Cellular respiration - how cells make energy

- Oxygen is needed for cellular respiration [OVERHEAD, fig. 6.2, p. 90]
  - 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]
  - 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 6.4 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].
      - 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 looses electrons (to hydrogen).
- frequently, an in between step involves the formation of something called NADH.

  - think of this as a place to temporarily place electrons and $H^+$ ions.

  - 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]

  - 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.

So how do we actually go from sugar to ATP?

- Three main steps [OVERHEAD, fig. 6.6 p. 93]:

  1) Glycolysis - this actually breaks down sugar, and makes 2 molecules of pyruvic acid, 2 ATP and 2 NADH's.

    An in-between step that converts pyruvic acid into Acetyl CoA, makes a two more NADH's and 2 $CO_2$'s

  2) Krebs cycle - breaks down Acetyl CoA; for each molecule of glucose this makes 4 $CO_2$'s, 6 NADH's, 2 FADH$_2$'s (similar to NADH) and 2 ATP's.

  3) Electron transport chain - takes all this NADH (and the FADH2) and converts these into 34 ATP's (it does this using something called chemiosmosis - see your text if you're interested)...

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

  - each NADH makes about 3 ATP's, each FADH$_2$ about 2 ATP's

- Incidentally, the 5th edition refers to the Krebs cycle as the citric acid cycle. We'll stick with “Krebs” cycle (it's been called the Krebs cycle for over half a century!)
- Note also that many poisons work by interfering with the electron transport chain. See your text for details (e.g., cyanide blocks one of the proteins in the electron transport chain).

Summary [OVERHEAD, fig. 6.12, p. 100]:

- 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 FADH$_2$'s from the Krebs cycle make 2 ATP's each for a total of 4 ATP's
    - 2 NADH's each from glycolysis and the in-between step (conversion of pyruvic acid to acetyl CoA), so a total of 4 NADH's yield another 12 ATP's.
    - thus, $18 + 4 + 12 = 34$ ATP's.
  - without oxygen, we only get about 2 ATP's out of the system instead of 38.
    - the electron transport chain requires oxygen.
    - the Krebs cycle doesn't directly require oxygen, but it shuts down without 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].
  - Yeast: a byproduct of this “fermentation” is alcohol (ethanol) and CO$_2$.
    - this alcohol is obviously what is used in beer and wine.
    - CO$_2$ provides the “bubbles” in beer (though many beers are brewed in such a way so that the “tap” adds CO$_2$ which has been lost).
    - CO$_2$ 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. 6.15 p. 102]:

- 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. 6.16, p. 103]:

- 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.