Chapter 4—Functional Anatomy of Prokaryotic and Eukaryotic Cells

I. Comparing Prokaryotic and Eukaryotic Cells.
   a. Prokaryote comes from the Greek words for pre-nucleus.
   b. Eukaryote comes from the Greek words for true nucleus.
   c. Prokaryotes:
      i. One circular chromosome, not contained in a membrane.
      ii. No histones or introns are present in Bacteria; both are found in Eukaryotes and Archaea.
      iii. No membrane-bound organelles. (Only contain non membrane-bound organelles).
      iv. Bacteria contain peptidoglycan in cell walls; Eukaryotes and Archaea do not.
      v. Binary fission.
   d. Eukaryotes:
      i. One to many linear chromosomes bound by a nuclear membrane.
      ii. Contain histones and introns.
      iii. Contain membrane-bound and non membrane-bound organelles.
      iv. No peptidoglycan in cell walls.
      v. Divide by mitosis and meiosis.

II. Size, Shape, and Arrangement of Bacterial Cells.
   i. Average size of prokaryotic cells: 0.2 -2.0 μm in diameter × 1-10 μm (0.001 – 0.01 mm)
      1. Typical eukaryote 10-500 μm in length (0.01 – 0.5 mm).
      2. Typical virus 20-1000 nm in length (0.00000002 – 0.000001 m).
      3. Thiomargarita is the largest bacterium known. It is about the size of a typed period (0.75 mm).
      4. Nanoarchaeum is the smallest cell known. It is at the lower theoretical limit for cell size (0.4 μm).
   ii. Basic bacterial shapes:
      1. Coccus (sphere/round). Fig. 1.
      2. Bacillus (staff/rod-shaped). Fig. 2.
      3. Spirilla (rigid with a spiral/corkscrew shape). Fig. 4.
         a. Flagella propel these bacteria.
      4. Vibrio (curved rod).
      5. Spirochetes (flexible with a spiral shape). Axial filaments (endoflagella) propel these bacteria.
   iii. Descriptive prefixes:
      1. Diplo (two cells).
      2. Tetra (four cells).
      3. Sarcinae (cube of 8 cells).
      4. Staphylo (clusters of cells).
      5. Strepto (chains of cells).
   iv. Unusual bacterial shapes: Fig. 5.
      1. Star-shaped Stella.
      2. Square/rectangular Haloarcula.
   v. Arrangements:
      1. Pairs: diplococci, diplobacilli
      2. Clusters: staphylococci
   vi. Most bacteria are monomorphic. They do not change shape unless environmental conditions change.
   vii. A few are pleomorphic. These species have individuals that can come in a variety of shapes.
III. Structures External to the Prokaryotic Cell Wall. Fig. 6.

a. Glycocalyx (sugar coat).
   i. Usually very sticky.
   ii. Found external to cell wall.
   iii. Composed of polysaccharide and/or polypeptide.
   iv. It can be broken down and used as an energy source when resources are scarce.
   v. It can protect against dehydration.
   vi. It helps keep nutrients from moving out of the cell.
      1. A capsule is a glycocalyx that is neatly organized and is firmly attached to the cell wall.
         a. Capsules prevent phagocytosis by the host’s immune system.
      2. A slime layer is a glycocalyx that is unorganized and is loosely attached to the cell wall.
      3. Extracellular polysaccharide (extracellular polymeric substance) is a glycocalyx made of sugars and allows bacterial cells to attach to various surfaces.

b. Prokaryotic Flagella. Fig. 8.
   i. Long, semi-rigid, helical, cellular appendage used for locomotion.
   ii. Made of chains of the protein flagellin.
      1. Attached to a protein hook.
   iii. Anchored to the cell wall and cell membrane by the basal body.
   iv. Motile Cells. Fig. 9.
      1. Rotate flagella to run and tumble.
      2. Move toward or away from stimuli (taxis).
         a. Chemotaxis.
         b. Phototaxis.

c. Axial Filaments (Endoflagella). Fig. 10.
   i. In spirochetes:
      1. Anchored at one end of a cell.
      2. Covered by an outer sheath.
      3. Rotation causes cell to move like a corkscrew through a cork.

d. Fimbriae. Fig. 11.
   i. Shorter, straighter, thinner than flagella.
   ii. Not used for locomotion.
   iii. Allow for the attachment of bacteria to surfaces.
   iv. Can be found at the poles of the cell, or covering the cell’s entire surface.
   v. There may be few or many fimbriae on a single bacterium.

e. Pili (sex pili).
   i. Longer than fimbriae.
   ii. Only one or two per cell.
   iii. Are used to transfer DNA from one bacterial cell to another, and in twitching & gliding motility.

IV. The Prokaryotic Cell Wall. Fig. 6.

a. Chemically and structurally complex, semi-rigid, gives structure to and protects the cell.

b. Surrounds the underlying plasma membrane.

c. Prevents osmotic lysis.

d. Contributes to the ability to cause disease in some species, and is the site of action for some antibiotics.

e. Made of peptidoglycan (in bacteria). Fig. 12.
   i. Polymer of a disaccharide.
      1. N-acetylg glucosamine (NAG) & N-acetylmuramic acid (NAM).
   ii. Disaccharides linked by polypeptides to form lattice surrounding the cell. Fig. 13a.
   iii. Penicillin inhibits this lattice formation, and leads to cellular lysis.
f. Gram-positive cell walls. Fig. 13b.
   i. Many layers of peptidoglycan, resulting in a thick, rigid structure.
   ii. Teichoic acids.
      1. May regulate movement of cations (+).
      2. May be involved in cell growth, preventing extensive wall breakdown and lysis.
      3. Contribute to antigenic specificity for each Gram-positive bacterial species.
      4. Lipoteichoic acid links to plasma membrane.
      5. Wall teichoic acid links to peptidoglycan.

g. Gram-negative cell walls. Fig. 13c.
   i. Contains only one or a few layers of peptidoglycan.
      1. Peptidoglycan is found in the periplasm, a fluid-filled space between the outer
         membrane and plasma membrane.
         a. Periplasm contains many digestive enzymes and transport proteins.
   ii. No teichoic acids are found in Gram-negative cell walls.
   iii. More susceptible to rupture than Gram-positive cells.
   iv. Outer membrane:
      1. Composed of lipopolysaccharides, lipoproteins, and phospholipids.
      2. Protects the cell from phagocytes, complement, antibiotics, lysozyme, detergents,
         heavy metals, bile salts, and certain dyes.
      3. Contains transport proteins called porins.
      4. Lipopolysaccharide is composed of:
         a. O polysaccharide (antigen) that can be used to ID certain Gram-negative
            bacterial species.
         b. Lipid A (endotoxin) can cause shock, fever, and even death if enough is
            released into the host’s blood.

h. Gram Stain Mechanism.
   i. Crystal Violet-Iodine (CV-I) crystals form within the cell.
   ii. Gram-positive:
      1. Alcohol dehydrates peptidoglycan.
      2. CV-I crystals cannot leave.
   iii. Gram-negative:
      1. Alcohol dissolves outer membrane and leaves holes in peptidoglycan.
      2. CV-I washes out.
      3. Safranin stains the cell pink.
   iv. Table 1, pg. 94, compares Gram-positive and Gram-negative bacteria.

i. Damage to Prokaryotic Cell Walls.
   i. Because prokaryotic cell walls contain substances not normally found in animal cells,
      drugs or chemicals that disrupt prokaryotic cell wall structures are often used in
      medicine, or by the host to combat the bacteria.
      1. Lysozyme digests the disaccharides in peptidoglycan.
      2. Penicillin inhibits the formation of peptide bridges in peptidoglycan.
   ii. A protoplast is a Gram-positive cell whose cell wall has been destroyed, but that is still
       alive and functional. (Lost its peptidoglycan).
   iii. A spheroplast is a wall-less Gram-negative cell. (Lost its outer membrane and
        peptidoglycan).
   iv. L forms are wall-less cells that swell into irregular shapes. They can live, divide, and
       may return to a walled state.
   v. Protoplasts and spheroplasts are susceptible to osmotic lysis.
   vi. Gram-negative bacteria are not as susceptible to penicillin due to the outer membrane and
       the small amount of peptidoglycan in their walls.
   vii. Gram-negative bacteria are susceptible to antibiotics that can penetrate the outer
        membrane (Streptomycin, chloramphenicol, tetracycline).
V. Structures Internal to the Cell Wall.
   a. Plasma Membrane (Inner Membrane). Fig. 6.
      i. Phospholipid bilayer lying inside the cell wall. Fig. 14.
         1. The phospholipid bilayer is the basic framework of the plasma membrane.
         2. The bilayer arrangement occurs because the phospholipids are amphipathic molecules. They have both polar (charged) and nonpolar (uncharged) parts with the polar “head” of the phospholipid pointing out and the nonpolar “tails” pointing toward the center of the membrane, forming a nonpolar, hydrophobic region in the membrane’s interior.
      ii. Much of the metabolic machinery is located on the plasma membrane. Photosynthesis, aerobic cellular respiration, and anaerobic cellular respiration reactions occur here. This means that there is a surface area to volume ratio at which bacteria reach a critical size threshold, beyond which bacteria can’t survive.
         1. *Thiomargarita* (0.75 mm) is the largest known bacterium and is larger than most eukaryotic cells. It has many invaginations of the plasma membrane, which increases its surface area relative to its volume.
      iii. Peripheral proteins.
         1. Enzymes.
         2. Structural proteins.
         3. Some assist the cell in changing membrane shape.
      iv. Integral proteins and transmembrane proteins.
         1. Provide channels for movement of materials into and out of the cell.
   v. Fluid Mosaic Model.
      1. Membrane is as viscous as olive oil.
      2. Proteins move to function.
      3. Phospholipids rotate and move laterally.
   vi. Selective permeability allows the passage of some molecules but not others across the plasma membrane.
      1. Large molecules cannot pass through.
      2. Ions pass through very slowly or not at all.
      3. Lipid soluble molecules pass through easily.
      4. Smaller molecules (water, oxygen, carbon dioxide, some simple sugars) usually pass through easily.
   vii. The plasma membrane contains enzymes for ATP production.
   viii. Photosynthetic pigments are found on in-foldings of the plasma membrane called chromatophores or thylakoids. Fig. 15.
   ix. Damage to the plasma membrane by alcohols, quaternary ammonium compounds (a class of disinfectants) and polymyxin antibiotics causes leakage of cell contents.
   x. Movement of Materials Across Membranes.
      1. Passive Processes:
         a. Simple diffusion: Movement of a solute from an area of high concentration to an area of low concentration (down its concentration gradient) until equilibrium is reached. Fig. 16.
         b. Facilitated diffusion: Solute combines with a transport protein in the membrane, to pass from one side of the membrane to the other. The molecule is still moving down its concentration gradient. The transport proteins are specific. Fig. 17.
         c. Osmosis.
            i. Movement of water across a selectively permeable membrane from an area of higher water concentration to an area of lower water concentration.
            ii. Osmotic pressure.
1. The pressure needed to stop the movement of water across the membrane.
   iii. Isotonic, hypotonic, and hypertonic solutions. Fig. 18.

2. Active Processes:
   a. Active transport of substances requires a transporter protein and ATP. The solute molecule is pumped against its concentration gradient. Transport proteins are specific.
      i. In group translocation (a special form of active transport found only in prokaryotes) movement of a substance requires a specific transport protein.
         1. The substance is chemically altered during transport, preventing it from escaping the cell after it is transported inside.
         2. This process requires high-energy phosphate compounds like phosphoenolpyruvic acid (PEP) to phosphorylate the transported molecule, preventing its movement out of the cell.
   b. Cytoplasm. Fig. 6.
      i. Cytoplasm is the substance inside the plasma membrane.
      ii. It is about 80% water.
      iii. Contains proteins, enzymes, carbohydrates, lipids, inorganic ions, various compounds, a nuclear area, ribosomes, and inclusions.
   c. Nuclear Area (Nucleoid).
      i. Contains a single circular chromosome made of DNA.
         1. No histones or introns in bacteria.
         2. The chromosome is attached to the plasma membrane at a point along its length, where proteins synthesize and partition new DNA for division during binary fission.
      ii. Is not surrounded by a nuclear envelope the way eukaryotic chromosomes are.
      iii. Also contains small circular DNA molecules called plasmids.
         1. Plasmids can be gained or lost without harming the cell.
         2. Usually contain less than 100 genes.
         3. Can be beneficial if they contain genes for antibiotic resistance, tolerance to toxic metals, production of toxins, or synthesis of enzymes.
         4. They can be transferred from one bacterium to another.
         5. Plasmids are used in genetic engineering.
   d. Ribosomes. Fig. 19.
      i. Site of protein synthesis.
      ii. Composed of a large and small subunit, both made of protein and rRNA.
      iii. Prokaryotic ribosomes are 70S ribosomes.
         1. Made of a small 30S subunit and a larger 50S subunit.
      iv. Eukaryotic ribosomes are 80S ribosomes.
         1. Made of a small 40S subunit and a larger 60S subunit.
      v. Certain antibiotics target only prokaryotic ribosomal subunits without targeting eukaryotic ribosomal subunits.
   e. Inclusions.
      i. Reserve deposits of nutrients that can be used in times of low resource availability.
      ii. Include:
         1. Metachromatic granules (volutin). Reserve of inorganic phosphate for ATP.
         3. Lipid inclusions.
4. Sulfur granules. Energy reserve for “sulfur bacteria” that derive energy by oxidizing sulfur and sulfur compounds.
5. Carboxysomes. Contain an enzyme necessary for bacteria that use carbon dioxide as their only source of carbon for carbon dioxide fixation.
7. Magnetosomes. Made of iron oxide, they serve as ballast to help some bacteria sink until reaching an appropriate attachment site. They also decompose hydrogen peroxide. Fig. 20.

f. Endospores. Fig. 21.
   i. Resting Gram-positive bacterial cells that form when essential nutrients can no longer be obtained.
   ii. Resistant to desiccation, heat, chemicals, radiation.
   iii. *Bacillus anthracis* (anthrax), *Clostridium* spp. (gangrene, tetanus, botulism, food poisoning).
   iv. Sporulation (sporogenesis): the process of endospore formation within the vegetative (functional) cell. This takes several hours.
      1. Spore septum (invagination of plasma membrane) begins to isolate the newly replicated DNA and a small portion of cytoplasm. This results in the formation of 2 separate membrane bound structures.
      2. The plasma membrane starts to surround the DNA, cytoplasm, and the new membrane encircling the material isolated in step 1, forming a double-layered membrane-bound structure called a forespore.
      3. Thick peptidoglycan layers are laid down between the two membranes of the forespore.
      4. Then a thick spore coat of protein forms around the outer membrane of the forespore, which is responsible for the durability of the endospore.
      5. When the endospore matures, the vegetative cell wall ruptures, killing the cell, and freeing the endospore.
         a. The endospore is metabolically inert, and contains the chromosome, some RNA, ribosomes, enzymes, other molecules, and very little water.
         b. Endospores can remain dormant for millions of years.
   v. Germination: the return to the vegetative state.
      1. Triggered by damage to the endospore coat. The enzymes activate, breaking down the protective layers. Water then can enter, and metabolism resumes.
   vi. Endospores can survive conditions that vegetative cells cannot: boiling, freezing, desiccation, chemical exposure, radiation, etc.

VI. Eukaryotic Cells. Fig. 22. (Table 2 lists major differences between prokaryotes and eukaryotes).
   a. Make up algae, protozoa, fungi, higher plants, and animals.
   b. Flagella and Cilia. Fig. 23.
      i. Cilia are numerous, short, hair-like projections extending from the surface of a cell. They function to move materials across the surface of the cell, or move the cell around in its environment.
      ii. Flagella are similar to cilia but are much longer, usually moving an entire cell. The only example of a flagellum in the human body is the sperm cell tail.
         1. Eukaryotic flagella move in a whip-like manner, while prokaryotic flagella rotate.
   c. Cell Wall.
      i. Simple compared to prokaryotes.
         1. No peptidoglycan in eukaryotes.
            a. Antibiotics that target peptidoglycan (penicillins and cephalosporins) do not harm us.
      ii. Cell walls are found in plants, algae, and fungi.
      iii. Made of carbohydrates.
1. Cellulose in algae, plants, and some fungi.
2. Chitin in most fungi.
3. Glucan and mannan in yeasts (unicellular fungi).

**d. Glycocalyx.**

i. Sticky carbohydrates extending from an animal cell’s plasma membrane.

ii. Glycoproteins and glycolipids form a sugary coat around the cell—the glycocalyx—which helps cells recognize one another, adhere to one another in some tissues, and protects the cell from digestion by enzymes in the extracellular fluid.

1. The glycocalyx also attracts a film of fluid to the surface of many cells, such as RBC’s, making them slippery so they can pass through narrow vessels.

**e. Plasma Membrane.**  *[Students should read this section on their own].*

i. The plasma membrane is a flexible, sturdy barrier that surrounds and contains the cytoplasm of the cell.

1. The fluid mosaic model describes its structure.
2. The membrane consists of proteins in a sea of phospholipids.
   a. Some proteins float freely while others are anchored at specific locations.
   b. The membrane lipids allow passage of several types of lipid-soluble molecules but act as a barrier to the passage of charged or polar substances.
   c. Channel and transport proteins allow movement of polar molecules and ions across the membrane.

ii. Phospholipid bilayer.

1. Has the same basic arrangement as the prokaryotic plasma membrane.

iii. Arrangement of Membrane Proteins.

1. The membrane proteins are divided into integral and peripheral proteins.
   a. Integral proteins extend into or across the entire lipid bilayer among the fatty acid tails of the phospholipid molecules, and are firmly anchored in place.
      i. Most are transmembrane proteins, which span the entire lipid bilayer and protrude into both the cytosol and extracellular fluid.
   b. Peripheral proteins associate loosely with the polar heads of membrane lipids, and are found at the inner or outer surface of the membrane.

2. Many membrane proteins are glycoproteins (proteins with carbohydrate groups attached to the ends that protrude into the extracellular fluid).

iv. Functions of Membrane Proteins.

1. Membrane proteins vary in different cells and function as:
   a. Ion channels (pores): Allow ions such as sodium or potassium to cross the cell membrane; (they can't diffuse through the bilayer). Most are selective—they allow only a single type of ion to pass. Some ion channels open and close.
   b. Transporters: selectively move a polar substance from one side of the membrane to the other.
   c. Receptors: recognize and bind a specific molecule. The chemical binding to the receptor is called a ligand.
   d. Enzymes: catalyze specific chemical reactions at the inside or outside surface of the cell.
   e. Cell-identity markers (often glycoproteins and glycolipids), such as human leukocyte antigens.
   f. Linkers: anchor proteins in the plasma membrane of neighboring cells to each other or to protein filaments inside and outside the cell.

2. The different proteins help to determine many of the functions of the plasma membrane.
v. Selective permeability of the plasma membrane allows passage of some molecules.
   1. Transport mechanisms:
      a. Simple diffusion.
      b. Facilitated diffusion.
      c. Osmosis.
      d. Active transport. (No group translocation in Eukaryotes).
      e. Vesicular Transport.
         i. A vesicle is a small membranous sac formed by budding off from an existing membrane.
         ii. Two types of vesicular transport are endocytosis and exocytosis.
            1. Endocytosis.
               a. In endocytosis, materials move into a cell in a vesicle formed from the plasma membrane.
               b. Viruses can take advantage of this mechanism to enter cells.
               c. Phagocytosis is the ingestion of solid particles, such as worn out cells, bacteria, or viruses. Pseudopods extend and engulf particles.
               d. Pinocytosis is the ingestion of extracellular fluid. The membrane folds inward bringing in fluid and dissolved substances.
            2. In exocytosis, membrane-enclosed structures called secretory vesicles that form inside the cell fuse with the plasma membrane and release their contents into the extracellular fluid.
   f. Cytoplasm. Fig. 22.
      i. Substance inside the plasma membrane and outside nucleus.
      ii. Cytosol is the fluid portion of cytoplasm.
      iii. Cytoskeleton.
         1. The cytoskeleton is a network of several kinds of protein filaments that extend throughout the cytoplasm, and provides a structural framework for the cell.
         2. It consists of microfilaments, intermediate filaments, and microtubules.
            a. Most microfilaments (the smallest cytoskeletal elements) are composed of actin and function in movement (muscle contraction and cell division) and mechanical support for the cell itself and for microvilli.
            b. Intermediate filaments are composed of several different proteins and function in support and to help anchor organelles such as the nucleus.
            c. Microtubules (the largest cytoskeletal elements) are composed of a protein called tubulin and help determine cell shape; they function in the intracellular transport of organelles and the migration of chromosome during cell division. They also function in the movement of cilia and flagella.
      iv. Cytoplasmic streaming.
         1. Movement of cytoplasm and nutrients throughout cells.
         2. Moves the cell over surfaces.
   g. Organelles.
      i. Organelles are specialized structures that have characteristic shapes and perform specific functions in eukaryotic cellular growth, maintenance, and reproduction.
         1. Nucleus. Fig. 24.
            a. The nucleus is usually the most prominent feature of a eukaryotic cell.
            b. Most have a single nucleus; some cells (human red blood cells) have none, whereas others (human skeletal muscle fibers) have several in each cell.
c. The parts of the nucleus include the:
   i. Nuclear envelope (a double membrane), which is perforated by channels called nuclear pores, that control the movement of substances between the nucleus and the cytoplasm.
      1. Small molecules and ions diffuse passively, while movement of most large molecules out of the nucleus involves active transport.
   ii. Nucleoli function in producing ribosomes.

d. Genetic material (DNA). Within the nucleus are the cell’s hereditary units, called genes, which are arranged in single file along chromosomes. Each chromosome is a long molecule of DNA that is coiled together with several proteins (including histones).

2. Ribosomes.
   a. Sites of protein synthesis.
   b. 80S in eukaryotes.
      i. Membrane-bound ribosomes found on rough ER.
      ii. Free ribosomes found in cytoplasm.
   c. 70S in prokaryotes.
      i. Also found in chloroplasts and mitochondria.

3. Endoplasmic Reticulum. Fig. 25.
   a. The endoplasmic reticulum (ER) is a network of membranes extending from the nuclear membrane that form flattened sacs or tubules.
   b. Rough ER is continuous with the nuclear membrane and has its outer surface studded with ribosomes, which synthesize proteins. The proteins then enter the space inside the ER for processing (into glycoproteins or for attachment to phospholipids) and sorting, and are then either incorporated into organelle membranes, inserted into the plasma membrane, or secreted via exocytosis.
   c. Smooth ER extends from the rough ER to form a network of membrane tubules, but it does not contain ribosomes on its membrane surface. In humans, it synthesizes fatty acids and steroids, detoxifies drugs, removes phosphate from glucose 6-phosphate (allowing free glucose to enter the blood), and stores and releases calcium ions involved in muscle contraction.

4. Golgi Complex. Fig. 26.
   a. The Golgi complex consists of four to six stacked, flattened membranous sacs (cisterns). The cis (entry) face faces the rough ER, and trans (exit) face faces the cell’s plasma membrane. Between the cis and trans faces are the medial cisternae.
   b. The cis, medial, and trans cisternae each contain different enzymes that permit each to modify, sort, and package proteins received from the rough ER for transport to different destinations (such as the plasma membrane, to other organelles, or for export out of the cell).

5. Lysosomes.
   a. Lysosomes are membrane-enclosed vesicles that form from the Golgi complex and contain powerful digestive enzymes.
   b. Lysosomes function in digestion of substances that enter the cell by endocytosis, and transport the final products of digestion into the cytosol.
   c. They digest worn-out organelles (autophagy).
   d. They digest their own cellular contents (autolysis).
   e. They carry out extracellular digestion (as happens when sperm release lysosomal enzymes to aid in penetrating an oocyte).
6. Vacuoles.
   a. Space in the cytoplasm enclosed by a membrane called a tonoplast.
   b. Derived from the Golgi complex.
   c. They serve in the following ways:
      i. Temporary storage for biological molecules and ions.
      ii. Bring food into cells.
      iii. Provide structural support.
      iv. Store metabolic wastes.

7. Peroxisomes.
   a. Peroxisomes are similar in structure to lysosomes, but are smaller.
   b. They contain enzymes (oxidases) that use molecular oxygen to oxidize
      (remove hydrogen atoms from) various organic substances.
   c. They take part in normal metabolic reactions such as the oxidation of
      amino and fatty acids.
   d. New peroxisomes form by budding off from preexisting ones.
   e. They produce and then destroy \( H_2O_2 \) (hydrogen peroxide) in the process
      of their metabolic activities.

8. Centrosomes.
   a. Centrosomes are dense areas of cytoplasm containing the centrioles, which
      are paired cylinders arranged at right angles to one another, and serve as
      centers for organizing microtubules and the mitotic spindle during mitosis.

9. Mitochondria. Fig. 27.
   a. Found in nearly all eukaryotic cells.
   b. A mitochondrion is bound by a double membrane, with a fluid-filled space
      between called the intermembranous space. The outer membrane is
      smooth, while the inner membrane is arranged in folds called cristae. The
      mitochondrial matrix is found inside the inner mitochondrial membrane.
   c. The folds of the cristae provide a large surface area for the chemical
      reactions that are part of the aerobic phase of cellular respiration. These
      reactions produce most of a eukaryotic cell’s ATP, and the enzymes that
      catalyze them are located on the cristae and in the matrix.
   d. Mitochondria self-replicate using their own DNA and contain 70S
      ribosomes. They grow and reproduce on their own in a way that is similar
      to binary fission. Mitochondrial DNA (genes) is inherited only from the
      mother, since sperm normally lack most organelles such as mitochondria,
      ribosomes, ER, and the Golgi complex. Any sperm mitochondria that do
      enter the oocyte are soon destroyed.

10. Chloroplasts. Fig. 28.
    a. Found only in algae and green plants.
    b. Contain the pigment chlorophyll and enzymes necessary for
        photosynthesis.
    c. Chloroplasts self-replicate using their own DNA and contain 70S
        ribosomes. They grow and reproduce on their own in a way that is similar
        to binary fission.

VII. Endosymbiotic Theory.
    a. Large bacterial cells lost their cell walls and engulfed smaller bacteria.
    b. A symbiotic (mutualistic) relationship developed.
       i. The host cell supplied the nutrients.
       ii. The engulfed cell produced excess energy that the host could use.
       iii. The relationship evolved.
    c. Evidence:
       i. Mitochondria and chloroplasts resemble bacteria in size and shape.
1. They divide on their own—indeedependently of the host, and contain their own DNA (single circular chromosome). This process is nearly identical to binary fission seen in bacteria.
2. They contain 70S ribosomes.
3. Their method of protein synthesis is more like that of prokaryotes (no RNA processing).
4. Antibiotics that inhibit protein synthesis on ribosomes in bacteria also inhibit protein synthesis on ribosomes in mitochondria and chloroplasts.

ii. See Fig. 3, pg. 295 for a modern example of a bacterium living inside a protistan (eukaryotic) host.