Lecture 6

Energy

Cellular Energetics

Energy carrying molecules

ATP Synthesis

Overview of cellular energetics in a heterotroph

Heterotrophs get energy and small molecules from breakdown of large organic molecules (e.g., animals)

Photosynthesis and Respiration

Complementary processes

Acetate

Eating

Next Two Lectures

ECB Fig. 3-10
Cells obey the 2nd law of thermodynamics
Systems change spontaneously in direction that increases disorder (entropy)
Yet cells are highly ordered structurally (organelles) and biochemically (polymers etc)

Disordered cell and environment
Ordered cell, disordered environment

Lecture 6
Energy carrying molecules in cellular energetics
Electrochemical gradients
ATP
Redox reactions
NADH, NADPH

ATP stores energy in phosphoanhydride bond
\[ \Delta G^0 = -7.3 \text{ kcal/mole} \]
Pi of ATP is transferred to other molecules forming high energy intermediates

Fig. 3-34

Reactions involving movement of electron from one molecule to another
Molecule gaining an electron becomes REDUCED
Molecule donating an electron becomes OXIDIZED

Oxidation and Reduction

Assessing the state of oxidation/reduction

\[
\begin{align*}
\text{CO}_2 & \rightarrow \text{COOH} \rightarrow \text{-CHO} \rightarrow \text{-CH}_2\text{OH} \rightarrow \text{-CH}_3 \\
\text{Acid} & \quad \text{Aldehyde} & \text{Alcohol} & \text{Methyl}
\end{align*}
\]
Coupling of redox Reactions

Oxidation of one molecule coupled to reduction of another

\[ \begin{align*}
B-H &\leftrightarrow B + e^- + H^+ & \Delta G = x \\
A + e^- + H^+ &\leftrightarrow AH & \Delta G = y \\
B-H + A &\leftrightarrow B + AH & \Delta G = x + y
\end{align*} \]

Example

\[
\begin{align*}
\text{NADH} &\leftrightarrow \text{NAD}^+ + H^+ + 2e^- & \Delta G = -7.4 \text{ kcal/mol} \\
\frac{1}{2} O_2 + 2H^+ + 2e^- &\leftrightarrow H_2O & \Delta G = -18.8 \text{ kcal/mol} \\
\text{NADH} + \frac{1}{2} O_2 + H^+ &\leftrightarrow \text{NAD}^+ + H_2O & \Delta G = -26.2 \text{ kcal/mol}
\end{align*}
\]

Cells store reducing power as NADH and NADPH

\[
\begin{array}{c}
\text{NAD}^+ \\
\text{H}^+ + 2e^- \\
\text{NADH}
\end{array}
\]

NADH and NADPH reduce other molecules

Forms of stored energy in cells

Electrochemical gradients

Covalent bonds (ATP)

Reducing power (NADH)

During ATP synthesis, photosynthesis, respiration and glycolysis these forms of energy are converted from one to another.

Next two lectures
Lecture 6

Energy

Cellular Energetics

Energy carrying molecules
ATP Synthesis

H+ moving down EC gradient can do work
Chemiosmotic coupling (chemiosmotic hypothesis)

Light (plants, bacteria) or chemical energy (plants, animals, bacteria) drives H⁺ out of cell
H⁺ flows back into cell to turn bacterial flagella, drive coupled transport and synthesize ATP

Where in the cell is ATP made?
1. Bacterial plasma membrane
2. Mitochondrial inner membrane
3. Chloroplast thylakoid membrane

ATP synthase
Bacterial, mito and chloro proteins are related evolutionarily
Synthase ↔ ATPase

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Rotary enzyme - can turn in either direction

Experimental evidence for ATP synthesis

Sealed vesicles from bacterial cell

Bacteriorhodopsin pumps H⁺ into vesicle using light energy

Mechanism of ATP synthesis

γ subunit rotates, forces α and β subunits into different conformations

Conformational changes in β subunits allow it to bind ADP + Pi and make ATP
ATP synthesis movies

ATPSYN-1.MOV

L6 movies/14.4-ATP_synthase_disco.mov

See animation on ECB Interactive CD