

## **Cellular Respiration**

### Study Guide

Oxidative respiration in mitochondria (citric acid cycle & oxidative phosphorylation) versus glycolysis: Difference in location in the cell, differential dependence on oxygen, and difference in ATP energy yield

Fermentation: Location in cell, role, different types, and examples

Principal differences between fast-twitch glycolytic and slow-twitch oxidative muscle fibers

Know the basic principle of how ATP is generated in mitochondria

Know why brown fat cells are able to generate heat and why some phytochemicals and carbon monoxide or cyanide are toxic

The use of carbohydrates, fats, and proteins as fuels via cellular respiration pathway

**Suggested Readings from the Textbook** (Campbell and Reece's BIOLOGY, Seventh Edition)  
corresponding to lectures on "Cellular respiration"

### **Chapter 9 Cellular Respiration**

Overview: Life is Work

Concept 9.1 Only: The stages of cellular respiration: A preview (without substrate-level phosphorylation), only p. 164

Concept 9.2 Glycolysis harvests chemical energy by oxidizing glucose to pyruvate (not Figs. 9.8 and 9.9), only p. 165

Concept 9.4 During oxidative phosphorylation chemiosmosis couples electron transport to ATP synthesis, skim p. 170, then read pp. 171 (right column only) - 174

Concept 9.5 Fermentation, pp. 174-176

Concept 9.6 Glycolysis and the citric acid cycle connect to many other pathways, pp. 176-177 (skim p. 178)

## Cellular Respiration: *Food-to-Energy*

Fig. 9.1; Fig. 8.3

Cellular respiration breaks down energy-rich molecules to CO<sub>2</sub> and water, removing their energy.

Low potential energy

Fig. 9.2

High potential energy

C - H bonds

•First part of cellular respiration occurs *outside* mitochondria:

Fig. 9.18

Partial break-down of glucose in glycolysis

•*Only if oxygen is available* are these glucose break-down products completely broken down in mitochondria

**Glycolysis and fermentation under *anaerobic* conditions**

Fig. 9.17

*Alcohol fermentation (forms ethanol plus CO<sub>2</sub>)* by yeasts and bacteria (fermentation and baking industries) under anaerobic conditions

*Lactic acid fermentation* by other fungi and bacteria (dairy industry) as well as by muscle cells under anaerobic conditions

**“Production of Foods and Fuels** In the home and in industry, microbes are used in the production of fermented foods. Yeasts are used in the manufacture of beer and wine [*alcohol fermentation*] and for the leavening of breads [*from the CO<sub>2</sub> gas formed*], while lactic acid bacteria are used to make yogurt, cheese, sour cream, buttermilk and other fermented milk products [*lactic acid fermentation*]. Vinegars are an acetic acid fermentation. Other fermented foods include soy sauce, sauerkraut, dill pickles, olives, salami, cocoa and black teas...”

<http://www.bact.wisc.edu/themicrobialworld/Effects.html>

“The microbes that normally live in associations with humans on the various surfaces of the body (called the **normal flora**), such as *Lactobacillus* and *Bifidobacterium*, are known to protect their hosts from infections, and otherwise promote nutrition and health. *Lactobacillus acidophilus* and a [cell of the] vaginal [lining]. *L. acidophilus* ... colonizes the vagina during child-bearing years. As a lactic acid bacterium, the organism creates a low pH (acidic environment) on the tissues which prevents colonization by potentially harmful yeast and other bacteria.”

### “Production of Foods and Fuels

... Yeast are also involved in fermentations to convert corn and other vegetable carbohydrates into ethanol to make gasohol.”

<http://www.bact.wisc.edu/themicrobialworld/Effects.html>

Alcoholic fermentation is used for the conversion of hexose sugars to ethanol as biofuel - from sugar cane sucrose *or* corn starch *or* cellulose!

### Fermentation versus oxidative respiration      Fig. 9.18

Different human muscle fibers use different metabolism:

- Slow-twitch oxidative fibers (used for extended exercise) use oxidative respiration that yields much more energy (and have lots of mitochondria).
- Fast-twitch glycolytic fibers (used for sprint) use mostly glycolysis that is quick, but does not provide a lot of energy.

### Macromolecules other than glucose can enter cellular respiration at different points.      Fig. 9.19

Carbohydrates (from glycogen, etc.) yield energy quickly (during e.g. a sprint).

Fats can provide sustained energy for extended exercise.

**Sugars are broken down in several steps, starting with glycolysis in the cytosol. Fig. 9.6**

The product of glycolysis is broken down all the way to CO<sub>2</sub> in the citric acid cycle in the mitochondria.

Energy is removed by transferring electrons (& protons) from high energy C-H bonds to the electron carriers NADH and FADH<sub>2</sub>, which then feed these energy-rich electrons into the electron transport chain to make ATP.

Cellular respiration breaks down energy-rich molecules to CO<sub>2</sub> and water, removing their energy. **Fig. 9.2**

Overall accounting of ATP synthesis from complete breakdown of glucose: most of the ATP comes from oxidative phosphorylation in the electron transport chain. **Fig. 9.16**

**Mitochondria Fig. 6.17**

Fluid space: Citric acid cycle; Folded inner membrane: Electron transport chain

**Fig. 9.15; Fig. 8.7c** The electron transport chain is bound to the inner mitochondrial membranes. Electron transport is coupled with proton transport, leading to build-up of high H<sup>+</sup> concentration within intermembrane space.

**Fig. 10.16** Same principle is used for ATP formation in mitochondria & chloroplasts

[http://www.vivo.colostate.edu/hbooks/pathphys/misc\\_topics/brownfat.html](http://www.vivo.colostate.edu/hbooks/pathphys/misc_topics/brownfat.html)

•**Brown adipocytes** with many lipid droplets and many mitochondria. •**White adipocytes** with single large lipid droplet.

Brown fat cells have many mitochondria; they are involved in heat generation.

“Brown fat is of particular importance in neonates, small mammals in cold environments, and animals that hibernate, because it has the ability to dissipate stored energy as heat. In contrast to other cells, including white adipocytes, brown adipocytes express *mitochondrial uncoupling protein*, which gives the cell's mitochondria an ability to uncouple oxidative phosphorylation and utilize substrates to generate heat rather than ATP.”

**What do you think the mitochondrial uncoupling protein does?**

## What would be the result of uncoupling (= no proton gradient forms)?

Skunk cabbage in Japan. <http://www.sciencenews.org/articles/20031213/bob9.asp>

Skunk cabbage in the northeastern US. <http://www.damninteresting.com/?author=865>

**Figure 1** Thermal image of the inflorescence of *Philodendron selloum* during thermogenesis (Ito and Seymour 2005). The warm spadix is visible, because the spathe (V-shaped structure) has been cut away. Sterile male florets in the center of the spadix are warmest, but the fertile male florets also produce heat. Female florets at the base of the spadix do not produce significant heat. <http://4e.plantphys.net/article.php?ch=e&id=126>

*Nature* 426, 243-244 (20 November 2003) | doi:10.1038/426243a

*Environmental biology: Heat reward for insect pollinators*

Roger S. Seymour, Craig R. White and Marc Gibernau

*Scarab beetles save on energy by making themselves at home inside a warm flower*

*In neotropical forests, adults of many large scarab beetle species spend most of their time inside the floral chambers of heat-producing flowers, where they feed and mate throughout the night and rest during the following day, before briefly flying to another flower. Here we measure floral temperatures in *Philodendron solimoesense* (Araceae) in French Guiana and the respiration rates of *Cyclocephala colasi* beetles at floral and ambient temperatures, and show that the beetles' extra energy requirements for activity are 2.0–4.8 times greater outside the flower than inside it. This finding indicates that heat produced by the flower constitutes an important energy reward to pollinators, allowing them to feed and mate at a fraction of the energy cost that would be required outside the flower.*

*Floral scents, leaf volatiles and thermogenic flowers in Magnoliaceae*

Hiroshi Azuma, Leonard B. Thien, and Shoichi Kawano

*Plant Species Biology*, doi:10.1046/j.1442-1984.1999.00015.x

Volume 14 Issue 2 Pages 121-127, August 1999

*The Role of Thermogenesis in the Pollination Biology of the Amazon Waterlily *Victoria amazonica**

ROGER S. SEYMOUR and PHILIP G. D. MATTHEWS

2006 *Annals of Botany*, doi:10.1093/aob/mcl201

**What would be the result of an inhibition of ATP synthase (example: excessive concentrations of many phytochemicals)?**

Examples of phytochemicals that can inhibit ATP synthase at excessively high concentrations: red wine resveratrol, green tea EGCG, soy isoflavones, and many others.

**What would be the result of an inhibition of electron carriers (example: cyanide or carbon monoxide)?**

Normally, two electrons are loaded onto oxygen to form water:  $O + 2 \text{ electrons } (+ 2 H^+) = H_2O$

Sometimes, O gets away with only 1 electron: This is reactive oxygen!

**Fig. 9.19** Macromolecules other than glucose can enter cellular respiration at different points. Carbohydrates yield energy quickly (during e.g. a sprint). Fats can provide sustained energy for extended exercise. Proteins are typically used for energy only during starvation periods.

Programmed Cell Death (= Apoptosis): “Opening the mitochondrial poison cabinet”

[http://www.imgenex.com/emarketing/081606\\_LivinorSurvivin/LivinorSurvivin\\_forweb.htm](http://www.imgenex.com/emarketing/081606_LivinorSurvivin/LivinorSurvivin_forweb.htm)

Programmed cell death: The last electron carrier of the mitochondrial electron transport chain (Cytochrome C) is released from the mitochondrion and triggers the formation of “cellular demolition experts” (caspases) that kill and digest the cell. Many diseases involve excessive programmed cell death.

*Dictionary.com: Apoptosis*

*“A natural process of self-destruction in cells that are genetically programmed to have a limited life span or are damaged. Can be induced either by a stimulus, such as irradiation or toxic drugs ... cancer may result when this process of cell death is somehow interrupted, allowing cells to grow unchecked.”*

**Fig. 21.19** Finger formation                      Metamorphosis                      100,000 pubs

**•Misregulation of programmed cell death:** Apparent opposite extremes: e.g. bipolar disease, AD(H)D (*too much* pruning) vs. autism (*insufficient* pruning)