PowerLecture:
Chapter 8
How Cells Release Stored Energy
Section 8.0: Weblinks and InfoTrac

See the latest Weblinks and InfoTrac articles for this chapter online or click highlighted articles below (articles subject to change)

- Section 8.0: Mitochondria Research Society
- Section 8.0: United Mitochondrial Disease Foundation
- Section 8.0: Friedreich's Ataxia Research Alliance
- Section 8.0: Mitochondria—The Nerve Cell's Source of Energy: Their Role in Ataxia. John Day. *Generations,* Spring 2004.
- Section 8.0: Piecing Together the Puzzle of Aging. Elizabeth Finkel. *The Lancet,* Oct. 18, 1997.

How Would You Vote?

The following is the question for this chapter. See national results below.

- Do you support taxpayer funding of orphan drugs and rare disorders research?

Impacts, Issues: When Mitochondria Spin Their Wheels

- More than 100 mitochondrial disorders are known
- *Friedreich's ataxia*, caused by a mutant gene, results in loss of cordination, weak muscles, and visual problems
- Animal, plants, fungus, and most protists depend on structurally sound mitochondria
- Defective mitochondria can result in life threatening disorders

Section 8.1: Weblinks and InfoTrac

See the latest Weblinks and InfoTrac articles for this chapter online or click highlighted articles below (articles subject to change)

- Section 8.1: Jon Maber's Biochemistry Pages
- Section 8.1: ATP: Supplement Your Energy. Dwayne Jackson et al. *Muscle & Fitness,* July 2004.

"Killer" Bees

- Descendents of African honeybees that were imported to Brazil in the 1950s
- More aggressive, wider-ranging than other honeybees

- Africanized bee's muscle cells have large mitochondria

ATP Is Universal Energy Source

- Photosynthesizers get energy from the sun

- Animals get energy second- or third-hand from plants or other organisms

- Regardless, the energy is converted to the chemical bond energy of ATP

Making ATP

- Plants make ATP during photosynthesis
- Cells of all organisms make ATP by breaking down carbohydrates, fats, and protein

Main Types of Energy-Releasing Pathways

Anaerobic pathways

- Evolved first
- Don't require oxygen
- Start with glycolysis in cytoplasm
- Completed in cytoplasm

Aerobic pathways

- Evolved later
- Require oxygen
- Start with glycolysis in cytoplasm
- Completed in mitochondria

Summary Equation for Aerobic Respiration

$$C_6H_{12}0_6 + 6O_2 \quad 6CO_2 + 6H_20$$

glucose oxygen carbon dioxide water

Overview of Aerobic Respiration

The Role of Coenzymes

- NAD^+ and FAD accept electrons and hydrogen
- Become NADH and $FADH_2$
- Deliver electrons and hydrogen to the electron transfer chain

Section 8.2: Weblinks and InfoTrac

See the latest Weblinks and InfoTrac articles for this chapter online or click highlighted articles below (articles subject to change)

- Section 8.2: The Energetics of Glycolysis

- Section 8.2: Cancer Therapies: Cancer Cells Self-Destruct When "Sweet Tooth" Is Deprived. *Cancer Weekly Plus,* March 2, 1998.

Glucose

- A simple sugar
  ($C_6H_{12}O_6$)

- Atoms held together by covalent bonds

Glycolysis Occurs
in Two Stages

- Energy-requiring steps
  - ATP energy activates glucose and its six-carbon derivatives
- Energy-releasing steps
  - The products of the first part are split into three-carbon pyruvate molecules
  - ATP and NADH form

Energy-Requiring
Steps
Energy-Releasing Steps
Glycolysis: Net Energy Yield

Energy requiring steps:
2 ATP invested

Energy releasing steps:
2 NADH formed
4 ATP formed

Net yield is 2 ATP and 2 NADH

Section 8.3: Weblinks and InfoTrac

See the latest Weblinks and InfoTrac articles for this chapter online or click highlighted articles below (articles subject to change)

- Section 8.3: 1953: Hans Adolf Krebs (1900–81) and Fritz Albert Lipmann (1899–1986). Tonse N. K. Raju. *The Lancet,* May 8, 1999.

Second Stage Reactions

- Preparatory reactions
  - Pyruvate is oxidized into two-carbon acetyl units and carbon dioxide

- NAD^+ is reduced

➢ Krebs cycle
- The acetyl units are oxidized to carbon dioxide
- NAD^+ and FAD are reduced

Second Stage Reactions

Second Stage Reactions

Preparatory Reactions

Krebs Cycle

The Krebs Cycle

Overall Reactants

➢ Acetyl-CoA
➢ 3 NAD^+
➢ FAD
➢ ADP and P_i

Overall Products

➢ Coenzyme A
➢ 2 CO_2
➢ 3 NADH
➢ $FADH_2$
➢ ATP

Results of the Second Stage

➢ All of the carbon molecules in pyruvate end up in carbon dioxide
➢ Coenzymes are reduced (they pick up electrons and hydrogen)
➢ One molecule of ATP forms
➢ Four-carbon oxaloacetate regenerates

Coenzyme Reductions during First Two Stages

➢ Glycolysis	2 NADH
➢ Preparatory reactions	2 NADH
➢ Krebs cycle	2 $FADH_2$ + 6 NADH
➢ Total	2 $FADH_2$ + 10 NADH

Section 8.4: Weblinks and InfoTrac

See the latest Weblinks and InfoTrac articles for this chapter online or click highlighted articles below (articles subject to change)

- Section 8.4: Oxidative Phosphorylation Home Page

- Section 8.4: Nobel Prize in Chemistry, 1997—ATP Synthase

- Section 8.4: Molecular Architecture of the Rotary Motor in ATP Synthase. Daniela Stock et al. *Science,* Nov. 26, 1999.

- Section 8.4: Borrowing from Biology to Power the Petite. Robert Service. *Science,* Jan. 1, 1999.

Electron Transfer Phosphorylation

- Occurs in the mitochondria
- Coenzymes deliver electrons to electron transfer chains
- Electron transfer sets up H^+ ion gradients
- Flow of H^+ down gradients powers ATP formation

Creating an H^+ Gradient
Making ATP:
Chemiosmotic Model
Importance of Oxygen

- Electron transport phosphorylation requires the presence of oxygen

- Oxygen withdraws spent electrons from the electron transfer chain, then combines with H^+ to form water

Summary of Energy Harvest
(per molecule of glucose)

- Glycolysis
  - 2 ATP formed by substrate-level phosphorylation
- Krebs cycle and preparatory reactions
  - 2 ATP formed by substrate-level phosphorylation
- Electron transport phosphorylation
  - 32 ATP formed

Energy Harvest Varies

- NADH formed in cytoplasm cannot enter mitochondrion
- It delivers electrons to mitochondrial membrane
- Membrane proteins shuttle electrons to NAD^+ or FAD inside mitochondrion
- Electrons given to FAD yield less ATP than those given to NAD^+

Efficiency of
Aerobic Respiration

- 686 kcal of energy are released
- 7.5 kcal are conserved in each ATP

- When 36 ATP form, 270 kcal (36 X 7.5) are captured in ATP
- Efficiency is 270 / 686 X 100 = 39 percent
- Most energy is lost as heat

Section 8.5: Weblinks and InfoTrac

See the latest Weblinks and InfoTrac articles for this chapter online or click highlighted articles below (articles subject to change)

- Section 8.5: Wingate Anaerobic Test (exercise)

- Section 8.5: EPA—AgStar Biogas Program

- Section 8.5: The Advantages of Togetherness (fermentors and respirators). Edward Cox et al. *Science,* Apr. 20, 2001.

- Section 8.5: The Original Empirical Science (brewing). Jim Kling. *R & D,* Mar. 2002.

Anaerobic Pathways

- Do not use oxygen
- Produce less ATP than aerobic pathways
- Two types
  - Fermentation pathways
  - Anaerobic electron transport

Fermentation Pathways

- Begin with glycolysis
- Do not break glucose down completely to carbon dioxide and water
- Yield only the 2 ATP from glycolysis
- Steps that follow glycolysis serve only to regenerate NAD^+

Anaerobic Electron Transport

- Carried out by certain bacteria
- Electron transfer chain is in bacterial plasma membrane
- Final electron acceptor is compound from environment (such as nitrate), not oxygen
- ATP yield is low

Section 8.6: Weblinks and InfoTrac

See the latest Weblinks and InfoTrac articles for this chapter online or click highlighted articles below (articles subject to change)

- Section 8.6: Metabolic Pathways of Biochemistry

- Section 8.6: Molecule of the Month—Glycogen Phosphorylase

- Section 8.6: The Fuels for Exercise. John Hawley. *Australian Journal of Nutrition and Dietetics,* June 2001.

- Section 8.6: Speed Limits (physics and athletes). Guy Brown. *The Sciences,* Sept. 2000.

Section 8.7: Weblinks and InfoTrac

See the latest Weblinks and InfoTrac articles for this chapter online or click highlighted articles below (articles subject to change)

- Section 8.7: Darwin In Vitro: The Quest to Make Synthetic Self-Replicating Molecules. Richard Lipkin. *Science News,* Nov. 26, 1994.

Evolution of Metabolic Pathways

- When life originated, atmosphere had little oxygen
- Earliest organisms used anaerobic pathways
- Later, noncyclic pathway of photosynthesis increased atmospheric oxygen
- Cells arose that used oxygen as final acceptor in electron transport

Processes Are Linked