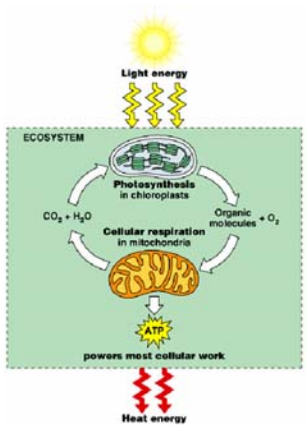
Energy metabolism

Photosynthesis

– Uses light as source of energy to make organic molecules from CO_2 and H_2O

Respiration

– Uses organic molecules and O_2 as source of energy, producing CO_2 and H_2O



These pathways involve redox (reduction- oxidation) reactions

- Remember OIL RIG
  oxidation is loss of electrons, reduction is gain
- When electrons leave an atom, it is "oxidized“.
- When they approach an atom, it is "reduced“.

Electronegativity

- Some elements attract shared electrons more strongly than others
- The most stable (low energy) covalent bonds are those that allow electrons to get close to electronegative atoms, therefore...
- The most stable bonds are those between strongly and weakly electronegative atoms.

Oxidation

- Recall that oxygen is very electronegative, relative to carbon, hydrogen.
- organic molecules can react with oxygen, giving CO_2 and H_2O because…..
- -C-C, -C-H, O=O bonds are less stable (higher energy) than O=C=O (carbon dioxide) and H-O-H (water)

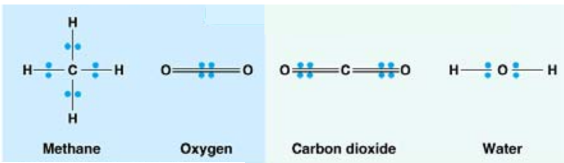
Combustion and the terms "reduction" and "oxidation"

- $CH_4 + 2\ O_2 \longleftrightarrow CO_2 + 2\ H_2O$ + heat
- Combustion was the first redox reaction described- what burned was said to be "oxidized" because it combined with oxygen
- Oxygen was "reduced" because the O_2 gas volume was reduced (got smaller).

Methane combustion as a redox reaction

A “redox” reaction moves electrons closer to electronegative atoms (e.g. oxygen).

$CH_4 + 2\ (O_2) \longleftrightarrow CO_2 + 2\ (H_2O) + \text{heat}$



The blue dots represent the shared electrons, and the lines represent the covalent bonds in the compounds

Spectacular example of redox reaction at Lakehurst, New Jersey May 6,1937

$H_2 + O_2 \rightarrow H_2O + \text{heat}$

Redox reactions don’t have to involve oxygen

- A “redox” reaction is just one that moves electrons closer to an electronegative atom.
- The electrons may come along with a hydrogen atom or some other atom or, in some reactions, may go by themselves
- Most chemical reactions in energy metabolism are redox reactions

The Fire of Life

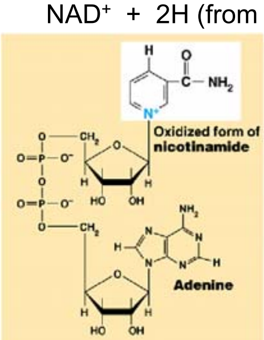
- The net reaction for the oxidation of glucose is:
  $C_6H_{12}O_6 + 6(O_2) \leftrightarrow 6(CO_2) + 6(H_2O) + 686$ kcal/mole
- The net reaction can occur by combustion or as the net result of a metabolic pathway.
- In metabolism, about 37% of the energy is “trapped” temporarily in chemical intermediates

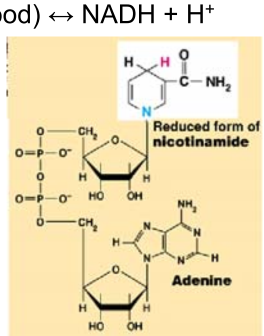
Respiration

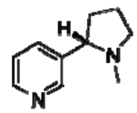
- Organic molecules are oxidized in a stepwise series of reactions that “traps energy” in chemical products, including:
- NADH nicotinamide adenine dinucleotide
- ATP adenosine triphosphate
- These compounds are reactants in metabolic pathways that accomplish energy-requiring processes

NADH redox reaction

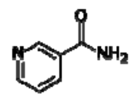
$NAD^+ + 2H$ (from food) $\leftrightarrow NADH + H^+$



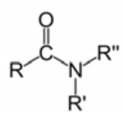




nicotine



nicotinamide



amide

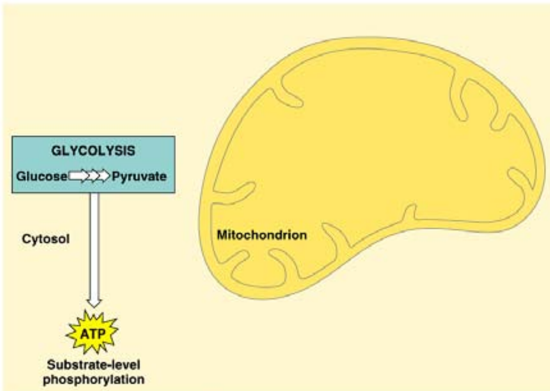
NADH is an electron shuttle

- Electrons from food transferred to NADH, which then transfers them to proteins
- This starts a metabolic pathway of redox reactions (the “electron transport chain”) that leads to ATP
- Eventually the electrons (and H) reach oxygen, forming water.
- NADH is also used in synthetic reactions

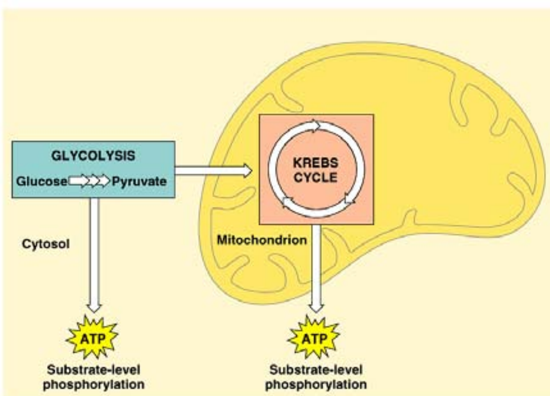
Respiration: three parts

- Glycolysis
  makes some ATP and NADH
- Krebs cycle
  makes a lot of NADH & $FADH_2$
- Electron transport and oxidative phosphorylation
  uses NADH and $FADH_2$ to make lots of ATP

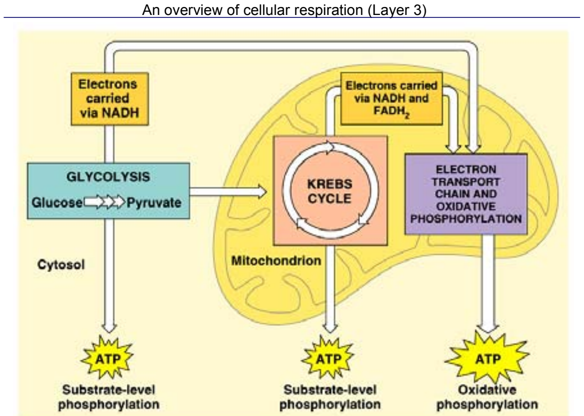
An overview of cellular respiration (Layer 1)



An overview of cellular respiration (Layer 2)



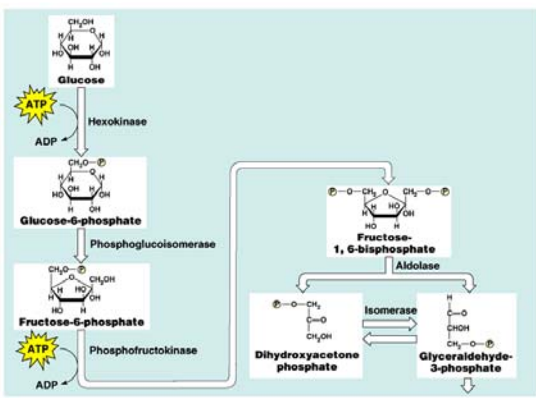
An overview of cellular respiration (Layer 3)



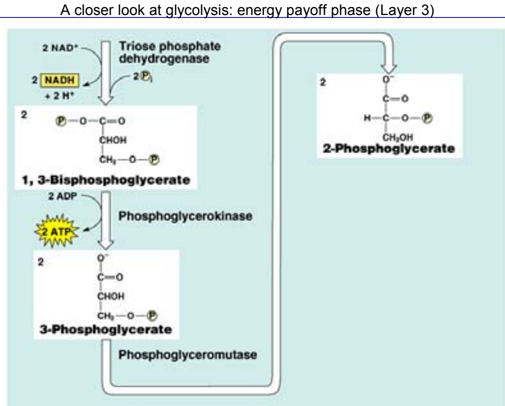
Glycolysis

- 10 enzyme-catalyzed steps in the cell cytoplasm
- Uses only glucose as fuel
- Net 2 ATP and 2 NADH per glucose
- Produces 2 pyruvate molecules

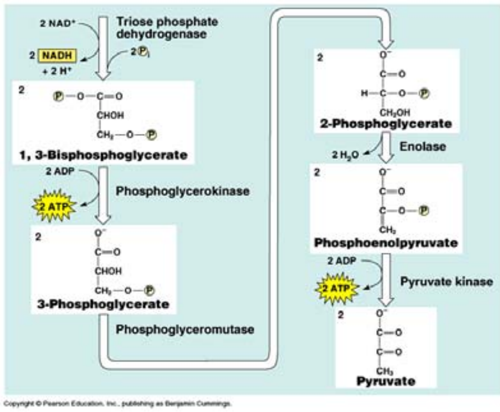
A closer look at glycolysis: energy investment phase (Layer 2)

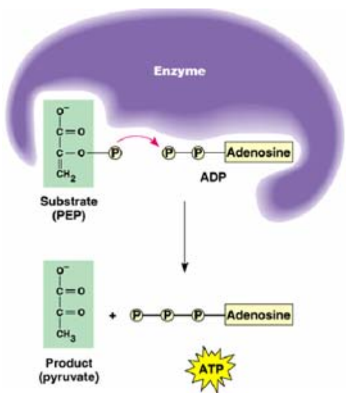


A closer look at glycolysis: energy payoff phase (Layer 3)



A closer look at glycolysis: energy payoff phase (Layer 4)



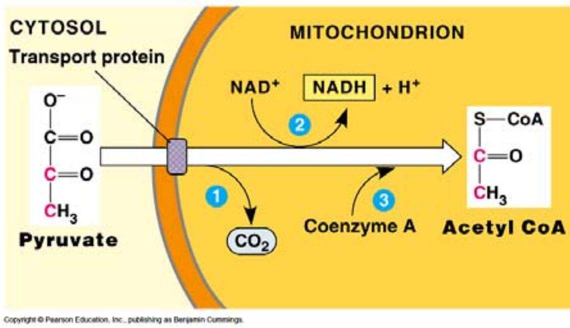


Substrate-level phosphorylation of ATP in glycolysis

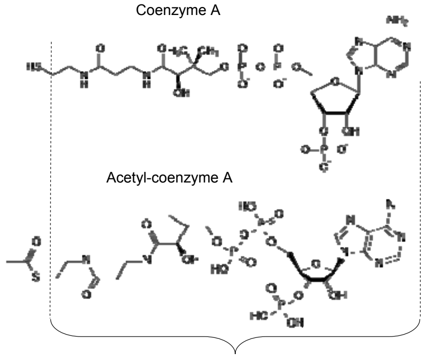
So, what happens to pyruvate?

- pyruvate enters the mitochondrion
- A 3 reaction path generates NADH, loses the carboxyl as CO_2, and links the remaining 2-carbon group (acetyl) to coenzyme A
- The acetyl-co-A passes acetyl into the metabolic pathway called Krebs cycle

Conversion of pyruvate to acetyl CoA, the junction between glycolysis and the Krebs cycle



Coenzyme A

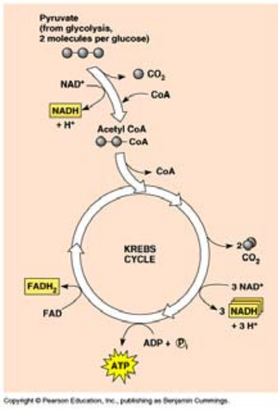


“CoA “ in previous diagram

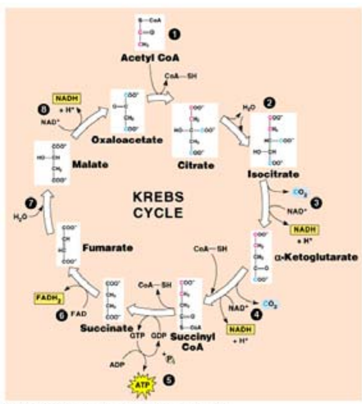
Kreb’s cycle

- Also called TCA or citrate cycle
- 8 enzyme-catalyzed steps in the mitochondrion.
- Cyclical because the last product (oxaloacetate) is one of the first reactants
- Produces ATP, NADH, $FADH_2$ and CO_2

A summary of the Krebs cycle



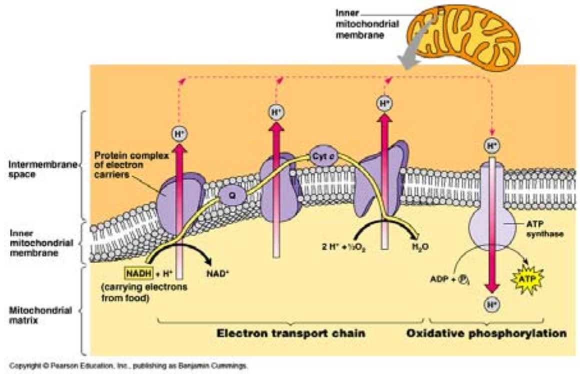
A closer look at the Krebs cycle (Layer 4)

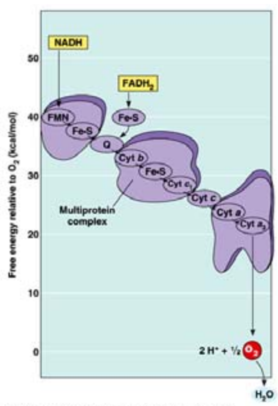


Electron transport chain

- Series of 9 proteins and one lipid bound to the inner mitochondrial membrane
- Undergo redox reactions starting with NADH and $FADH_2$
- These redox reactions are coupled to the active transport of H^+ across the inner membrane.
- Creates electrochemical gradient of H^+,

Chemiosmosis couples the electron transport chain to ATP synthesis



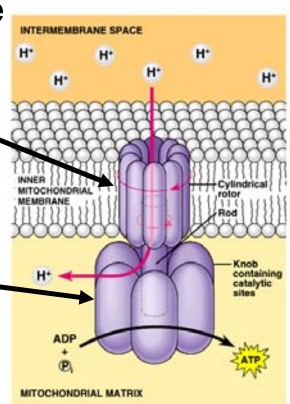


This diagram shows the free energy potential of the components of the electron transport chain, relative to O_2

ATP synthase

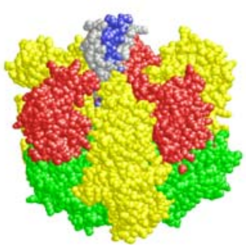
F_0 unit

F_1 unit



ATP synthase mechanism- wow!

- Proton flow powers clockwise rotation of the F_0 unit and central rod.
- Rotation causes active sites on F_1 to crunch ADP and P_i together into ATP.
- Nobel prize in 1997 to Paul Boyer (UCLA) and John Walker (Cambridge)
  http://www.nobel.se/chemistry/laureates/1997/index.html
- Link to videos by Wolfgang Junge:
  http://www.biologie.uni-osnabrueck.de/Biophysik/junge/picsmovs.html



Animated model of the conformational changes in the F_1 unit of ATP synthase

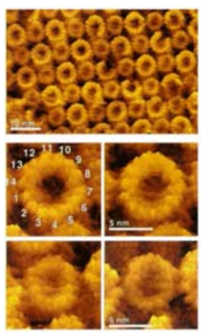
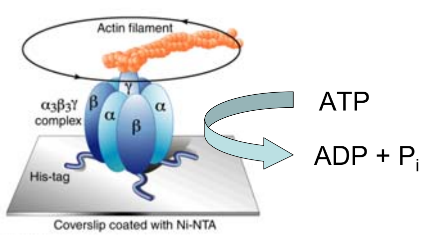


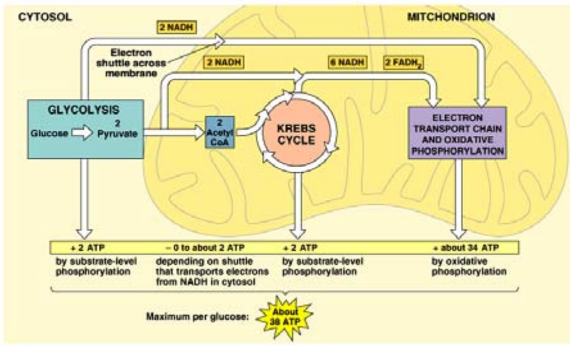
Photo of ATP synthase on chloroplast membrane



Isolated F_1 units can also spin the central rod (opposite direction) by hydrolyzing ATP – they might be used as nanomotors for nanomachines.

Related news link (if you are interested):
http://www.news.cornell.edu/releases/Nov00/propeller.hrs.html

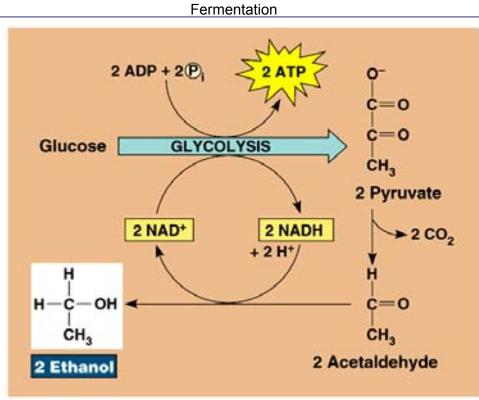
Review: how each molecule of glucose yields many ATP molecules during cellular respiration



What if there is no oxygen?

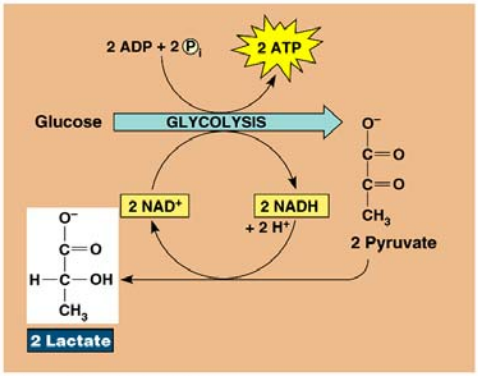
- Anaerobic energy metabolism uses glycolysis and fermentation to produce ATP without respiration.
- Glycolysis produces ATP and NADH
- Fermentation reactions recycle NADH to NAD^+ and remove pyruvate so that glycolysis can continue.

Fermentation



(a) Alcohol fermentation

Fermentation



(b) Lactic acid fermentation

Aerobic energy metabolism

- High efficiency: ~36 ATP per glucose
- High endurance: carbohydrates, fat, and protein can all be used.
- End products (CO_2 and water) are carried away easily.
- Low power: rate of ATP production is limited by the ability of cardiovascular system to deliver O_2 to mitochondria.

<u>An</u>aerobic energy metabolism

- Glycolysis plus fermentation
- Low efficiency: Net 2 ATP per glucose if lactate is the end product
- Low endurance: only glucose used (from glycogen)
- Lactate accumulates
- High power: ATP can be produced at a high rate for a brief period.

Aerobic vs anaerobic metabolism