<u>THE LIVING CELL</u>

A Tour of the cell

The cell is the smallest and the basic unit of structure of all organisms. There are two main types or categories of cells: <u>prokaryotic cells</u> and <u>eukaryotic cells</u>. Prokaryotic cells are independently functioning organisms, such as microscopic amoeba and bacteria cells whereas, eukaryotic cells generally function only when they are a part of a larger organism such as the cells that make up our body. An exception is yeast which is eukaryotic, yet lives as a single cell.

Many different types of cells are found in nature. Cells come in all shapes and sizes and perform various functions. In the body, there are brain cells, skin cells, liver cells, stomach cells and so on. All of these cells have unique functions and features.

While typical animal cells are about one-hundredth of a millimeter in diameter (1/100 mm), bacterial cells are only a few hundredth-thousandths of a centimeter in size (1/100,000 cm).

Cells also have variety of shapes. Plant cells are often rectangular or polygonal, while egg cells are usually spherical.

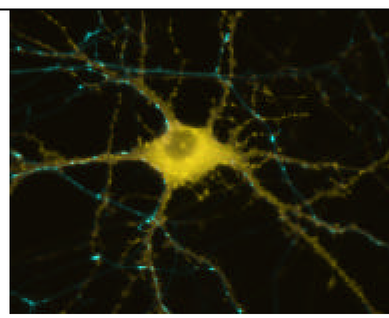
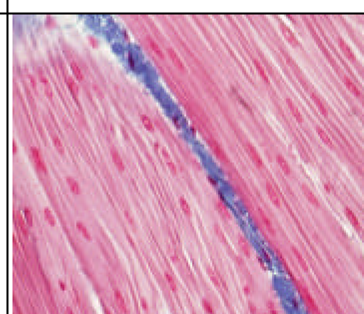
Bacterial cells may be rod shaped or spiral	Nerve cells are a complex array of fibers	Muscle cells are extremely elongated
 a	 b	 c

Figure 1: **a :** Rod shaped bacterial cells; **b:** Nerve cell; **c:** elongated muscle cell

The differences in shapes and sizes reflect the differences in the functions that the cells perform. Elongated muscle cells exert forces when they contract. Branched nerve cells transmit impulses to many other cells.

Bacterial cells operate independently and ensure their survival by reproducing in large numbers, whereas animal and plant cells have collective interdependence.

Organelles of the cell

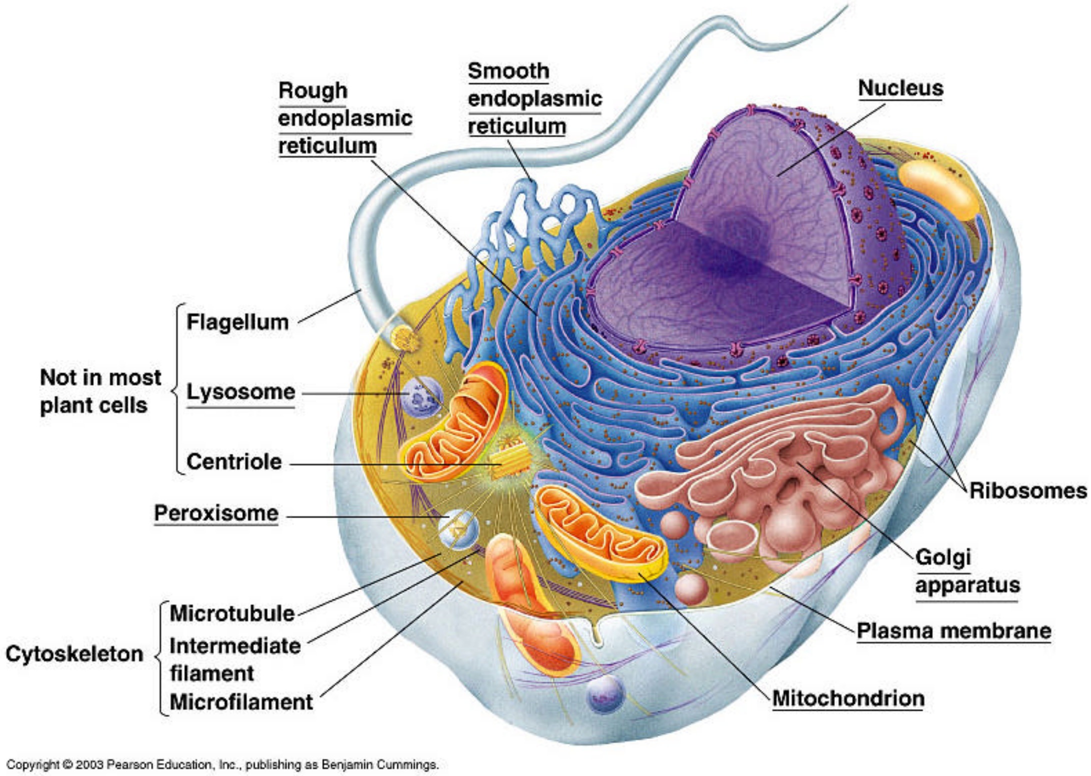


Figure 2 : Overview of an animal cell

Cell Membrane

All living cells, prokaryotic and eukaryotic, have a plasma membrane that encloses their contents and serves as a semi-porous barrier to the outside environment. The membrane acts as a boundary, holding the cell constituents together and keeping other substances from entering. The plasma membrane is permeable to specific molecules. It allows nutrients and other essential elements to enter the cell and waste materials to leave the cell. Small molecules, such as oxygen, carbon dioxide, and water, are able to pass freely across the membrane, but the passage of larger molecules, such as amino acids and sugars, is carefully regulated.

The basic molecular structure of a cell membrane is shown in Figure 3

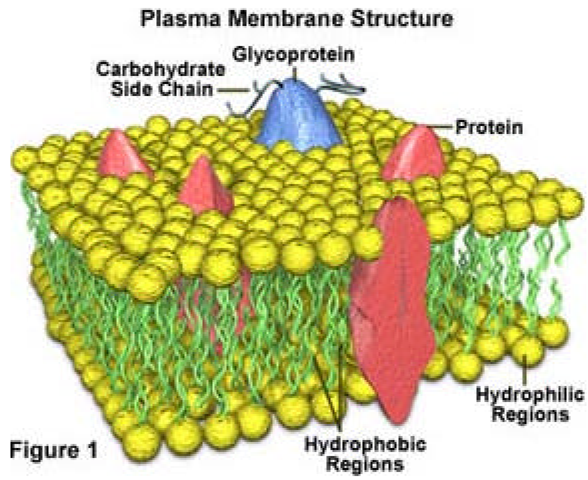


Figure 3: Sketch of an animal cell plasma membrane. All cells possess a lipid bilayer membrane studded with protein molecules. The membrane separates the inside of the cells from the outside.

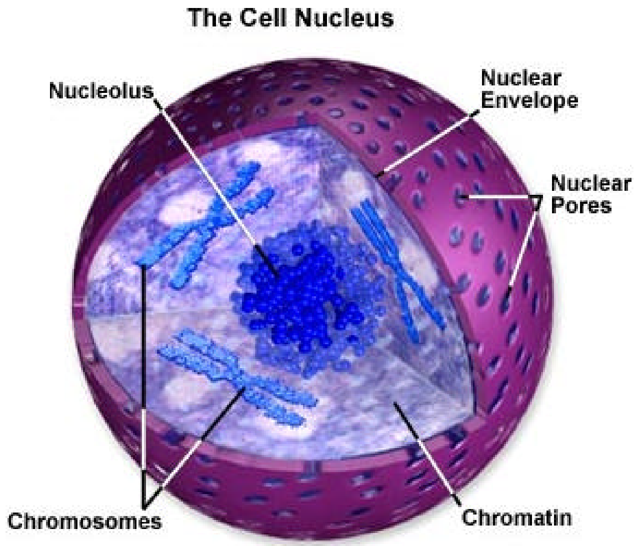
Within the phospholipid bilayer of the plasma membrane, many diverse proteins are embedded, while some proteins simply adhere to the surface of the bilayer. Some of these proteins, primarily carbohydrates are attached to their outer surfaces and are referred to as glycoproteins.

The arrangement also involves the presence of hydrophobic and hydrophilic regions of the lipid bilayer. The chain like lipid molecules are arranged in a bilayer with the hydrophobic ends or “tails” of the molecules pressed against each other and associating with the hydrophobic interior of the plasma membrane, and the hydrophilic ends of the molecule or the “head” groups on the outside of the plasma membrane, lining up both outside and inside of a cell.

Plasma membrane proteins function in several different ways. Many of the proteins play a role in the selective transport of certain substances across the phospholipid bilayer, either acting as channels or active transport molecules. Others function as receptors, which bind information-providing molecules, such as hormones, and transmit corresponding signals to the interior of the cell. Membrane proteins may also exhibit enzymatic activity, catalyzing various reactions related to the plasma membrane.

<u>Cell Nucleus</u>

The nucleus is the most prominent and the largest organelle in a cell. It is the brain of the cells that directs all activities in the cell. It stores genetic information for a cell. The nucleus houses the DNA (deoxyribonucleic acid) which contains the instructions for the day-to day chemical operation of the cells. The DNA contains instructions for the production of the cell's proteins and for reproduction. DNA is found within the chromosomes in the nucleus of the cell.



Not all cells have nuclei. In some cells, DNA is present in a tight coil but not enclosed in a nucleus. These sorts of primitive cells called ‘prokaryotes’ (“before the nucleus”) include bacteria.

Nucleus is only present in eukaryotic cells (eukaryotes = “true nucleus”) and there is only one of this in each cell. It is surrounded by a membrane, called the nuclear envelope, which is similar to the cell membrane. The envelope is riddled with holes, called nuclear pores, that allow specific materials to pass in and out of the nucleus, similar proteins in the plasma membrane regulate the movement of molecules in and out of the cell itself.

The nucleus has two membranes that may have evolved from two independent living prokaryotes. The idea is that at some point during evolution, a large cell engulfed a small cell and overtime a symbiotic relationship developed between these two cells. The double membrane nucleus is interpreted as having an inner membrane, descended from the original membrane of the swallowed cell, and an outer membrane that descended from the vesicle that formed when the first cell was enveloped.

The energy organelles of cells – Chloroplasts and Mitochondria

Chloroplasts: Chloroplasts are the main energy transformation organelles in plant cells. Chloroplasts convert light energy to chemical energy via the process of photosynthesis. They consist of chlorophyll which absorb energy from sunlight and convert it into chemical energy that is used for cell’s functions.

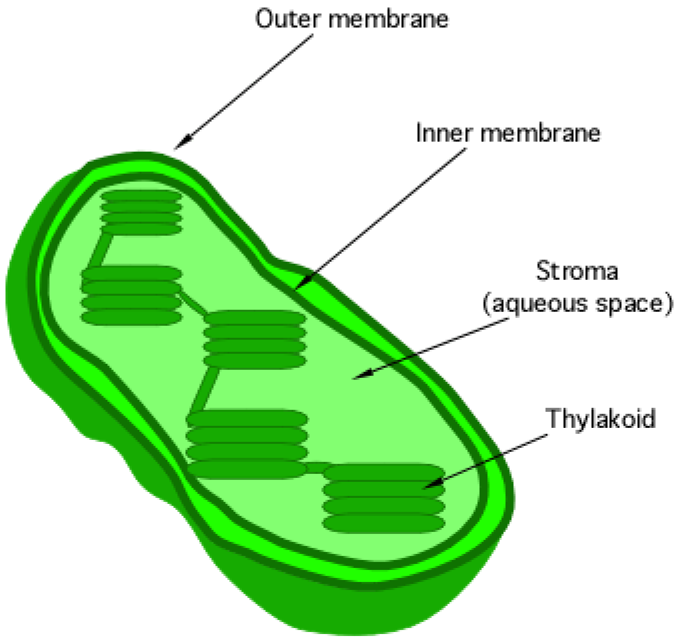


Figure 4: Sketch of a chloroplast, site of photosynthesis

Mitochondria: These are sausage shaped organelles where molecules derived from glucose react with oxygen to produce cell's energy. A mitochondrion can be considered as a cell's furnace where fuels are oxidized. A typical eukaryotic cell has anywhere from a few hundred to a few thousand mitochondria.

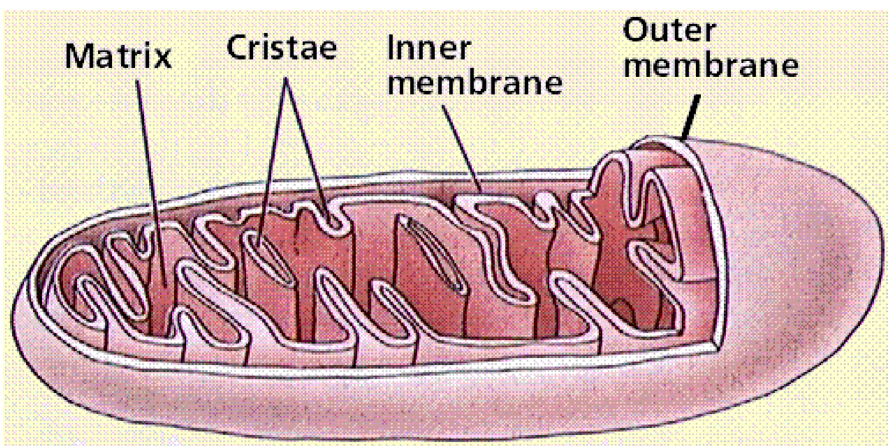


Figure 5: Sketch of a mitochondrion, site of cellular respiration

It has been suggested that mitochondria and chloroplasts may have originally arisen from prokaryotic invaders. Evidence for this includes the fact that both of these organelles contain their own DNA (separate from that in the nucleus) and they control their own replication within the cell. They both have double membranes suggesting one membrane originated from the plasma membrane of the cell and one from the plasma membrane of the hypothetical invader.

Cytoskeleton

It is a dynamic structure that maintains the shape of the cell, protects the cell, enables cellular motion, and plays important roles in both intracellular transport and cellular division. It may play a regulatory role by mechanically transmitting signals from the cell's surface to its interior. The cytoskeleton is a series of protein filaments that extend throughout the cell. Just as the skeleton of an animal helps fix the positions of other body parts, the cytoskeleton provides anchorage for many organelles, inside a cell.

Summary of the organelles of cells and their functions

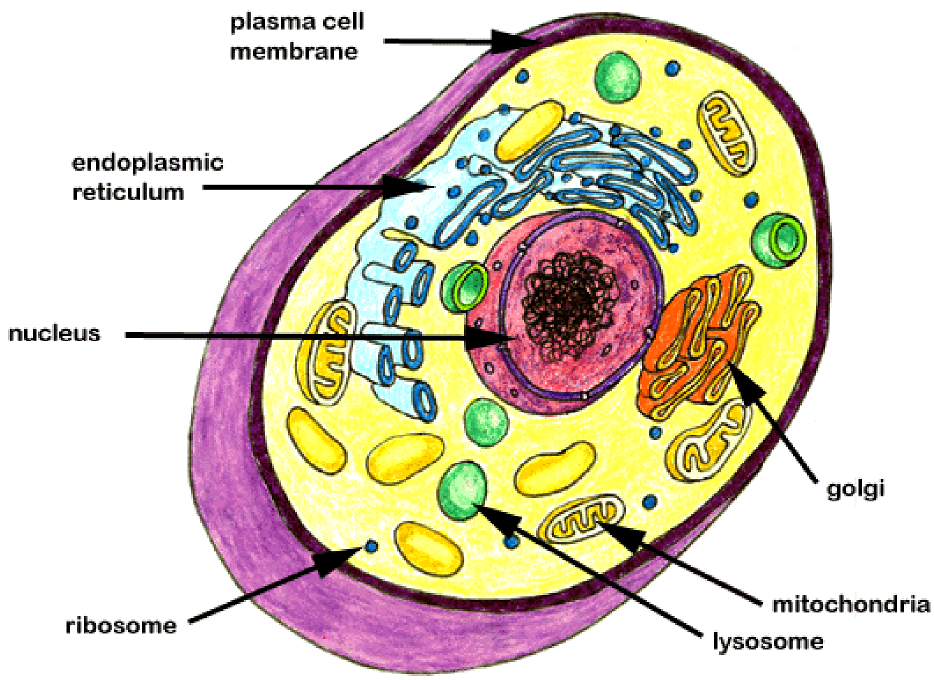


Figure 6: Overview of organelles of an animal cell

Plasma membrane – Protects the cell from outside environment

Nucleus - Controls all cell activities, stores genetic information

Endoplasmic Reticulum – Synthesis of proteins and lipids, in the metabolism of carbohydrates

Mitochondria – Production of energy for metabolism

Ribosomes – Site of protein synthesis

Golgi apparatus - Processes and packages substances for export from the cell and to other parts of the cell

Lysosomes – Digest waste or undesirable materials

Cytoskeleton - Structural support and cell movement

Energy and Life

ATP - Nature's Energy Store

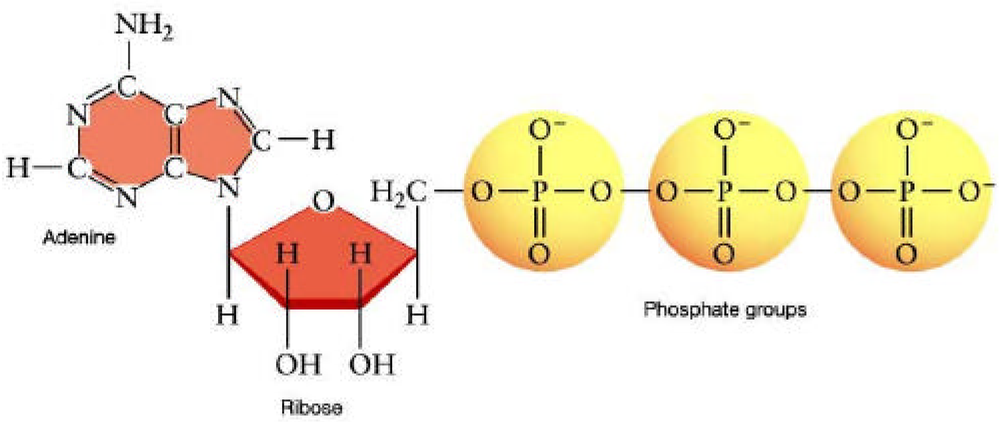
All living things, plants and animals, require a continual supply of energy in order to function. The energy is used for all the processes which keep the organism alive. The cell's process of deriving energy from its surroundings is called **Metabolism.** Metabolism is the set of chemical reactions that occur in living organisms in order to maintain life. These processes allow organisms to grow and reproduce, maintain their structures, and respond to their environments.

Animals obtain their energy by oxidation of foods, plants do so by trapping the sunlight using chlorophyll. However, before the energy can be used, it is first transformed into a form which the organism can use easily. This special carrier of energy is the molecule adenosine triphosphate, or ATP.

The ATP molecule is composed of three components. At the centre is a sugar molecule, ribose (the same sugar that forms the basis of DNA). Attached to one side of this is a *base* (a group consisting of linked rings of carbon and nitrogen atoms); in this case the base is adenine. The other side of the sugar is attached to a string of phosphate groups. These phosphates are the key to the activity of ATP.

ATP works by losing the endmost phosphate group when instructed to do so by an enzyme. This reaction releases a lot of energy, which the organism can then use to build proteins, contract muscles, *etc.* The reaction product is adenosine diphosphate (ADP). Even more energy can be extracted by removing a second phosphate group to produce adenosine monophosphate (AMP) (Figure 7).

When the organism is resting and energy is not immediately needed, the reverse reaction takes place and the phosphate group is reattached to the molecule using the energy obtained from food or sunlight. Thus the ATP molecule acts as a chemical 'battery', storing energy when it is not needed, but able to release it instantly when the organism requires it



Adenosine 5' monophosphate (AMP)

Adenosine 5' diphosphate (ADP)

Adenosine 5' triphosphate (ATP)

Figure 7: ATP, the cells energy currency. It is built from sugar (ribose), a base (adenine), and phosphate groups.

Photosynthesis in nature

Photosynthesis is the mechanism by which plants convert light energy into chemical energy that can be utilized for cellular work.

Photosynthesis is the single most vital metabolic process for all forms of life on earth. Life would not be possible without radiant energy from the sun. Living forms have evolved to their present state in part because photosynthesis has been providing us with the usable energy.

The mechanism by which light energy is converted to chemical energy in photosynthesis involves a complex series of reactions and involves interaction of many compounds. The process begins with absorption of sunlight by a large molecule called Chlorophyll in plants. After a series of chemical reactions, this energy is ultimately stored in a set of molecules including ATP. These series of reactions are called light reactions and take place in the presence of sunlight. The energy produced by the light reactions is then used by another complex series of reactions called dark reactions to produce carbohydrates.

The most important carbohydrate molecule is glucose which is an energy-rich sugar molecule. The dark reactions do not require direct sunlight, however, dark reactions in most plants occur during the day.

The end result of photosynthesis is the conversion of light energy from the sun into chemical energy that is stored in the bonds holding the carbohydrate molecules together.

$$\mathbf{6CO_2 + 12H_2O + LIGHTENERGY} \text{ ® } \mathbf{C_6H_{12}O_6 + 6O_2 + 6H_2O}$$

The energy that falls as sunlight on the leaves of plants is white light. Chlorophylls in the leaves absorb the blue and red regions of the visible spectrum, reflecting green light and thereby appear green. In addition to chlorophyll, other secondary molecules are also involved in the process of photosynthesis. These molecules absorb blue light and so they appear to be red and orange. A normal plant leaf contains more chlorophyll than these secondary molecules and therefore appear mostly green. In the fall, however, when the leaves begin to die and chlorophyll is no longer produced, its underlying color is visible.

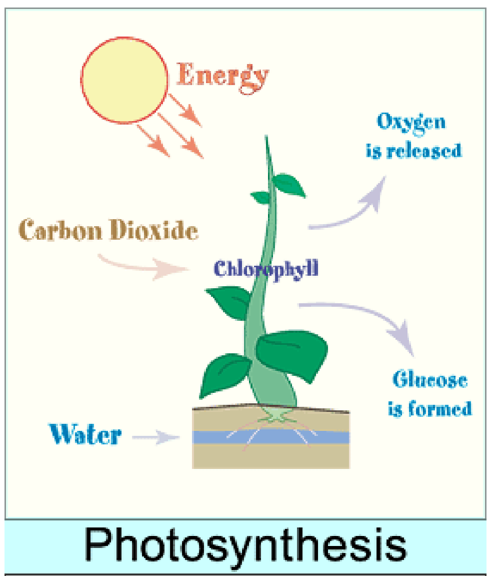


Figure 8: Overview of process of photosynthesis in plants

Cellular Respiration - Harvesting Chemical Energy

As we have seen earlier, plants use photosynthesis to convert light energy from the Sun into chemical energy, which is stored in the form of carbohydrates and other organic compounds.

The process by which these carbohydrates and organic compounds are broken down to release energy for work is called Cellular respiration. The primary source of energy for all living things comes from the oxidation of carbohydrates such as glucose. We breathe in oxygen produced by plants and breathe out carbon dioxide which is the end product of breakdown of carbohydrates that we ingest in our food. Respiration retrieves the energy stores in carbohydrates in a complex series of cellular chemical reactions.

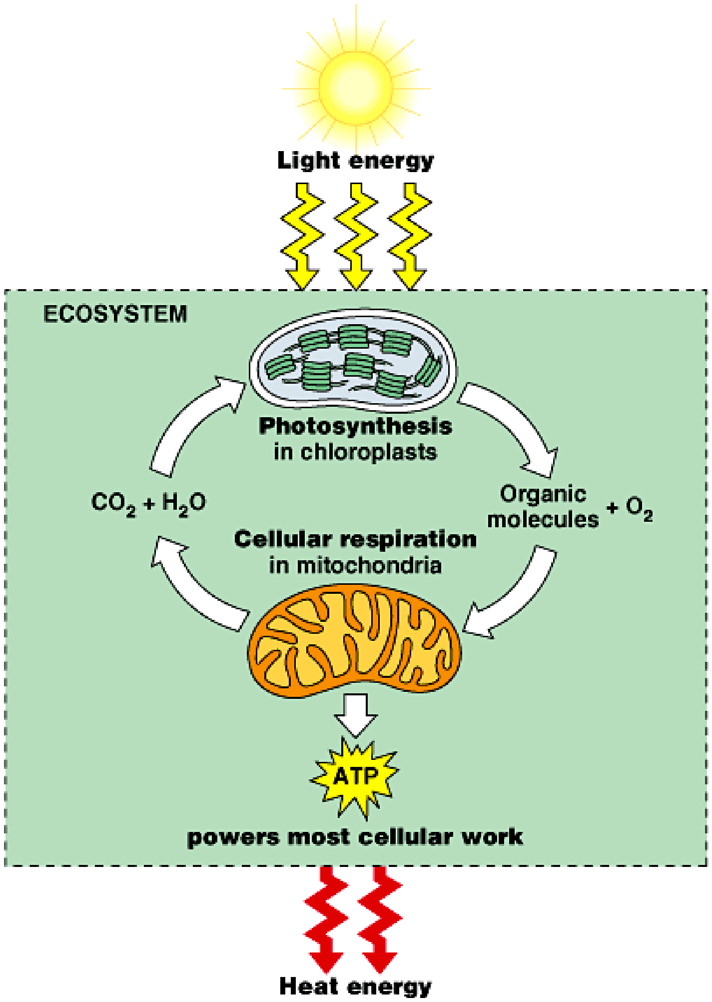


Figure 9: Overview of generation of energy for cellular work

Cellular Respiration begins with a Biochemical Pathway called **Glycolysis**. Glycolysis is the first step in energy generation in the cell. This complex series of reactions takes place in the cytoplasm of the cells in nine separate steps, each of which is governed by a specific enzyme. A single molecule of glucose is split into two smaller molecules called **Pyruvic acids**. The reaction also generates two molecules of ATP and two molecules of other energy carriers. In most cells the energy that is stored in other carriers is ultimately converted to two or three more molecules of ATP. Thus each glucose molecule yields 6-8 molecules of ATP through glycolysis.

The process of cellular respiration continues in two different ways:

1. <u>Aerobic (in the presence of oxygen)</u>

   In cells where oxygen is available, mainly in mitochondria, **pyruvic acids** enter a complex series of chemical reactions called Krebs cycle or Citric acid cycle. In the course of this cycle the original glucose molecule is broken down and its carbon is converted into carbon dioxide and energy is released into ATP molecules. Aerobic respiration recovers lot more energy from food molecules than glycolysis. It is the means by which plant and animal cells derive most of their energy. During aerobic respiration, the metabolism of a single glucose molecule ultimately produces 36-38 molecules of ATP which is used by the cell to run the rest of the cellular machinery.

   $$C_6H_{12}O_6 + 6O_2 \text{ ? } 6CO_2 + 6H_2O + 38 \text{ ATP}$$

2. <u>Anaerobic (in the absence of oxygen) also known as Fermentation.</u>

   In the absence of oxygen, **pyruvic acid** is metabolized by fermentation. **Fermentation** enables some cells to produce ATP without the help of oxygen. Unlike aerobic respiration, pyruvic acid is not transported into the mitochondrion, but remains in the cytoplasm, where it is converted into some "waste" product that may be removed from the cell and to a little bit of energy (only two molecules of ATP). Two of the most common types of fermentation include **lactic acid fermentation** and **alcohol fermentation.**

   Lactic acid fermentation is carried out by some fungi or bacteria in yogurt, and sometimes by our muscles. Normally our muscles do cellular respiration like the rest of our bodies, using O_2 supplied by our lungs and blood. However, under greater exertion when the oxygen supplied by the lungs and blood system can't get there fast enough to keep up with the muscle's needs, our muscles can switch over and do lactic acid fermentation. In the process of lactic acid fermentation, the 3-carbon pyruvic acid molecules are turned into **lactic acid**. It is the presence of lactic acid in yogurt that gives it its sour taste, and it is the presence of lactic acid in our over-exerted muscles that makes then feel stiff and sore even if they haven't been physically injured. Lactic acid is ultimately gradually washed away by the blood stream.

   Alcohol fermentation is done by yeast and some other kind of bacteria. In yeast, the waste products are ethanol and carbon dioxide. Humans have long taken advantage of this process in making bread, beer, and wine.

   Anaerobic respiration is less efficient at using the energy from glucose since 2 ATP are produced during anaerobic respiration per glucose, compared to the 38 ATP per glucose produced by aerobic respiration. This is because the waste products of anaerobic respiration still contain plenty of energy. Ethanol, for example, can be burned as a fuel.

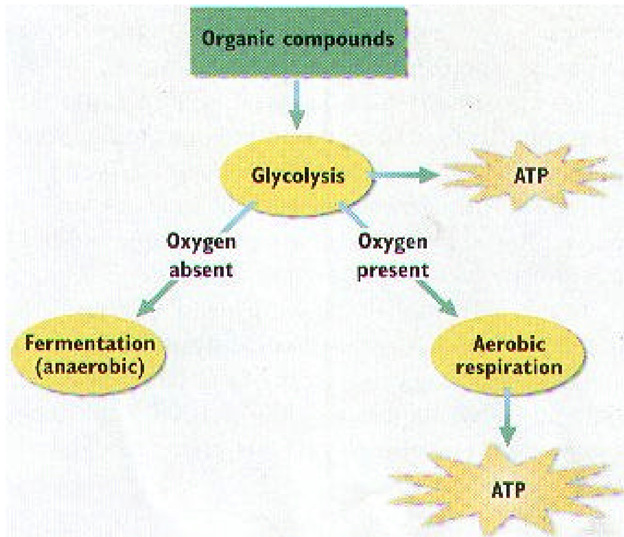


Figure 10: Overview of process of cellular respiration

The process of breathing and respiration

For respiration to occur in the mitochondria of each cell, oxygen must reach the cell. Oxygen present in atmospheric air is used for this purpose by breathing the air in. Air passes through nostrils and trachea to lungs (Figure 11) where oxygen enters the blood by binding to hemoglobin in red blood cells. The blood circulation carries the bound oxygen to different tissues where it exchanges oxygen with carbon dioxide (produced in the metabolism process). The oxygen inside the cell finds its way to mitochondria where it reacts with dietary carbohydrate or carbohydrate produced from fat and proteins to produce biological energy currency, ATP (Figure 12).

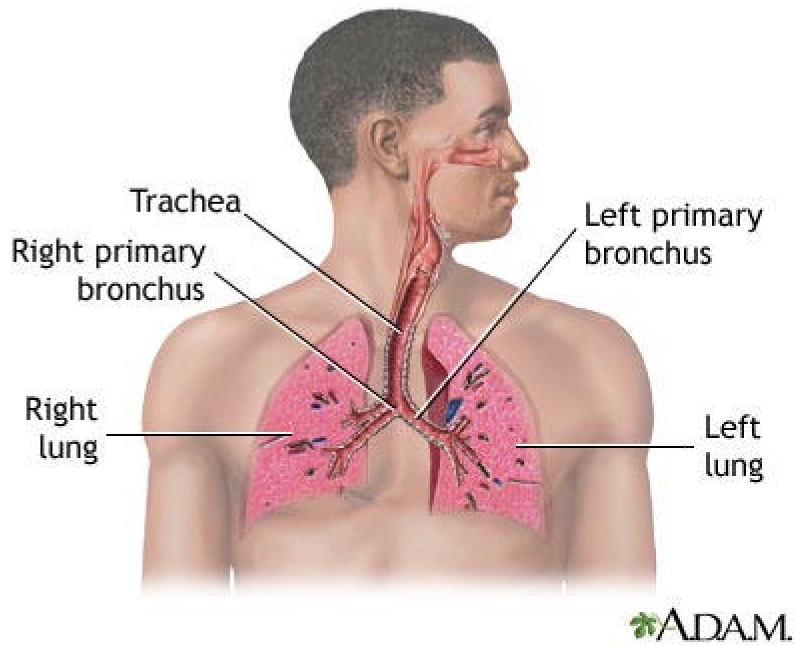


Figure 11. Air is breathed in (inhaled) through the nasal passageways, and travels through the trachea and bronchi to the lungs. (From http://adam.about.com/reports/Sickle-cell-disease.htm).

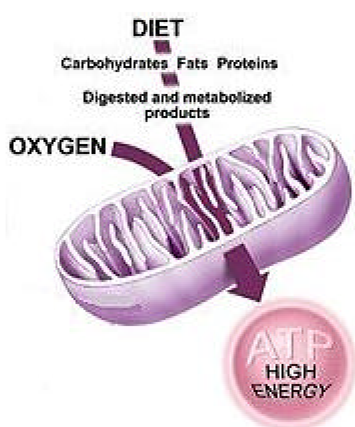


Figure 12. Oxygen carried to the cell and mitochondria by blood circulation combines with dietary materials (carbohydrate, fats, and proteins) to ATP (From http://www.keelynet.com/mitochondria.jpg)