Cell Structure & Function

Lecture 1

Objectives

Understand/know/focus on/note

- what the 3 "domains" of life are
- what features are in the eukaryotic cell
- 3 features common between all domains are
- describe or define the following terms: cytosol, cytoplasm, organelle, nucleus, plasma membrane/cell membrane
- what limits cell size
- two kinds of microscopy (light, electron) and what they see
- two kinds of electron microscopy (TEM, SEM)
- examples of how cell structure is optimizied to its function

Goals of a Cell & Organism

- Maintain its survival

  Done by achieving a metabolic stability or homeostasis (not chemical equilibrium)

- Perpetuate its kind (species)
  - Mechanisms for cellular longevity
  - Mechanisms for cellular / organismal dormancy
  - Mechanisms to create genetic diversity during sexual reproduction in order to adapt to changing environments

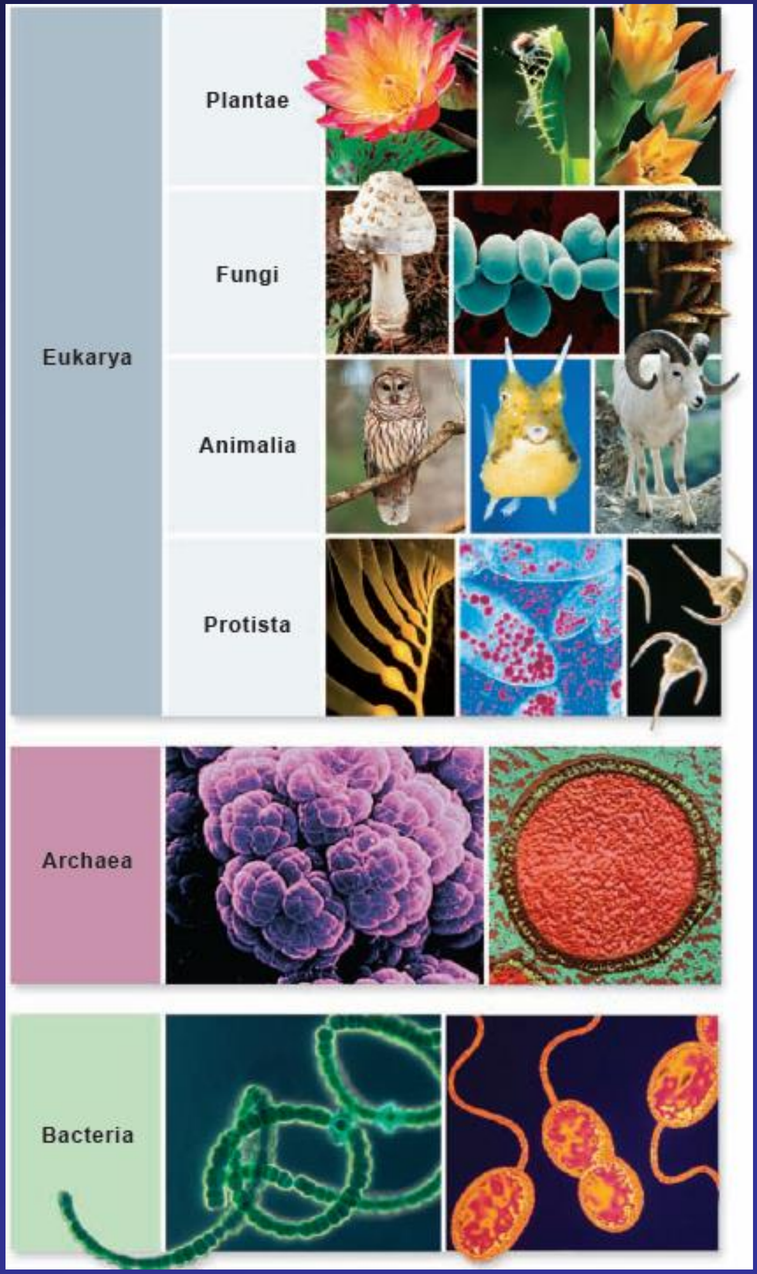
Biological World

Domains (Woese)

1. Archaea
2. Bacteria

} (prokaryotes)

3. Eukarya (eukaryotes)
   - Four kingdoms
   - uni- and multicellular organisms



Comparing The Domains

A Comparison of Some Properties of Bacterial, Archaeal, and Eukaryotic Cells*

	Prokaryotes		
Property	**Bacteria**	**Archaea**	**Eukaryotes**
Typical size	Small (1–5 μm)	Small (1–5 μm)	Large (10–100 μm)
Nucleus and organelles	No	No	Yes
Microtubules and microfilaments	Actin-like and tubulin-like proteins	Actin-like and tubulin-like proteins	Actin and tubulin proteins
Exocytosis and endocytosis	No	No	Yes
Cell wall	Peptidoglycan	Varies from proteinaceous to peptidoglycan-like	Cellulose in plants, fungi; none in animals, protozoa
Mode of cell division	Binary fission	Binary fission	Mitosis or meiosis plus cytokinesis
Typical form of chromosomal DNA	Circular, few associated proteins	Circular, associated with histone-like proteins	Linear, associated with histone proteins
RNA processing	Minimal	Moderate	Extensive
Transcription initiation	Bacterial type	Eukaryotic type	Eukaryotic type
RNA polymerase	Bacterial type	Some features of both bacterial, eukaryotic types	Eukaryotic type
Ribosome size and number of proteins	70S with 55 proteins	70S with 65 proteins	80S with 78 proteins
Ribosomal RNAs	Bacterial type	Archaeal type	Eukaryotic type
Translation initiation	Bacterial type	Eukaryotic type	Eukaryotic type
Membrane phospholipids	Glycerol-3-phosphate + linear fatty acids	Glycerol-1-phosphate + branched polyisoprenoids	Glycerol-3-phosphate + linear fatty acids

from Table 4-1 in Hardin, Bertoin, Kleinsmith (eds.) Becker's World of The Cell, 8th Ed, 2012

Prokaryotes

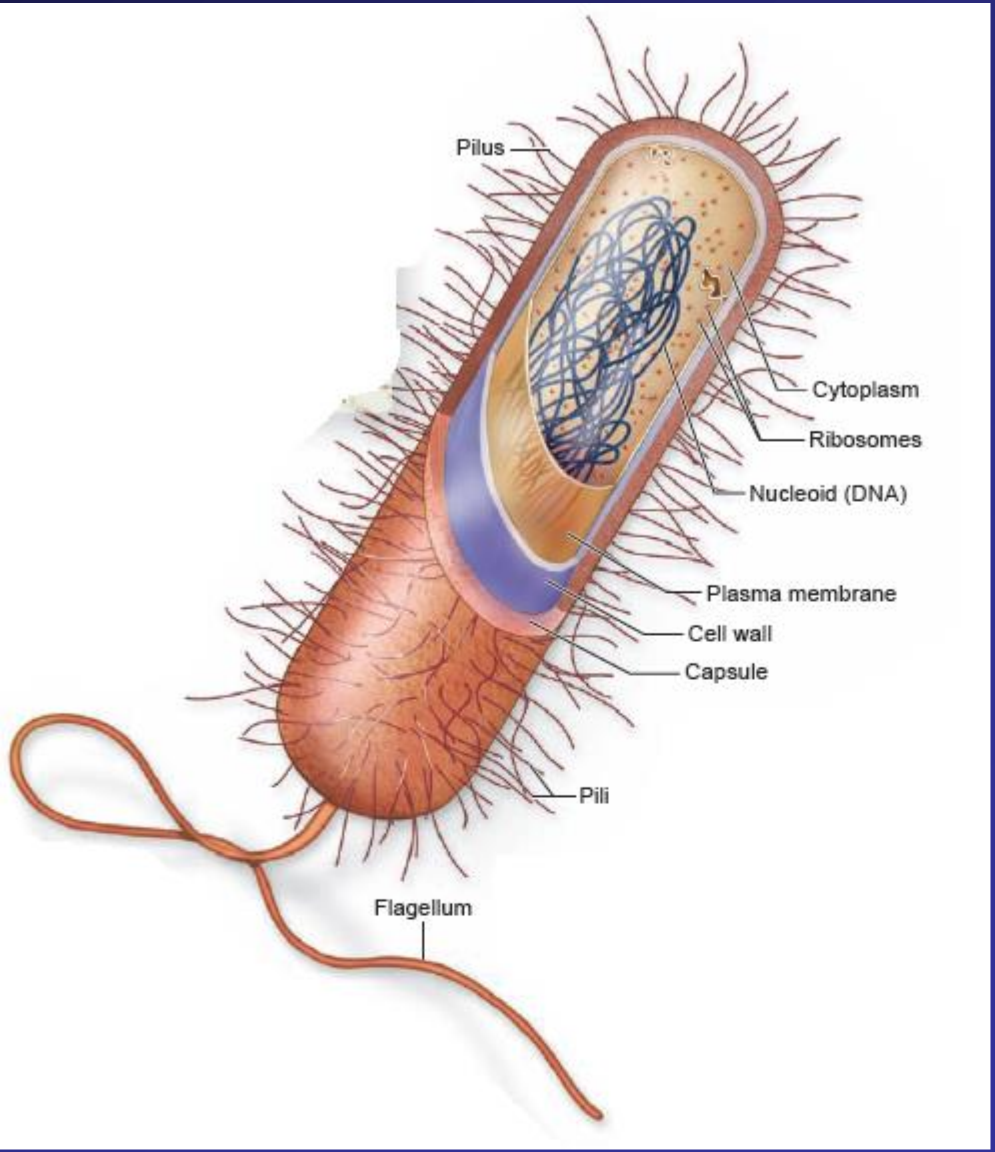
Bacteria

- Common features with eukaryotes
  - cytoplasm
  - plasma membrane
  - DNA organized as chromosome
- Unique features
  - cell wall
  - capsule
  - pili
  - flagella
- Missing features

  nucleus & other membranous organelles

Generalized Bacterial Cell

- Flagellum
  motility
- Pilus
  - attachment
  - exchange of genetic material with other bacteria
- cell wall
  - integrity under stress (changes in osmolarity)
- capsule
  - attachment
  - virulence



Eukaryotic Cells

Basics

- plasma (cell) membrane
- nucleus
- cytoplasm
  - cytosol
  - organelles

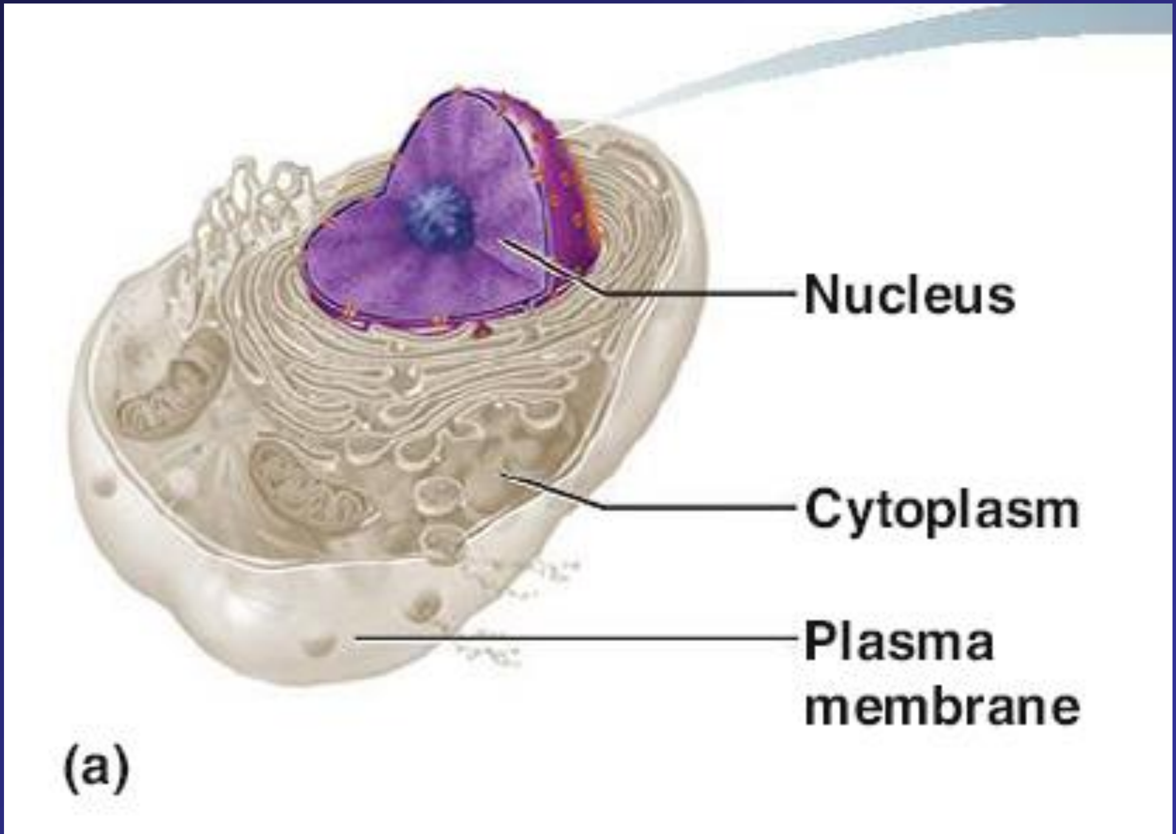
Organelles

- mitochondria
- endoplasmic reticulum
- Golgi complex
- lysosomes (animals)
- peroxisomes

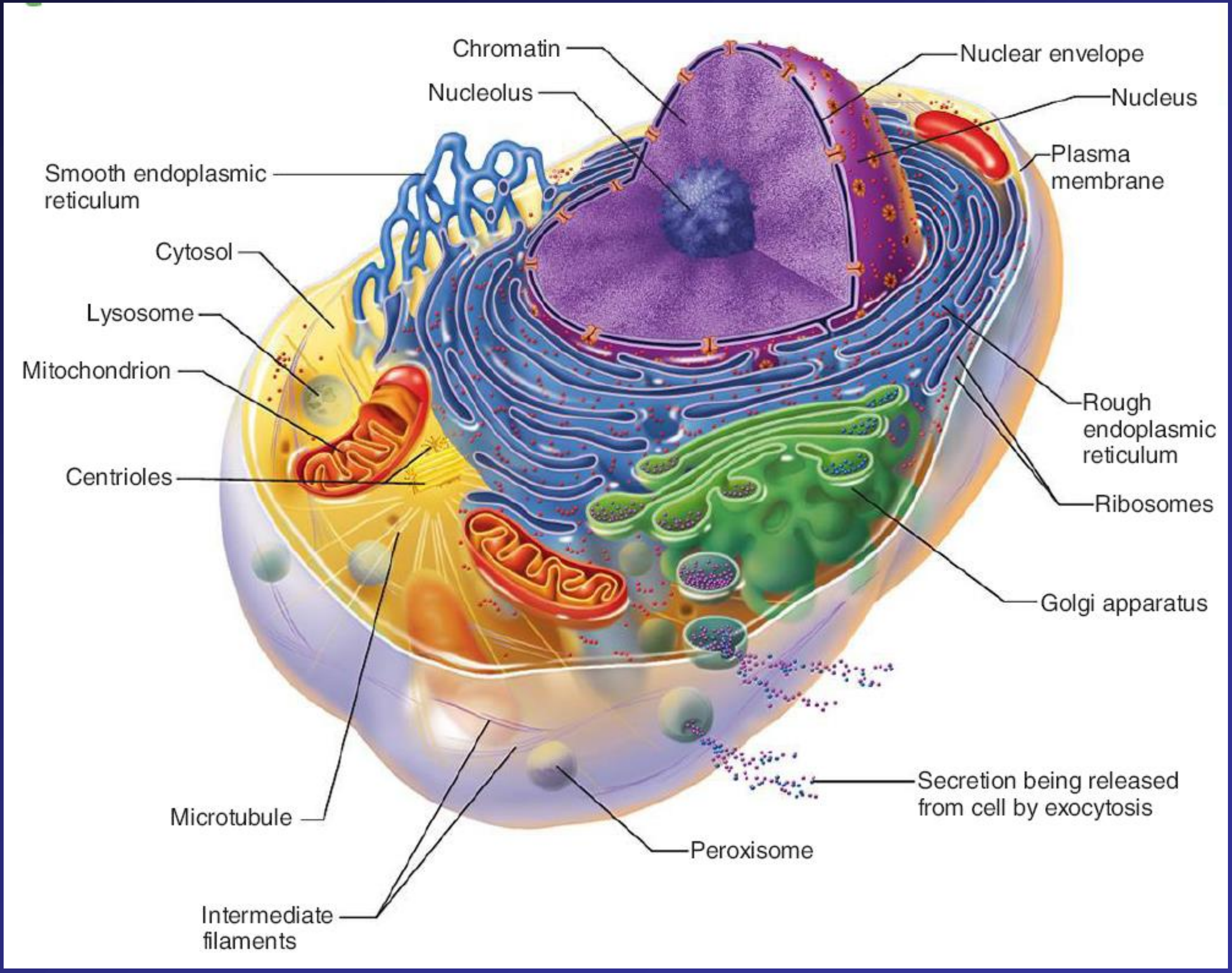
- chloroplasts (plants)
- vacuole (plants)
- primary & secondary walls (plants)

Eukaryote Basics Visualized

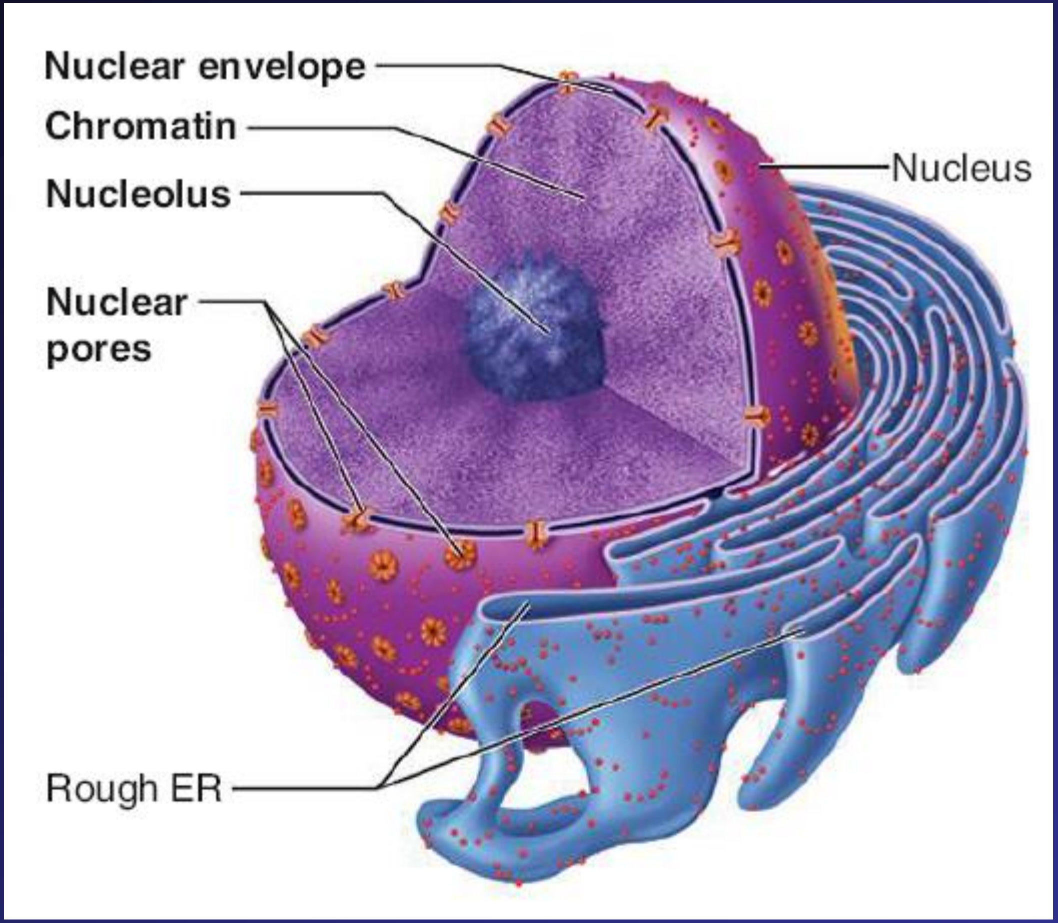
- No cell wall
- Organelle-rich cytoplasm



View of Animal Cell Features



Detail of Nucleus & ER



- Continuity of nuclear envelope with ER "endomembrane system"
- Nuclear pores

Figure 4.6 Structure of an animal cell. In this generalized diagram of an animal cell, the plasma membrane encases the cell, which contains the cytoskeleton and various cell organelles and interior structures suspended in a semifluid matrix called the cytoplasm. Some kinds of animal cells possess finger-like projections called microvilli. Other types of eukaryotic cells—for example, many protist cells—may possess flagella, which aid in movement, or cilia, which can have many different functions.

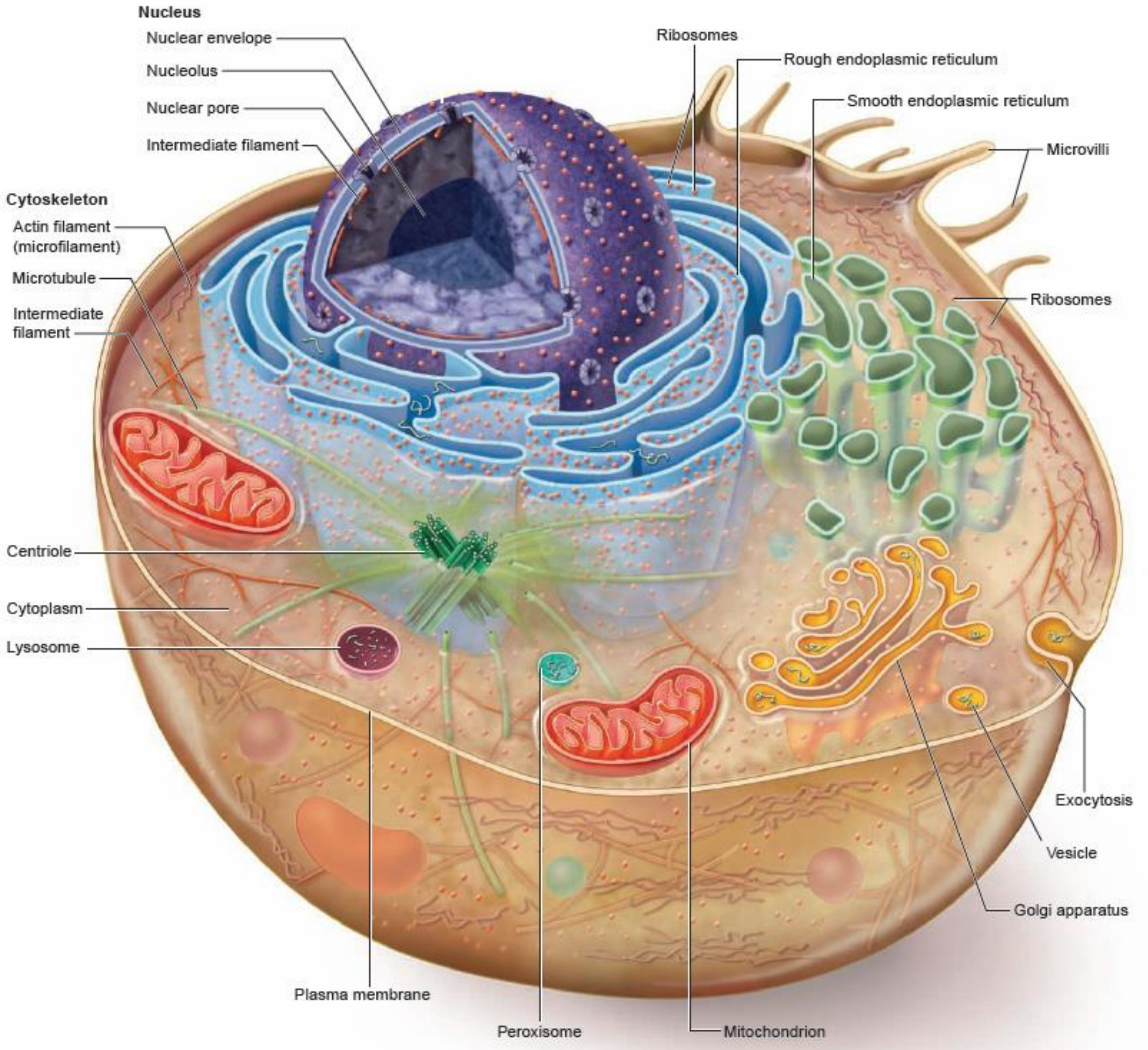
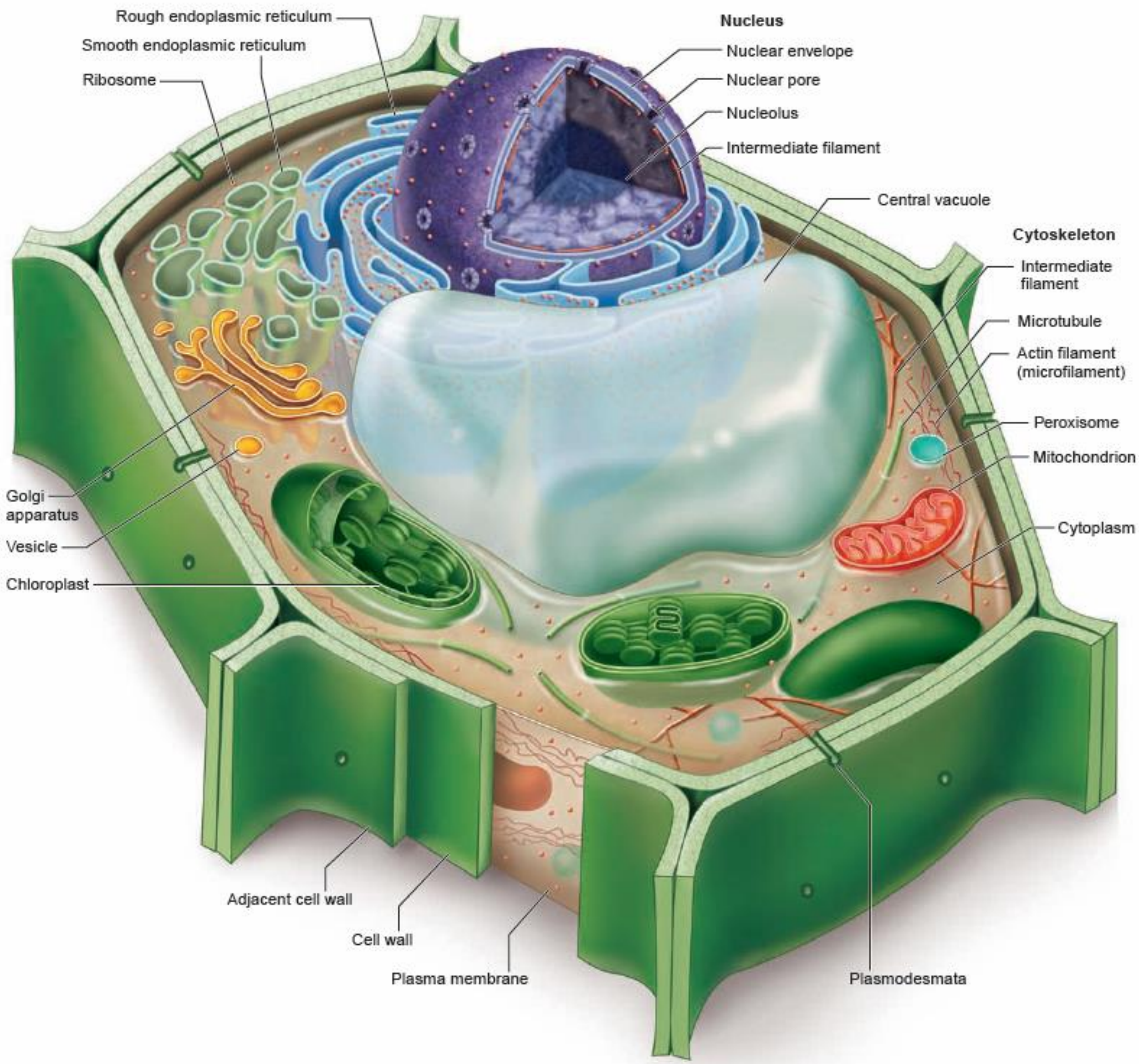


Figure 4.7 Structure of a plant cell. Most mature plant cells contain a large central vacuole, which occupies a major portion of the internal volume of the cell, and organelles called chloroplasts, within which photosynthesis takes place. The cells of plants, fungi, and some protists have cell walls, although the composition of the walls varies among the groups. Plant cells have cytoplasmic connections to one another through openings in the cell wall called plasmodesmata. Flagella occur in sperm of a few plant species, but are otherwise absent from plant and fungal cells. Centrioles are also usually absent.



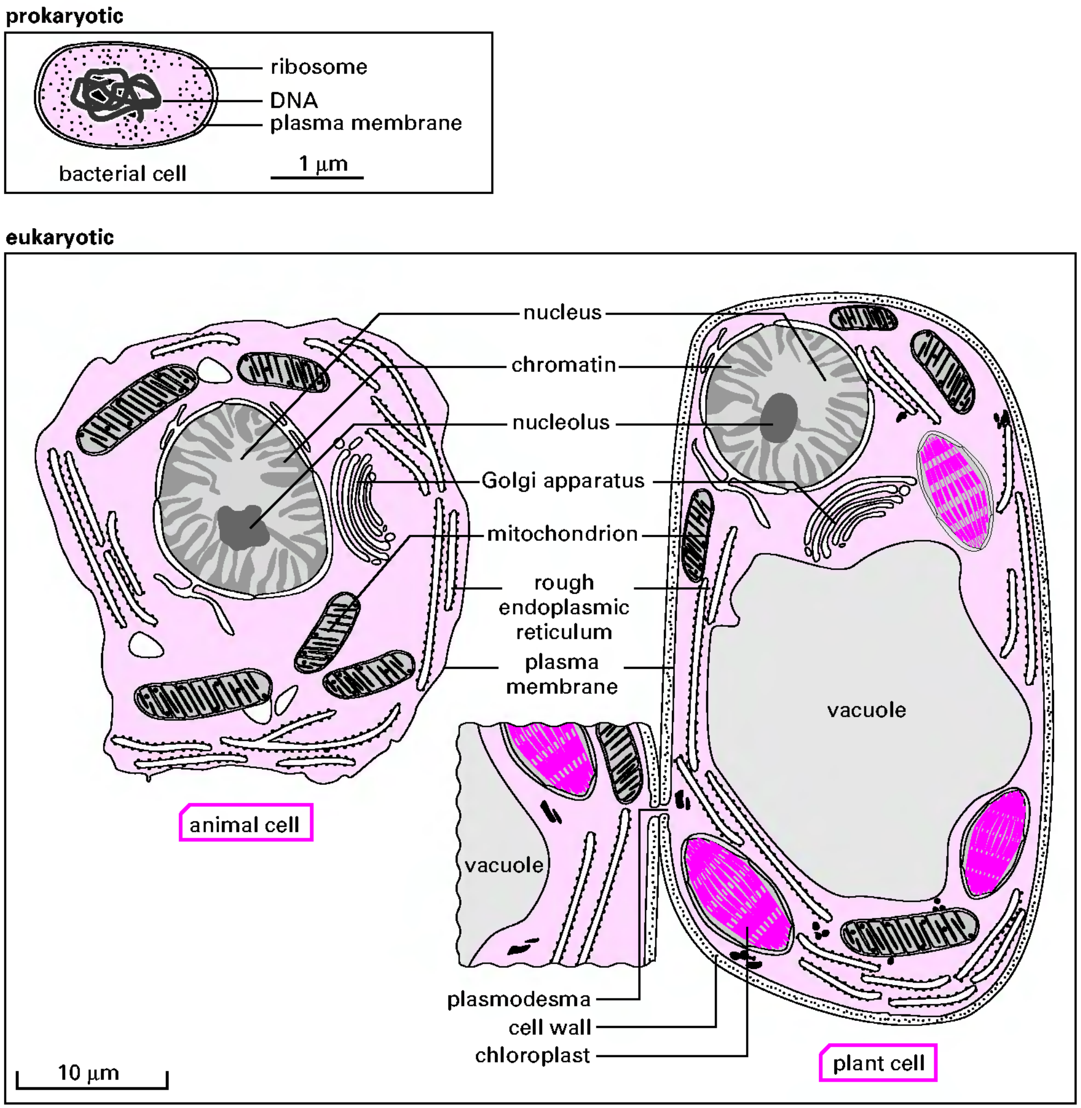
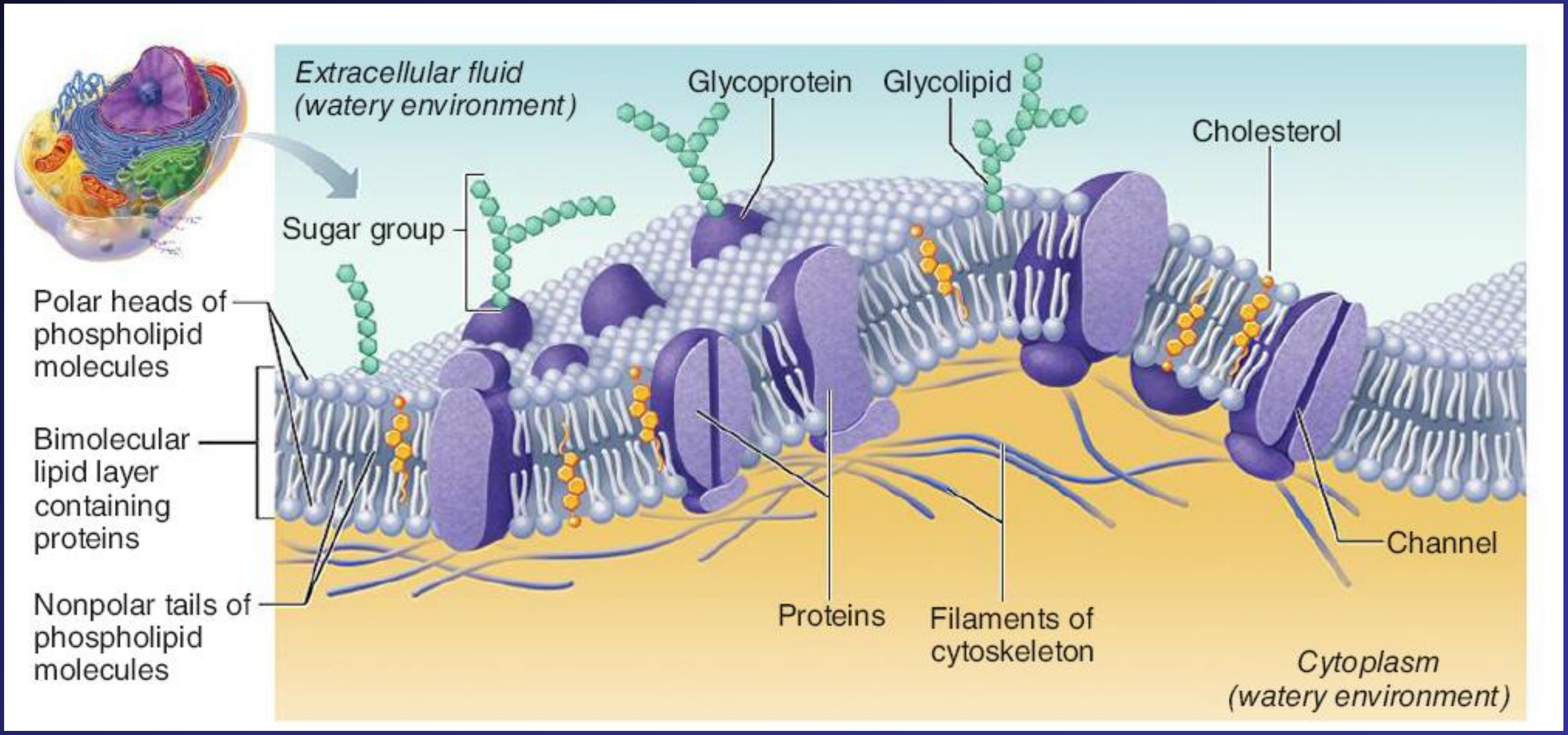


Figure 1.7. Organization of prokaryotic and eukaryotic cells.

Animal Cell Plasma Membrane



Terms/Definitions/Descriptions

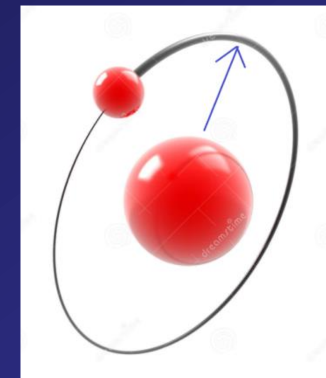
- Cytoplasm
  - The cell contents bounded by the cell's plasma membrane and excluding the nucleus (for eukaryotes)
  - It is composed of cytosol and the cell's organelles
- Cytosol
  - a viscous matrix composed of a water solvent and solutes that supports cell metabolism, structure and function
  - the solutes are small metabolites and large biomolecules: carbohydrates, lipids, amino acids, proteins
- Organelle
  - definitions vary widely!!
  - minimum (safest and actually smartest) definition is a subcellular structure usually bounded by a membrane

Terms/Definitions/Descriptions

- Plasma Membrane / Cell Membrane
  - a structure that encloses the contents (cytoplasm, nucleus) of a cell from its environment
  - usually composed of a bilayer of polar lipids with interspersed proteins specific for the cell interacting with its surroundings
- Nucleus

  Found only in eukaryotes, it contains the genetic information (DNA) specifying the structure and function of the cell and is responsible for organizing the timely expression and copying (during cell replication) of that information

Thinking About Size

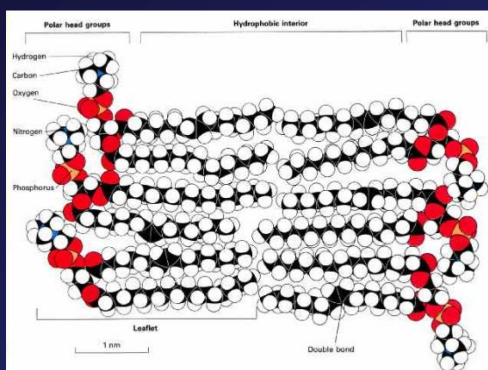


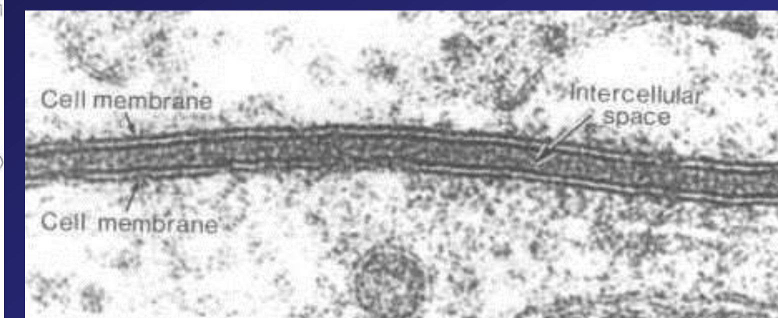
- Hydrogen atom radius

0.5 Å = 50 pm = 0.05 nm = 5×10^{-11} m

- Cell membrane bilayer

5 nm = 50 Å = 5×10^{-9} m = 100 × H atom radius





- Red blood cell

7 µm = 7000 nm = 70,000 Å = 7×10^{-6} m
= 140,000 × H atom radius

Size & Geometry

- Larger cells have lower surface area-to-volume ratios
  - given a spherical cell: volume (r^3) increases more rapidly than surface area (r^2) as a cell gets larger
- Biomolecules diffuse in, out and through the cell
- Cell can only be as big as the biomolecules vital to its survival can efficiently be at physiologically important locations
- Rate of diffusion dependencies
  - cell surface area
  - concentration gradients
  - temperature
  - traversal distance

Size Limitations

1. Cell must have enough surface area to accommodate nutrients entering and wastes exiting for its volume
2. Cell must not be so big such that limits on nutrient and waste substance diffusion causes a stressful (toxic/deficient) condition
3. Biochemical reactions depend on maintaining adequate concentrations of reactants and enzymes, more easily done in a smaller containing space than a larger one

Seeing Structure: Light Microscopy

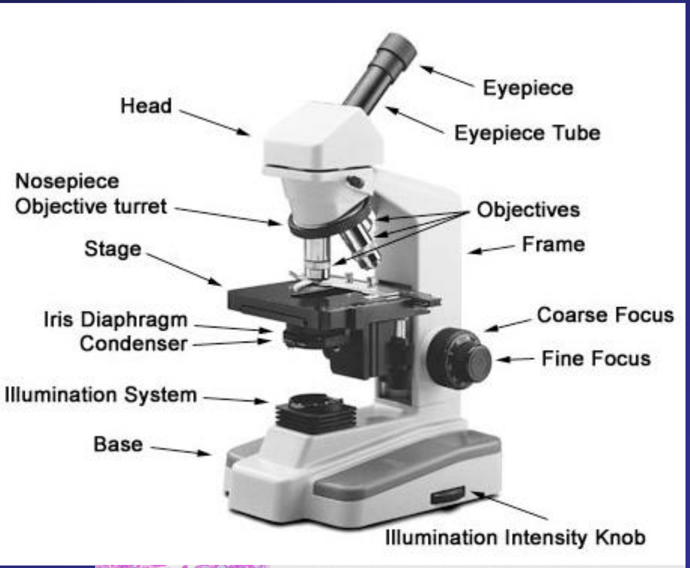
Light Microscopy

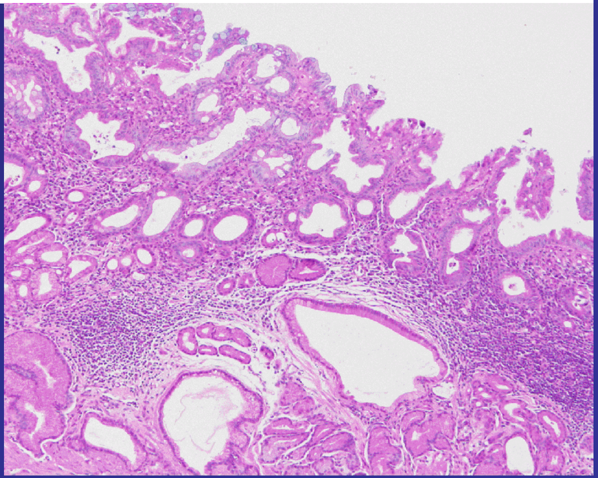
resolution barely below 1 µm

- brightfield
  - must use stains to provide contrast
  - would use to see stained tissue sections

    e.g. hematoxylin-and-eosin (H&E) of stomach wall (figure)
- phase contrast

  imaging living cells in culture/fluid medium





http://www.nikon.com/products/instruments/resources/tech/guide/overview/img/pic_06.jpg

Seeing Structure: Light Microscopy

- confocal
  - reduces flare problem in fluorescence microscopy
  - able to focus within narrow field of depth
  - creates sharper images
  - can generate 3D images with rapid automated positioning

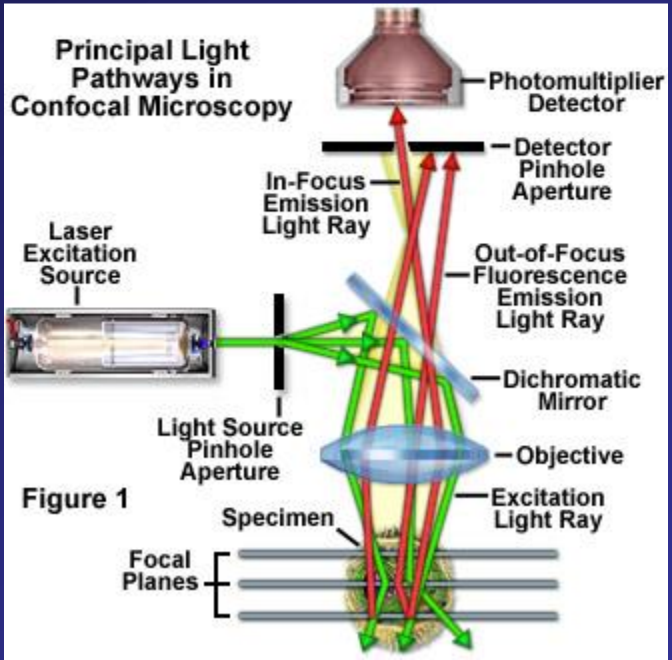


Figure 1

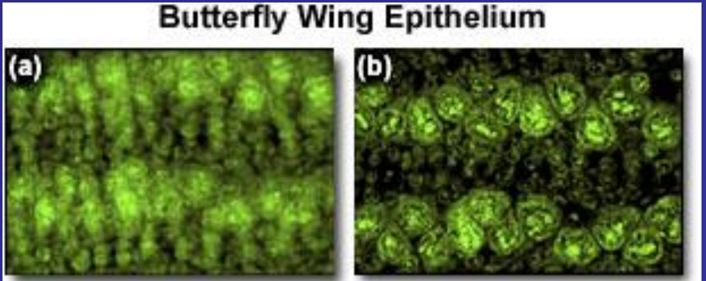
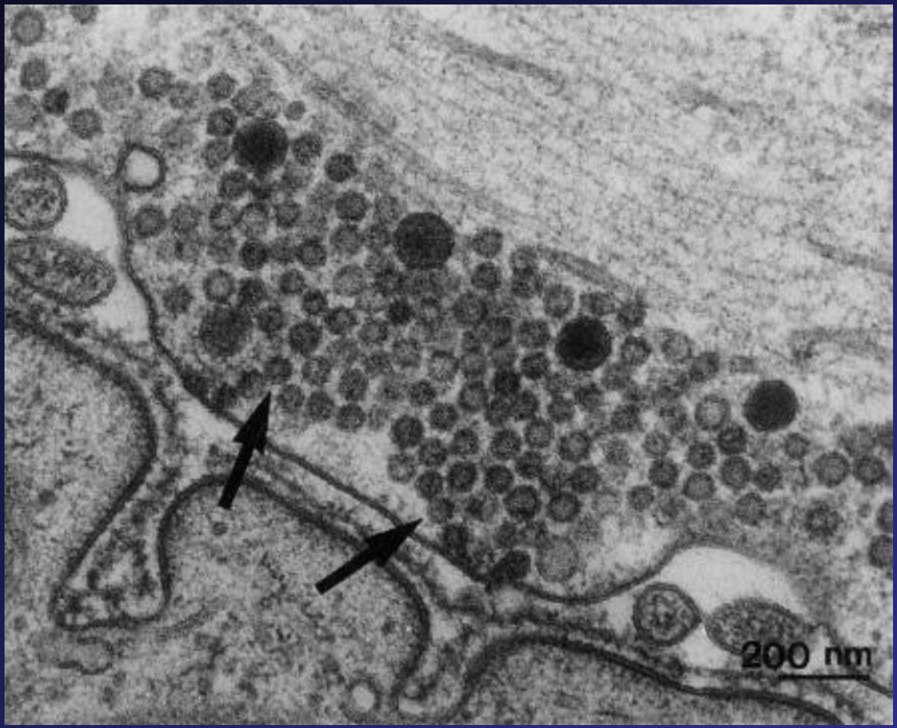


Figure 3

Seeing Structure: Electron Microscopy

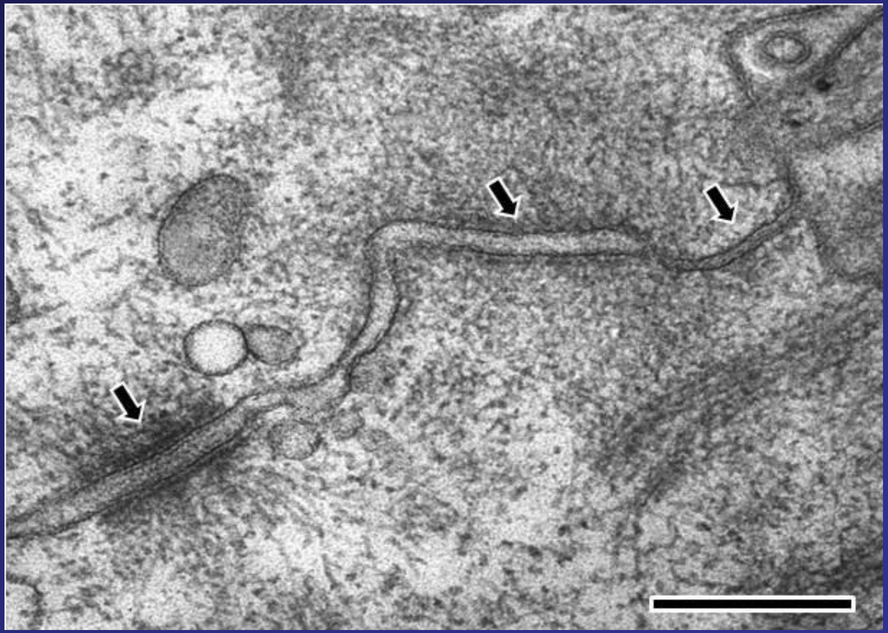
- Transmission Electron Microscopy (TEM)
  - specimens fixed (dehydrated & embedded in resin/plastic) are sectioned in an ultra-microtome (50-100 nm thick), then coated/stained with electron-dense, electron-scattering metal salts (often lead or uranium) to improve contrast
  - Best magnifications: resolve objects separated by 0.2 nm
- Scanning Electron Microscopy (SEM)
  - specimens fixed & dehydrated resin/plastic) then coated/stained with electron-dense, electron-scattering metal salts (gold/palladium) to improve imaging
  - Best magnifications: resolve objects separated by 10 nm

TEM Examples



http://starklab.slu.edu/neuro/nmj.jpg

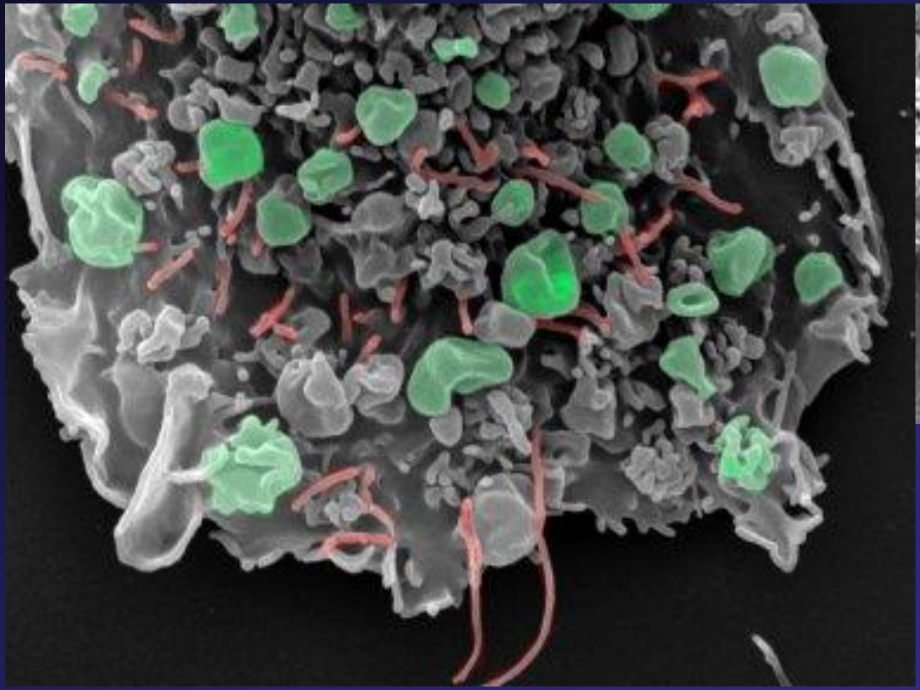
TEM of a neuromuscular junction, with axon terminal containing numerous vesicles on top and evaginated folds to increase surface contact with muscle cell on bottom. Electron-dense material is in the intercellular space



http://www.mechanobio.info/figure/1384242441141.jpg.html

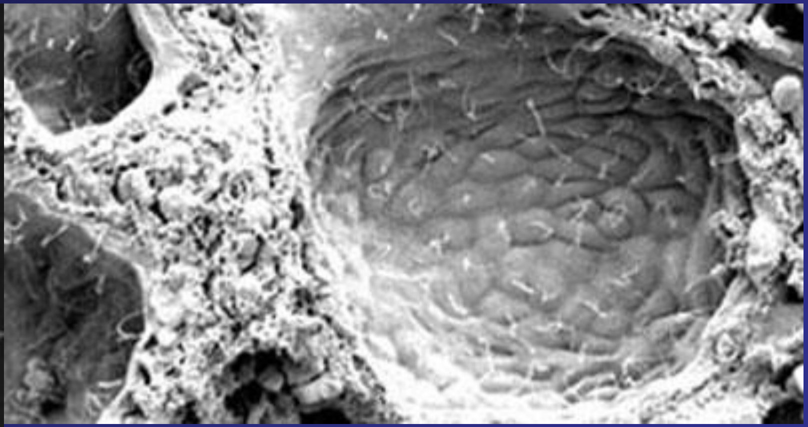
Electron microscopy image of rat intestinal mucosa epithelial cell-cell junctions. The cell is orientated such that the top right hand corner is apical and the bottom left hand corner is more basal. .From left to right; the first arrow points to a desmosome with dense desmosomal plaques seen either side of the intercellular space of approximately 240 angstroms in width, the second arrow points to an adherens junction with an intercellular space of approximately 200 angstroms and the third arrow points towards a tight junction that shows close apposition of the plasma membrane leaflets, as inferred from the absence of an intercellular gap. (Scale bar 250 nm).

SEM Examples



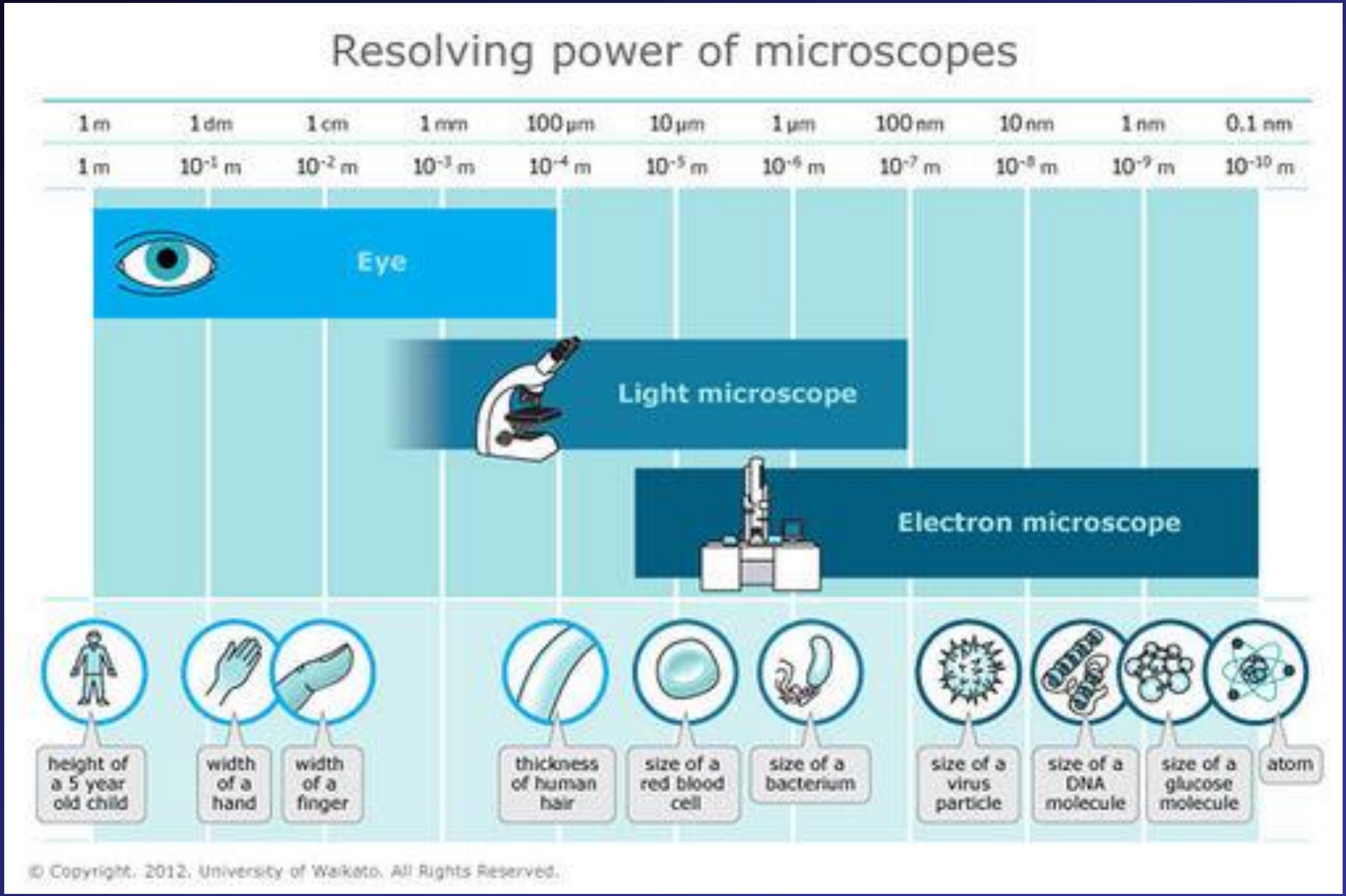
http://www.lincoln.ox.ac.uk/Undergraduates-Subjects-Medicine

Scanning electron micrograph of the effect the human breast cancer-associated gene has on cell behavior. The budding vesicles (green) generate fragments of cancer cell that can be detected in the blood and the adhesion processes (red) are altered making the cell less attached to its surroundings and more able to migrate to distant sites.



Scanning electron micrograph of ciliated cholangiocytes lining each liver cyst in an autosomal recessive polycystic kidney disease animal model.

http://www.mayo.edu/research/~/media/kcms/gbs/research/images/2013/05/19/11/02/cilated-cholangiocytes-index.ashx


Resolving power of microscopes
1 m
1 dm
1 cm
1 mm
100 µm
10 µm
1 µm
100 nm
10 nm
1 nm
0.1 nm
1 m
10⁻¹ m
10⁻² m
10⁻³ m
10⁻⁴ m
10⁻⁵ m
10⁻⁶ m
10⁻⁷ m
10⁻⁸ m
10⁻⁹ m
10⁻¹⁰ m
Eye
Light microscope
Electron microscope
height of a 5 year old child
width of a hand
width of a finger
thickness of human hair
size of a red blood cell
size of a bacterium
size of a virus particle
size of a DNA molecule
size of a glucose molecule
atom
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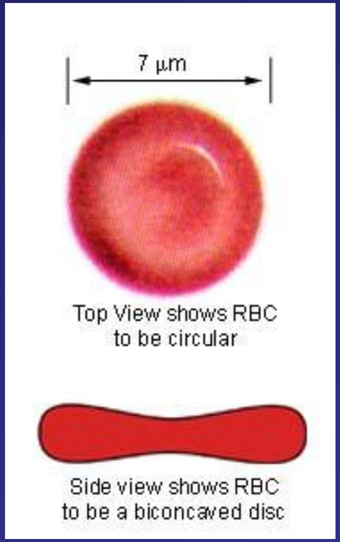
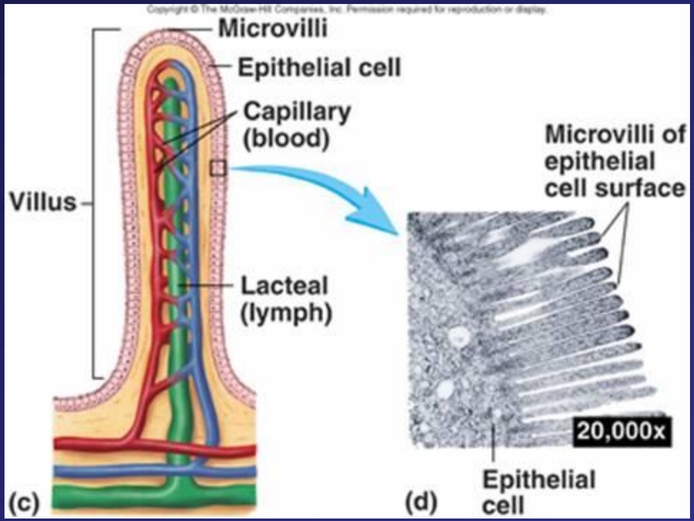
Structure-Function Optimization

Erythrocyte

- Disk-shaped with biconcavity
- Optimized for rapid association and dissociation of O_2 with the heme group enveloped by hemoglobin polypeptides within the RBC



http://www.biosbcc.net/doohan/sample/images/blood%20cells/RBC.jpg



http://www.rci.rutgers.edu/~uzwiak/AnatPhys/Digestive_System_files/image030.jpg

Intestinal Epithelial Cell

- situated on an intestinal villus to improve nutrient absorption
- its apical (luminal) surface has microvilli to further improve nutrient absorption

Subcellular Structures

Organelles ("little organs")

- Mitochondria
- Endoplasmic Reticulum (ER) / Endomembrane sys
  - "rough ER" (RER)
  - "smooth ER" (SER)
- Golgi complex / apparatus
- Lysosomes
- Peroxisomes

Subcellular Structures

Other specialized features

- Ribosomes (organelle?)

  subunit macromolecular assemblies of dozens of proteins weaved around RNA polymers
- Cytoskeleton

  microfilaments, microtubules, intermediate filaments
- Centrioles
- Cilia
- Flagella
- Microvilli

Cells Are "Living"

- Cells are the fundamental "unit" of "life" – the living thing

  the organism can be a single cell or multicellular
- Viruses
  - appear life-like in that they can perpetuate their existence in large numbers, replicate selves
  - without host cells, they cannot: no free-living existence
  - same applies to viroids and prions

Reading (Sources)

- Marieb: part I of chapter 3
- Becker's WotC: Chapter 4
- Raven: Chap 4.2, 4.3,