SAT Biology Review: Cellular Energetics

Important Molecules

ATP

ATP, adenosine triphosphate, is an RNA nucleotide that is also used as the main energy storage molecule in the cell. Attached to the ribose sugar and adenine nitrogenous base are three phosphate groups. The covalent bond between the phosphate groups is a high-energy **phosphodiester bond,** and when broken, it provides energy that can be used for many different purposes in the cell. The energy can be used to build or break down biomolecules, to power active transport proteins in the membranes, or to allow cells or organelles to move.

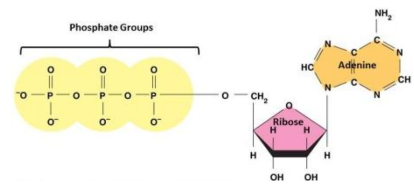

Figure 1. The structure of ATP

The final phosphate group is usually the one removed to gain energy, creating ADP (adenosine diphosphate) and a free phosphate group (P_i): ATP → ADP + P_i

One of the most important aspects of ATP is that it is rechargeable. With an input of energy (from photosynthesis, cell respiration, or fermentation) the phosphate group can be reattached to ADP reforming ATP.

NAD^+ and other electron carriers

NAD^+, nicotinamide adenine dinucleotide, is one of a family of RNA electron carriers that also includes $NADP^+$ and FAD^+. Each molecule can carry two electrons, which are picked up from glucose (or what is left of it) in cellular respiration and fermentation, or from the electron transport chain in photosynthesis. When carrying electrons, they are written as NADH•H^+, NADPH•H^+, and $FADH_2$.

The electrons they carry are used in the ETC to pump protons to make ATP in cellular respiration and to make glucose in photosynthesis.

Fermentation

Fermentation is the oldest and most evolutionarily conserved way for cells to get energy. In fermentation, glucose is broken down into two pyruvates, and then the pyruvates are converted into another product. In most animals, the pyruvate is converted into lactic acid (or lactate), in other life forms into ethanol.

Fermentation yields very little (only 2) ATP. It occurs in animals when there is not enough oxygen to reset the electron transport chain.

In animals, who usually run cellular respiration, the primary purpose of fermentation is to serve as a dump for the electrons that build up in in NADH•H^+.

Cell Respiration

Cellular respiration is a process in which one glucose molecule is broken down into six carbon dioxide molecules; in order for this to proceed completely, six oxygen molecules are converted into six water molecules. The overall equation is:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

This series of reactions occurs in both the cytosol and the mitochondria. (In aerobic bacteria, it occurs in the cytosol and in the cell membrane.) Cell respiration yields 36-38 ATP per glucose.

Glycolysis

Occurring in the cytosol, this initial step breaks glucose into two pyruvates. This process requires the consumption of two ATP to "prime" glucose for breakdown. It produces four ATP total, or two ATP net. ATP made here and in the Krebs cycle are made through a process called **substrate-level phosphorylation**. Electrons are picked up by two NAD^+, making two $NADH{\bullet}H^+$. Note that fermentation is mainly glycolysis with one additional step added.

Movement into the Mitochondria

To pump the pyruvate across the double membrane of the mitochondria, a transport protein both moves the pyruvate across the membrane and converts it into a new molecule. As pyruvate crosses the membrane, a carbon dioxide is broken off and is lost as waste. All that remains is an acetyl group, which is picked up by coenzyme A, forming, acetyl-CoA. In addition, electrons are picked up by two NAD^+, making two $NADH{\bullet}H^+$.

Krebs Cycle

The Krebs cycle occurs in the mitochondrial matrix. In the Krebs cycle, the two acetyl-CoA (all that remains from the glucose) are completely broken down into four carbon dioxides (two per acetyl-CoA). Only two ATP are made (one per acetyl-CoA). However, many electrons are taken: three $NADH{\bullet}H^+$ and one $FADH_2$ per acetyl-CoA (for six and two total).

The Krebs cycle is, of course, a cycle. The ending product recombines with acetyl-CoA to remake the starting product. Cycles are important because they save energy and raw material.

You do not have to know all of the molecules in the Krebs cycle.

Electron Transport Chain

Note that up to this point, we have made very little ATP but have many electrons in $NADH{\bullet}H^+$. $NADH{\bullet}H^+$ and $FADH_2$ drop off their electrons into proton pumps (returning to oxidized NAD^+ and FAD^+) embedded on the inner membrane in the mitochondria. The flowing electrons (an electrical current) provide energy for the pumps to move protons from the matrix into the space between the inner and outer mitochondrial membranes. At the third and final proton pump, the spent electrons are picked up by molecules of oxygen, which is converted into water.

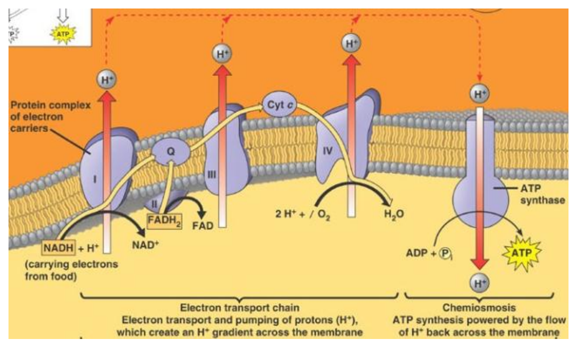

Figure 2. The electron transport chain

The protons that have built up in the intermembrane space will diffuse back into the matrix through a doorknob-shaped ATPase. The movement of protons from high concentration to low concentration across the mitochondrial membrane is called **chemiosmosis**. As they diffuse, the energy of their movement is harnessed to make ATP. Most of the ATP in cellular respiration is made in this process. The ATP made by electron transport chains are made through **oxidative phosphorylation**.

Photosynthesis

Photosynthesis is made up of two distinct but entwined processes. In the Light Reactions, sunlight is used to liberate electrons from chlorophyll; creating much ATP. Six water molecules are needed to reset the reaction: they are converted into six molecules of oxygen, which are toxic to photosynthesis and are given off as waste. In the Calvin cycle, the ATP and electrons made in the light reactions are used to fix six carbon dioxide molecules from the air into one glucose molecule. The overall reaction for both processes is as follows:

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

Light Reactions

The light reactions utilize an electron transport chain very similar to the one in the mitochondria. There are three integral membrane proteins, in order photosystem II (PSII), a proton pump, and photosystem I (PSI). The photosystem proteins are associated with chlorophyll, a plant pigment containing magnesium. Chlorophyll absorbs

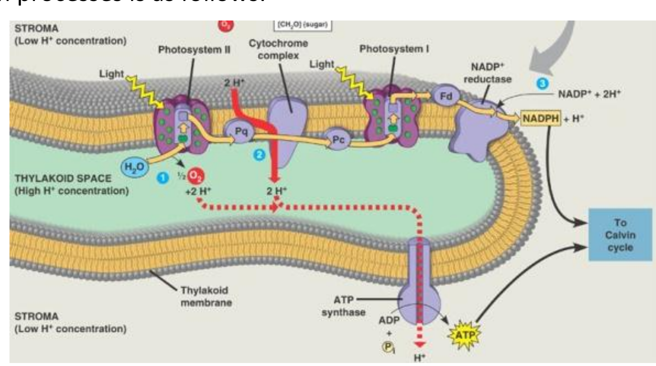

Figure 3. The light reactions of photosynthesis.

most wavelengths of light *except* green, which reflects back and causes plants to appear green.

Light knocks two electrons out of the orbitals of magnesium on a chlorophyll near PSII. These electrons travel through the proton pump, which pumps protons so that they build up in high concentration inside the thylakoid. The electrons continue to PSI, where they are reenergized by being struck with another photon. These electrons are then picked up by $NADP^+$ (becoming $NADPH \bullet H^+$) and are carried to the Calvin cycle. The chlorophyll near PSII lost its electrons at the start of this process. PSII replaces the electrons lost with two from a molecule of water; the water decomposes into oxygen gas, which is a waste product.

ATP is made when the protons, which have built up in high concentration inside the thylakoid, chemiosmose out through an ATP synthase. There is no way to quantify how much ATP is made in photosynthesis—as long as the sun shines and there is water, protons are pumped and ATP is made.

Calvin Cycle

The Calvin cycle is also called the Dark reactions or the Light Independent reactions, because it does not need light to work. This cycle occurs in the stroma of the chloroplast. It is a cycle, meaning the last product of the reaction is converted back into the first, to save energy and raw materials.

Carbon dioxide enters the reaction and is acted upon by the first enzyme, **RuBisCo** . After one cycle, one 3-carbon compound, glyceraldehyde-3-phosphate (G3P), is made. Two cycles are needed to make enough G3P to make one glucose. Fixing CO_2 from the atmosphere is very expensive, and it takes far more ATP to make glucose than you get from breaking it down.

High levels of oxygen gas interfere with RuBisCo, and poison the Calvin Cycle. Called **photorespiration**, this often occurs when plants close their stomata to slow water loss.

Important Points to Remember

- ATP is used as an energy molecule in all known life forms.
- All plant cells use cellular respiration. Some plant cells photosynthesize. Plant cells always in the dark, like the stem and roots, can only burn sugar in their mitochondria. Even leaf and other photosynthetic cells use their mitochondria and cellular respiration when it is cloudy or at night.