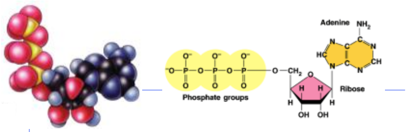
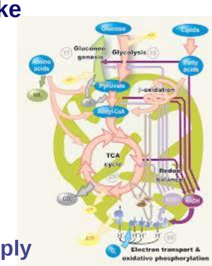


Cellular Respiration
Harvesting Chemical Energy

Metabolism

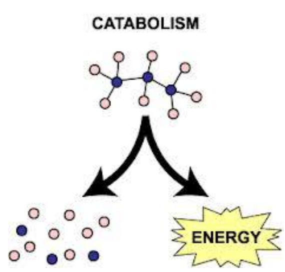
Metabolism: all of the chemical reactions that take place within an organism

- 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.

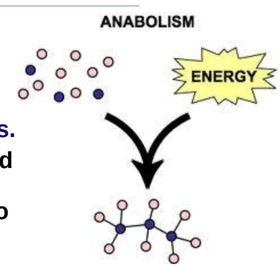


Two types of general metabolism…

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



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



Energy Entering the ecosystem

**Remember Autotrophs vs. Heterotrophs!

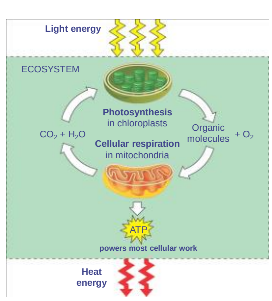
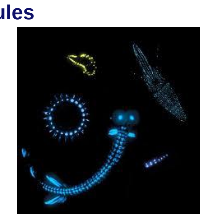


Figure 9.2

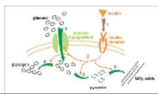
All living things need to do Work

- 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

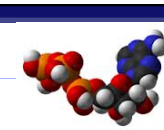


Work

- 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
  - $C_6H_{12}O_6 + 6O_2 \rightarrow 6\ CO_2 + 6H_2O + 2870\ kJ$

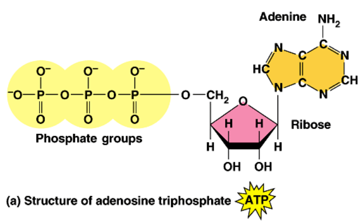


ATP

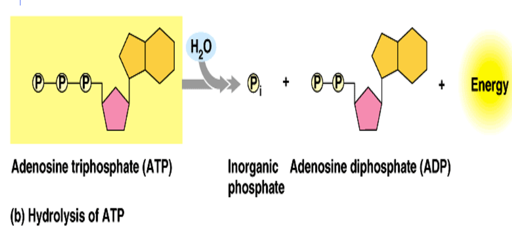


- ATP powers cellular work
- A cell does three main kinds of work:
  - *Mechanical work,* beating of cilia, contraction of muscle cells, and movement of chromosomes
  - *Transport work,* pumping substances across membranes against the direction of spontaneous movement
  - *Chemical work,* driving endergonic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



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



So what?

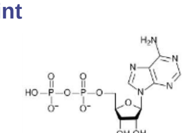
- Energy is stored in these bonds.
- So?
- The breaking of the chemical bond releases the energy

$ATP + H_2O \rightarrow ADP + P +$ ENERGY

This releases 30.5kJ/mol of energy!

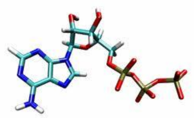
These reactions are reversible

- $ATP + H_2O \rightarrow\leftarrow ADP + H_3PO_4 + +/30.5kJ$
- 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



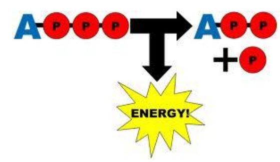
ATP and work

- 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



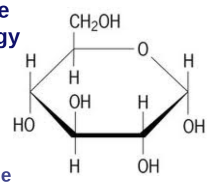
Energy Transfers

- 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

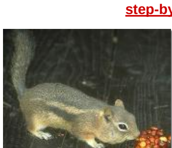
–Is the most prevalent and efficient catabolic pathway

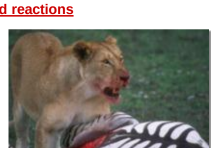
–Consumes oxygen and organic molecules such as glucose

–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

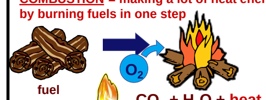
- Glucose is the model
  - catabolism of glucose to produce ATP

respiration

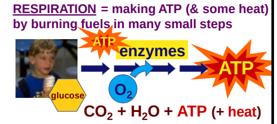
glucose + oxygen → energy + water + carbon dioxide

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

COMBUSTION = making a lot of heat energy by burning fuels in one step



RESPIRATION = making ATP (& some heat) by burning fuels in many small steps



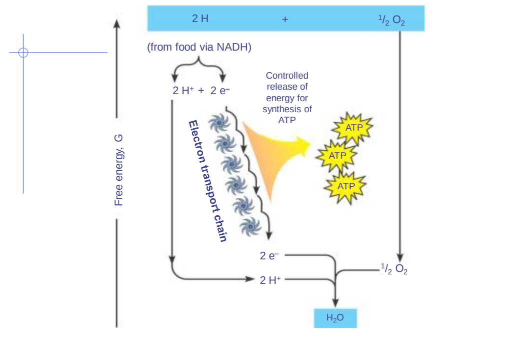
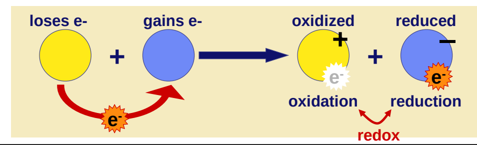


Figure 9.5 B (b) Cellular respiration

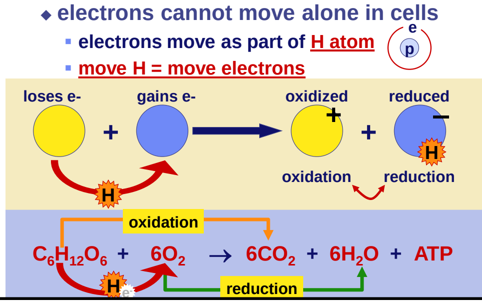
How do we harvest energy from fuels?

- 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



How do we move electrons in biology?

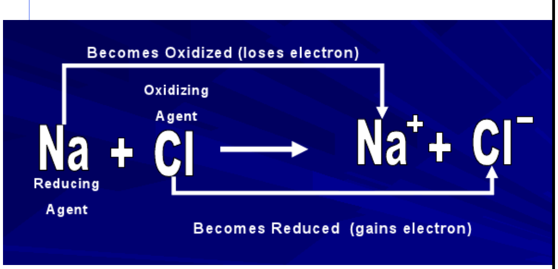
- Moving electrons in living systems
  - electrons cannot move alone in cells
    - electrons move as part of H atom
    - move H = move electrons



Redox Reactions

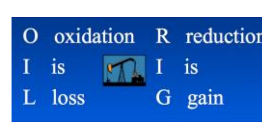
- Redox reactions: involve the transfer of electrons from one compound to another
- Oxidation: When a substance loses electrons in a redox reaction
  - The substance accepting the electron is known as the oxidizing agent
- Reduction: When a substance gains electrons in a redox reaction
  - The substance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

Example: Sodium Chloride



Remember: OIL RIG!

- Oxidation is Losing
- Reduction is Gaining



•Some redox reactions

–Do not completely exchange electrons

–Change the degree of electron sharing in covalent bonds

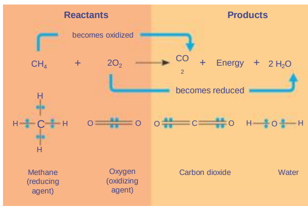


Figure 9.3

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

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

reduction

Oxidation & reduction

- Oxidation
  - adding O
  - removing H
  - loss of electrons
  - releases energy
  - exergonic
- Reduction
  - removing O
  - adding H
  - gain of electrons
  - stores energy
  - endergonic

oxidation

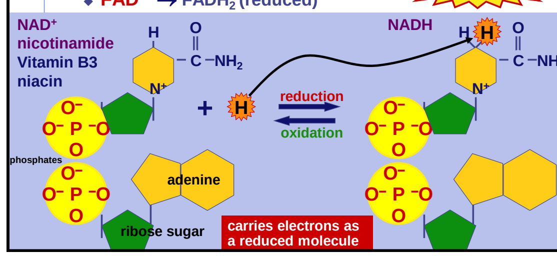
$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + ATP$$

reduction

Moving electrons in respiration

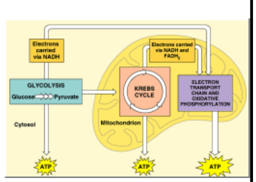
reducing power!

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

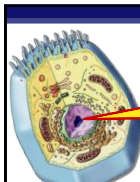


Overview of cellular respiration

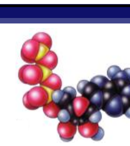
- 4 metabolic stages
  - Anaerobic respiration
    1. Glycolysis
       - respiration without O_2
       - in cytosol
  - Aerobic respiration
       - respiration using O_2
       - in mitochondria
    2. Pyruvate oxidation (Link Reaction)
    3. Krebs cycle
    4. Electron transport chain



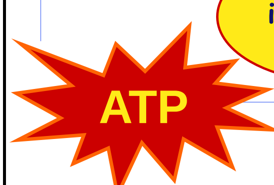
$$C_6H_{12}O_6 + 6O_2 \rightarrow ATP + 6H_2O + 6CO_2 \text{ (+ heat)}$$



What's the point?

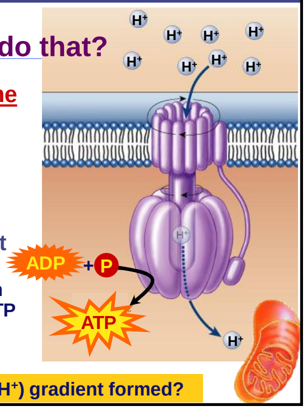


The point is to make ATP!

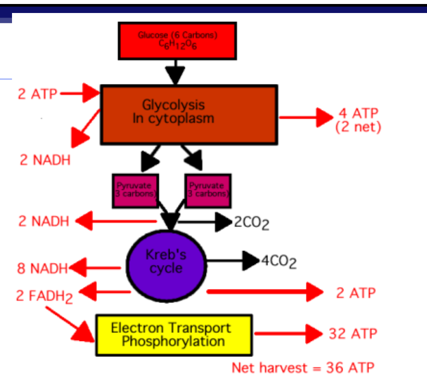


And how do we do that?

- <u>ATP synthase enzyme</u>
  - 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?

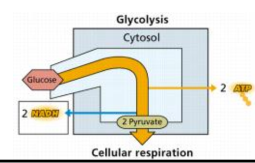


Glycolysis

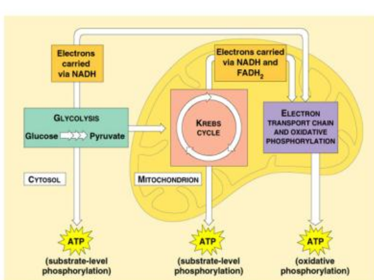
- Glyco = glucose   Lysis = break down
- Glycolysis thus splits up glucose molecules
- <u>Occurs in the cytoplasm</u>
- This stage occurs in BOTH aerobic and anaerobic respiration
- Glucose breaks down into 2 pyruvate (2 ATP are also made)
  - Glucose is a 6-carbon sugar
  - Pyruvate is a 3-carbon molecule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

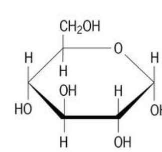


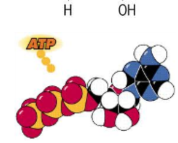
We are going to OXIDIZE GLUCOSE into CO2 and ENERGY!



Back to the Glycolytic Pathway…

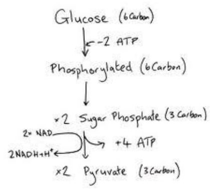
- Remember what we have:
  - A whole bunch of glucose
  - Some energy to expend as input if necessary
- We want energy from this, but we need it in an efficient manner





Phosphorylation, Part 1

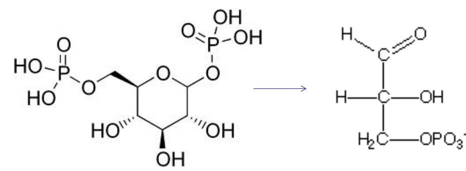
- Recall that glucose doesn't react easily
- Energy is input to the pathway to phosphorylate glucose
  - 2 ATP molecules per molecule of glucose
  - Turns glucose into hexose bisphosphate (Cambridge name)



Phosphorylation, Part 2

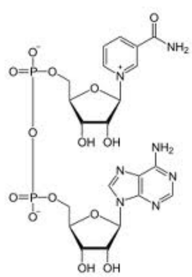
Hexose bisphosphate breaks into two molecules of triose phosphate

- There are intermediaries in this process, but you don't need to memorize them!



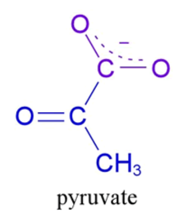
Phosphorylation, Part 3

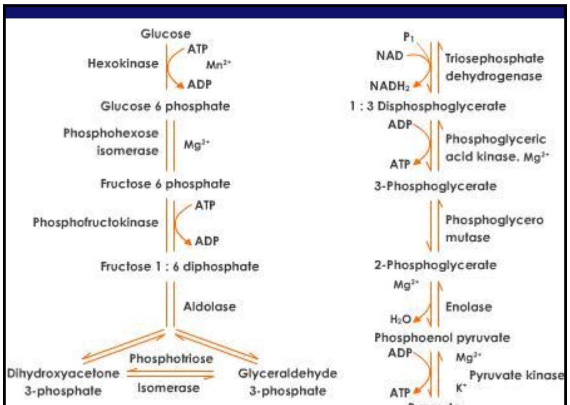
- Triose phosphates LOSE a hydrogen each to the carrier molecule NAD (nicotinamide adenine dinucleotide)
- 2 NAD are reduced for each molecule of glucose
- Hydrogen ions carried by NAD are used later in respiration to make more ATP

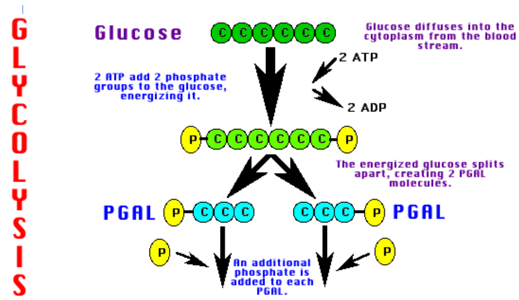


Glycolysis End Products

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







**PGAL becomes pyruvate eventually

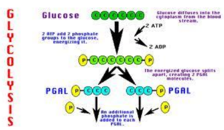
Glycolysis Reactants and Products

Reactants

- 1 glucose
- Enzymes are needed
- 2 ATP are needed to start

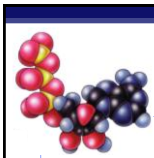
Products

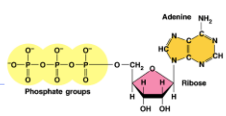
- 2 Pyruvates (go to next step)
- 4 ATP (2 are gained)
- 2 NADH (go to ETC)– we'll worry about this later!



Overview: http://www.youtube.com/watch?v=8Kn6BVGqKd8

A really uncomfortable song: http://www.youtube.com/watch?v=EfGlznwfu9U

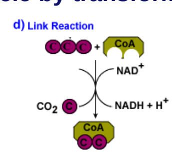




Cellular Respiration
The Link Reaction

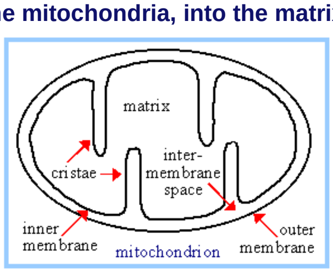
The Link Reaction

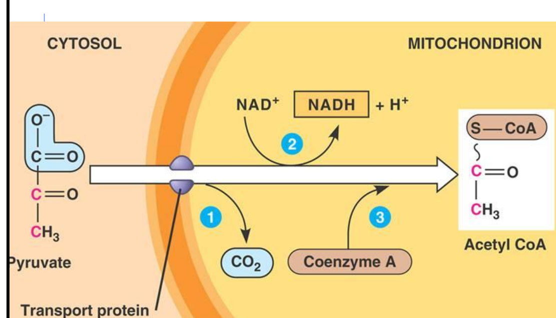
- Pyruvate is awesome, but as is it cannot be passed through the pathway that leads to the most ATP (The Krebs Cycle and ETC)
- Thus, we have to link glycolysis and the Krebs cycle by transforming pyruvate



Pyruvate Transport

- Passes by ACTIVE transport from the cytoplasm, through both membranes of the mitochondria, into the matrix

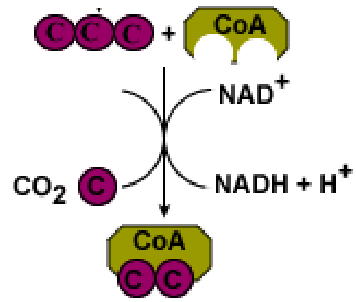




Pyruvate → ?

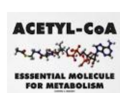
- Pyruvate loses a CO_2 (decarboxylation) and a Hydrogen (dehygrogenation)
  - Hydrogen again reduces NAD+ to NADH which floats off for later
- Product then combines with Coenzyme A
- Final product of the Link Reaction is ACETYL COENZYME A
  - This is also called Acetyl CoA

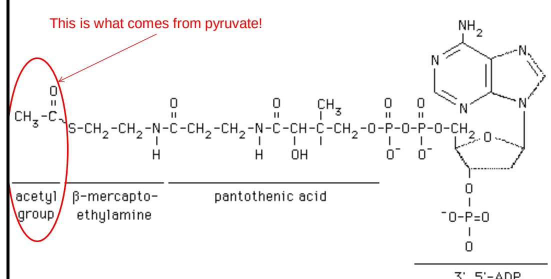
d) Link Reaction



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 hydrolising fatty acid chains, two-carbon acetyl group at a time
  - These acetyls combine with Coenzyme A as well
  - Happens in the mitochondria





Acetyl coenzyme A, showing its constituents

Link Reaction Reactants and Products

Reactants	Products
2 pyruvate (from glycolysis)	2 Acetyl CoA (goes to next step)
2 NAD+ (sort of)	2 CO_2 (given off as waste)
2 Coenzyme A	2 NADH (for later)