

Cellular Respiration
Harvesting Chemical Energy

ATP

Metabolism

Metabolism: all of the chemical reactions that take place within an organism

- Metabolic pathways alter molecules in a series of steps.
- Enzymes selectively accelerate each step.
 - enzymes are regulated to maintain a balance of supply and demand.

Two types of general metabolism...

- Catabolic reactions give off energy by breaking down complicated molecules to simpler compounds.

CATABOLISM

- Anabolic reactions use energy to build complicated molecules from simpler compounds.
- The energy released by catabolic pathways is used to drive anabolic pathways.

ANABOLISM

Energy Entering the ecosystem

****Remember Autotrophs vs. Heterotrophs!**

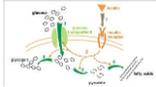
Figure 9.2

All living things need to do Work

- To build more complex molecules (anabolic)
- To break down into simple molecules (catabolic)
- Active transport
- Mechanical work like muscle contractions
- Strange examples of work like electric energy or bioluminescence
- Homeostasis in mammals and birds

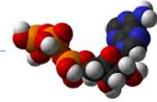
Work

- Requires that energy-needing reactions work together with energy-supplying reactions
- Changing glucose into Carbon Dioxide gives us a LOT of energy, but it requires work
 - Activation energy of glucose
 - $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 2870\text{ kJ}$

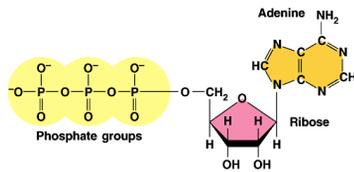


ATP

- ATP powers cellular work
- A cell does three main kinds of work:
 - Mechanical work*, beating of cilia, contraction of muscle cells, and movement of chromosomes
 - Transport work*, pumping substances across membranes against the direction of spontaneous movement
 - Chemical work*, driving endergonic reactions such as the synthesis of polymers from monomers

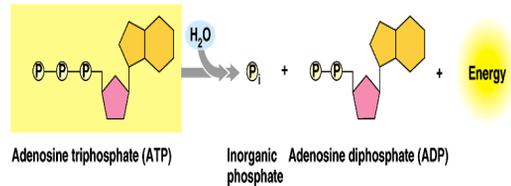


- ATP (adenosine triphosphate) is a type of nucleotide consisting of the nitrogenous base adenine, the sugar ribose, and a chain of three phosphate groups.



(a) Structure of adenosine triphosphate - ATP

- The bonds between phosphate groups can be broken by hydrolysis.



(b) Hydrolysis of ATP

So what?

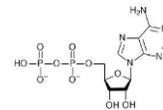
- Energy is stored in these bonds.
- So?
- The breaking of the chemical bond releases the energy



This releases 30.5kJ/mol of energy!

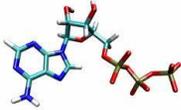
These reactions are reversible

- $ATP + H_2O \rightarrow \leftarrow ADP + H_3PO_4 + +/30.5\text{kJ}$
- Converting back and forth is what provides energy for a cell
- Back and forth is VERY quick
 - We use about 40kg of ATP each day but only have about 0.005kg in our body at any point



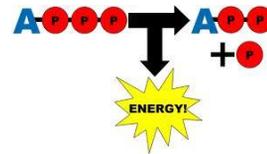
ATP and work

- The reactions that make ATP are linked to energy-creating reactions
- ATP is the constant known intermediary between reactions that make energy and reactions that require energy
- Hence, ATP is the “energy currency” of the cell
 - ♦ Cell moves and trades ATPs rather than using lots of intermediaries



Energy Transfers

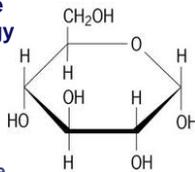
- Ultimately, they're pretty inefficient
- Heat energy always given off as waste
- Some process use less energy than the conversion of ATP → ADP. This excess is given off as heat.



Energy Currency vs. Storage

- Energy currency acts as the intermediary between energy needing and energy giving reactions (ATP)
- Energy storage gives energy to a reaction

- ♦ Sugars are short-term storage (glucose, sucrose)
- ♦ Starches and polysaccharides are long-term storage (glycogen, starch, triglycerides, etc.)



Cellular Respiration

- Cellular respiration

- Is the most prevalent and efficient catabolic pathway
- Consumes oxygen and organic molecules such as glucose
- Yields ATP

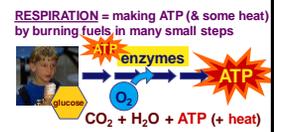
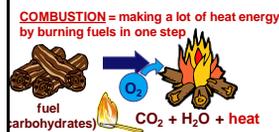
Harvesting stored energy

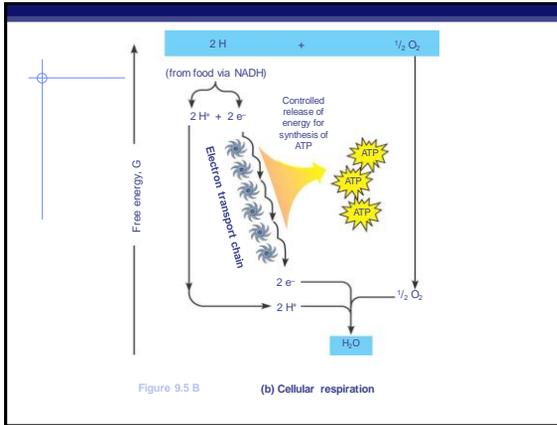
- Energy is stored in organic molecules
 - ♦ **carbohydrates, fats, proteins**
- **Heterotrophs** eat these organic molecules → **food**
 - ♦ digest organic molecules to get...
 - **raw materials** for synthesis
 - **fuels** for energy
 - controlled release of energy
 - “burning” fuels in a series of **step-by-step enzyme-controlled reactions**



Harvesting stored energy

- Glucose is the model
 - ♦ **catabolism** of glucose to produce ATP





How do we harvest energy from fuels?

- Digest large molecules into smaller ones
 - ♦ break bonds & **move electrons** from one molecule to another
 - as electrons move they "**carry energy**" with them
 - that energy is **stored in another bond**, **released as heat** or **harvested to make ATP**

loses e⁻ + gains e⁻ → oxidized + reduced

oxidation reduction

redox

How do we move electrons in biology?

- Moving electrons in living systems
 - ♦ electrons cannot move alone in cells
 - electrons move as part of **H atom**
 - **move H = move electrons**

loses e⁻ + gains e⁻ → oxidized + reduced

oxidation reduction

redox

oxidation

reduction

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + ATP$

Redox Reactions

- **Redox reactions:** involve the transfer of electrons from one compound to another
- **Oxidation:** When a substance loses electrons in a redox reaction
 - ♦ The substance accepting the electron is known as the **oxidizing agent**
- **Reduction:** When a substance gains electrons in a redox reaction
 - ♦ The substance donating the electron is known as the **reducing agent**

Example: Sodium Chloride

Becomes Oxidized (loses electron)

Oxidizing Agent

$Na + Cl \rightarrow Na^+ + Cl^-$

Reducing Agent

Becomes Reduced (gains electron)

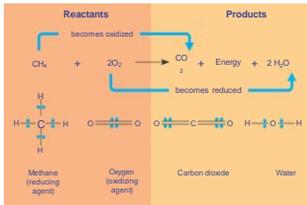
Remember: OIL RIG!

- Oxidation is Losing
- Reduction is Gaining

O oxidation R reduction
I is I is
L loss G gain

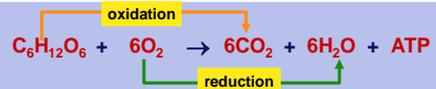
•Some redox reactions

- Do not completely exchange electrons
- Change the degree of electron sharing in covalent bonds



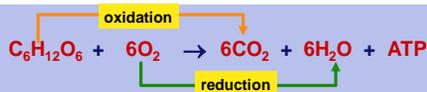
Coupling oxidation & reduction

- REDOX reactions in respiration
 - ♦ release energy as breakdown organic molecules
 - break C-C bonds
 - strip off electrons from C-H bonds by removing H atoms
 - ♦ $C_6H_{12}O_6 \rightarrow CO_2$ = the fuel has been **oxidized**
 - electrons attracted to more electronegative atoms
 - ♦ in biology, the most electronegative atom? O_2
 - ♦ $O_2 \rightarrow H_2O$ = oxygen has been **reduced**
 - ♦ **couple REDOX reactions & use the released energy to synthesize ATP**



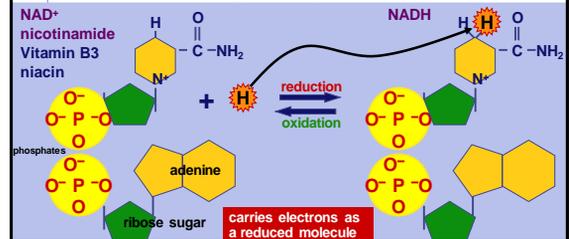
Oxidation & reduction

- | | |
|--|---|
| <ul style="list-style-type: none"> ▪ Oxidation ♦ adding O ♦ removing H ♦ loss of electrons ♦ releases energy ♦ exergonic | <ul style="list-style-type: none"> ▪ Reduction ♦ removing O ♦ adding H ♦ gain of electrons ♦ stores energy ♦ endergonic |
|--|---|



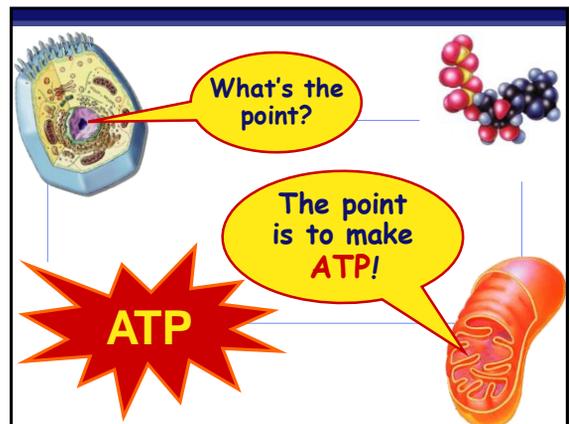
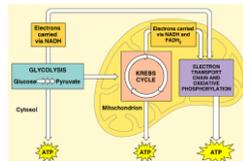
Moving electrons in respiration

- **Electron carriers** move electrons by shuttling H atoms around
 - ♦ $NAD^+ \rightarrow NADH$ (reduced)
 - ♦ $FAD^{+2} \rightarrow FADH_2$ (reduced)



Overview of cellular respiration

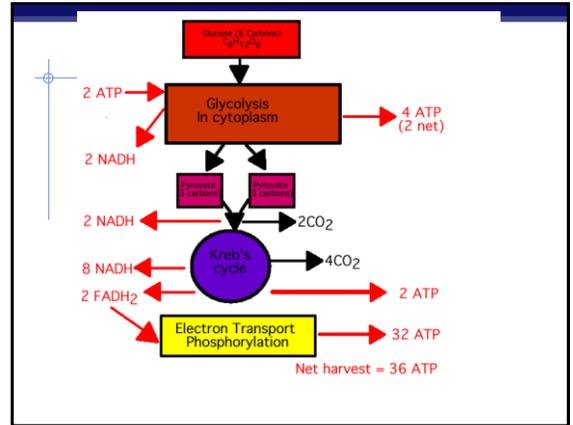
- 4 metabolic stages
 - ♦ **Anaerobic respiration**
 1. **Glycolysis**
 - ♦ respiration without O_2
 - ♦ in cytosol
 - ♦ **Aerobic respiration**
 - ♦ respiration using O_2
 - ♦ in mitochondria
 2. **Pyruvate oxidation (Link Reaction)**
 3. **Krebs cycle**
 4. **Electron transport chain**



And how do we do that?

- ATP synthase enzyme
 - H⁺ flows through it
 - conformational changes
 - bond P_i to ADP to make ATP
 - set up a H⁺ gradient
 - allow the H⁺ to flow down concentration gradient through ATP synthase
 - ADP + P_i → ATP

But... How is the proton (H⁺) gradient formed?

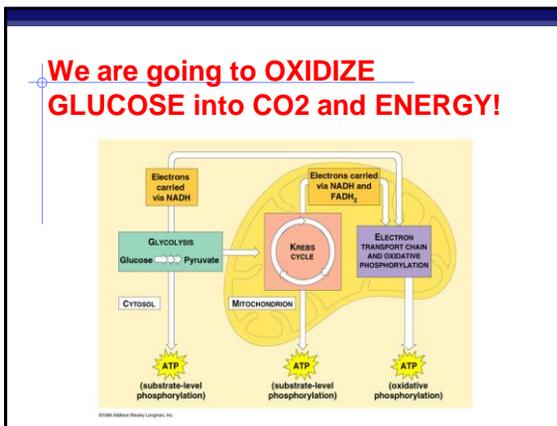


Glycolysis

- Glyco = glucose Lysis = break down
- Glycolysis thus splits up glucose molecules
- Occurs in the cytoplasm
- This stage occurs in BOTH aerobic and anaerobic respiration
- Glucose breaks down into 2 pyruvate (2 ATP are also made)
 - Glucose is a 6-carbon sugar
 - Pyruvate is a 3-carbon molecule (there are two of them)

Glycolysis

- Energy is needed in the first steps, but released in the later, so glycolysis is a net energy-creating pathway
- However, it's not very efficient
- Like much of respiration, powered by redox reactions

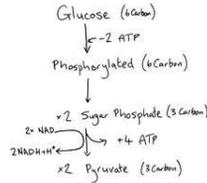


Back to the Glycolytic Pathway...

- Remember what we have:
 - A whole bunch of glucose
 - Some energy to expend as input if necessary
- We want energy from this, but we need it in an efficient manner

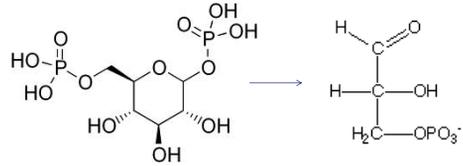
Phosphorylation, Part 1

- Recall that glucose doesn't react easily
- Energy is input to the pathway to phosphorylate glucose
 - 2 ATP molecules per molecule of glucose
 - Turns glucose into **hexose biphosphate** (Cambridge name)



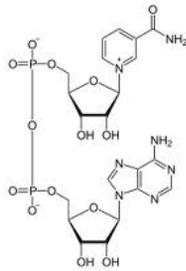
Lysis, Part 2

- Hexose biphosphate** breaks into two molecules of **triose phosphate**
 - There are intermediaries in this process, but you don't need to memorize them!



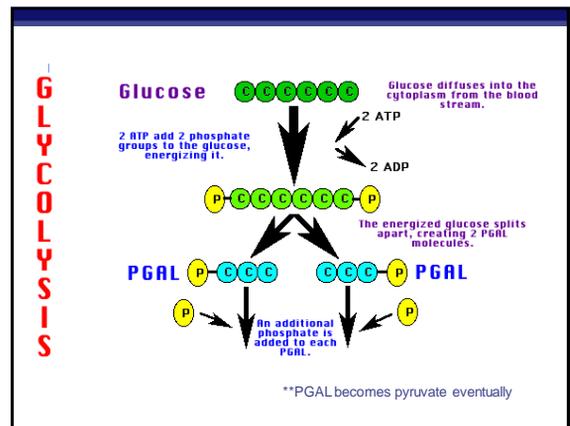
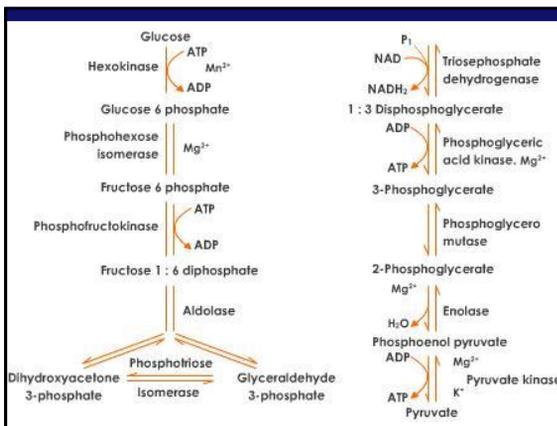
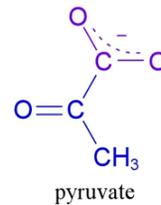
Dehydrogenation, Part 3

- Triose phosphates **LOSE** a **hydrogen** each to the carrier molecule **NAD** (nicotinamide adenine dinucleotide)
 - 2 NAD are reduced for each molecule of glucose
 - Hydrogen ions carried by NAD are used later in respiration to make more ATP



Glycolysis End Products

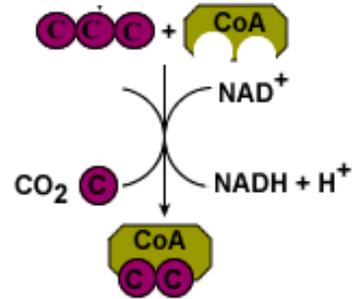
- After all this nonsense, we get the end product of 2 Pyruvates!



Pyruvate → ?

- Pyruvate loses a CO₂ (decarboxylation) and a Hydrogen (dehydrogenation)
 - Hydrogen again reduces NAD⁺ to NADH which floats off for later
- Product then combines with **Coenzyme A**
- Final product of the Link Reaction is **ACETYL COENZYME A**
 - This is also called **Acetyl CoA**

d) Link Reaction

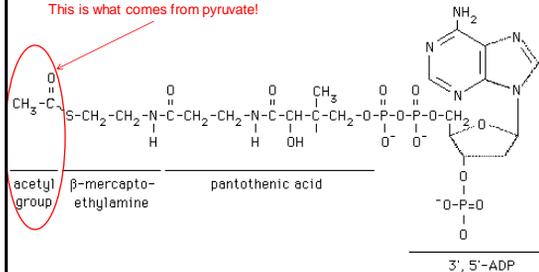


Coenzyme A

- Nucleoside (adenine nucleotide + ribose sugar)**
 - Attached to this is a vitamin
- Carries acetyl groups to the Krebs cycle
- Can also be formed by hydrolysing fatty acid chains, two-carbon acetyl group at a time
 - These acetyls combine with Coenzyme A as well
 - Happens in the mitochondria



This is what comes from pyruvate!



Acetyl coenzyme A, showing its constituents

Link Reaction Reactants and Products

- | Reactants | Products |
|---|---|
| <ul style="list-style-type: none"> 2 pyruvate (from glycolysis) 2 NAD⁺ (sort of) 2 Coenzyme A | <ul style="list-style-type: none"> 2 Acetyl CoA (goes to next step) 2 CO₂ (given off as waste) 2 NADH (for later) |