SGCEP BIOL 1010K
Introduction to Biology I
Spring 2012 Sections 20585 & 20586

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First off . . .

It’s time for another in-class assignment. Considering that I am only presenting the material required by the teaching objectives of this course as laid out by the Board of Reagents and the South Georgia College Entry Program . . .

Tell me what has worked best for you this semester so far regarding my lectures. In other words, what works best for you — do you want more, or less — animations, videos, pictures, text, or interactive activities? Do you have any other ideas?

What is hardest about the exams; why are so many of you having such a difficult time (other than the multiple choice format itself)?

Make your responses legible and be sure to put your name and course and section number on the paper. Get them to me for credit as you leave!

Monday, February 27, 2012
Secondly . . .

* Some of you are being very naive not to pick up your old exams.

* As I’ve said before: “the comprehensive final will come directly from these old exams.” I may revise questions some, but only to clarify things. I will pick and choose the most important concepts from all those questions that you’ve already seen (the only exception is the final lecture).

* That is why I give you back your old exams — take advantage of it — one of the best forms of learning is that from your mistakes. You’ve certainly made lots of them, so learn from them!
Finally . . .

I have to turn in MidTerm grades this week. They don’t mean a whole lot, since they are only based on one exam, your lab activities, and your in-class-participation-to-date (and any extra credit you’ve turned in). Therefore, for the purpose of that grade, only, the exam will contribute 20%, the lab activities 40%, and the in-class stuff another 40%. However, as the syllabus states, each Section exam counts 10%, and your in-class participation 20%, of your final lecture grade.
Now: All cells process the energy in food to make ATP.

Why should I care? Well . . .
Metabolic Disease of aerobic respiration, e.g.:

* Some types of diabetes are associated with defects in glucokinase, the enzyme responsible for the first phosphorylation step in glycolysis (http://omim.org/entry/138079)

* Leber hereditary optic neuropathy is a mid-life onset blindness associated with mutations in the mitochondrial proteins of the electron transport chain (http://omim.org/entry/535000)

* Friedreich Ataxia is an autosomal recessive disease that causes limb incoordination and a host of neural, skeletal, and muscular defects. It is associated with a trinucleotide repeat in the frataxin gene which may regulate iron concentration within the mitochondrion (http://omim.org/entry/229300)

* Plus many poisons kill by interfering with key points of aerobic respiration. As seen here...
For instance:
* Arsenic blocks the Krebs cycle.
* Mercury interferes with the electron transport chain.
* Cyanide and Carbon Monoxide block the final transfer of electrons to oxygen in the electron transport chain.
ATP powers every activity that requires energy input in the cell.

- This explains all organisms' (even plants) constant need for food (a form of potential energy).

- Three ATP-generating pathways:
  1) Aerobic respiration;
  2) Anaerobic respiration; and . . .
  3) Fermentation.
Aerobic cellular respiration . . .

- Takes in oxygen and produces carbon dioxide.
- Explains why we and most other organisms (even photosynthesizers do this) must take oxygen into our bodies and get rid of carbon dioxide.
Much happens in the mitochondrion.

And remember where mitochondria originally came from!

Cellular respiration

Oxygen and glucose consumed:

\[ \text{O}_2 + C_6H_{12}O_6 \]

Carbon dioxide, water, and energy produced:

\[ \text{CO}_2 + \text{H}_2\text{O} + \text{ATP} \]
Aerobic cellular respiration is another redox reaction

- Oxygen strongly attracts electrons compared to carbon. Therefore, ...
- Aerobic respiration oxidizes (remove electrons from) glucose to reduce (add electrons to) oxygen.
- The released energy is trapped in ATP.
- But not all at once – the cell would explode!
The metabolic pathways of aerobic respiration can be broken down into three main processes; in order:

1) Glycolysis;
2) Krebs cycle;
3) Electron transport chain.
1) Glycolysis — glucose (6 C’s) → 2 pyruvates (3 C’s @) + 2 ATP’s & contribute electrons to NADH.

2) Krebs cycle — pyruvate → CO$_2$ + 2 ATP’s & contribute electrons to NADH & FADH$_2$.

3) The electron transport chain — uses all that energy stored up in the high energy electron carriers NADH and FADH$_2$ to generate 26 more ATP’s from the phosphorylation of ADP with the aid of several membrane bound proteins.
Much of this happens in the mitochondrion, but . . .

* All glycolysis occurs in the cytoplasm without any compartmentalization regardless of the life form. However, . . .

* Bacteria and Archaea don’t have mitochondria, so everything happens in the cytoplasm, and the necessary proteins are embedded in the main cell membrane.

* Eukaryotes do the rest (Krebs cycle and electron transport) in the mitochondrion.
Let's review: Mitochondria

- They have an...
  - Outer membrane, which contains it all;
  - Inner membrane, which holds the proteins of the electron transport chain;
  - Intermembrane compartment; and a...
  - Matrix enclosed by a highly folded inner membrane, which is where the Krebs cycle occurs.

- ATP synthase and all the other proteins of the electron transport chain are embedded in this inner mitochondrial membrane.
A closer look (e.g. in a plant cell):

- Cell wall
- Chloroplast
- Cell membrane
- Matrix (site of Krebs cycle)
- Inner mitochondrial membrane (site of electron transport chain)
- Outer mitochondrial membrane
- Cytoplasm (site of glycolysis)
- Folds of inner membrane
- Intermembrane compartment
- Cytoplasm
In more detail:
Glycolysis — nearly ubiquitous.

* Takes ten steps — all occur in the cytoplasm.
* The first five steps ‘activate’ glucose, requiring ATP.
* The last steps extract energy, regaining invested energy plus two ‘free’ ATP.
* The ATP is produced by substrate-level phosphorylation — donor molecule transfers P to ADP.
* Does not require oxygen.
* Net gain of two ATPs. And . . .
* Two pyruvates and two NADH per glucose.
A whole lot going on! Let's concentrate on the steps of glycolysis first.
The activation steps use ATP to ‘activate’ glucose. Two ATP’s are consumed in the phosphorylation processes. Five steps have occurred by the end of activation.
The second five steps generate ATP through substrate-level phosphorylation — four per starting glucose, a net gain of two.
Substrate-level phosphorylation — a direct transfer of a phosphate group to ADP creating ATP — with the assistance of an enzyme.
And animations help break it all down . . .

- From quite simple to very comprehensive:
  - [http://www.bio.fsu.edu/~stevet/VSU/animations/Chapter06/glycolysis.swf](http://www.bio.fsu.edu/~stevet/VSU/animations/Chapter06/glycolysis.swf)
  - [http://www.northland.cc.mn.us/biology/Biology1111/animations/glycolysis.html](http://www.northland.cc.mn.us/biology/Biology1111/animations/glycolysis.html)
  - [http://www.johnkyrk.com/glycolysis.html](http://www.johnkyrk.com/glycolysis.html)
  - [http://www.iubmb-nicholson.org/swf/glycolysis.swf](http://www.iubmb-nicholson.org/swf/glycolysis.swf)
On to the Krebs Cycle.

- A.k.a. the Citric Acid or Tricarboxylic Acid Cycle.
- Used by all organisms that respire with oxygen.
- Pyruvate moves into the mitochondrial matrix.
- Acetyl CoA enters the Krebs cycle.
- Citrate is oxidized and rearranged in several steps.
- Electrons are transferred to NADH and FADH$_2$.
- ATP is produced by substrate-level phosphorylation.
- Carbon dioxide exits as a waste product.
- Cells can use intermediate products to produce other organic molecules.
Breaking it down — Acetyl CoA formation links glycolysis to the Krebs cycle. For every glucose that entered glycolysis, two acetyl CoA's can enter the Krebs cycle.
The actual cycle – two turns per glucose.

**Input**
- 2
- 2 ADP + 2 P \( \rightarrow \) 2 ATP
- 6 NAD\(^+\)
- 2 FAD

**Output**
- 4 CO\(_2\)
- 6 NADH
- 2 FADH\(_2\)

Krebs cycle occurs 2 times for each glucose entering glycolysis.
Again, animations may help.

* From simple to complex:
  * [http://www.johnkyrk.com/krebs.html](http://www.johnkyrk.com/krebs.html)
  * [http://highered.mcgraw-hill.com/sites/0072507470/student_view0/chapter25/animation__how_the_krebs_cycle_works__quiz_1_.html](http://highered.mcgraw-hill.com/sites/0072507470/student_view0/chapter25/animation__how_the_krebs_cycle_works__quiz_1_.html)
And the last part of aerobic respiration – the real power step!

- The electron transport chain.
- It is embedded in the inner mitochondrial membrane.
- NADH and FADH$_2$ are left over from the Krebs cycle — this is where they come in. They are used to make a bunch more ATP by transferring electrons from proton pump protein to proton pump protein.
- In aerobic respiration, the final electron acceptor is oxygen, which becomes water.
This sets up Chemiosmotic phosphorylation.

* H⁺ ions are removed from the carriers NADH and FADH₂ in the matrix and are...

* Pumped into the intermembrane compartment creating a proton gradient.

* Protons moving down the gradient through ATP synthase power the production of subsequent ATP.
The proton pump grabs protons from the matrix and releases them into the intermembrane space. The protons create a pH and electric charge gradient establishing an electrochemical potential that acts as a reservoir of stored energy.

http://www.bio.fsu.edu/~stevet/VSU/animations/Chapter06/protonPump.swf
A schematic shows all the protons moving around.
The electron path through the three major respiratory complexes

INTERMEMBRANE SPACE

inner mitochondrial membrane

MATRIX

NADH

\( 2e^- \)

ubiquinone

NADH dehydrogenase complex

\( H^+ \)

cytochrome c

cytochrome oxidase complex

\( H_2O \)

\( 2H^+ + \frac{1}{2}O_2 \)

10 nm
ATP synthase is reversible, depending on the needs of the cell.
In all of aerobic respiration . . .

* Most of the ATP is generated from chemiosmotic phosphorylation by the electron transport chain. The whole thing, from the beginning . . .
* Produces about . . .
* 30 ATP total per glucose molecule.
* Overall efficiency: about 32% of kilocalories in one glucose molecule’s bonds are recovered.
* Compare this to a gasoline internal combustion engine – here the number is about 20% or so!
* The rest of the potential energy lost as heat.
Let’s see what animations are available for this.

* This one’s really nice . . .
* [http://vcell.ndsu.edu/animations/etc/advanced.htm](http://vcell.ndsu.edu/animations/etc/advanced.htm); it goes way beyond the “First Look” example from the same Virtual Cell series we’ve used before.

* And McGraw-Hill has these two . . .
* [http://www.bio.fsu.edu/~stevet/VSU/animations/Chapter06/electron_transport_system.swf](http://www.bio.fsu.edu/~stevet/VSU/animations/Chapter06/electron_transport_system.swf)

* Plus check out:
* [http://www.johnkyrk.com/mitochondrion.html](http://www.johnkyrk.com/mitochondrion.html)
And this animated movie summarizes all of cellular respiration quite nicely.

http://www.bio.fsu.edu/~stevet/SGCEP/Bio1010K/CellularRespiration.mpg
What about foods other than carb’s?

* Proteins and lipids are also used for energy.
* Glucose is not our only food! Duh . . .
* Usually a cell uses amino acids from the diet to make more proteins. However, it . . .
* May use amino acids for energy. Plus . . .
* Fats can be broken down into glycerol and fatty acids.
* Long fatty acid molecules can yield a bunch of acetyl CoA molecules.
* All can feed into glycolysis and the Krebs cycle at various points in the pathways.
For example...

Complete oxidation of acetyl CoA to $H_2O$ and $CO_2$ produces ATP and much NADH and FADH$_2$, which in turn yield ATP via electron transport and chemiosmosis.
But not all of life uses oxygen!

- So there’s those other two ways to make ATP we mentioned at the beginning:

2) Anaerobic respiration is . . .
   - Essentially the same as aerobic respiration;
   - However, the final electron acceptor is not O$_2$ (e.g. it may be nitrate or sulfate) . . .
   - And it has a lower ATP yield.

3) Fermentation in Bacteria, Archaea, and Eukaryota, which . . .
   - Stops after glycolysis; and is . . .
   - Far less efficient than aerobic respiration.
   - Two main types — alcoholic or lactic acid fermentation.
The alternatives . . .

NADH and FADH$_2$ from glycolysis and Krebs cycle go to electron transport.

- Uses $O_2$ as a terminal electron acceptor in the electron transport chain.
  - Aerobic respiration

- Uses electron acceptor other than $O_2$ in the electron transport chain.
  - Anaerobic respiration

NADH from glycolysis reduces pyruvate.

- Fermentation
In fermentation...

a. Alcoholic fermentation

\[
\text{Glucose} \rightarrow \text{Glycolysis} \rightarrow 2 \text{ATP} \rightarrow 2 \text{NADH} \rightarrow 2 \text{CO}_2 \rightarrow 2 \text{Ethanol} \rightarrow 2 \text{NAD}^+
\]

b. Lactic acid fermentation

\[
\text{Glucose} \rightarrow \text{Glycolysis} \rightarrow 2 \text{ATP} \rightarrow 2 \text{NADH} \rightarrow 2 \text{NAD}^+ \rightarrow 2 \text{Lactic acid}
\]

for example, by brewer’s and baker’s yeasts.
Let’s see what some of the key players of cellular respiration really look like!

At Molecules To Go . . .

* ATP synthase (at least part of it):
  http://helixweb.nih.gov/cgi-bin/moldraw?1Q01

* The catalytic core (subunits I and II) of cytochrome C oxidase 2:
  http://helixweb.nih.gov/cgi-bin/moldraw?2GSM
Some other great Web sites for metabolism include:


* I’ve shown some of the resources at NCBI, the National Center for Biotechnology Information. It’s great for so many things. But check out their full version of *The Molecular Biology of the Cell*: http://www.ncbi.nlm.nih.gov/books/bv.fcgi?rid=mboc4

* They also have a structural database interface, e.g. http://www.ncbi.nlm.nih.gov/Structure/mmdb/mmdbsrv.cgi?uid=11641
I realize this is a huge amount of material . . .

* But it’s stuff we need to get through.

* Check out the sites I didn’t visit, and . . .

* Just remember — it’s the big concepts that matter, not all the little details.

* They help fill in the connections, so you can understand the big picture better.

* See you next time.
And don’t forget . . .

* We have our second sectional exam of the semester then!

* Again, it’s not all the little details that matter . . .

* Just the big concepts that I emphasize in lecture.