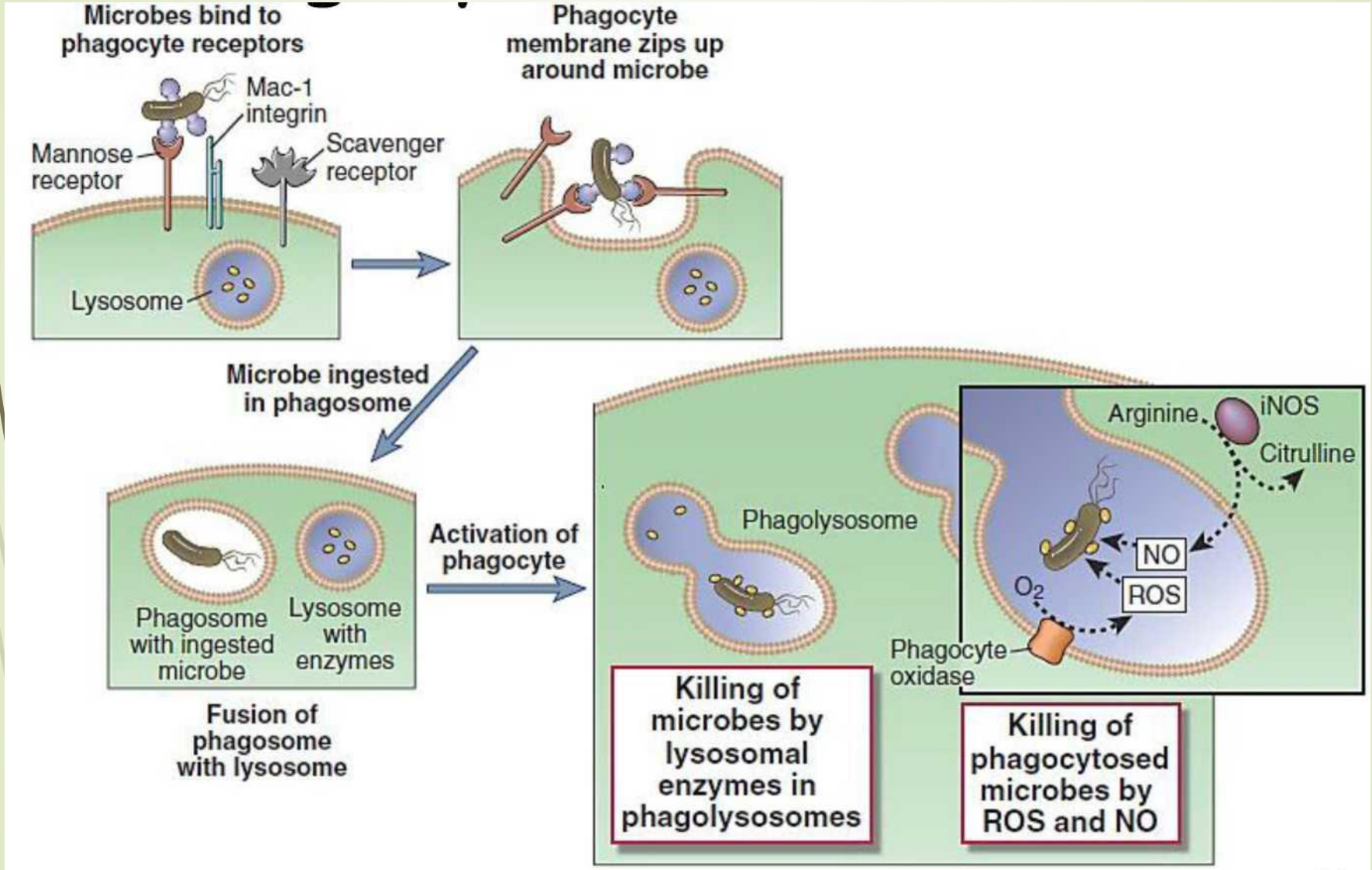






http://www.shayda.us/WebCT/AP1/AP1_Ex2_Materials/GA_Pag2.jpg

Phagocytosis of microbes



Abbas *et al*, Cellular and Molecular Immunology; 2012.

Characteristics of Transport Mechanisms

Characteristic	Passive Transport		Active Transport
	Simple Diffusion	**Facilitated Diffusion**	
Membrane component responsible "or transport	Lipids	Proteins	Proteins
Binding of transported substance	No	Yes	Yes
Energy source	Concentration gradients	Concentration gradients	ATP hydrolysis or concentration gradients
Direction of transport	With gradient of transported substance	With gradient of transported substance	Against gradient of transported substance
Specificity for molecules or molecular classes	Nonspecific	Specific	Specific
Saturation at high concentrations of transported molecules	No	Yes	Yes

Russell et al. Biology the dynamic science; 2008

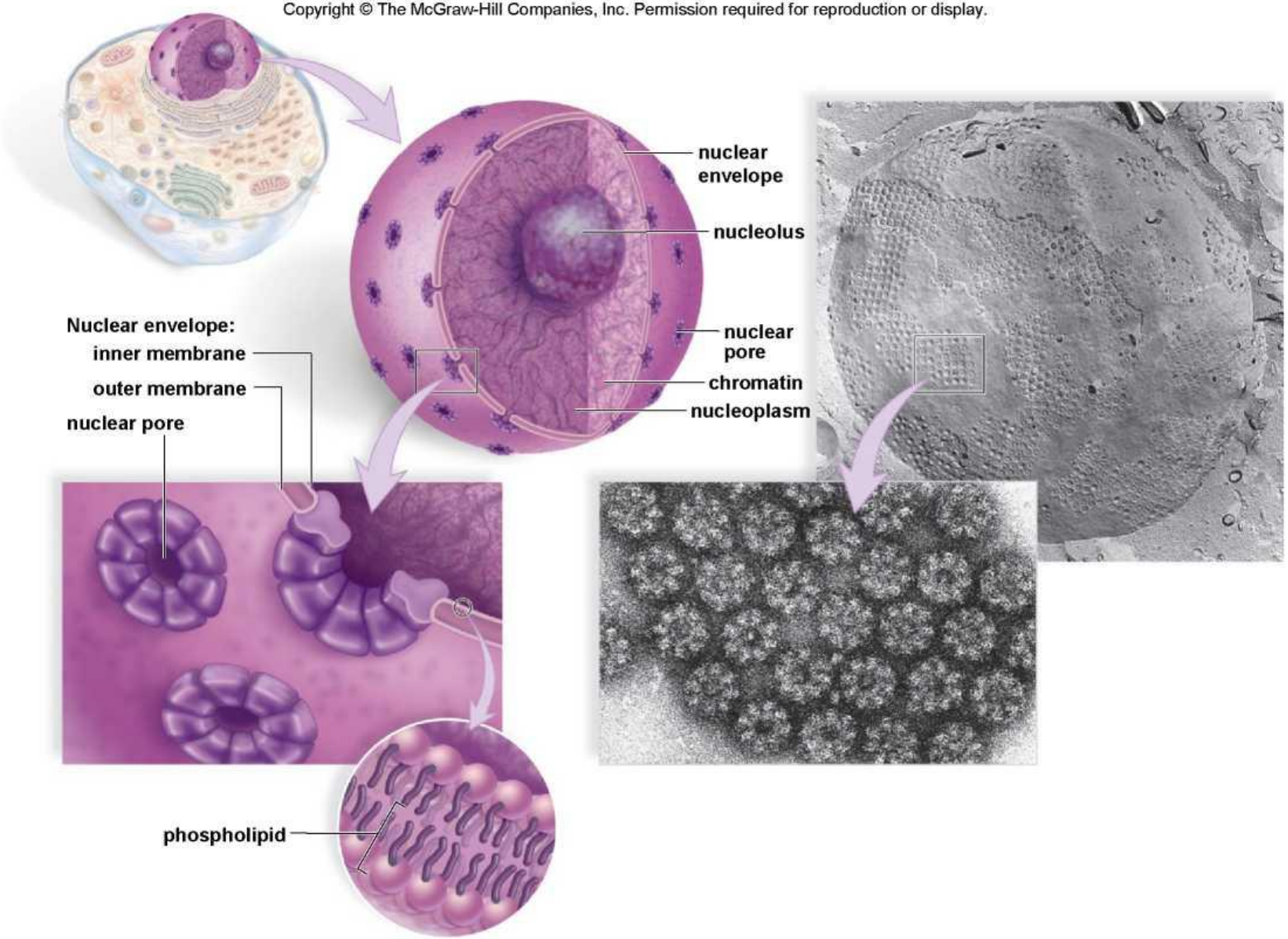
Eukaryotic Cells: Organelles

- Eukaryotic cells are compartmentalized
  - They contain small structures called **organelles**
    - Perform specific functions
    - Isolates reactions from others
- Two classes of organelles:
  - **Endomembrane system**
    - Organelles that communicate with one another
      - Via membrane channels
      - Via small vesicles
  - Energy related organelles
    - **Mitochondria** and **chloroplasts**
    - Independent and self-sufficient

The Nucleus and Ribosomes

- The Nucleus
  - Command center of cell, usually near center
  - Separated from cytoplasm by **nuclear envelope**
    - Consists of double layer of membrane
    - **Nuclear pores** permit exchange between nucleoplasm & cytoplasm
  - Contains **chromatin** in semifluid **nucleoplasm**
    - Chromatin contains DNA of genes, and proteins
    - Condenses to form **chromosomes**
      - Chromosomes are formed during cell division
  - Dark nucleolus composed of rRNA
    - Produces subunits of ribosomes

Anatomy of the Nucleus

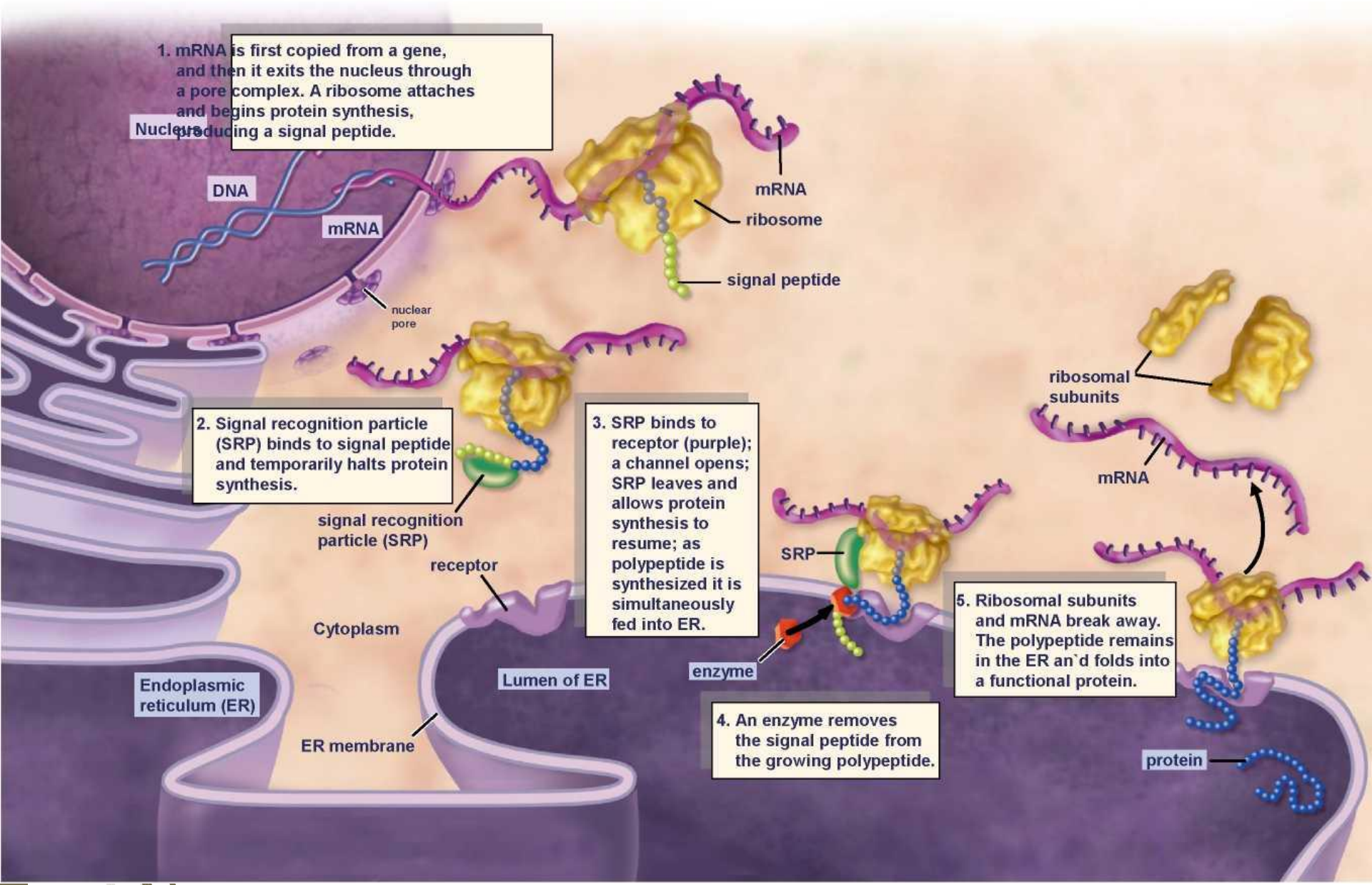


(Bottom): Courtesy Ron Milligan/Scripps Research Institute; (Top right): Courtesy E.G. Pollock

Ribosomes

- Are the site of protein synthesis in the cell
- Composed of rRNA
  - Consists of a large subunit and a small subunit
  - Subunits made in nucleolus
- May be located:
  - On the endoplasmic reticulum (thereby making it “rough”), or
  - Free in the cytoplasm, either singly or in groups, called **polyribosomes**

Function of Ribosomes



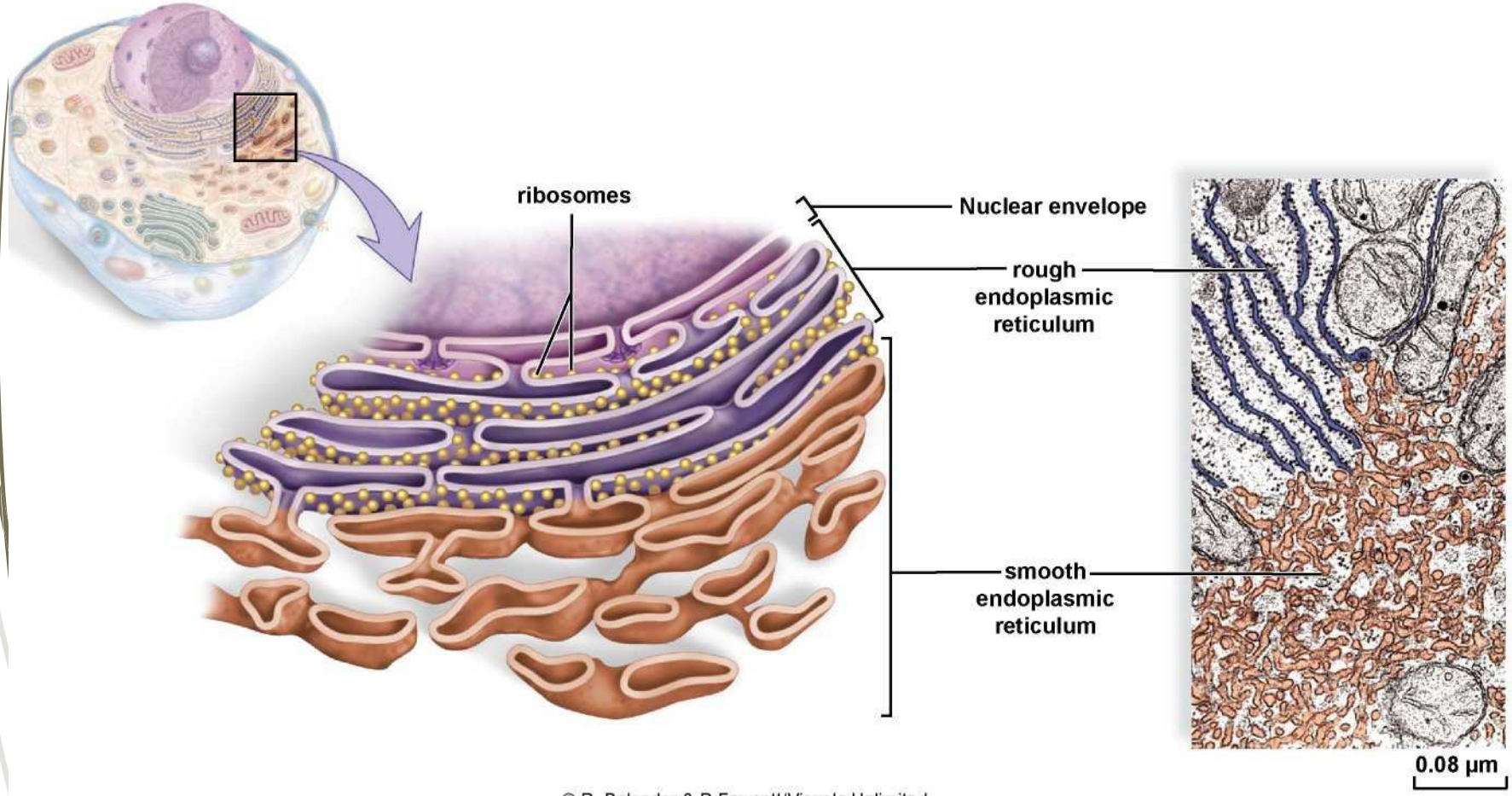
The Endomembrane System

- Series of intracellular membranes that compartmentalize the cell
- Restrict enzymatic reactions to specific compartments within cell
- Consists of:
  - Nuclear envelope
  - Membranes of endoplasmic reticulum
  - **Golgi apparatus**
  - **Vesicles**
    - Several types
    - Transport materials between organelles of system

Endoplasmic Reticulum

- A system of membrane channels and saccules (flattened vesicles) continuous with the outer membrane of the nuclear envelope
- **Rough ER**
  - Studded with ribosomes on cytoplasmic side
  - Protein anabolism
    - Synthesizes proteins
    - Modifies and processes proteins
      - Adds sugar to protein
      - Results in glycoproteins
- **Smooth ER**
  - No ribosomes
  - Synthesis of lipids
  - Site of various synthetic processes, detoxification, and storage
  - Forms **transport vesicles**

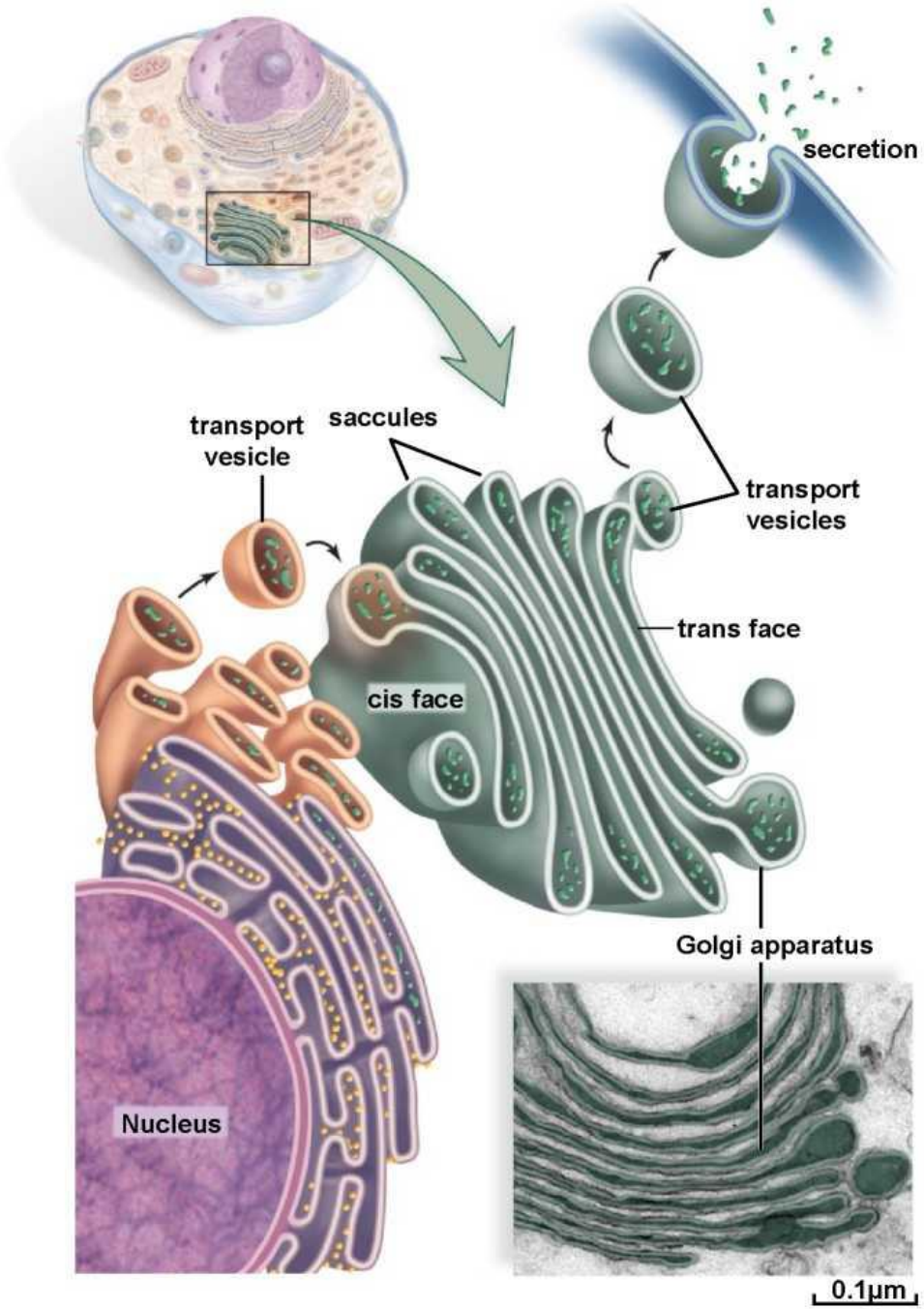
Endoplasmic Reticulum



The Golgi Apparatus

- **Golgi Apparatus**
  - Consists of flattened, curved saccules
  - Resembles stack of hollow pancakes
  - Modifies proteins and lipids
    - Receives vesicles from ER on cis (or inner face)
    - Packages them in vesicles
    - Prepares for “shipment” and packages them in vesicles from trans (or outer face)
      - Within cell
      - Export from cell (secretion, exocytosis)

Golgi Apparatus

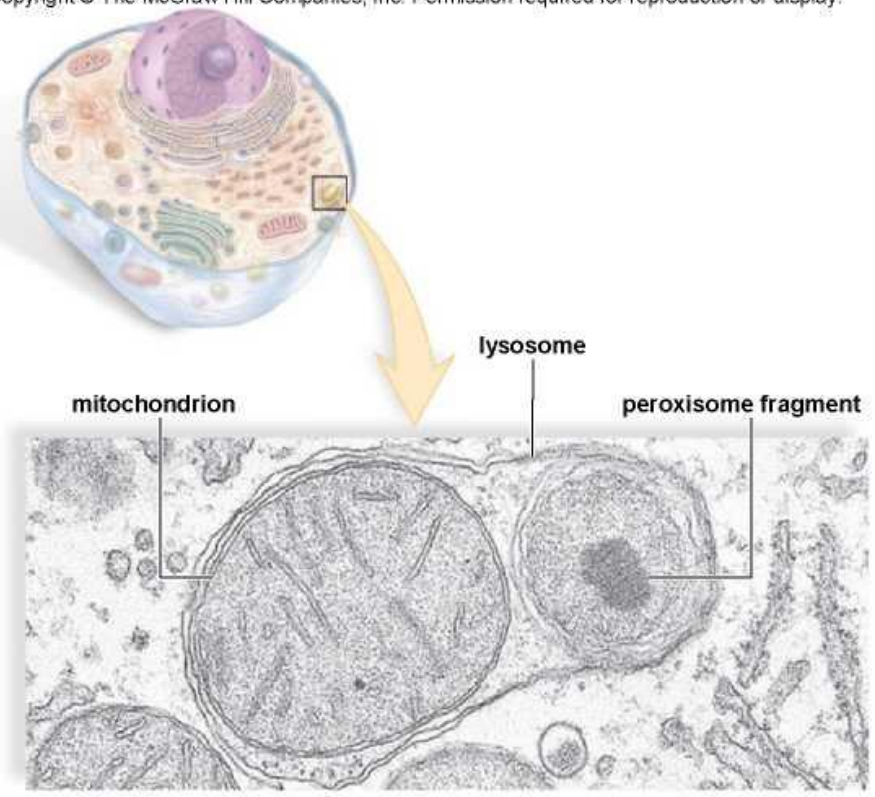


Courtesy Charles Flickinger, from Journal of Cell Biology 49:221-226, 1971, Fig. 1 page 224

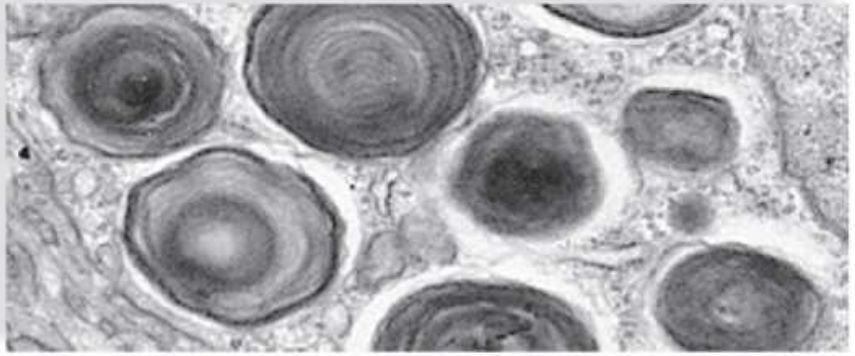
Lysosomes

- Membrane-bound vesicles (not in plants)
  - Produced by the Golgi apparatus
  - Contain powerful digestive enzymes and are highly acidic
    - Digestion of large molecules
    - Recycling of cellular resources
- Some genetic diseases
  - Caused by defect in lysosomal enzyme
  - Lysosomal storage diseases (Tay-Sachs)

Lysosomes



a. Mitochondrion and a peroxisome in a lysosome



b. Storage bodies in a cell with defective lysosomes

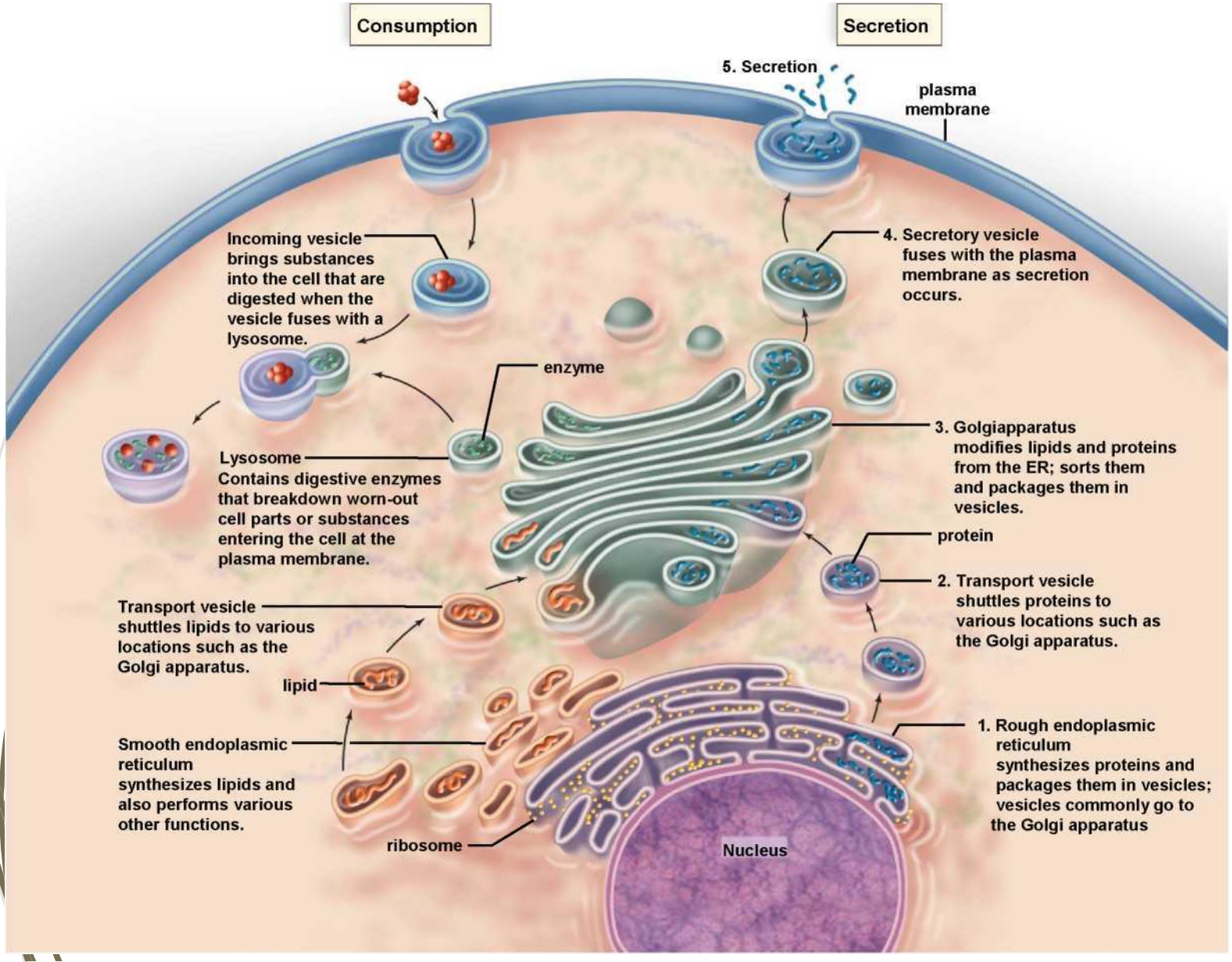
a: Courtesy Daniel S. Friend; b: Courtesy Robert D. Terry/Univ. of San Diego School of Medicine

Endomembrane System

Summary

- Proteins produced in rough ER and lipids from smooth ER are carried in vesicles to the Golgi apparatus.
- The Golgi apparatus modifies these products and then sorts and packages them into vesicles that go to various cell destinations.
- Secretory vesicles carry products to the membrane where exocytosis produces secretions.
- Lysosomes fuse with incoming vesicles and digest macromolecules.

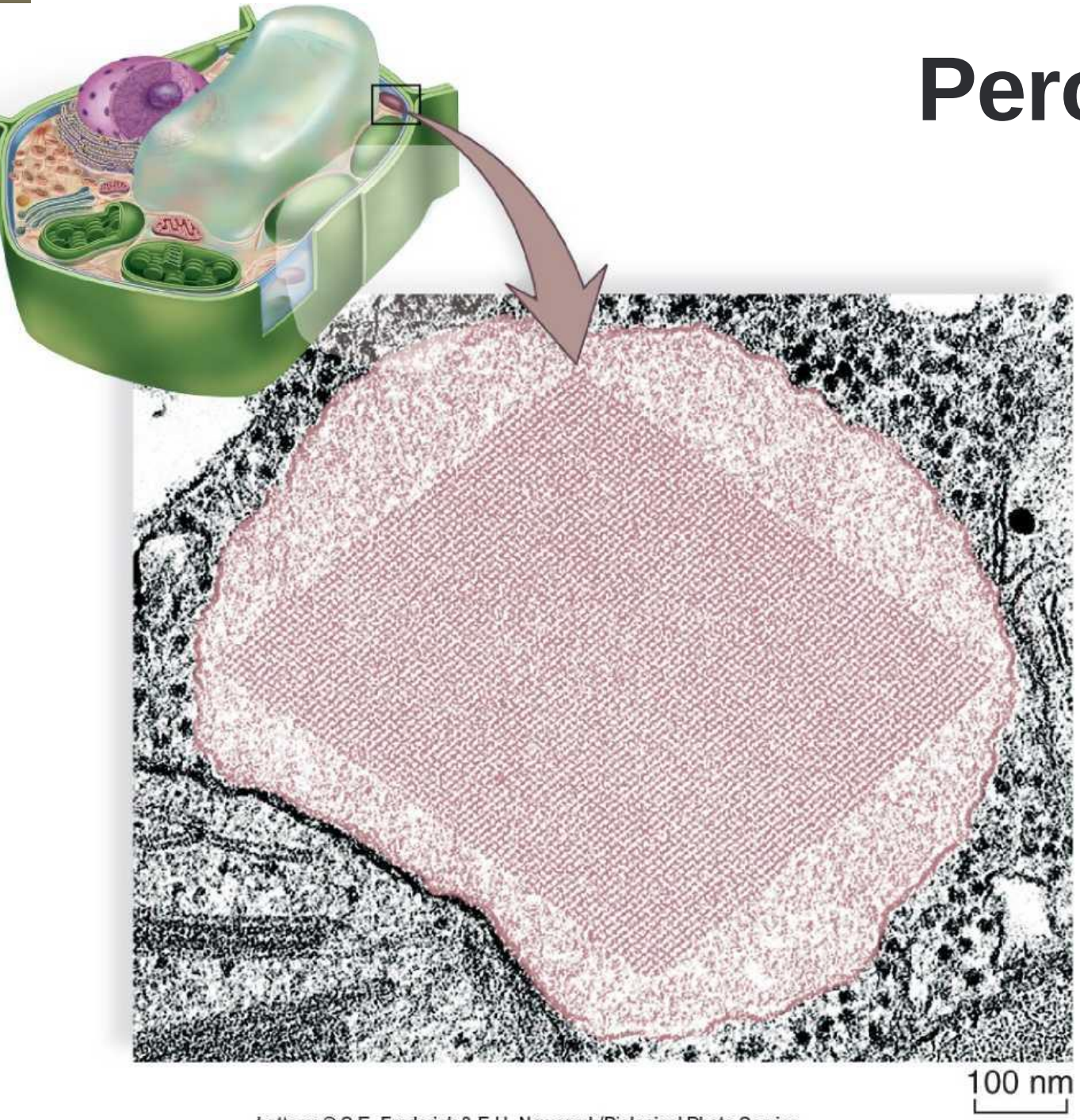
Endomembrane System



Other Vesicles and Vacuoles

- **Peroxisomes**
  - Similar to lysosomes
    - Membrane-bounded vesicles
    - Enclose enzymes
  - However
    - Enzymes synthesized by free ribosomes in cytoplasm (instead of ER)
    - Active in lipid metabolism
    - Catalyze reactions that produce hydrogen peroxide H_2O_2
      - Toxic
      - Broken down to water & O_2 by catalase

Peroxisomes



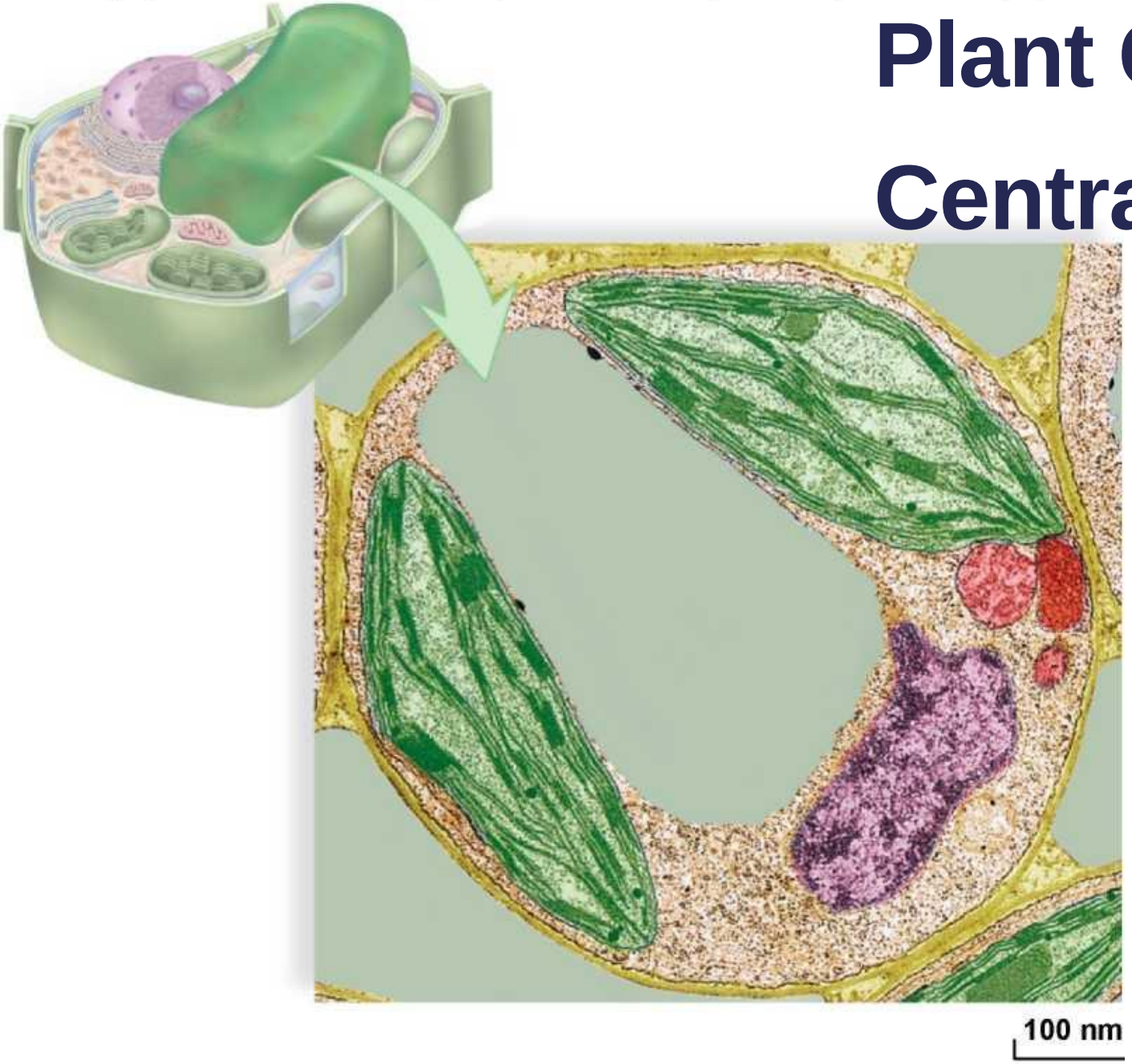
bottom: © S.E. Frederick & E.H. Newcomb/Biological Photo Service

Vacuoles

- Membranous sacs that are larger than vesicles
  - Store materials that occur in excess
  - Others very specialized (contractile vacuole)
- Plants cells typically have a **central vacuole**
  - Up to 90% volume of some cells
  - Functions in:
    - Storage of water, nutrients, pigments, and waste products
    - Development of turgor pressure
    - Some functions performed by lysosomes in other eukaryotes

Plant Cell

Central Vacuole



Energy-Related Organelles

* Chloroplasts

- Bounded by double membrane
- Inner membrane infolded
  - * Forms disc-like **thylakoids**, which are stacked to form **grana**
  - * Suspended in semi-fluid stroma
- Green due to chlorophyll
  - * Green photosynthetic pigment
  - * Found ONLY in inner membranes of chloroplast

Chloroplasts

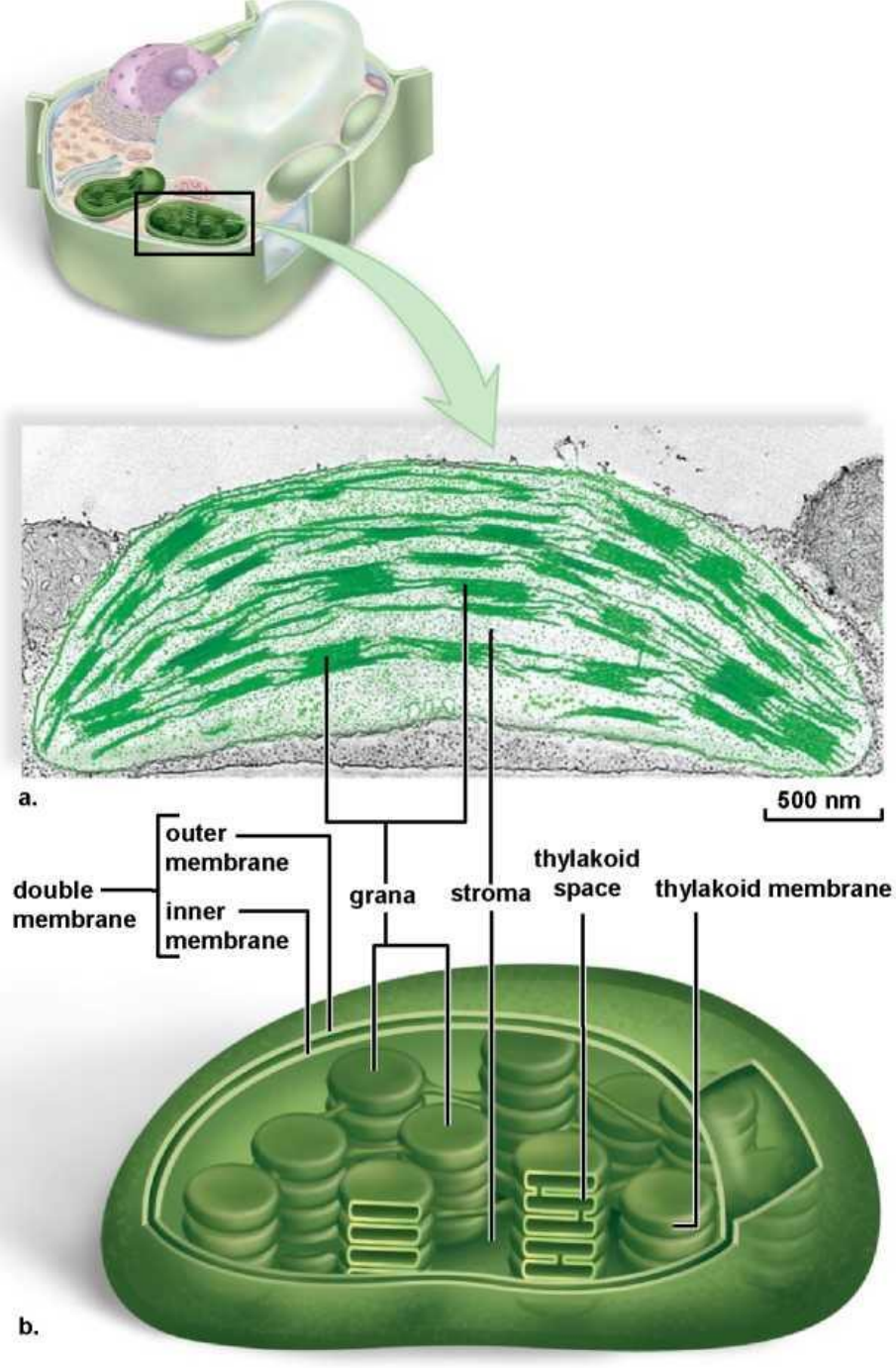
- Membranous organelles (a type of **plastid**) that serve as the site of photosynthesis
- Captures light energy to drive cellular machinery
- Photosynthesis
  - Synthesizes carbohydrates from CO_2 & H_2O
  - Makes own food using CO_2 as only carbon source
  - Energy-poor compounds converted to energy-rich

compounds solar energy + carbon dioxide + water ^

carbohydrate + oxygen

  - Only plants, algae, and certain bacteria are capable of conducting photosynthesis

Chloroplast Structure

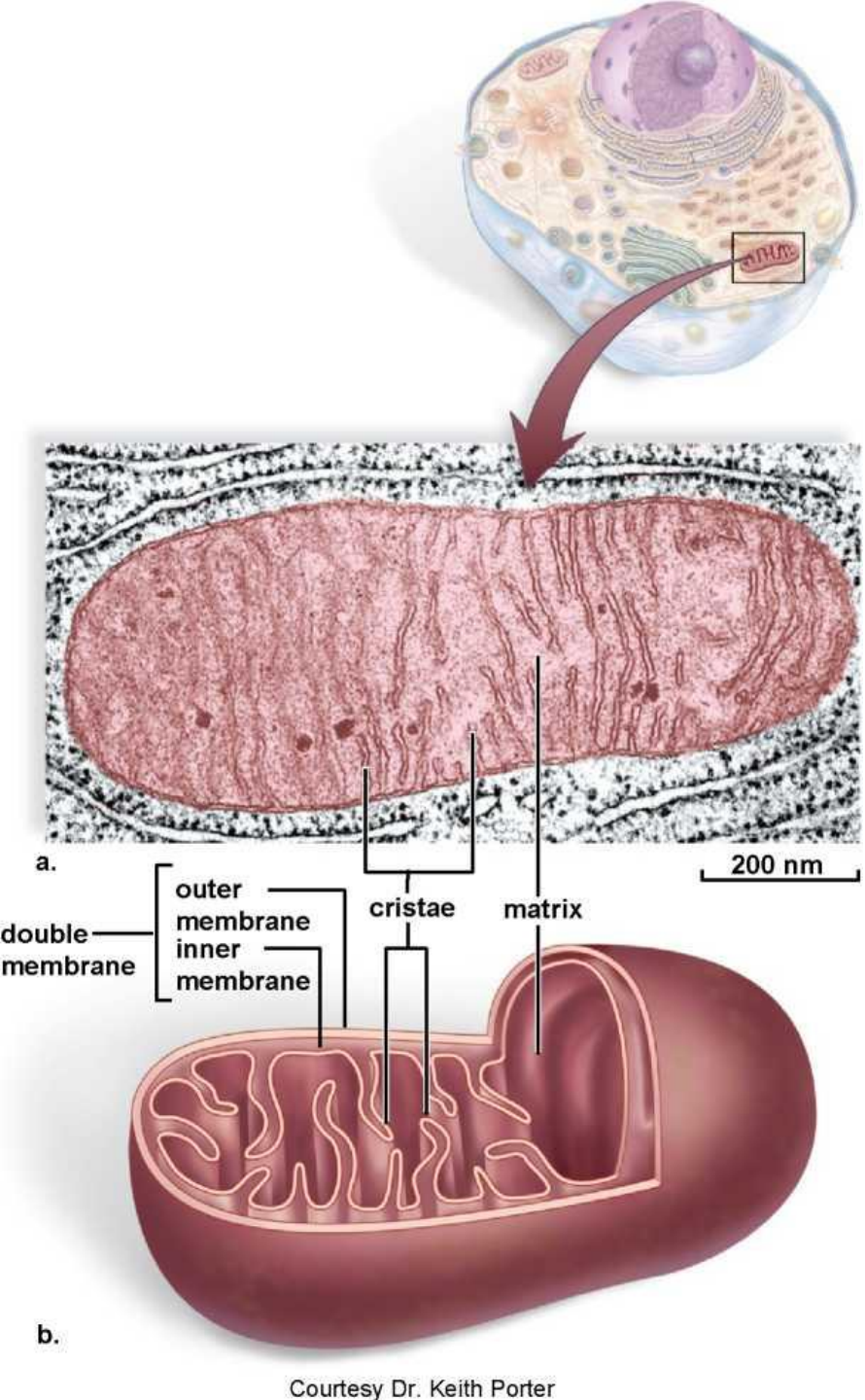


Courtesy Herbert W. Israel, Cornell University

Mitochondria

- Smaller than chloroplast
- Contain ribosomes and their own DNA
- Surrounded by a double membrane
  - Inner membrane surrounds the **matrix** and is convoluted (folds) to form **cristae.**
  - Matrix - Inner semifluid containing respiratory enzymes
    - Break down carbohydrates
- Involved in cellular respiration
- Produce most of ATP utilized by the cell

Mitochondrion Structure



Courtesy Dr. Keith Porter

The Cytoskeleton

- Maintains cell shape
- Assists in movement of cell and organelles
- Three types of macromolecular fibers

  Actin filaments

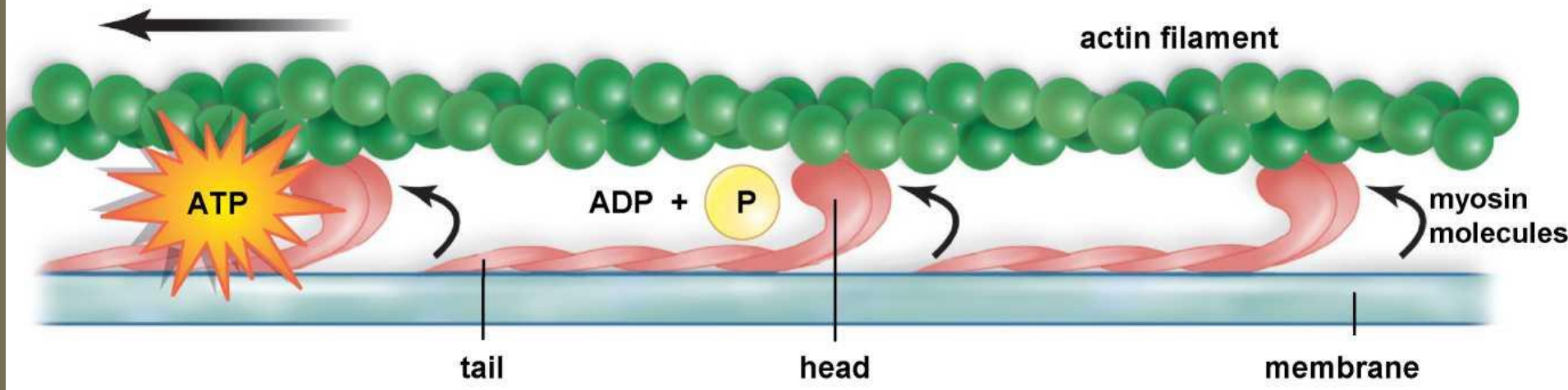
  Intermediate filaments

  Microtubules
- Assemble and disassemble as needed

Actin Filaments

- Extremely thin filaments like twisted pearl necklace
- Dense web just under plasma membrane maintains cell shape
- Support for microvilli in intestinal cells
- Intracellular traffic control
  - For moving stuff around within cell
  - Cytoplasmic streaming
- Function in pseudopods of amoeboid cells
- Important component in muscle contraction (other is myosin)

Actin Filament Operation



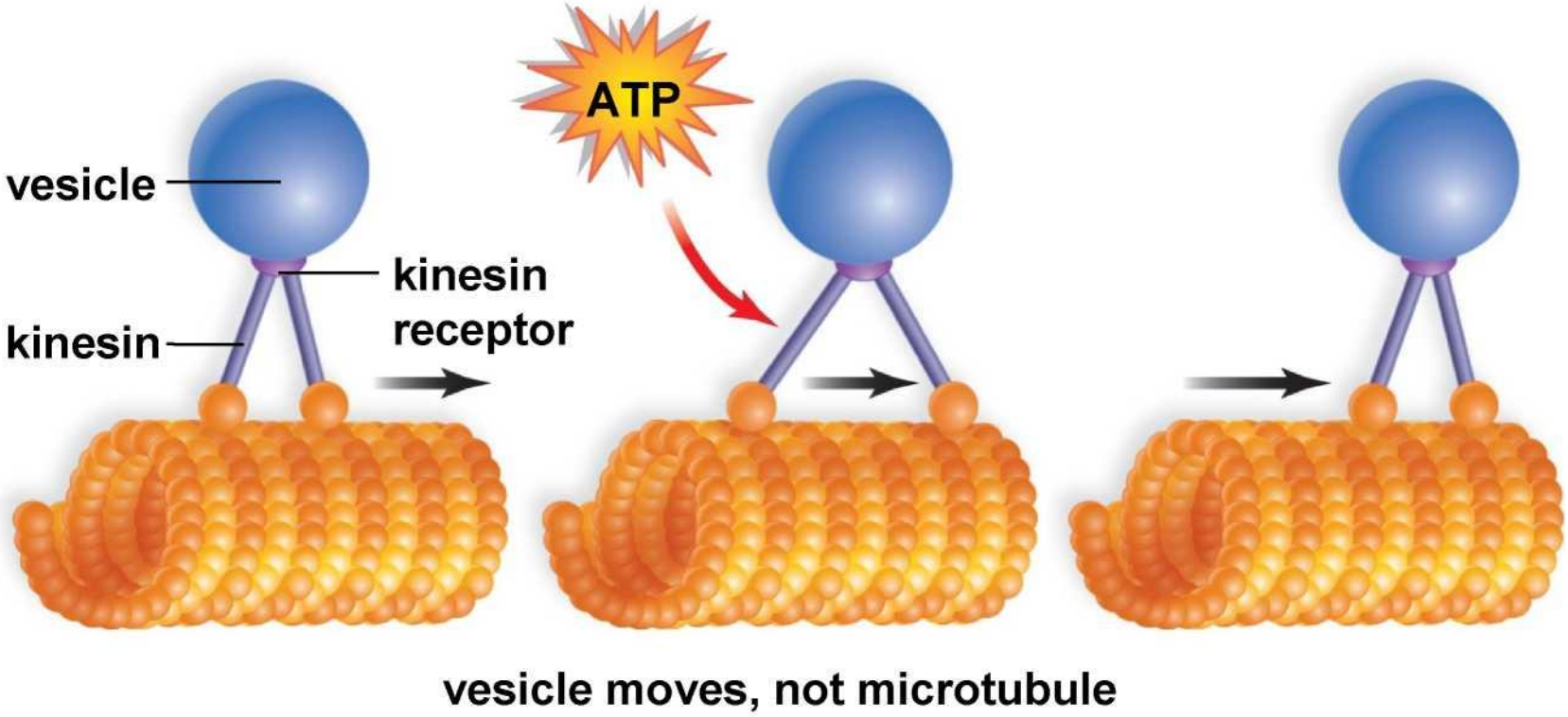
Intermediate Filaments

- Intermediate in size between actin filaments and microtubules
- Rope-like assembly of fibrous polypeptides
- Vary in nature
  - From tissue to tissue
- Function:
  - Support nuclear envelope
  - Cell-cell junctions, like those holding skin cells tightly together

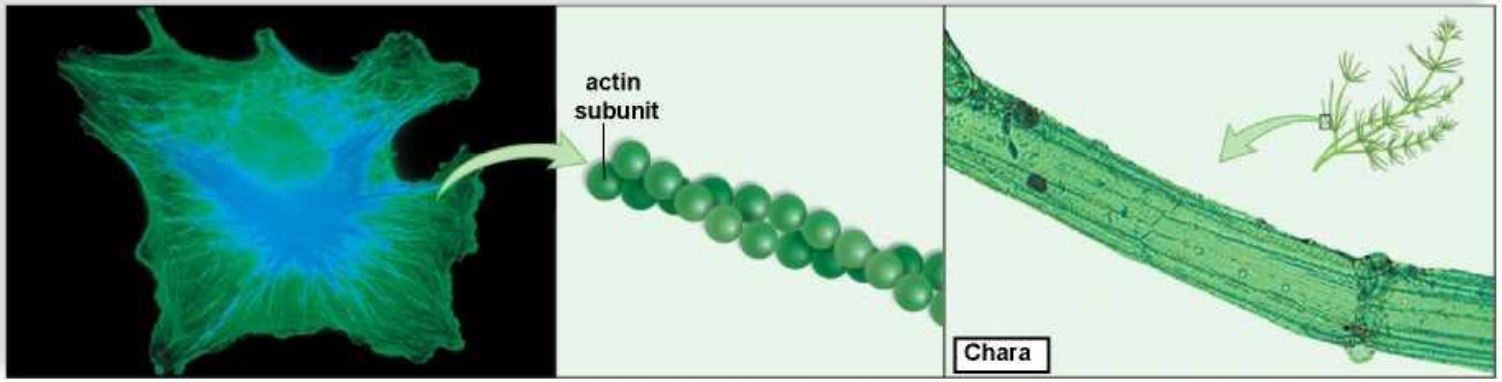
Microtubules

- Hollow cylinders made of two globular proteins called **a** and **p** tubulin
- Spontaneous pairing of **a** and **p** tubulin molecules form structures called dimers
- Dimers then arrange themselves into tubular spirals of 13 dimers around
- Assembly:
  - Under control of Microtubule Organizing Center (MTOC)
  - Most important MTOC is centrosome
- Interacts with proteins kinesin and dynein to cause movement of organelles

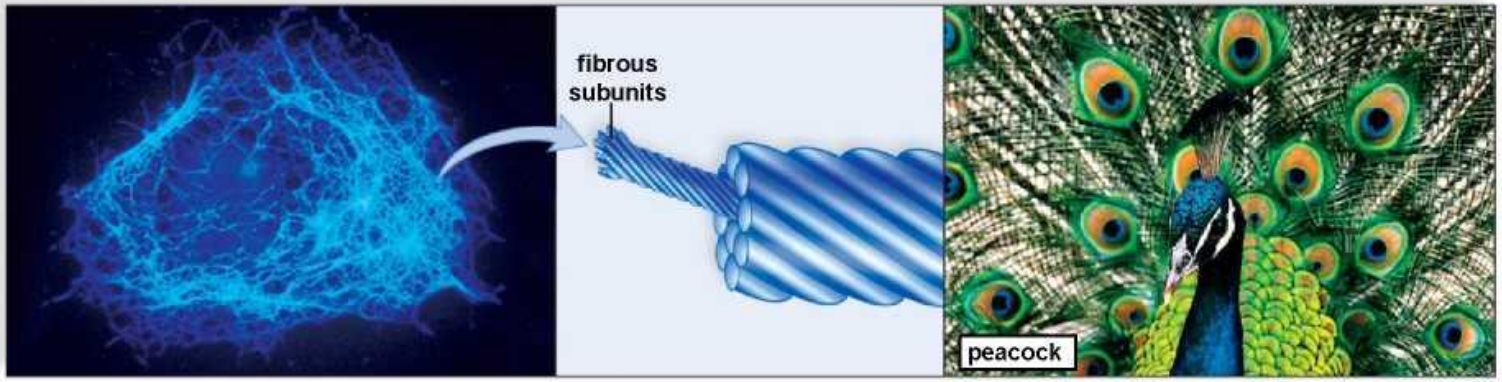
Microtubule Operation



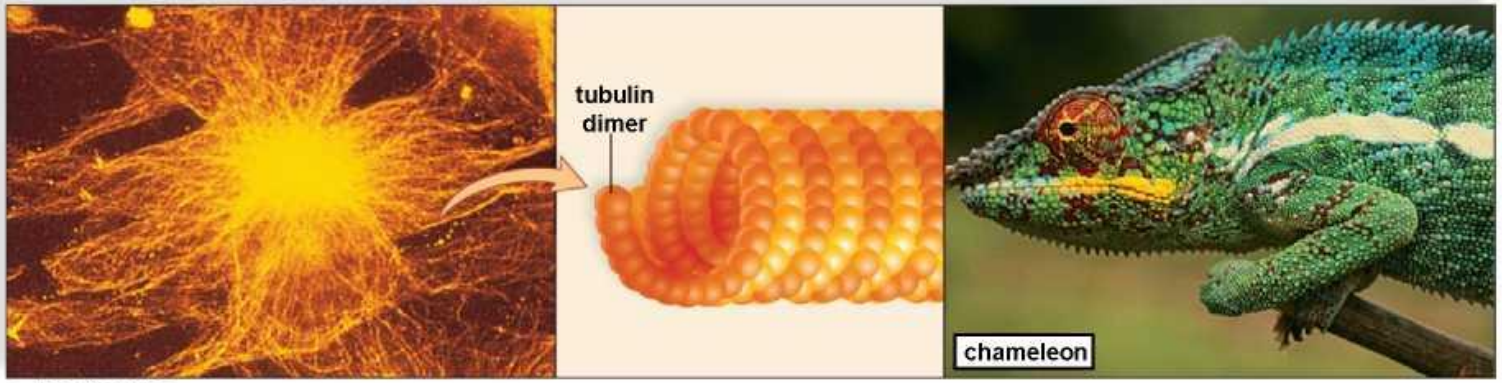
vesicle moves, not microtubule



a. Actin filaments



b. Intermediate filaments

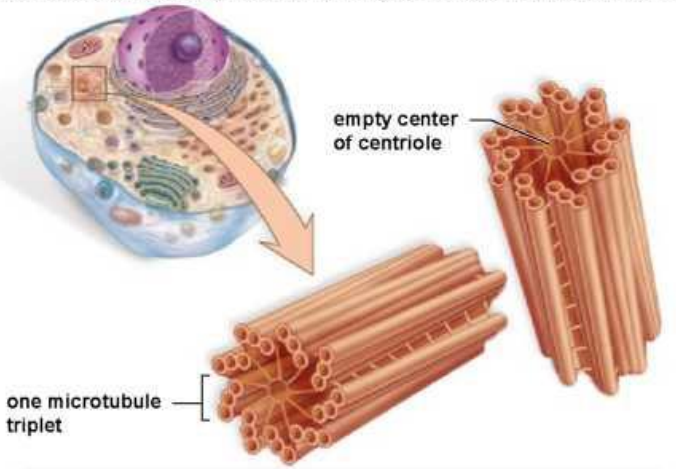


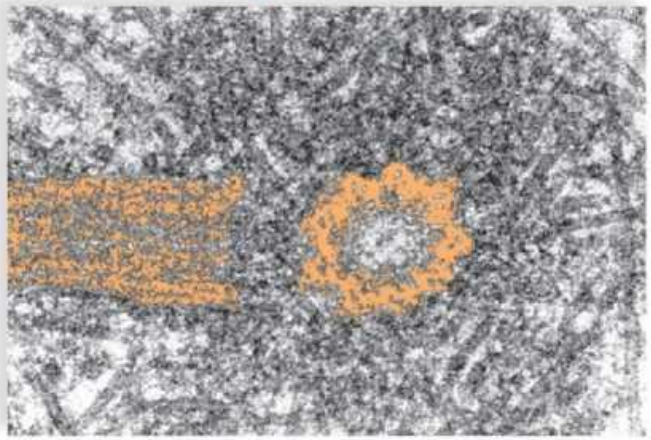
c. Microtubules

Centrioles

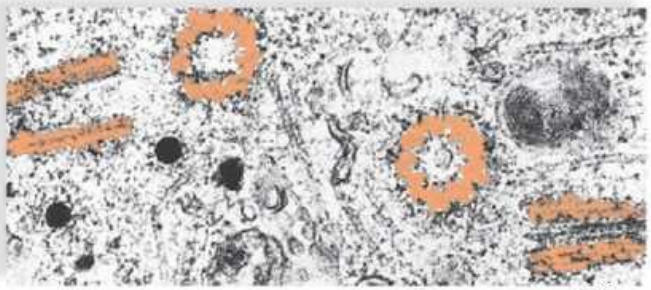
- Short, hollow cylinders
  - Composed of 27 microtubules
  - Microtubules arranged into 9 overlapping triplets
- One pair per animal cell
  - Located in **centrosome** of animal cells
  - Oriented at right angles to each other
  - Separate during mitosis to determine plane of division
- May give rise to basal bodies of **cilia** and **flagella**

Centrioles





one centrosome: one pair of centrioles

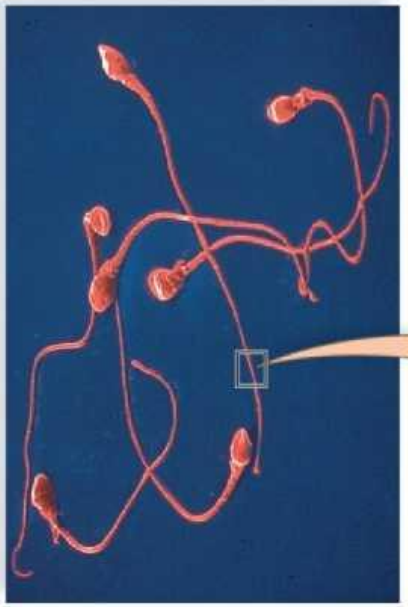


two centrosomes: two pairs of centrioles

Cilia and Flagella

- Hair-like projections from cell surface that aid in cell movement
- Very different from prokaryote flagella
  - Outer covering of plasma membrane
  - Inside this is a cylinder of 18 microtubules arranged in 9 pairs
  - In center are two single microtubules
  - This 9 + 2 pattern used by all cilia & flagella
- In eukaryotes, cilia are much shorter than flagella
  - Cilia move in coordinated waves like oars
  - Flagella move like a propeller or cork screw

Structure of a Flagellum



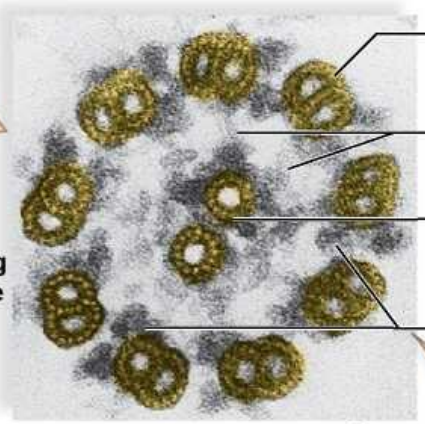
Sperm

Flagellum

shaft

The shaft of the flagellum has a ring of nine microtubule doublets anchored to a central pair of microtubules.

plasma membrane



outer microtubule doublet

radial spoke

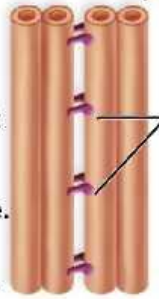
central microtubules

dynein side arm

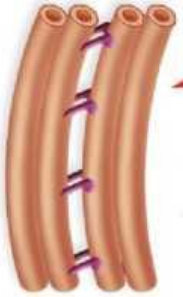
Flagellum cross section

25 nm

The side arms of each doublet are composed of dynein, a motor molecule.



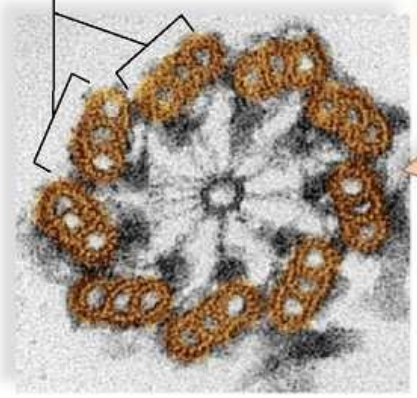
dynein side arms



ATP

In the presence of ATP, the dynein side arms reach out to their neighbors, and bending occurs.

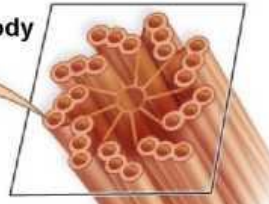
triplets



Basal body cross section

100 nm

Basal body



The basal body of a flagellum has a ring of nine microtubule triplets with no central microtubules.

Thank you for attention