**January 30 - lecture notes**
**Cellular respiration and anaerobic respiration (fermentation)**

**Cellular respiration**: The process by which organisms break down 'food' molecules* (especially glucose) to make ATP:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + (32\ ATP)$$

[Note that this is the reverse of photosynthesis (which we will cover over the next three lectures) except that lots of ATP is made!]

* FYI: other food molecules include the other carbohydrates, and also fats and proteins that can be broken into the 3-carbon molecule pyruvate…(we will not study this in detail…)

**Mitochondrion** (pl = mitochondria): eukaryote organelle in which cellular respiration takes place (most of the process, anyways – we won't delve into the detailed chemistry). For this reason, mitochondria are known collectively as the "powerhouse(s) of a cell".

**ATP** (Adenosine triphosphate): A molecule whose bonds have very high potential energy and which serves as the universal, usable energy (E) currency in cells.
(FYI: The breakdown of ATP to ADP + P produces energy that is used by cells for most processes that require energy: from transmembrane proteins to the twitching of muscle fibers in animals. – I won't ask this parenthetical material on exams.)

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No need to know this information:

**NAD and FAD**: $H^+$ and electron "Shuttle molecules" in cellular respiration.

**(**NAD and FAD accept hydrogen atoms (and become **NADH / $FADH_2$**) that are split off of glucose during glycolysis, and off of shorter 3-C chains during the Krebs cycle) and they "shuttle" the H atoms (and their electrons!!) from these first two stages of cellular respiration to the electron transport chain).

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So, at its essence, respiration is just the conversion of stored chemical energy in glucose to immediately usable chemical energy of ATP!!

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

(stored chemical energy) (usable chemical energy)

| Molecule | Biochemical role | Banking analog |
|---|---|---|
| **Starch / Fats (triglycerides)*** | Medium – long term and stable energy storage | Bank account |
| **Glucose / Sucrose** | Short-term and transportable energy storage | Traveler's check or personal check |
| **ATP** | Immediate energy source for cellular processes | CASH!!! |

*we'll discuss fats (triglycerides) in lab

Some toxins act by interfering with cellular respiration – two examples we mentioned in lecture were rotenone (found seeds, stems, and leaves of jicama, *Pachyrhizus erosus* FABACEAE, and relatives), and cyanide (found in many grasses, family POACEAE). How is this an adaptive trait?

**Bamboo & panda biology we discussed:**

**1) Bamboo and cyanide**

Bamboo is a type of grass (grass family = POACEAE). It turns out that pandas have an ability to neutralize the cyanide – but how they do so is not yet known!

**2) Bamboo is largely cellulose**

Pandas live almost exclusively off of bamboo. Bamboo is mostly cellulose, and as you know (or should know!) animals cannot digest cellulose. So, how do pandas survive on this relatively low calorie diet? Two possible explanations are: 1) they *might* have gut bacteria that digest cellulose – this is a relatively new and controversial finding. 2) They simply eat a LOT of bamboo (by some estimates, up to half of their body weight every day)! Pandas spend most of their waking hours sitting around eating bamboo, and they do not hibernate in part because this low calorie food does not provide the energy required to store enough fat to carry pandas through a winter hibernation.

**3) Bamboo mass flowering**

Bamboo (and all grasses) are flowering plants. Most species of bamboo flower very infrequently – often times not flowering for up to many decades at a time. Amazingly in some species of bamboo, all individual plants flower at all locations across the globe. How do they "know" to do so? This is a mystery! Not mysterious is the impact on panda survival: species of bamboo plants eaten by pandas die off after flowering. Because of mass flowering, the ensuing mass die-offs place pandas at risk of starvation in large areas.

OK, back to cellular respiration:
Why is this process called cellular "respiration" – isn't respiration 'breathing'? It is referred to as respiration because the process requires $O_2$ and generates $CO_2$ – and this is exactly why we need to breathe – to provide cells with $O_2$ and get rid of the $CO_2$ waste product!!

So, what happens when we can't breathe, or can't breathe fast enough to supply the $O_2$ needed for cellular respiration?

If $O_2$ is not available for cellular respiration, some organisms have evolved a mechanism for making ATP when $O_2$ is absent – fermentation!

**Anaerobic respiration (a.k.a., fermentation)** – a way of making ATP in the absence of $O_2$.

- There are two types of fermentation (that we will study…and these are the prominent in nature), and each named after the principal waste product that is generated
    1) Lactic acid fermentation
    2) Alcohol fermentation

- Fermentation only yields 2 ATP per molecule of glucose

**Lactic acid fermentation**
Waste product: lactic acid
ATP produced per glucose molecule: 2 ATP
Happens in:

A) Animals deprived of $O_2$ – such as you when fleeing from your older brother or other authority figure!!

B) Some bacteria (used in production of dairy products such as cheese and yogurt – why some yogurt says "contains live cultures"). In fact, this is where the term *Lactic* acid fermentation (as in *Lactose*) comes from. The bacteria in cheese and yogurt ferment lactose (milk sugar – contains glucose) into lactic acid, which gives this process its name. Lactic acid also gives yogurt and cheese its tangy flavor.

C) A small number of fungi. We did not discuss these.

We discussed the process of cheese making – you should know the following general overview:

1) Milk is allowed to curdle (form solids, curds). Curdling is due to denaturing of casein proteins in the milk. In some cases, these proteins are denatured by lactic acid produced by bacteria, but more typically by the enzyme rennin (which, until very recently, has been obtained from the stomachs of calves at slaughter houses ).
2) Cheese curds are strained, water and the whey (the other major class of proteins in milk, which are not denatured and remain liquid) are eliminated.
3) Curdles are pressed in a mold.
4) Cheese is aged with bacteria or fungi (or both!). Lactic acid produced by these organisms helps flavor the cheese, imparting a "sour" or "tangy" flavor. Other microbes produce wastes that impart other flavors – such as the *Penicillum* spp. used in "blue cheeses" and brie, among others.

…and in swiss cheese…(you don't need to know this…except perhaps for extra credit…?)

5) In "Swiss cheese", fermentation occurs in (at least) two stages: 1) one guild of bacteria converts sugars to lactic acid (lactic acid fermentation), and 2) other bacteria convert the lactic acid to other acids and $CO_2$. As the $CO_2$ is trapped in the cheese, it forms air pockets that causes "holes" in Swiss cheese.

**Alcohol fermentation**
Waste products: ethanol, and $CO_2$.
ATP produced per glucose molecule: 2 ATP
Happens in: Yeasts and some bacteria.

- Yeasts in anaerobic conditions are what generate ethanol and $CO_2$ in production of alcoholic beverages.
- In wine the $CO_2$ is allowed to escape, in beer it is contained…hence bubbles…).
- In wine, the sugar source is glucose and fructose in grapes.
- In beer, the story is a bit more complicated, but the sugar source (mostly) is glucose locked up as starch...we'll discuss further in lab and future lectures.
- We will discuss this more in lab during week 4.