

Cellular respiration - how cells make energy

- Oxygen is needed for cellular respiration [**OVERHEAD, fig. 6.2, p. 90 / 4th: 6.1**]
 - this is provided by the lungs
 - lungs provide oxygen to blood, blood brings oxygen to the cells.
- ATP
 - the main energy currency in the cell. [**OVERHEAD, fig. 6.3 p. 91 / 4th: 6.2A & B**]
 - glucose is converted to energy (as ATP).
 - efficiency is about 40% (40% of the available energy in glucose is converted into ATP)
 - without oxygen, efficiency drops to 2%.
 - Kcal - basic unit of energy
 - calorie - amount of energy needed to raise 1 gram of water 1 degree Celsius.
 - extra energy is needed near freezing and boiling.
 - 1000 calories = 1 Kcal.
 - **Table in section 6.3** shows energy expenditure for a number of different activities.
- Moving energy around
 - What happens is that electrons move from a high energy state to a low energy state.
 - cellular respiration involves tapping into the energy electrons loose as they do this.
 - Usually when we move electrons we're also moving hydrogen (sometimes indirectly):
 - E.g, hydrogen is split off from glucose; it joins up with oxygen (makes water). Oxygen is pulling on the electrons that come with hydrogen.
 - As the electrons are pulled in by oxygen, they release energy [**OVERHEAD, fig. 6.5A p. 92 / 4th: 6.4**].
 - so often "gaining electrons" is similar to "gaining hydrogen"
 - applying this to fig. 6.5, we get:
 - oxygen gains electrons (from hydrogen & makes water).
 - glucose loses electrons (to hydrogen).

- [OVERHEAD, fig. 6.5B / 4th: 6.5, p. 92]

- multi carbon compound loses electrons (as two hydrogens).
- NAD⁺ gets the electrons and becomes NADH. It also picks up a hydrogen atom in the process.
 - another hydrogen atom (ion) is put into the solution surrounding the membrane.
 - NADH will use its new found energy in an electron transport chain.

- The electron transport chain takes the electrons from NADH [OVERHEAD, fig. 6.5C p. 92 / 4th: 6.6A]

- a sequence of proteins, each of which takes the electron and passes it on to the next one.
- at each step in the chain, a little energy is released that can be used by the cell.
 - oxygen is what ultimately pulls on these electrons and powers the chain.
- if all the energy were released at once, an explosion would happen.
- NADH is recycled into NAD⁺ (a H⁺ ion is also released (which makes water)).

Making ATP

- Two ways of making ATP. One uses the electron transport chain described, the other makes ATP directly using enzymes.
- Chemiosmosis (this is actually described better in the 4th edition)
 - describes the process of using the electron chain to set up a chemical gradient of H⁺ ions.
 - Since H⁺ ions (like anything else) want to move from a high concentration to a low concentration, they do so.
 - but - can't move through membrane (it blocks H⁺ ions).
 - special proteins will let the H⁺ ions through.
 - as ions move through, the protein (ATP synthase) is able to add phosphorus back onto ADP to make ATP

- [OVERHEAD, not in 5th. / 4th: 6.7A, p. 94]

- substrate level phosphorylation [OVERHEAD, 6.7B / 4th: same]

- In this case, an enzyme takes a phosphorus group from an organic molecule and puts it onto ADP making ATP.

- much simpler, but not nearly as common or important as chemiosmosis.

Going from sugar to ATP

- Now we tie all these pieces together.

- Three main steps [OVERHEAD, fig. 6.6 p. 93 / 4th: 6.8] :

Glycolysis - breaking down sugar into pyruvic acid and making 2 ATP (some CO₂ is also made getting pyruvic acid ready for the Krebs cycle)

Krebs cycle - breaking down Acetyl CoA, making CO₂ lots of NADH, some FADH₂ (behaves like NADH) and 2 more ATP

Electron transport chain - taking all the NADH, the FADH₂, and making 34 ATP's.

- Overall, each molecule of glucose yields about 38 ATP's.

- Incidentally, the 5th edition refers to the Krebs cycle as the citric acid cycle. We'll stick with "Krebs" cycle.

- Step 1: glycolysis [OVERHEAD, fig. 6.7A, p. 94 / 4th: 6.9A] :

- glycolysis refers to the breaking apart a sugar molecule (into two molecules of pyruvic acid).

- to start glycolysis, two molecules of ATP are needed

- once this has been done, we get energy in the next few steps.

- 2 NADH molecules are produced

- 4 ATP molecules are produced

- net gain is 2 ATP molecules, plus the 2 NADH's (which won't be used until later)

- the ATP produced yields 5% of the energy a cell gets from glucose

- the NADH yields another 16%, but only if oxygen is there

- some organisms use only glycolysis. Not terribly efficient, but it does not require oxygen.

- Step 1½: Moving from glycolysis to Krebs [**OVERHEAD, fig. 6.8, p. 96 / 4th: 6.10**]
 - pyruvic acid is not directly usable for the Krebs cycle
 - each pyruvic acid molecule is converted into a molecule of acetyl CoA
 - in the process CO₂ is made, and another molecule of NAD⁺ is converted to NADH.
 - (remember that there are two molecules of pyruvic acid for every molecule of glucose).

- Step 2: Krebs cycle [**OVERHEAD, fig. 6.9A, p. 96 / 4th: 6.11A**]
 - each molecule of acetyl CoA produces 2 CO₂'s, a molecule of ATP, 3 molecules of NADH, and 1 molecule of FADH₂.
 - FADH₂ is similar to NADH, but doesn't have quite as much energy
 - acetyl CoA provides the energy to keep the cycle going.
 - like with glycolysis, we will not go into the details of the Krebs cycle.

- Step 3: Electron chain.
 - Although some ATP's are produced by both glycolysis and the Krebs cycle, we now need to deal with all the NADH's (and an FADH₂ or two)
 - We already discussed the basics of this - we use chemiosmosis.
 - several proteins are embedded in the inside membrane of mitochondria [**OVERHEAD, fig. 6.10, p. 98 / 4th: 6.12, p. 100**]
 - these proteins function in the electron transport chain.
 - electrons are passed down through these proteins
 - as NADH contributes it's electrons, H⁺ ions are moved to the outside of the membrane, setting up a concentration gradient.
 - remember, oxygen is needed as the ultimate electron acceptor.
 - when the H⁺ ions try to move back in, they are forced through ATP synthase, which takes this energy (of movement), and uses it to convert ADP into ATP by adding another high energy phosphorus group.
 - some poisons can interfere with the electron transport chain [**OVERHEAD, fig. 6.11, p. 99 / 4th: 6.13, p. 101**]
 - rotenone, cyanide & carbon monoxide all block the action of the

electron chain at various points.

- electrons can no longer get to oxygen.
- oligomycin interferes with ATP synthase
 - oligomycin is an antibiotic - often used in skin fungal creams
 - kills bacteria, but can't get into living skin cells.
- DNP (dinitrophenol)
 - makes the membrane leaky to H⁺ ions
 - if the membrane is leaky, most H⁺ ions no longer go through ATP synthase, so no ATP is made.

Summary [**OVERHEAD, fig. 6.12, p. 100 / 4th: 6.14**] :

- for each molecule of glucose, we get about 38 molecules of ATP
 - 2 from glycolysis
 - 2 from the Krebs cycle
 - 34 from the electron transport chain
 - 6 NADH's from the Krebs cycle make 3 ATP's each for a total of **18 ATP's**
 - 2 FADH₂'s from the Krebs cycle make 2 ATP's each for a total of **4 ATP's**
 - 2 NADH's each from glycolysis and conversion of pyruvic acid to acetyl CoA (4 total NADH's) yield another **12 ATP's**.
 - thus, $18 + 4 + 12 = 34$ ATP's.
- without oxygen, we only get about 4 ATP's out of the system instead of 38.
 - the electron chain requires oxygen.
 - without oxygen, cells can die quickly due to lack of energy.

Fermentation:

But, some cells can make due with just glycolysis.

- [**OVERHEAD, fig. 6.13 A & B, p. 101 / 4th: 6.15 A & B, p. 103**].
- Yeast: a byproduct of this “fermentation” is alcohol (ethanol) and CO₂.

- this alcohol is obviously what is used in beer and wine.
- CO₂ provides the “bubbles” in beer (though many beers are brewed in such a way so that the “tap” adds CO₂ which has been lost).
- CO₂ also is the reason that bread rises.
- some cells produce lactic acid instead of ethanol.
 - fast muscle cells produce lactic acid when not enough oxygen is around.
 - this is eventually carried to the liver and converted back to pyruvic acid.
 - lactic acid does not seem to be the cause of muscle soreness (most of it is washed out of the muscles shortly after extreme exercise).
 - muscle soreness is most likely caused by minor muscle damage.
 - Note that in both cases the energy in NADH isn't captured (since oxygen isn't being used).

Using other molecules [**OVERHEAD, fig. 6.14 p. 102 / 4th: 6.16, p. 104**]:

- molecules other than glucose can be used.
 - glycogen and starch are kind of obvious - break them down into individual glucose molecules.
 - proteins - need to be broken down into amino acids. Many of these are recycled by the body for its own proteins.
 - others can be converted into pyruvic acid or acetyl CoA.
 - fats
 - glycerol can be converted to an intermediate product of glycolysis.
 - fatty acids can be converted into acetyl CoA.
 - each gram of fat can yield twice the energy of a gram of sugar or protein.
 - burning too much fat (or solely fat) is not good, though.
 - can produce a strongly acid byproduct, which is one of the problems in diabetes.

Making molecules [**OVERHEAD, fig. 6.15, p. 103 / 4th: 6.17, p. 105**]:

- These processes can be reversed (they're not exactly reversed, though close) to make

molecules. Both the Krebs cycle and glucose synthesis (the reverse of glycolysis) can be used to make needed amino acids (& proteins), sugars, fats etc..

- This eventually can be used to build up cells & tissues.
- Obviously requires the input of lots of ATP.