Cell I: Introduction to Cells and Prokaryotes:

In 1805 Lorenz Oken made several statements that together make up the cell theory. Here are the four parts of the cell theory:

1) All living things are made of cells.
2) Cells are alike in structure and function.
3) Cells need information in order to survive.
4) New cells come from old cells.

Why are cells so small?
The cell theory never states that cells must be small. Why are cells so small? Two reasons may be given:

1) By breaking the cell up into smaller cells, the surface area is increased. Cells require nutrients and oxygen and must get rid of wastes. These nutrients/waste must move across the membrane and through the cell. If the cell were too big, the nutrients/wastes would have to cover large distances in order to get to the proper destinations.
2) Having numerous small cells permits specialization. In multicellular organisms, different cells have different functions.

There are two types of cells.

1) Prokaryotic cells: Bacterial cells that make up the Kingdom Monera.
2) Eukaryotic cells: All other cells that make up the Kingdoms Protista, Fungi, Plantae, and Animalia.

Eukaryotic:

Animal Cells: All eukaryotic cells are very complicated. All animals are made up from these cells. Animal cells contain structures; called organelles, that have specific functions. The organelles are found in a jelly like medium called cytoplasm, and everything is held within the cell by a membrane called the cell membrane.

Plant Cells: Plant cells have three more organelles than the animal cells. Plant cells have a cell wall, chloroplasts and a large central vacuole.

Prokaryotic:

Bacterial Cells: These are the simplest of all cells. Bacterial cells only have a cell wall and one organelle: ribosomes.

Prokaryotes: Bacteria

The first life forms were probably similar to the modern group of bacterial cells. This includes regular bacteria and cyanobacteria.

Early in the history of life, the prokaryotes split into two main groups: Archaeabacteria and Eubacteria. Eukaryotes split off of archaeabacteria. Archaeabacteria, eubacteria, and eukaryotes for the three domains over the five kingdoms. All of the following information will describe Eubacteria. All the organisms are primarily unicellular, although some form filaments made of many cells (cyanobacteria).

Bacterial cells are called PROKARYOTES. All PROKARYOTES have the following characteristics.

1) Nucleoid: Their DNA is in a naked loop (not associated with proteins) in the cytoplasm. The DNA loop is a long, single fiber, which contains almost all of the genetic material of the prokaryote. The rest of the genetic material can be contained in the plasmids.

2) Plasmid: small circular loops of extra-chromosomal DNA. These can contain genes for antibiotic resistance.

3) They have ribosomes floating freely in the cytoplasm. The ribosome is the site for protein synthesis. Interestingly, antibiotics, such as tetracycline and streptomycin bind to the prokaryotic ribosome and interfere with the ability of the prokaryote to produce proteins.
4) Most prokaryotes have a cell wall. All, except one of the, classes of monerans except for one have cell walls. The functions of the cell wall are to:
   A) gives the cell shape.
   B) protects the cell from an unfavorable environment. (They can also prevent the cell from bursting.)

There are two types of cell walls, which are made up of peptidoglycans (sugars and protein). Bacteria are classified by the type of cell wall they have.
   A) Gram positive cell wall. The gram-positive bacteria have a thick peptidoglycan (special sugar derivative with amino acids) layer with no outer membrane layer.
   B) Gram negative cell wall. Gram-negative bacteria have a multilayered and complex cell wall. The outside layer is a membrane made of lipopolysaccharide (special sugar derivative with lipids) with a thin peptidoglycan layer inside. These bacteria are usually the ones that can cause diseases—the toxins (proteins) formed enter the periplasmic space. The outer layer can protect the bacterium and are usually more resistant to antibodies.

The antibiotic penicillin inhibits the development of the cell wall. This prevents the reproduction of the prokaryote cell. An enzyme in tears, mucus and saliva dissolves the cell wall which rupturing the cell and killing the bacteria.

5) Some bacteria develop a capsule, which is a jelly like coating that surrounds the cell wall. There are four functions of the capsule:
   A) prevents the cells from drying out.
   B) helps the cells stick together or on other surfaces such as the tissues of other organisms.
   C) helps prokaryotes slide on surfaces.
   D) keeps some bacteria from being destroyed by the host organism.

6) Half of all prokaryotes have a flagellum or many flagella that provide locomotion. Flagella: These are solid crystal proteins that stick out through the holes in the cell membrane and spin like propellers. Prokaryotic flagella are structurally different from plant and animal cell flagella. Interestingly, the prokaryotic flagellum is the only example of a wheel in nature.

7) Some bacteria have structures called pili or pili:
Pili are short bristle-like appendages, which have two functions:
   1) attach bacteria to surfaces.
   2) assist in the transfer of DNA from one bacterium to another.

8) There are three main shapes of eubacteria:
   a) coccus (pl. cocci): sphere shaped
   b) bacillus (pl. bacilli): rod shaped
   c) helices: spirilla (spirillum) and spirochetes

Advantages of various shapes:
Being round, cocci allows for less distortion in a dried out organism.
Rods have more surface area than the cocci. This allows the rod to take up more nutrients from the environment.
Helices are very motile; they move by using a corkscrew motion.

How do prokaryotes move?
Prokaryotes move by chemotaxis. Chemotaxis is the movement of an organism towards or away from a chemical. Chemicals that cause the organism to move toward them (positive chemotaxis) are called attractants. Chemicals that induce the organism to move away (negative chemotaxis) are called repellents.

This response has been studied extensively. Chemotaxis suggests some type of sensing and response. Bacterial behavior can be described as a combination of runs and twiddles (tumbles).
Run is a steady swim
Twiddle occurs when an organism stops and jiggles in place. This causes a change in direction.

As bacteria experience higher concentrations of the attractant, the twiddling movement becomes less frequent and they run for longer periods of time.

Temporal sensing can explain the above phenomenon. Bacteria sense the environment. There are receptors on the cell, which can transfer molecules into the cell. The bacteria swim toward a higher concentration of attractant.

Prokaryote Survival:
Resting Cells: When environmental conditions are unfavorable, the bacterium becomes inactive. Some species of bacteria form endospores. An endospore is a thick wall that surrounds the genetic material while the rest of the cell disintegrates. The endospore is dormant and doesn't reproduce or show any signs of life, similar to a 'seed.' Endospores can withstand harsh environmental conditions (boiling, freezing, drying out). When the conditions are favorable, the endospore germinates to form an active cell.

Reproduction: Making copies of the bacteria. When conditions are favorable, monerans reproduce rapidly (i.e. E. coli can reproduce once every 20 minutes).

There are two types of reproduction: asexual and sexual.

Asexual Reproduction:
Asexual Fission/Binary Fission: The single loop of DNA is copied, and both loops attach to the cell membrane. The cell grows and divides by pinching between the two DNA loops.

Sexual Reproduction: The transfer of genetic material (DNA) from one bacterium to another happens infrequently. There are 3 types of sexual reproduction:

1) Conjugation: a bridge is formed between two cells using the pili. Conjugation requires a plasmid called the F plasmid (F for fertility). The F plasmid contains approximately 25 genes and controls the formation of the F pilus. The F pilus is a long, rod shaped structure, which will connect two different bacteria.

If a bacterium contains the F plasmid, it is known as an F+ cell. If a bacterium does not contain the F plasmid, it is known as an F-cell. An F+ cell attaches to an F- cell with its F pilus. After connecting, the F+ cell will give a copy of the F plasmid to the F- cell, making the F- cell an F+ cell.

The F factor can become integrated into the bacterial DNA. When this happens the cell is called an Hfr (high frequency recombination) cell. An Hfr cell, when attached to an F- cell, will transport a copy of its DNA to the F- cell. DNA recombination may then occur in the F- cell after the Hfr DNA has entered it.

The R plasmid
The R plasmid contains genes that make a bacterium resistant to certain antibiotics. These genes can be transmitted, on a plasmid through conjugation, to other bacteria. Once the DNA molecule has been integrated into the main DNA of the cell, the cell is resistant. Any offspring cells formed by binary fission will also be resistant.

2) Transformation: A living bacterium absorbs the genetic material of a dead cell or 'naked' genetic material in the environment.

3) Transduction: Transfer of DNA from a host to another cell by means of a virus. Viruses are pieces of DNA or RNA, enclosed by a protein coat that can infect bacterial. Their DNA is small and contains information for making proteins involved in infection.

During the lytic cycle of a virus life cycle, the virus makes use of the host cell's resources. All parts of new viruses are
made independently in the host cell and put together prior to cell lysis. The great number of viruses in a cell will cause the cell to lyse or break and release newly formed viruses.

The viral nucleic acid (DNA) is usually incorporated into the host cell's DNA strand as the virus is producing all of the viral parts. The viral nucleic acid is in a long sequence of repeating units. Each unit will be placed in the protein capsid or coat prior to cell lysis. A viral enzyme will cut each viral DNA unit, and this sequence will be packaged into the capsid by another viral enzyme.

Sometimes the viral enzyme cuts a host cell's DNA, and this DNA can be incorporated into a capsid. The virus is released when the cell lyses. The virus recognizes and attaches to a new host cell. The virus will then inject the nucleic acid found in the capsid into the new host cell. This DNA (containing bacterial DNA) can integrate with the new DNA of the new host cell.

Metabolic Diversity with Prokaryotes:
Heterotroph: organism that is dependent upon outside sources of organic molecules.
Autotroph: organism that is able to synthesize organic molecules from inorganic substances.
Chemotroph: organisms that obtain energy from chemicals taken from the environment.
Phototroph: organisms that use light energy to produce energy and a source of carbon.

1) Photosynthetic autotrophs (Photoautotrophs): organisms that harness light energy to drive the synthesis of organic compounds from CO₂. These organisms use an internal membrane system with light harnessing pigments, ie. cyanobacteria, algae and plants.

2) Photoheterotrophs: organisms that can use light to produce ATP but they must obtain organic carbon from another source. The proks change the organic carbon to a sugar or a form they can use. This type of metabolism is only found in prokaryotes.

3) Chemoautotrophs: organisms that need only carbon dioxide as the carbon source. They obtain energy by oxidizing (removing electrons from the) inorganic substances like hydrogen sulfide, ammonia, ferrous or other ions. This group is unique to prokaryotes.

4) Chemoheterotrophs: organisms must consume organic molecules for both energy and carbon. Found widely among prokaryotes, protists, fungi, and animals.

The majority of bacteria are chemoheterotrophs. There are three different types:
1) Saprobites: decomposers that absorb nutrients from dead organic material.
2) Parasites: absorb nutrients from the body fluids of living hosts.
3) Phagotrophs: ingest food and digest it enzymatically within cells or multiple cellular bodies.

Oxygen requirements can also be used in classifying prokaryotes.
Obligate aerobes: use oxygen for cellular respiration and cannot survive without it.
Facultative anaerobes: will use oxygen if present, but can grow by fermentation in an environment without oxygen.
Obligate anaerobes: cannot use oxygen and are killed by it.
Nitrogen metabolism: Nitrogen is essential in the synthesis of proteins and nucleic acids. Prokaryotes can metabolize most nitrogenous compounds. Some bacteria can convert ammonia to nitrates. Other bacteria can convert atmospheric nitrogen to ammonia: this process is called nitrogen fixation. Cyanobacteria can fix nitrogen. In fact, cyanobacteria only require light, carbon dioxide, atmospheric nitrogen, water and some minerals in order to survive. They are among the most self-sufficient of all organisms.

Diversity: Prokaryotes can be divided into many different groups. The prokaryotes split early in the history of life. One branch produced Archaeabacteria and the other produced Eubacteria. Archaeabacteria split again to form eukaryotes.
Archaebacteria: The characteristics of archaebacteria are as follows: Their cell walls lack peptidoglycan, the cell membrane has a unique lipid composition, most live in extreme environments, and they have different ribosomal RNA structure than eubacteria and eukaryotes.

There are three subgroups:
1) Methanogens: use elemental hydrogen (H₂) to reduce carbon dioxide into methane. They are obligate anaerobes (cannot live in the presence of oxygen). Methanogens live in swamps, marshes and in the anaerobic environment of the guts of animals such as cows, sheep, and camels. They are important as decomposers in sewage treatment plants.

2) Extreme Halophiles: (halo- salt, phile- lover): These organisms live in high salinity environments. Colonies of halophiles can color salt ponds pink. This color is due to their photosynthetic pigment called bacteriorhodopsin.

3) Thermoacidophiles: Need environment that is both hot (60-80°C) and acidic (pH of 2-4). Ie. hot springs, water heaters, coal piles. Thermoacidophiles have no cell wall and can grow aerobically and anaerobically.

Let’s compare Eubacteria, Archaebacteria and Eukarya (eukaryotes)

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<th>Eubacteria</th>
<th>Archaebacteria</th>
<th>Eukarya</th>
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<tr>
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In discussing prokaryotes, I’d like to discuss in great detail the cell membrane of all organisms. You’ll need to remember this when we discuss the eukaryotic cell. You’ll notice that this organelle is important for all cells.

Cell membrane: The Fluid-Mosaic Model
The cell membrane is a plasma membrane that surrounds all cells. The main components of the cell membrane are phospholipids, proteins, cholesterol, carbohydrates, glycoproteins, and glycolipids.

Fluidity:
The membrane must be fluid to work properly. If a membrane solidifies, its permeability changes, and the enzymes become deactivated.

Cholesterol in eukaryotic membranes controls the fluidity of membranes in two ways.
1) In warmer temperatures it decreases fluidity by restraining phospholipid movement.
2) In colder temperatures it increases fluidity by preventing the close packing of phospholipids.

Mosaic:
A mosaic of proteins is embedded and dispersed in the phospholipid bilayer. There are two types of proteins depending on their location.
1) Integral Proteins are inserted into the membrane so that the hydrocarbon portion of the phospholipid surrounds the hydrophobic region of the protein. There are two types of integral proteins.
   a) Unilateral-- reaching only partway across the membrane.
   b) Transmembrane-- completely span the membrane. These proteins have hydrophilic ends with a hydrophobic midsection.
2) Peripheral Proteins: not embedded in membrane, but attached to the membrane surface.
Carbohydrates are also found on the cell surface, and these carbohydrates allow for cells to recognize other cells. These carbohydrates are oligosaccharides (less than 15 sugars long). Some of these carbohydrates are bonded to lipids (glycolipids) or proteins (glycoproteins). These surface molecules also allow transport of materials and are enzymes. These surface molecules start the signal transduction pathway, Attach to the cytoskeleton, join cells, bind molecules, and allow cell to cell recognition.

One of the main functions of the cell membrane is to act as a selectively permeable barrier. This tight barrier prevents the passive movement of most molecules; thus substances cannot easily enter or leave the cell. The hydrophobic interior impedes ions and polar molecules from moving through. Hydrophobic molecules can pass through the membrane easier.

There are seven ways substances can get into the cell.
1) Bulk Flow
2) Diffusion
3) Osmosis
4) Facilitated Diffusion
5) Active Transport
6) Vesicle Mediated Transport
7) Cell-Cell Junction

1) Bulk flow: Molecules move all together in the same direction. Hydrostatic pressure forces molecules through the plasma membrane.

2) Diffusion: The movement of molecules from a high to low concentration; this process requires no energy. Only very small molecules can diffuse through the membrane.

3) Osmosis: The movement of water through a semi-permeable membrane from an area of higher water potential to an area of lower water potential until an equilibrium is reached. It does not require energy.

Water potential refers to the potential energy of water; thus water moves from a higher potential energy state to a lower energy state as it moves through a semi-permeable membrane. The water potential of pure water is zero. The more solute dissolved in water, the lower (more negative) the water potential. The units of water potential as the same as those of pressure; common units are atmospheres, bars or megapascals.

There are three types of osmotic environments.
A) Isotonic or isosmotic environment: The aqueous environment has the same solute concentration as the cell. Water flows in and out of the cell equally in both directions.
B) Hypertonic or hyperosmotic environment: the aqueous environment surrounding the cell has a higher solute concentration than does the cell. Through osmosis the water moves from the cell to the external environment. If the process continues, the cell collapses and dies.
C) Hypotonic or hypoosmotic environment: The environment has a lower solute concentration than does the cell. Water moves from the environment into the cell by osmosis. The cell expands, causing turgor pressure in plant cells. Since animal cells lack cell walls, they will burst if placed in a solution that is hyperosmotic.

Osmotic Pressure:
Osmotic pressure is zero if the solute concentration on both sides of the selectively permeable membrane is equal. If there is a barrier that prevents the hypertonic solution in a cell from expanding, the solution in the cell will exert an increasingly greater outward pressure.
As the pressure increases, the flow of water molecules into the hypertonic solution decreases. The pressure required to stop the osmotic movement of water into a solution is called osmotic pressure. The lower the water potential, the more water that can move into the cell by osmosis; thus the greater the osmotic pressure that will develop.

It is important to remember that water always moves from a Hypotonic environment to a Hypertonic environment. Hypo to Hyper.

Example: Turgor Pressure.
Plant cells have a central vacuole filled with solutes and thus have a lower water potential than the surroundings. Therefore water enters the cells. In mature cells, the cell wall does not expand. Since the wall does not expand, it exerts an inward pressure, called cell wall pressure, on the solution. This pressure prevents the net movement of water molecules into the cell. However, the cells remain hyperosmotic to the environment and the tendency of water molecules to continue to move into the cells keeps the plant cells fully hydrated and turgid. This internal pressure outward is called turgor pressure and keeps the cell rigid. If water is not available, turgor pressure falls because water leaves the cells. Then the plant wilts.

4) Facilitated Diffusion. Since the lipid layer is amphipathic, most polar molecules cannot pass through the nonpolar region. Since most organic molecules are polar, they are unable to pass through the cell membrane by simple diffusion. For example, glucose enters cells by facilitated diffusion, and water can enter through aquaporins. This process does not require energy.

The transport of hydrophilic molecules across the cell membrane depends upon integral membrane proteins, called transport proteins. The transport proteins are highly selective. The tertiary and even quaternary structures of the transport proteins determine which molecules are transported. These transport proteins are called PERMEASES.

Some of these transport proteins are gated channels, which can open and close depending on chemical and electrical stimulus.

Types of transport proteins:
1) Uniport: carries a single molecule across the membrane.
2) Symport: moves two different molecules at the same time in the same direction. Both molecules must bind to the protein for transport.
3) Antiport: exchanges two molecules by moving them in opposite directions.

Molecules that resemble the molecule normally carried by the protein can inhibit these proteins.

5) Active Transport: This type of transport requires energy and membrane proteins. Active transport occurs in situations where a substance is moved across the cell membrane and against its concentration gradient.

6) Vesicle Mediated Transport: Found in eukaryotic cells. Vesicles or vacuoles can fuse with the cell membrane. Vesicles formed inside the cell can move to the cell membrane, fuse with the outer cell membrane, and expel their contents outside the cell into the surroundings. This process is called EXOCYTOSIS. In ENDOCYTOSIS, vesicles formed at the surface of the cell can capture substances outside the cell, and deposit their contents into the cell. There are three types of endocytosis.
   A) Phagocytosis (cell eating): When the substance taken into the cell is a solid, the process is called phagocytosis. A vesicle forms around the object taken into the cell. Once the solid is in the cell, a lysosome joins with the vesicle and enzymes digest the solid.
   B) Pinocytosis (cell drinking): When the substance taken into the cell is a fluid, the process is called pinocytosis.
   C) Receptor-Mediated Endocytosis: The molecule attaches to a specific receptor on the cell surface before a vesicle forms around the molecule. Any molecule that binds to a receptor is called a ligand.
Cells II: Eukaryotic Cells:

Most organisms, the kind usually studied in general biology rather than microbiology classes, are eukaryotic. As a rule, their cells are larger than bacteria and they contain not only a nucleus but also complex organelles and elaborate membrane systems; for example, mitochondria, plastids (in photosynthesizers), undulipodia, Golgi bodies, and the endoplasmic reticulum.

Organelles are microscopic structures found in cells; these organelles carry out specific functions. There are two classes of organelles. 1) Those that contain their own DNA and genes. Mitochondria and Plastids are organelles that reproduce by dividing like independent cells. 2) Those that do not contain their own DNA; for example, endoplasmic reticulum, ribosomes, Golgi bodies, undulipodia.

Unlike prokaryotes, most eukaryotes are capable of cell eating (phagocytosis) and cell drinking (pinocytosis). In times of scarcity, some of the cells can make thick walled, desiccation resistant cysts in which they reproduce and wait for more favorable conditions. Some single celled eukaryotes form poison darts (trichocysts or toxicysts) that they use to sting their prey.

Some questions arise: What did the first eukaryotic cells look like? When did the first eukaryotic cells appear? How did they form?

We cannot answer these questions with any certainty. The first eukaryotic cells were probably protists that were anaerobic, aquatic, unicellular organisms; for example, Giardia, trichomonads, microsporidia are all eukaryotic cells without mitochondria. They appear to be some of the oldest eukaryotes.

It is extremely difficult to trace the origin of eukaryotic cells through fossils. Most of the primitive eukaryotes lived in the sea or in pond water, formed no hard parts, and their soft bodies broke open when they died. Most of the studies of primitive eukaryotes come from studies of modern ones. This lack of fossil evidence makes it hard to date the appearance of the first eukaryotic cell. We know they must have evolved before the larger and more advanced eukaryotes. We estimate that the first eukaryote appeared one billion years ago.

This leaves the last question: how did eukaryotic cells first develop? There is a theory of eukaryotic cell development that involves mutualistic symbiosis. Mutualistic symbiosis is a relationship in which two organisms live in close physical proximity to one another for most of their life cycle.

The symbiotic theory of eukaryotic cell evolution states the following: Independent bacteria joined together, casually at first, then in a more stable association. As time passed, and as evolutionary pressures favored these symbiotic relationships, the partner microbes became permanently joined in a new cell composed of interdependent components. According to this theory three classes of organelles:
   a) Plastids
   b) Mitochondria
   c) Undulipodia

Once lived as independent prokaryotes. For example, the mitochondrion was a small prokaryote that could use oxygen to produce energy. This prokaryote needed protection from predators and hid inside a larger prokaryote. The larger prokaryote received energy from the pre-mitochondria cell and could live in an oxygen rich environment, and the pre-mitochondria cells were protected by the larger prokaryote.

Organelles:
1) Nucleus: the most prominent and the most easily stained of organelles in the cell-- averaging about 5 µm in diameter. The nucleus contains the chromosomes composed of nucleic acids or DNA. RNA, another nucleic acid, is also found in the nucleus. The DNA is associated with proteins (histone) and forms chromatin. Chromatin can be packaged into at least two chromosomes and some cells have up to 1,000 chromosomes. The nucleus of human cells contains 46 (23
pairs) chromosomes. However, the sperm and egg each contain 23 chromosomes. There is a distinct membrane that separates the nucleus from the cytoplasm: the nuclear membrane (envelope).

The nuclear envelope is a double membrane (two lipid bilayers). The two membranes are separated by a space of about 20 to 40 nm. Lining the inner membrane is a layer of proteins called the nuclear lamina, a net-like array of protein filaments, that help maintain the shape of the nucleus and which may also help maintain the organization of the genetic material. The envelope has a direct influence on the development of chromosomes. The phosphate groups of DNA strands are negatively charged and repel each other. However, the fluid of the nucleus contains a high concentration of sodium ions (Na\(^+\)), higher than the rest of the cell. The sodium ions neutralize the repelling phosphate groups, and allow DNA to coil tightly (there may also be a nuclear matrix in the nuclear interior). The nuclear membrane contains pore complexes that allow materials to move in and out of the nucleus.

The nucleus controls mRNA, tRNA, rRNA, and protein synthesis. The nucleus contains DNA, which has the instructions for the amino acid sequence of proteins.

2) Nucleolus: This is a dense, irregularly shaped body in the nucleus. The nucleolus makes and stores RNA. Each nucleolus will form new ribosomes. Sometimes there are two or more nucleoli. The nucleolus is composed of the collection of a number of ends of chromosomes. This is not really a structure. This is an area of the nucleus that stains dark due to the high density of chromosomal material (loops).

3) Mitochondria: These are small, distinct, oval shaped, double membrane bounded bodies, 1 to 10 µm long, that float in the cytoplasm. Mitochondria are some of the largest organelles in the cell. They contain their own DNA that resembles bacterial DNA; if this DNA mutates, then the mitochondria usually become inactive, this maybe a cause of cell aging as less energy becomes available. Time-lapse films of living cells reveal mitochondria moving around, changing their shapes, and dividing into two.

Eukaryotic cells contain many mitochondria. A higher concentration of mitochondria is found in cells that produce more energy, cells such as muscle cells. They are potent generators of ATP. Mitochondria can produce 36-38 ATP molecules per molecule of glucose in aerobic respiration.

Mitochondria contain two lipid bilayer membranes. The outer phospholipid bilayer is smooth, but the inner membrane has inward folds called cristae that are embedded with proteins. Cristae provide a surface for the energy generating, biochemical reactions that take place in the mitochondria.

The mitochondrial matrix is the compartment enclosed by the inner membrane. Many of the metabolic steps of cellular respiration occur in the matrix, where various enzymes are located.

How did the mitochondria evolve?
As the oxygen concentration of the atmosphere increased, non-photosynthetic respiring microbes evolved and they were dependent upon oxygen to produce energy. It is believed that free-living aerobic bacteria that looked similar to the modern mitochondria at first established casual relationships with larger anaerobic bacteria. Maybe the first casual relationship was that of a predator and prey, the mitochondria being the predator, which bored into the larger prokaryote.

Some anaerobes developed a tolerance for their predators, which resided for extended periods of time in the interior of the anaerobe host cell. This tolerance would have required the protection of the host cell's DNA from oxygen. If this oxygen protection theory were correct, then the host cell would have had to develop a nuclear membrane or other mechanisms to shield the DNA from the poisonous gas.
If this theory were correct, such a partnership would be favored as the oxygen concentration in the atmosphere increased. The host cell would use the products of the aerobes metabolism while the anaerobe lived in a rich soup, the waste products of the host fermentation, and the aerobes were sheltered. After some time, the hosts became dependent upon their former enemies and their guests gave up their individual lifestyles.
4) Plastids: These organelles became integrated in the same manner as the mitochondria—some eukaryotic cells acquired other bacteria. These bacteria added photosynthetic powers to the host cell. Like the bacteria that became dependent upon mitochondria, the photosynthetic partners eventually grew dependent upon their host and became integrated into the host cells as plastids.

There are three types of plastids:
   a) Amyloplasts: white in color, stores starch—found in roots and tubers. No photosynthesis occurs here.
   b) Chromoplasts: many colors, important to photosynthesis—contain accessory pigments.
   c) Chloroplasts: green in color, important to photosynthesis—found in leaves and stems.

The chloroplast has two membranes, which are responsible for its photosynthetic functions.

The inside of the double membrane are flattened, membranous discs known as thylakoids. Thylakoids form stacks called grana and are surrounded by a matrix called the stroma (sound familiar? Look at photosynthesis notes—see the similarities). As with mitochondria, the chloroplasts move around the cell and occasionally pinch in two to divide.

5) Ribosomes: These are non-membrane bounded organelles that are the most numerous of the cell organelles. Made of RNA and proteins, there are three classes of ribosomes named for their size. These are produced in the nucleolus.
   a) 70S: found in prokaryotes. These ribosomes are smaller than eukaryotic ribosomes and have a slightly different molecular composition.
   b) Bound Ribosomes: associated with eukaryotic endoplasmic reticulum). These ribosomes generally make proteins that are destined either for inclusion into the membrane, for packaging within certain organelles, or for export from the cell.
   c) Free Ribosomes: found in the cytoplasm in eukaryotes. These produce proteins for the cell.

The difference between prokaryotic and eukaryotic ribosomes is medically significant. Certain drugs can paralyze prokaryotic ribosomes without inhibiting the ability of eukaryotic ribosomes to make proteins. These drugs, which include tetracycline and streptomycin, are used as antibiotics to combat bacterial infections.

Functions: Ribosomes are sites where proteins are synthesized. They translate the mRNA code into proteins.

6) Endoplasmic Reticulum (ER): The word 'endoplasmic' means "within" the cytoplasm, and 'reticulum' is derived from the Latin word meaning, "network." It is a complex membrane system that takes up a large (accounts for ½ of the total membrane of the eukaryotic cell) part of the cytoplasm in eukaryotic cells. The endoplasmic reticulum is a network of interconnecting flattened sacs, tubes and channels that, along with attached ribosomes are engaged in protein synthesis and protein transport and modification. These tubes or sacks are called Cisternae. The internal compartment is called the Cisternal Space. The amount of ER can increase or decrease depending on the cell's activity.

The ER is a dynamic organelle that changes its structure. It is often continuous with the cell membrane and the outer membrane of the nucleus. This whole system of ER, Golgi body and nuclear membrane is sometimes called the endomembrane system.

The membranes of the endoplasmic reticulum have the same basic structure as the cell membrane. Sometimes the membrane can balloon out and pinch off to become closed sacs or vesicles.

There are two main types of endoplasmic reticulum:
   a) Rough ER (RER) is associated with ribosomes and is the site of protein and glycoprotein synthesis. Most secretory proteins are GLYCOPEPTIDES (proteins that are covalently bonded to carbohydrates). In the cisternal space the carbohydrate is attached to the protein by enzymes built into the ER membrane. The carbohydrate appendage of a glycoprotein is an oligosaccharide. If the protein is to be secreted, it must go to the golgi complex for modifications.
In addition to making secretory proteins, the rough ER is a membrane factory that grows in place by adding proteins and phospholipids to itself.

b) Smooth ER (SER) is not associated with ribosomes. It is found in cells that synthesize, secrete, and/or store carbohydrates, steroids, hormones, lipids, or other non-protein products. The SER also helps detoxify drugs. They do this by adding a hydroxyl group to the drugs that makes them more soluble in water and easier to flush out of the body. The use of drugs may increase the number of SER, which increases the tolerance to the drugs. The SER in muscles pumps calcium ions from the cytosol (cytoplasm) into the cisternal space (this SER is called the Sarcoplasmic Reticulum—you’ll see this later). The SER also converts cholesterol to steroid hormones.

Functions of the Endoplasmic Reticulum:
   i) The ER provides some internal framework of the cell. Gives the cell some support.
   ii) The ER provides a means of transporting materials through the cell via a canal system rather than by diffusion.
   iii) The ER or ER vesicles provide a way of storing material.
   iv) Large proteins are synthesized in the ER and the proteins are either:
      a) Secreted,
      b) Become part of the cell’s biochemical processes, or
      c) Integrated into the cell membrane.
   v) Membranes are synthesized in the ER.
   vi) Phospholipids are synthesized.

The ER forms close associations with other organelles, ie. mitochondria, chloroplasts, lysosomes. These associations are probably related to intracellular transport.

7) Golgi complex (Bodies): Camillo Golgi, an Italian cytologist, discovered these in 1890. The Golgi complex is highly variable. A cell may produce a lot of Golgi structures; then they may disappear.

Basic Structure of the Golgi complex: The Golgi Complex consists of flattened membranous sacs that are stacked together. Each flattened sac is called a cisterna. The interior of each sac is the lumen.

The Golgi apparatus generally has a distinct polarity, with the membranes of cisternae at opposite ends of a sac differing in thickness, molecular composition, and function. The two poles of a Golgi stack are referred to as the CIS FACE (the forming face) and the TRANS FACE (the maturing face).

The cis face is usually located near the ER. Transport vesicles move material from the ER to the Golgi. A vesicle that buds from the ER will add its membrane and its contents to the cis face by fusing with the Golgi membrane. The trans face gives rise to vesicles, which pinch off from and travel to other sites. During the transit from the cis pole to the trans pole of the Golgi products of the ER are modified.

In addition, the golgi complex can produce and modify its own products. The products begin production in the cis face and the vesicles are transferred from cisternae to cisternae until the trans face. Each cisternae contains different enzymes for the different stages of the modification process.

Functions of the Golgi complex:
   a) Carries out biochemical reactions that are often the antagonist to what has happened in the ER. For example, The ER builds up glycoproteins, and the Golgi breaks them down.
   b) Concentrates materials in the condensing vesicles.
   c) Forms the cell wall.
   d) Produces lysosomes.
   e) Can manufacture certain macromolecules by itself, for example, hyaluronic acid. Hyaluronic acid is a sticky substance that helps animal cells glue together.
Simply, the Golgi complex manufacture, warehouses, sorts and stores.

8) Lysosomes: These are single membrane bounded vesicles, which contain highly reactive enzymes, which can break down proteins, nucleic acids and lipids. Lysosomes are formed in the Golgi complex.

Characteristics of Lysosomes:
   a) Lysosomes are bounded by a single membrane
   b) They contain two or more hydrolases (enzymes):
      i) Proteases: breaks down protein
      ii) Nucleases: breaks down nucleic acids
      iii) Lipases: break down lipids
   c) Lysosomes release the enzymes when the lysosome membrane is damaged. Because of this characteristic, it has been dubbed the ‘suicide bag.’ When the lysosome releases the enzymes, cell will die.

Enzymes in lysosomes work best in an acidic environment, at about a pH of about 5. The lysosomal membrane maintains this low internal pH by pumping H+ from the cytoplasm into the lysosome. If the lysosome should break open or leak its contents, the enzymes would not be very active in the neutral pH of the cytosol. However, excessive leakage from a large number of lysosomes can destroy a cell by autodigestion.

Functions of the Lysosome:
   a) Lysosomes are involved in the digestion of organelles: destroys the old to make room for the new (autophagy).
   b) They are also involved in programmed death. Lysosomes kill the cell when necessary in certain stages of development.
   c) Lysosomes aide in the digestion of phagocytized material, e.g. food or infecting bacteria.
   d) They are involved with the assimilation of cholesterol.

FYI: Tay Sachs: The brain becomes impaired from a build up of lipid in cells. The lysosome is missing the lipid-digesting enzyme.

9) Peroxisomes or Microbodies: These are large vesicles containing oxidative enzymes, which transfer hydrogen from various substrates to oxygen. Purines, fats, alcohol, poisons, and several other types of compounds are broken down by peroxisomes. The peroxisomes remove hydrogen and transfer it to the oxygen. These reactions cause the breakdown of compounds and the formation of hydrogen peroxide. The peroxisomes contain catalase that breaks down hydrogen peroxide into water and oxygen. The Microbodies protect our cells from hydroxyl radicals and free radicals. First they contain superoxide dismutase which converts the radicals to hydrogen peroxide and catalase will break down the hydrogen peroxide to water and oxygen.

In plants, peroxisomes are also involved in a series of reactions that occur in sunlight when the cell contains an increased oxygen concentration. This is photorespiration; purines are broken down with oxygen. Special peroxisomes, called glyoxysomes, help convert fat into usable sugars in germinating plant seeds.

Peroxisomes are not produced by the endomembrane system; they split in two when they reach a certain size.

10) Vacuole: This is a general term for a membrane-bounded body with little or no inner structure. Generally vacuoles hold substances, but the contents vary from one cell to another. Some examples of substances held in vacuoles: water, food, waste, pigment, and enzymes. Vacuoles are formed by the pinching in of the cell membrane.

Vacuoles can also have a variety of functions: contractile vacuoles pump out excess water in protists. In plants, the large central vacuole, which is enclosed by a tonoplast (membrane), contains a variety of substances.
11) Cell membrane: The Fluid-Mosaic Model
The cell membrane is a plasma membrane that surrounds all cells. The main components of the cell membrane are phospholipids, proteins, cholesterol, carbohydrates, glycoproteins, and glycolipids.

Fluidity:
The membrane must be fluid to work properly. If a membrane solidifies, its permeability changes, and the enzymes become deactivated.

Cholesterol in eukaryotic membranes controls the fluidity of membranes in two ways.
   A) In warmer temperatures it decreases fluidity by restraining phospholipid movement.
   B) In colder temperatures it increases fluidity by preventing the close packing of phospholipids.

Mosaic:
A mosaic of proteins is embedded and dispersed in the phospholipid bilayer. There are two types of proteins depending on their location.
   A) Integral Proteins are inserted into the membrane so that the hydrophobic region of the protein is surrounded by the hydrocarbon portion of the phospholipid. There are two types of integral proteins.
      1) Unilateral-- reaching only partway across the membrane.
      2) Transmembrane-- completely span the membrane. These proteins have hydrophilic ends with a hydrophobic midsection.
   B) Peripheral Proteins: not embedded in membrane, but attached to the membrane surface.
      1) May be attached to integral proteins.
      2) May be held by filaments from the cytoskeleton.

One of the main functions of the cell membrane is to act as a selectively permeable barrier. This tight barrier prevents the passive movement of most molecules; thus substances cannot easily enter or leave the cell.

There are seven ways substances can get into the cell.
A) Bulk Flow
B) Diffusion
C) Osmosis
D) Facilitated Diffusion
E) Active Transport
F) Vesicle Mediated Transport
G) Cell-Cell Junction

A) Bulk flow: Molecules move all together in the same direction. Hydrostatic pressure forces molecules through the plasma membrane.

B) Diffusion: The movement of molecules from a high to low concentration; this process requires no energy. Only very small molecules can diffuse through the membrane.

C) Osmosis: The movement of water through a semipermeable membrane from an area of higher water potential to an area of lower water potential until an equilibrium is reached. It does not require energy.

Water potential refers to the potential energy of water; thus water moves from a higher potential energy state to a lower energy state as it moves through a semipermeable membrane. The water potential of pure water is zero. The more solute dissolved in water, the lower (more negative) the water potential. The units of water potential as the same as those of pressure; common units are atmospheres, bars or megapascals.
There are three types of osmotic environments.
1) Isotonic or isosmotic environment: The aqueous environment has the same solute concentration as the cell. Water flows in and out of the cell equally in both directions.
2) Hypertonic or hyperosmotic environment: the aqueous environment surrounding the cell has a higher solute concentration than does the cell. Through osmosis the water moves from the cell to the external environment. If the process continues, the cell collapses and dies.
3) Hypotonic or hypoosmotic environment: The environment has a lower solute concentration than does the cell. Water moves from the environment into the cell by osmosis. The cell expands, causing turgor pressure in plant cells. Since animal cells lack cell walls, they will burst if placed in a solution that is hyperosmotic.

Osmotic Pressure:
Osmotic pressure is zero if the solute concentration on both sides of the selectively permeable membrane is equal. If there is a barrier that prevents the hypertonic solution in a cell from expanding, the solution in the cell will exert an increasingly greater outward pressure.

As the pressure increases, the flow of water molecules into the hypertonic solution decreases. The pressure required to stop the osmotic movement of water into a solution is called osmotic pressure. The lower the water potential, the more water that can move into the cell by osmosis; thus the greater the osmotic pressure that will develop.

Example: Turgor Pressure.
Plant cells have a central vacuole filled with solutes and thus have a lower water potential than the surroundings. Therefore water enters the cells. In mature cells, the cell wall does not expand. Since the wall does not expand, it exerts an inward pressure, called cell wall pressure, on the solution. This pressure prevents the net movement of water molecules into the cell. However, the cells remain hyperosmotic to the environment and the tendency of water molecules to continue to move into the cells keeps the plant cells fully hydrated and turgid. This internal pressure outward is called turgor pressure and keeps the cell rigid. If water is not available, turgor pressure falls because water leaves the cells. Then the plant wilts.

D) Facilitated Diffusion. Since the lipid layer is amphipathic, most polar molecules cannot pass through the nonpolar region. Since most organic molecules are polar, they are unable to pass through the cell membrane by simple diffusion. For example, glucose enters cells by facilitated diffusion. This process does not require energy. However, the process occurs faster than simple diffusion (this is a key!!).

The transport of large hydrophilic molecules across the cell membrane depends upon integral membrane proteins, called transport proteins. The transport proteins are highly selective. The tertiary and even quaternary structures of the transport proteins determine which molecules are transported. These transport proteins are called PERMEASES.

Types of transport proteins:
a) Uniport: carries a single molecule across the membrane.
b) Symport: moves two different molecules at the same time in the same direction. Both molecules must bind to the protein for transport.
c) Antiport: exchanges two molecules by moving them in opposite directions.

These proteins can be inhibited by molecules that resemble the molecule normally carried by the protein.

E) Active Transport: This type of transport requires energy and membrane proteins. Active transport occurs in situations where a substance is moved across the cell membrane and against its concentration gradient.

F) Vesicle Mediated Transport:
Vesicles or vacuoles can fuse with the cell membrane. Vesicles formed inside the cell can move to the cell membrane, fuse with the outer cell membrane, and expel their contents outside the cell into the surroundings. This process is called EXOCYTOSIS. In ENDOCYTOSIS, vesicles formed at the surface of the cell can capture substances outside the cell,
and deposit their contents into the cell. There are three types of endocytosis.

A) Phagocytosis (cell eating): When the substance taken into the cell is a solid, the process is called phagocytosis. A vesicle forms around the object taken into the cell. Once the solid is in the cell, a lysosome joins with the vesicle and enzymes digest the solid.

B) Pinocytosis (cell drinking): When the substance taken into the cell is a fluid, the process is called pinocytosis.

C) Receptor-Mediated Endocytosis: The molecule attaches to a specific receptor (ligands) on the cell surface before a vesicle forms around the molecule.

G) Cell-Cell Junction:
In multicellular organisms, cells are organized into tissues. Cells need to communicate with each other directly. Some communications are accomplished by chemical signals produced by the cell. They are then exported through exocytosis, moved to the target cell, and bind to receptor sites on the target cell membrane. They are either taken into the target cell or activate a second messenger within the target cell, which will complete the message.

12) Cytoskeleton:
Background:
A) All cells have a distinct shape that varies with time and function. The cytoskeleton may enable a cell to change its shape.
B) Cells have a high degree of internal organization. Organelles have patterns and form relationships that often change. Organelles and even cytoplasmic enzymes may be held in place by anchoring them to the cytoskeleton. Organelles can also be transported along the cytoskeleton, which acts like a 'railroad track.'
C) Some cells have the ability to move. Movement of organisms like us depends on the same mechanisms used by the cells.

Functions and characteristics of the cytoskeleton:
1) Cytoskeleton elements are non-membrane bounded organelles.
2) Most cytoskeleton organelles have the ability for self-assembly.
3) The cytoskeleton organelles have specific lengths.
4) They are involved with the transport of organelles and cytoplasmic streaming.
5) The organelles transport soluble products.
6) They are altered when the cell comes into contact with a substrate; this may allow for cell-to-cell communication.
7) These organelles are not dependent on the nucleus for assembly.
8) The organelles for the cytoskeleton are inherited maternally.
9) They can regulate biochemical activities in the cell by transmitting a mechanical force from the cell surface into the nucleus.

Three organelles that make up the cytoskeleton are:
a) Microtubules
b) Actin fibrils or Microfilaments
c) Intermediate fibrils

A) Microtubules:
1) These are about 25 nm in diameter.
2) Microtubules are 200 nm to 25 mm in length
3) The microtubules are hollow tubes that are constructed from globular proteins called tubulins. A microtubule may elongate by the addition of tubulin proteins to one end of the tubule. Microtubules may be disassembled and their tubulin used to build microtubules elsewhere in the cell.
4) These may exist in singles, groups or complex arrangement.
5) They are composed of alpha and beta tubulin dimers.

Microtubules extend outwards from an organizing center (centrosome) that is near the nucleus to near the cell surface.
Plants do not have centrioles.

Functions of Microtubules:
   a) Microtubules play an important role in cell division. They move things within the cell, for example, chromosomes during mitosis; mitochondria, plastids and vesicles can move along microtubule tracks.
   b) They help maintain the structure of the cell. It is believed that microtubules act as temporary scaffolding for the construction of other cell structures.
   c) Microtubules probably guide secretory vesicles from the Golgi complex to the plasma membrane.
   d) Cilia and flagella are formed through a specialized arrangement of microtubules. Microtubules are associated with motor proteins called dynein and kinesin.

Centrosomes, centrioles, cilia and flagella are made up of microtubules. Centrosomes produce microtubules for the movement of chromosomes during mitosis. The centrioles are associated with the centrosomes, but the exact function is not known.

B) Microfilaments/Actin Filaments-- Characteristics and Functions:
   1) They are 6-7 nm in diameter.
   2) Microfilaments/Actin Filaments are solid rods composed of the protein actin in helical chain (globular protein subunits).
   3) They are involved with cytoplasmic streaming and pseudopodia movement.
   4) They help arrange the organelles.
   5) Microfilaments, actin, and myosin are the main component of muscle cells. Microfilaments are best known for their role in muscle contraction. 10% of all the protein in a cell is actin. Actin filaments are associated with motor proteins called myosin.
   6) They form the cleavage furrow in cell division.
   7) They change cell shape and will maintain cell shape.

If microtubules are compression-resisting pieces of the cytoskeleton, then actin filaments bear tension (pulling force). With other proteins, they form a 3-D network just inside the plasma membrane and help supports the cell shape. Actin filaments are best known for their role in cell mobility: muscle contraction, extension of pseudopodia, and cytoplasmic streaming.

C) Intermediate Fibrils-- Characteristics and Functions:
   1) They are 8-12 nm in diameter.
   2) Intermediate filaments comprise a diverse class of cytoskeletal elements, differing in protein composition from one type of cell to another.
   3) Intermediate fibrils are permanent and very stable.
   4) There are 5 classes of intermediate fibrils.
   5) They radiate from the nuclear envelope and associate with microtubules-- forming a cage in which the nucleus sits.
   6) Experiments suggest that intermediate filaments are important in reinforcing the shape of a cell and fixing the position of certain organelles.

D) Cell Movement:
   1) Undulipodia: Cilia and Flagella:
   Function of Undulipodia: moves the eukaryotic cell by undulating. There is no structural difference between eukaryotic flagella and cilia. If a protist has a flagellum, it is classified with the flagellates. If a protist has cilia, it is a ciliate. Flagella are longer (200 um in length) and few per cell. Flagellae move in an undulating motion, which generates a force in the same direction. Cilia are shorter (2-20 um in length), beat differently and are usually abundant. Cilia work like oars, they alternate between a power and recovery stroke.

   Undulipodia seen in a cross section are about 0.25 µm in diameter and show a circle of pairs of microtubules
(minute cylinders). There are nine fused microtubules that form a ring surrounding two additional fused microtubules (in the center). Microtubules are composed of tubulins. Both cilia and flagella are sheathed in an extension of plasma membrane.

Traces of RNA have been found inside the base of the undulipodium. It is hypothesized that undulipodia were once free-living spirochetes. These spirochetes formed association with heterotrophic protists. The spirochetes attached themselves to the host's surface to obtain food through the membrane. Eventually, the spirochete began to propel the host through the environment. There is a weakness in this theory; no genetic material has been found in the undulipodia. The genes that determine the amino acid sequence of the tubulin proteins that make up the undulipodia are found in the nucleus of the cell.

How do they work?
Cilia and flagella share a common Ultrastructure—a 9 + 2 arrangement. This means there are nine doublets of microtubules that form a ring around 2 single microtubules. Each of the doublets is connected to the center of the cilium/flagellum by radial spokes. Each doublet of the outer ring has pairs of arms evenly spread along the length of the microtubule. The whole microtubule assembly is anchored in the cell at the Basal Body (identical to the centriole).

The arms that extend from each doublet are made up of dynein (large protein). With the use of ATP, dynein changes shape, which causes the cilium/flagellum to bend. This is called dynein walking. The dynein arms attach to the other doublet and pulls, the doublets move in the opposite direction. The arms then let go, reattach and pull again. The doublets will bend in one direction.

2) Basal Bodies and Centriole:
Basal Body: These structures have the same diameter as cilia (about .2μm). They are composed of microtubules arranged in nine triplets instead of pairs. Cilia and flagella are formed from basal bodies. These structures can also anchor the cilia and flagellum to the cell—on the inside of the cell.
Centriole: In many cells the microtubules grow out from a region located near the nucleus called the centrosome. In animal cells, a pair of centrioles can be found in the centrosome. These are small cylinders (about .2μm), which contain nine microtubule triplets (identical to the basal bodies). Distribution in the cell is different.

In a non-dividing animal cell, centrioles lie in pairs at right angles to each other near the nuclear envelope, where the microtubules radiate. During cell division, centrioles organize the spindle. The spindle appears at the time of cell division and is involved with chromosome movement during mitosis. The spindle is composed of numerous microtubules.
Centrioles are not required for spindle formation. Plant cells, which lack centrioles, form spindles.

13) The Cell Surface:
A) Cell Walls: One of the features that distinguish plant cells from animal cells is the cell wall. The cell wall protects the plant cell, maintains its shape, and prevents excessive uptake of water. Organisms are usually classified by the major components of their cell wall.

Plant cell walls are much thicker than the plasma membrane and range from 0.1 to several um. Although the exact chemical composition of the wall varies from species to species and from one cell type to another in the same plant, the basic design of the wall is consistent. Fibers made of the polysaccharide cellulose are embedded in a matrix of other polysaccharides and protein.

A young plant cell first secretes a relatively thin and flexible cell wall called the primary cell wall. Between the primary walls of adjacent cells is the middle lamella, a thin layer rich in sticky polysaccharides called pectins. The middle lamella glues the cells together. When the cell matures and stops growing, it strengthens its wall. Some cells do this by secreting
hardening substances into the primary wall. Other plants cells add a secondary cell wall between the cell membrane and the primary wall. The secondary wall, made of several layers, has a strong and durable matrix that affords the cell protection and support. Wood consists of mainly secondary walls (lignin).

B) Extra Cellular Matrix (ECM): Animal cells lack-structured walls, but many have an extra cellular matrix. The main ingredients of the ECM are glycoproteins produced by the cell (usually collagen). Collagen is embedded in a network of proteoglycans (another class of glycoproteins that are rich is carbohydrates. Fibronectins, another type of glycoprotein, help attach the ECM to the cell. The fibronectin binds to a cell receptor protein called integrins.

C) Intracellular Junctions:
The many cells of an animal or plant are integrated into one functional organism. Neighboring cells often adhere, interact, and communicate through special patches of direct physical contact. The walls of plants are perforated with channels called plasmodesmata through which strands of cytoplasm connect the living contents of adjacent cells. In animals there are three main types of intracellular junctions: tight junctions, desmosomes, and gap junctions.

1) Tight Junction: continuous belt around the cell. The membranes of neighboring cells are fused at tight junctions. This is a leak-proof seal.

2) Desmosomes: These junctions function as rivets and join cells together. Intermediate filaments, made of keratin, reinforce the desmosomes.

3) Gap Junction: These are cytoplasmic channels between neighboring cells. Special membrane proteins surround each pore. These pores are large enough to allow salts, sugars, amino acids, and other small molecules to pass. The gap junction is analogous to plasmodesmata of a plant.

D) Cell-to-Cell Recognition: This is a function of the cell membrane.
Cell-to-cell recognition helps sorts cells into tissues and organs of a developing embryo and is used to reject foreign cells. How cells are recognized by membrane carbohydrates called oligosaccharides (fewer than 15 sugar units) some oligosaccharides are bonded to lipids to form glycolipids, but most are bound to proteins and are called glycoproteins. The oligosaccharide is usually found on the external side of the membrane and varies from species to species, cell type to cell type, individual to individual.