Cellular respiration

So why do we breathe?

The big picture

- Heterotrophs cannot make their own food to supply their energy needs
- Instead they break down food to use the chemical energy stored in organic molecules
- Almost all of this food can be traced back to the sun and photosynthesis

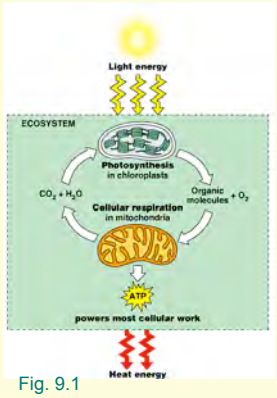


Fig. 9.1

Respiration and fermentation

- Energy stored in organic molecules is released and harnessed in a series of step-wise reactions (catabolism) using enzymes
- **Fermentation**: partial breakdown of sugars without using oxygen (examples?)
- **Respiration**: more complete and efficient breakdown of organic molecules (sugars, fats, and proteins) using oxygen
  - Occurs in mitochondria

Cellular respiration

- $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + energy
- Although we're focusing on glucose, respiration can be used to break down a wide variety of organic molecules
- Energy = ATP (adenosine triphosphate)
- Recall that ATP provides a phosphate group to other compounds in order for these compounds to do work (ATP becomes ADP)
- So, respiration essentially converts ADP back to ATP so it can do more work (e.g., ATP being formed/reformed in active muscle cells at the rate of ca. 10 million molecules per second)

Redox reactions

- Energy release = transfer of electrons during chemical reactions to make ATP
- Electrons are transferred from one reactant to another—oxidation-reduction reactions (=redox reactions)
  - **Oxidation**: loss of electrons from one reactant to another
  - **Reduction**: addition of electrons to one reactant from another
- When electrons are transferred, Hydrogen ions (H+) often are transferred, too.

Respiration as a redox rxn

- $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$
- Glucose is oxidized (loses electrons) and oxygen is reduced (gains electrons)
- Glucose is the reducing agent (electron donor) and oxygen (electron acceptor) is the oxidizing agent
- This transfer of electrons from organic molecules to oxygen releases energy that can be collected and used as ATP
- So we breathe because oxygen is a great electron acceptor

Controlled Release of Energy

- It's inefficient to release the energy from oxidation of glucose all at once
  - An analogy…
- The electrons are transferred to the oxygen, and the energy is harnessed, in small steps

NAD^+ - An electron carrier

- It's inefficient to release the energy from oxidation of glucose all at once
  - An analogy…
- Electrons from glucose are first transferred to a coenzyme, NAD^+— not oxygen
- So, NAD^+ acts as an electron acceptor (or an oxidizing agent) frequently during respiration
- Once NAD^+ accepts the electrons it forms NADH
  - NAD^+ accepts two electrons and one H^+. An enzyme called a dehydrogenase removes the hydrogen and electrons from the glucose.

Electron transport chain

- Respiration uses an electron transport chain to transfer electrons through a series of molecules (mostly proteins) that start with food and NADH, and end with oxygen
- In the process, ATP is produced

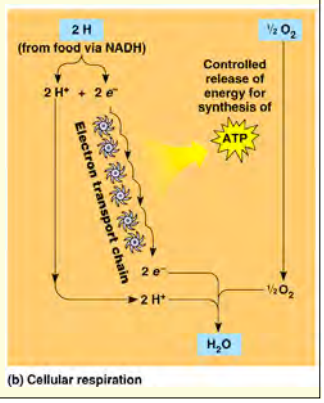


Fig. 9.5

Cellular respiration overview

- Three parts:
  - **Glycolysis**: Breaks down glucose into two molecules of pyruvate
  - **Kreb's cycle**: Breaks down pyruvate into carbon dioxide
  - **Electron transport chain and oxidative phosphorylation**: Makes most of the ATP and water

Glycolysis

- 'Splitting of sugar'
- 6C into two 3C's
- Occurs in the cytosol
- Does not require O_2
- 10 steps (i.e., rxns)
- Produces 2 NADH
- Produces 2 ATP via **substrate-level phosphorylation**

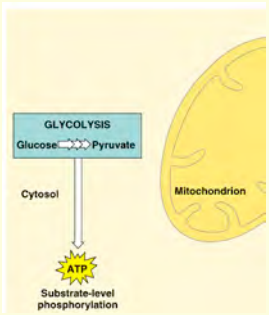
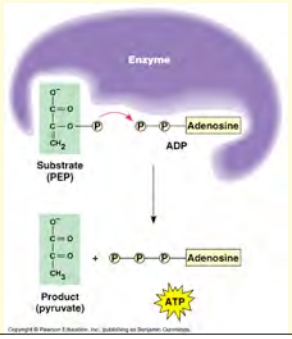


Fig. 9.6

Substrate-level phosphorylation

- Not the major way that ATP is produced
- Occurs when an enzyme transfers a phosphate group from a substrate molecule to ADP
- The substrate molecule is an organic molecule produced during the breakdown of glucose
- Allows for some ATP to be produced before the electron transport chain and oxidative phosphorylation

An example of substrate level phosphorylation in glycolysis



Krebs cycle

- If O_2 is present, pyruvate enters mitochondrion
- Pyruvate converted to acetyl coenzyme A (CoA) before entering Krebs
- 8 steps, CO_2 as waste
- Produces 8 NADH and 2 $FADH_2$
- Produces 2 ATP via sub-level phosphorylation

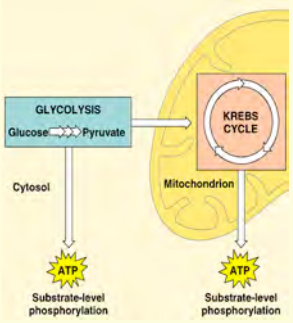


Fig. 9.6

Krebs cycle (2)

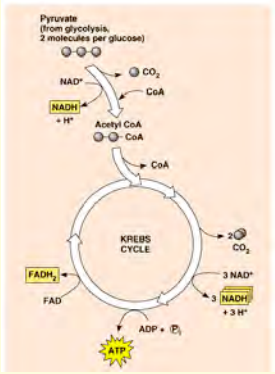
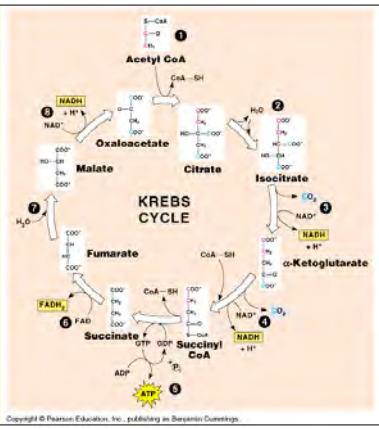


Fig. 9.12

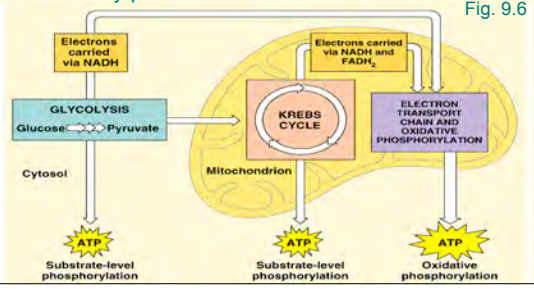
Things you don't need to know



Electron transport chain

- Most of the energy stored in glucose is now stored in the electron carriers, NADH and $FADH_2$
- Electrons transferred to oxygen and water is eventually produced

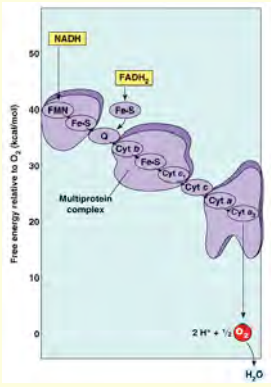
Fig. 9.6



Electron transport chain (2)

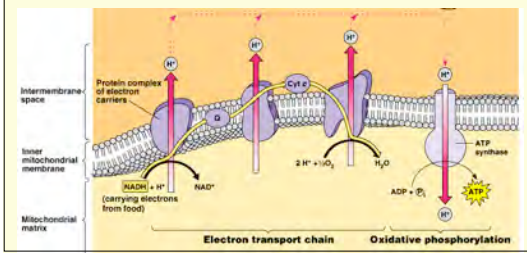
- Occurs in the inner membrane (cristae) of the mitochondria
- Many membrane-bound proteins transfer the electrons in a series of redox reactions

Fig. 9.13

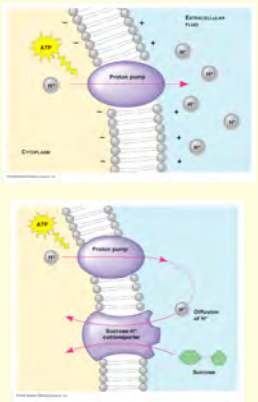


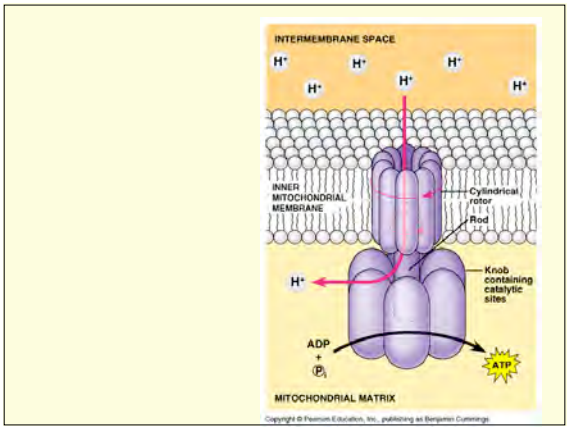
Oxidative phosphorylation

- Synthesis of ATP is powered by an electrochemical gradient generated by H^+
- So oxidative phosphorylation is powered by cotransport
- Gradient is produced by electron transport chain pumping H^+ across the inner membrane while it transfers electrons

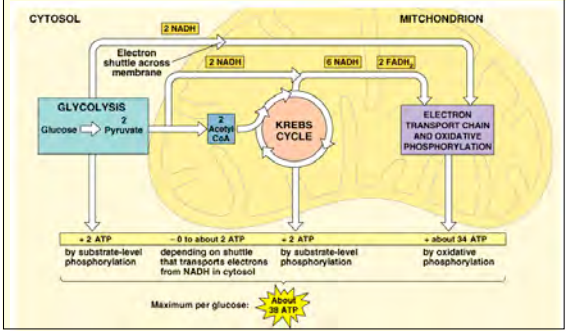


Remember Cotransport?





Cellular respiration review



Fermentation

- Oxidation of glucose without oxygen
- Uses NAD^+ as the oxidizing agent, not oxygen
- So, in anaerobic conditions, a small amount of ATP can be produced via glycolysis and substrate-level phosphorylation
  - Only 2 molecules of ATP vs. 38 in oxidative phosphorylation from a single molecule of glucose

The oxygen junction

- After pyruvate is formed in glycolysis, it can either enter the Kreb's cycle or fermentation depending on the presence of oxygen

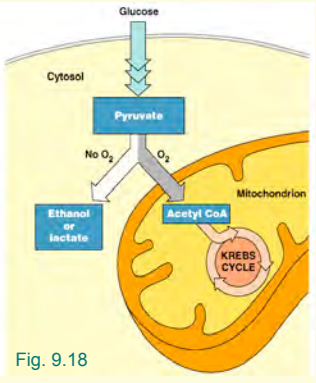
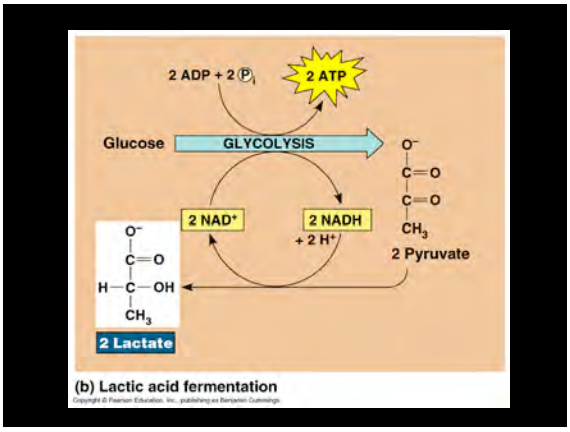
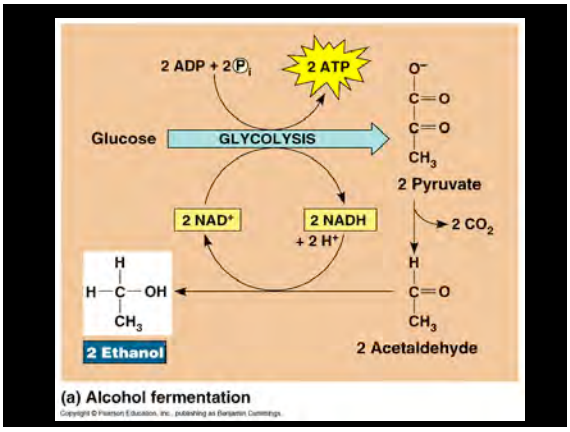


Fig. 9.18





Types of fermentation

- Alcohol: pyruvate is converted to ethanol
  - Yeast are used for making beer and wine
- Lactic acid: pyruvate is converted to lactate (ionized form of lactic acid)
  - Fungi and bacteria are used to make cheese and yogurt
  - Human muscle cells

Cellular Respiration of other molecules

- Lipids
  - Chop hydrocarbon chain into units two (acetate) or three (like pyruvate) carbons long
  - Feed into krebs cycle
- Proteins
  - Deaminate (remove amino group, get rid of nitrogenous waste)
  - Take carbon skeleton, chop into two and three carbon chunks, feed into krebs cycle