Biology 112: Organization of the Cell

→ Cells are small because most chemical reactions in cells require diffusion → diffusing molecules do not travel long distances because of their "random walk"

Distance traveled is proportional to the square root of time; distances for processes have to be very small so these processes can occur = tiny cells = small distances

- Cell size is limited by the need for a high surface area – to –volume ratio; only a high surface area compared to the volume allows diffusion to take place fast enough
  - The volume of a cell determines the amount of chemical activity it carries out per unit of time
  - The surface area of a cell determines the amount of substances that can enter it from the outside environment, and the amount of waste products that can exit to the environment
- Increasing size (= volume) of a cell decreases the surface area – to – volume ratio dramatically because volume increases with the power of three, but surface area only with the power of two

Cells show two organizational patterns:

- Prokaryotes:
  - Very small
  - Have no nucleus and hardly any membrane – enclosed compartments
  - DNA is usually a single circular chromosome located in a region called a **nucleoid**
  - The rest of the material enclosed in the plasma membrane is called the **cytoplasm**; has two components:
    - The **cytosol** consists mostly of water and contains dissolved ions, small molecules, and soluble macromolecules such as proteins
    - **Ribosomes** – complexes of RNA and proteins = sites of protein synthesis
  - Locomotion = **flagella**; Adherence = **pili**
- Eukaryotes:
  - Membrane – enclosed nucleus and many other membrane – enclosed compartments called organelles → therefore can be larger than prokaryotes (further internally subdivided)

Prokaryotes

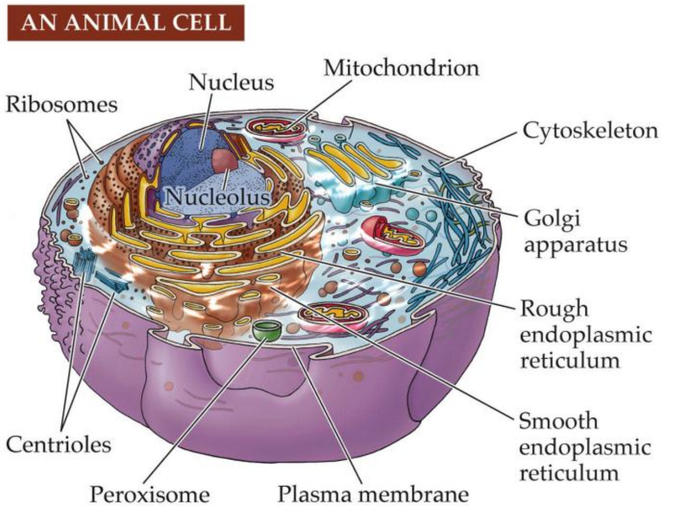
→ Prokaryotes inhabit the widest range of environmental extremes because they show the biggest **metabolic diversity** → can digest vide variety of food (the can gain energy using light or oxidizing hydrogen, sulfur, iron, nitrogen, or organic compounds, such as methane, benzene, or fluorocarbons)

→ Volume of a prokaryotic cell is generally about one fiftieth of the volume of a eukaryotic cell; range from 1 to 10 micrometers in length or diameter

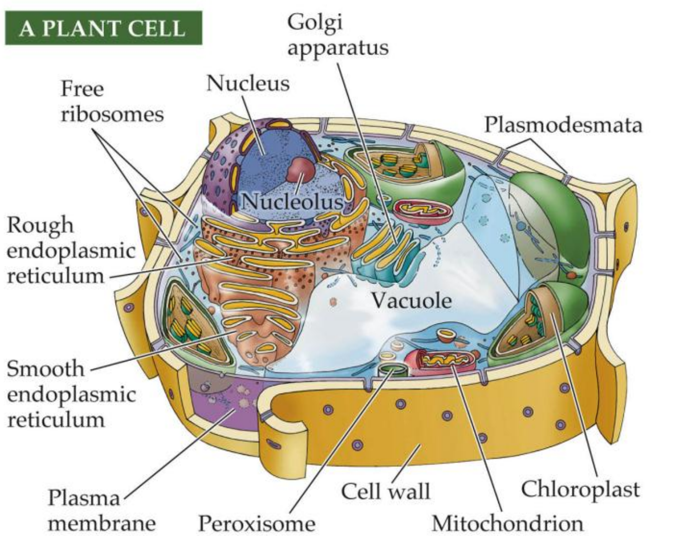
Eukaryotes

→ Compartmentalization is the key to eukaryotic cell function

- Each organelle or compartment has a specific role defined by chemical processes
- Membrane surrounding these organelles keep away inappropriate molecules → phospholipid bilayers



LIFE: THE SCIENCE OF BIOLOGY, Seventh Edition, Figure 4.7 Eukaryotic Cells (Part 5)



LIFE: THE SCIENCE OF BIOLOGY, Seventh Edition, Figure 4.7 Eukaryotic Cells (Part 6)

- Cell wall – cellulose; structure (rigid)
- Vacuole – stores water that keeps the cell rigid
- Plasmodesmata – cell to cell communication; tissues that substances can diffuse freely in and out
- Chloroplast – photosynthesis

The Endo-Membrane System

→ Interior membrane systems; orientation of membrane is always reserved (cytosolic surface of membrane remains cytosolic surface)

- The Nucleus
    - Contains most the cell's DNA
    - In the nucleolus, ribosomes are assembled from RNA and proteins
    - Function:
        - DNA is replicated;
        - DNA is transcribed into mRNA or rRNA by RNA polymerases;
        - rRNA is not translated (it directly folds into a 3D structure)
        - Ribosomes are made of 4 rRNAs and about 80 proteins in the nucleolus (RNAs largely determine structure and function)

In eukaryotes, functional ribosomes are found free in the cytoplasm, in mitochondria, bound to the endoplasmic reticulum, and in chloroplasts

  - Two lipid bilayers form the nuclear envelope, which is perforated with nuclear pores; mRNA and ribosomes pass through these pores; ribosomes translate mRNA into protein only in the cytoplasm
    - Nuclear envelope separates DNA transcription (which occurs in the nucleus) from translation (in the cytoplasm)

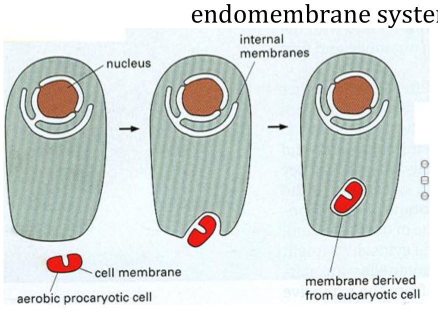
- The Endoplasmic Reticulum (ER)
  - Network of interconnecting membranes distributed throughout the cytoplasm
  - The ER's folding generates a surface area much greater than that of the plasma membrane
  - Functions: make phospholipids that make up the membrane; insert all membrane proteins
  - The internal compartment, called the lumen, is a separate part of the cell with distinct protein and ion composition → it communicated only with the outside of the cell
  - At certain sites, the ER membrane is continuous with the outer nuclear envelope membrane
  - Rough ER: contains ribosomes on the ER
    - Ribosomes come from the cytosolic pool of ribosomes and are directed to the ER after they have translated the first few amino acids containing a signal sequence that directs the ribosomes to the ER → The attached ribosomes are actively involved in protein synthesis
    - Oligosaccharides (3 – 12 subunit sugars) are attached to proteins inside the ER
    - The RER receives into its lumen certain newly synthesized proteins, segregating them away from the cytoplasm; also participates in transporting these proteins to other locations in the cell
    - While inside the RER, proteins can be chemically modified to alter their functions and to chemically "tag" them for delivery to specific areas
  - Smooth ER: does not contain ribosomes
    - Phospholipids are made
    - All lipids are synthesized in ER → enzymes in ER detoxify many substances (make them water soluble)
    - Within the lumen of the SER, some proteins that have been synthesized on the RER are chemically modified
    - Responsible for chemical modification of small molecules take in by the cell
    - It is the site for glycogen degradation in animal cells
    - It is the site for the synthesis of lipids and steroids
- The Golgi Apparatus
  - Consists of flattened membranous sacs (called *cisternae* → three regions contain different enzymes and perform different functions) and small membrane – enclosed vesicles
  - Functions:
    - Proteins inserted in the ER pinch off into vesicles and move to the Golgi → modified (sugar side chains are added)
    - Concentrate, package, and sort proteins before they are sent to their destinations (apical or basal side of cell membrane, lysosome)
    - When sugars are added to lipids in the Golgi, they are found on the outside of the cell membrane → the inner leaflet of the Golgi will be the outer leaflet of the cell membrane
- Lysosomes: contain a low pH and a large amounts of digestive enzymes to break down substances inside them
  - **Primary lysosomes** = originate from the Golgi; contain digestive enzymes and they are the sites where macromolecules are hydrolyzed into their monomers

- Site for the breakdown of food, other cells, or foreign objects → materials get into the cell by a process called *phagocytosis* → the phagosome fuses with a primary lysosome to form a **secondary lysosome**, in which digestion occurs

- Exocytosis: waste products, digestive enzymes are secreted out of the cell
- Endocytosis: processes of carrying lipids (cholesterol) and other substances into the cell; form pockets (lysosomes)

Endosymbiotic Organelles

- **Mitochondria** have an outer plasma membrane (smooth and protective) and a highly folded inner membrane
    - Folds of the inner membrane contain large protein molecules used in cellular respiration (ATP production)
    - The region enclosed by the inner membrane contains many enzymes, e.g. for citric acid cycle
    - **Mitochondrial matrix** → the space enclosed by the inner membrane; contains enzymes, ribosomes and DNA that are used to make some of the proteins needed for cellular respiration
- **Chloroplast** is one member of the **plastid** family of organelles
    - Chloroplasts contain the green pigment chlorophyll and are the sites of photosynthesis (energy source for most of the living world); other plastids store starch or pigments
    - Chloroplasts are surrounded by two membranes and have an internal membrane system
    - The internal stacks of membranes (each stack called **granum** consists of a series of flat, closely packed, circular compartments = **thylakoids**) contain chlorophyll and ATP synthase → they are derived from the inner membrane
        - In prokaryotes, the photosynthetic system also sits in the cell membrane
        - Carbon fixation occurs yielding sugars, amino acids, all fatty acids, DNA, RNA, and ribosomes
- Endosymbiont Theory
    - Mitochondria and chloroplasts are descendants of bacteria likely taken up by endocytosis
    - Evidence:
        - Double membrane
        - Own genome – own ribosomes more similar to Eubacteria; genes more similar to eubacterial genes
    - However, there is no vesicle exchange between the outer membrane and the endomembrane system



Cytoskeleton

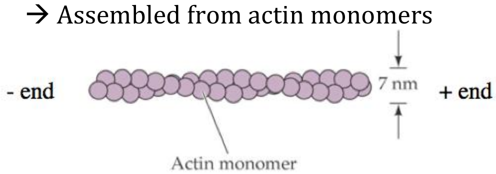
- Maintains cell shape and polarity
- It holds cell organelles in position within the cell
- Acts as track for "motor proteins" that help move materials within cells → It moves organelles within the cells
- It is involved with movements of the cytoplasm → cytoplasmic streaming

- It interacts with extracellular structures, helping to anchor the cell in place

→ Three components to the cytoskeleton: microfilaments, intermediate filaments, and microtubules

Microfilaments

→ They help the entire cell or parts of the cell to move
→ They determine and stabilize cell shape
→ Assembled from actin monomers

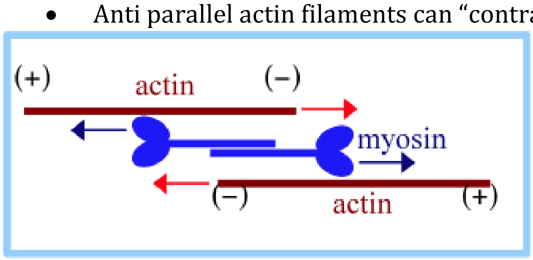


Actin Filaments

- Actin filaments are made of the protein **actin**
- Add structure to the plasma membrane and shape to cells
- Together with the motor myosin, they mediate cell shape changes, cell migration, and muscle contraction
- Actin exists in cells as monomers and filaments; there are many proteins that regulate polymerization and depolymerization

Actin-Myosin Contraction

- Coiled – coil tail domains of myosin II may interact to form anti parallel bipolar complexes
- These may contain many myosin molecules, as in thick filaments of skeletal muscle, or as few as two myosin's
- Myosin heads can move along actin filaments in only one direction
- Anti parallel actin filaments can "contract"



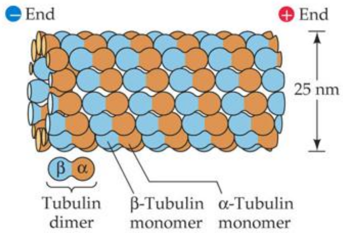
Intermediate Filaments

- Intermediate filaments (IF) are found only in multicellular organisms, forming ropelike assemblages in cells → more permanent than the other two types; do not form and re-form
- They have only structural functions:
    - Anchor the cell structures in places → stabilize the nucleus (lamins of the nuclear lamina are intermediate filaments)
    - Give mechanical strength to cells (coiled coils of keratins) → resist tension; maintain rigidity in body surface tissues

Microtubules

- Microtubules are hollow cylinders made from tubulin protein subunits
- Organize the cell:
    - Provide an intracellular skeleton
    - Determine cell polarity
    - Function as tracks, on which motor proteins can move vesicles and organelle → many proteins that regulate growth or shrinkage of microtubules; vesicles and organelles can be moved in both directions by dynein and kinesin
        - **Motor proteins** – specialized molecules that use cellular energy to change their shape and move
    - Have chromosomes

- They regularly form and disassemble as the needs of the cell change
- Assembled from *dimers* (a molecule made up of two monomers) of the protein *tubulin*
    - The two ends of the microtubule are different: one plus end and the other the minus end → rapidly add or subtract dimers, mainly at plus end = changing shape



- Cilia, common locomotion appendages of cells, are made of microtubules
    - **Cilia** are short and are usually present in great numbers
    - Cilia in oviduct to push the egg towards the uterus; in trachea in the lung
    - In cilia/flagella, two doublets are connected by linker proteins and dynein; therefore, movement of dynein results in bending
- Motion of cilia and flagella results from the sliding of the microtubule doublets past each other → drive by the motor protein **dynein**
    - Dynein molecules that are attached to one microtubules doublet bind to a neighboring doublet
    - As the dynein molecules change shape, they move the doublets past one another
    - Another molecule, **nexin**, can cross-link the doublets and prevent them from sliding past one another; in this case, the cilium bends
- Another motor protein, **kinesin**, carries protein-laden vesicles from one part of the cell to another → kinesin bind to a vesicle or other organelle, then "walk" it along a microtubule by a repeated series of shape changes

→ Dynein move attached organelles towards the minus end, while kinesin move them toward the plus end

Cell Adhesion

→ Cells can interact with the environment:

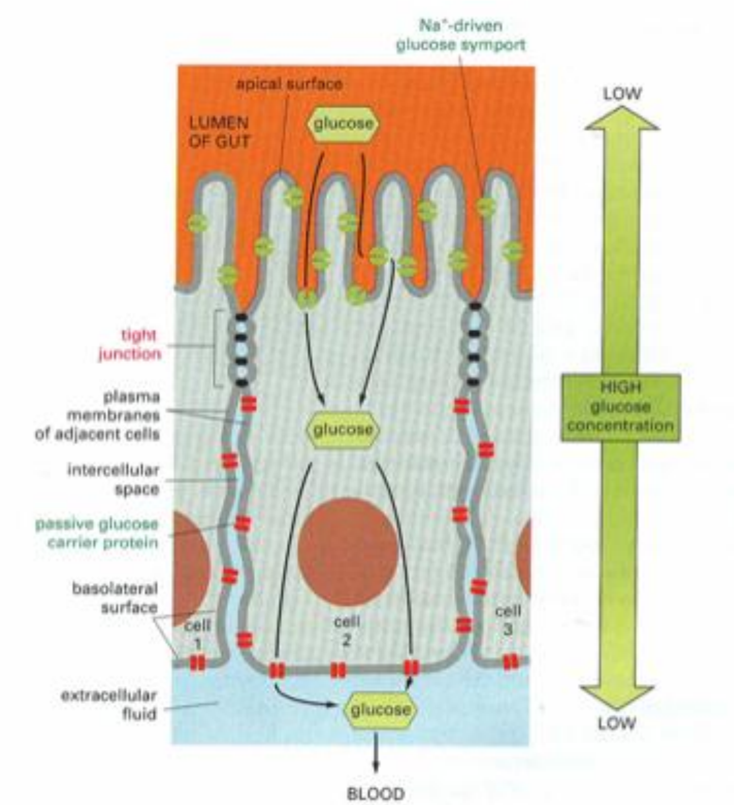
- In cell recognition, one cell specifically binds to another cells of a certain type; this can lead to phagocytosis, DNA exchange, sperm-egg fusion, cell adhesion, …
- In cell adhesion, cells **stably** bind to each other or the extracellular matrix
- Cell adhesion evolved from cell recognition

→ Animals have five major types of cell junctions

Definition: Basal lamina = a thin mat of extracellular matrix underlying epithelia, surrounding muscles, etc.

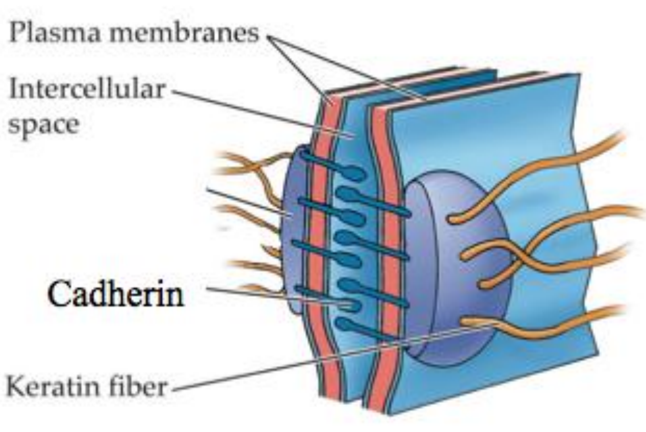
Definition: epithelium: the thin tissue forming the outer layer of a body's surface and lining the alimentary canal and other hollow structures → more specifically, the part of this derived from embryonic ectoderm and endoderm

(1) Tight Junction: Separates apical and basolateral membrane domain and their membrane proteins; prevents substances from moving through the intercellular space
    i. Particularly important in the epithelium lining the gut; function of tight junctions demonstrated by incubating one side of an epithelium with a solution of heavy metals (ruthenium red), then fixing and sectioning for EM. Ruthenium red stays on one side of TJ.

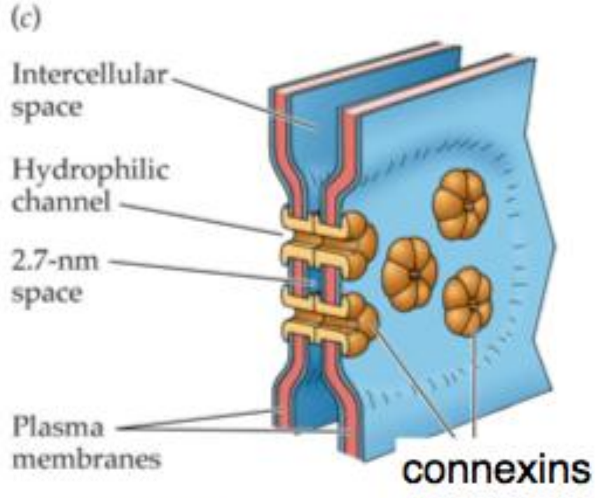


(2) Adhesion Junction: most important and ancient cell-cell junction; also first one to form during development
   i. Generally form a circumferential belt close to the apical-basolateral boundary
   ii. Made of transmembrane **cadherins**; several cadherins from two different cells bind to each other
   iii. Adhesion junctions connect to actin filaments

(3) Desmonsomes: provide mechanical strength (skin); connected to intermediate filaments



(4) Gap Junction: connections that facilitate communication between cells
   i. Low molecular weight molecules can freely diffuse from one cell to the next (e.g. Ca2+ ion to synchronize heart muscle contraction)
   ii. Gap junctions are made of proteins called **connexins**, which snap together to generate a pore



Gap junctions

(5) Focal Adhesions: most important cell-matrix junction
   i. They form distinct spots on the basal side of cells; connect skin to the underlying basal lamina, muscles to tendons, …
   ii. Made of transmembrane **integrins**; several integrins from one cell bind to extracellular matrix molecules
   iii. Focal adhesions connect to actin filaments