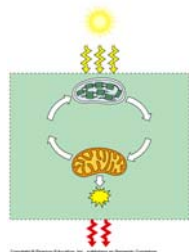


Cellular Respiration



Introduction to Cellular Respiration

- ATP is needed in order for cells to perform work.
- Mitochondria use O_2 in the process of cellular respiration.
- The muscular, respiratory, and circulatory systems combine forces to bring reactants (food molecules and O_2) to cells and remove waste products (CO_2 and H_2O) from cells.

Cellular respiration banks energy in ATP molecules

- Second law of thermodynamics: Wasted energy is lost to each system as random kinetic energy, heat.

Overall equation:



- The overall process in cells is about 40% efficient. Automobiles energy use only about 25% efficient.

Cells tap energy from electrons transferred from organic fuels to oxygen

- Just one glucose molecule contains more energy than a cell needs to use for a single job.
- The movement of hydrogens represents the movement of electrons.
- Cellular respiration involves a gradual series of steps, each coupling an exergonic with an endergonic reaction.
- At each step, electrons move from a chemical bond in a molecule where they have more energy to a bond where they have less energy.

- Oxygen atoms (from molecular oxygen, O_2) are the ultimate electron acceptor. When these oxygen atoms bind with hydrogen atoms carrying the electrons, they form water molecules with relatively low energy covalent bonds

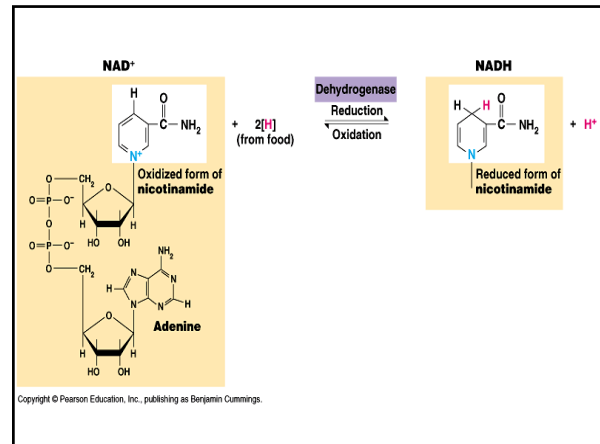
NOTE: The majority of energy is lost as heat. This should not be considered wasted energy since this heat is used to maintain body temperature.

Hydrogen carriers such as NAD⁺ shuttle electrons in redox reactions

- The paired endergonic-exergonic reactions at each step in the transfer of energy are known as redox (reduction-oxidation) reactions.
- Oxidation reactions involve electron loss and are the exergonic half.
- Reduction reactions involve electron gain and are the endergonic half.

- At each step in the breakdown of glucose, small redox reactions occur, involving an enzyme, dehydrogenase, and its coenzyme, NAD⁺, which functions as an electron shuttle.

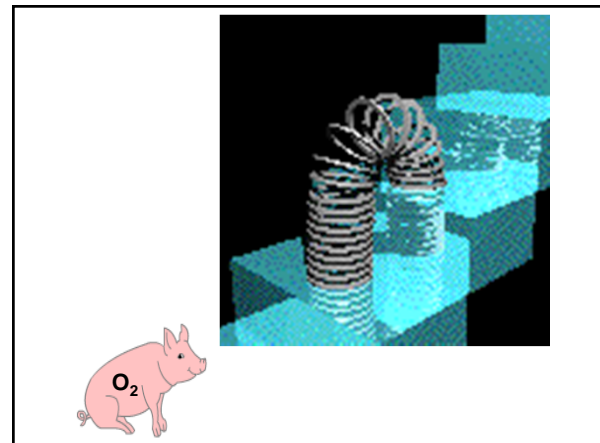
- During each step, the breakdown portion (glucose being stripped of its electrons) is oxidized while the NAD⁺ is reduced forming NADH.



Redox reactions release energy when electrons “fall” from a hydrogen carrier to oxygen

- At the beginning of a different set of reactions, all the NADH generated gives up its energetic electrons and NAD⁺ is regenerated.

- These energetic electrons then pass from molecule to molecule in an “energy cascade,” or electron transport chain. Each molecule is temporarily reduced by the oxidation of the previous molecule and, in turn, is oxidized when it reduces the next.

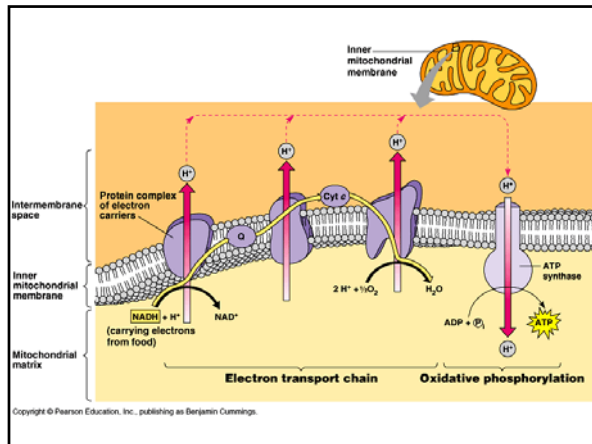


- The ultimate electron acceptor in this part of the overall reaction is oxygen.

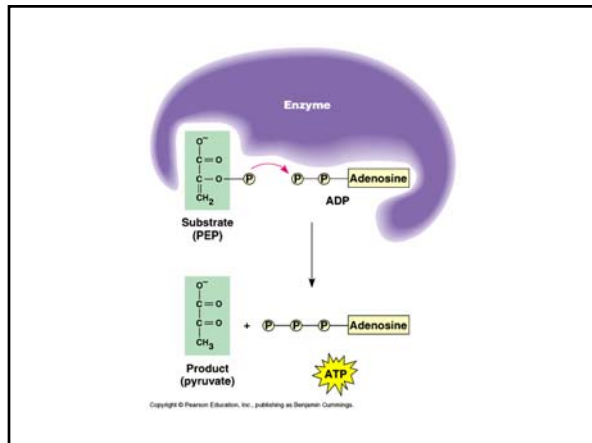
- During the cascade, small amounts of energy are released that can build ATP.

Two mechanisms generate ATP

- Chemiosmosis** is a process involving electron transport chain and ATP synthases. The electron transport chain temporarily produces potential energy in the form of an increase in H⁺ concentration on one side of a membrane; the ATP synthases use potential energy to generate ATP (from ADP and phosphate) by H⁺ flow through them -down the concentration gradient.

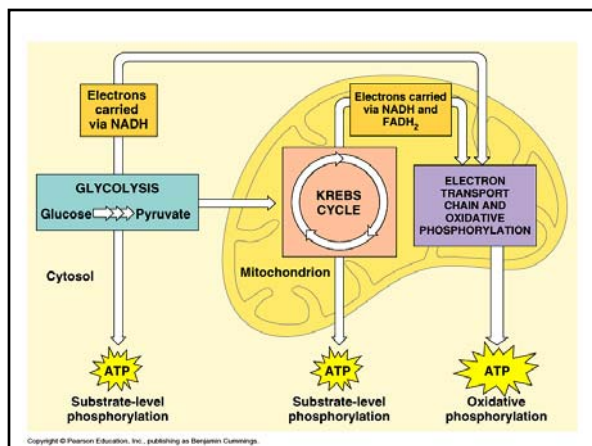


• **Substrate-level phosphorylation** involves neither the electron transport chain nor membranes and take place when a phosphorylated reactant gives up its covalently bonded phosphate to ADP with the aid of an enzyme.



3 Steps in Cellular Respiration

1. Glycolysis
2. Krebs Cycle
3. Electron Transport Chain & Oxidative Phosphorylation



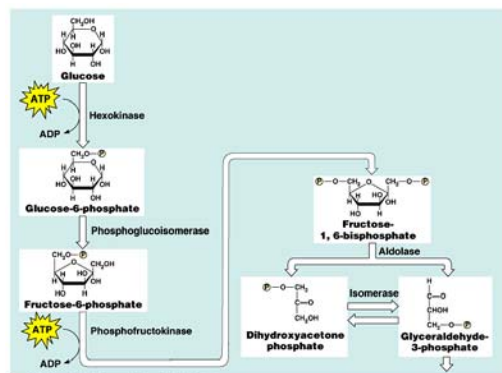
Glycolysis harvests chemical energy by oxidizing glucose to pyruvic acid

- Occurs in the cytoplasm
- There are 9 chemical steps, the net result of which is to split one six-carbon sugar molecule in to two three-carbon pyruvic acid molecules.
- Each step involves a different enzyme.

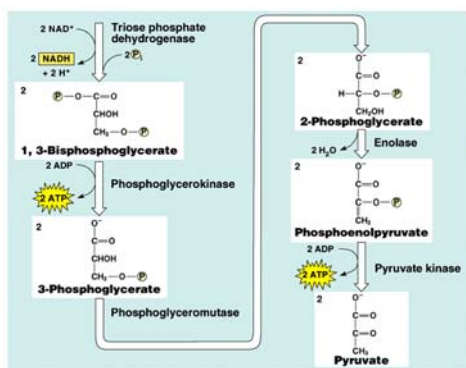
•In addition to glucose, ADP, phosphate, and NAD^+ are required as reactants. ATP is also required because in order to get some intermediates formed, energy must get expended.

•Glycolysis can be broken down into two phases: Step 1-4 are preparatory and require ATP input; Steps 5-9 are energy releasing producing ATP and NADH.

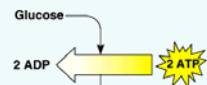
Investment Phase



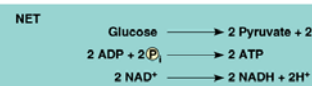
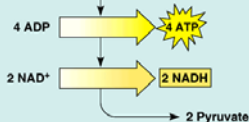
Payoff Phase



ENERGY INVESTMENT PHASE



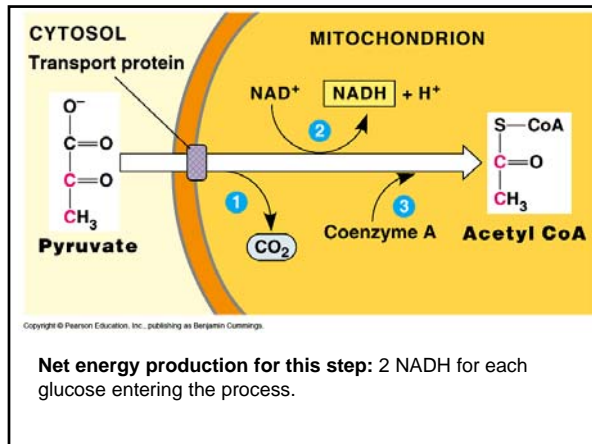
ENERGY PAYOFF PHASE



Net energy production for glycolysis:
 2 ATP (immediately usable) and 2 NADH
 for each glucose entering the process.

Pyruvic Acid is chemically groomed for the Krebs cycle

- This process occurs in the mitochondrial matrix.
- Oxidized, reducing NAD^+ to NADH.
- Stripped of carbon, releasing CO_2 .
- Complexed with coenzyme A, resulting in the molecule, acetyl coenzyme A (acetyl CoA), the high-energy (but not as high as glucose) fuel for the Krebs cycle.



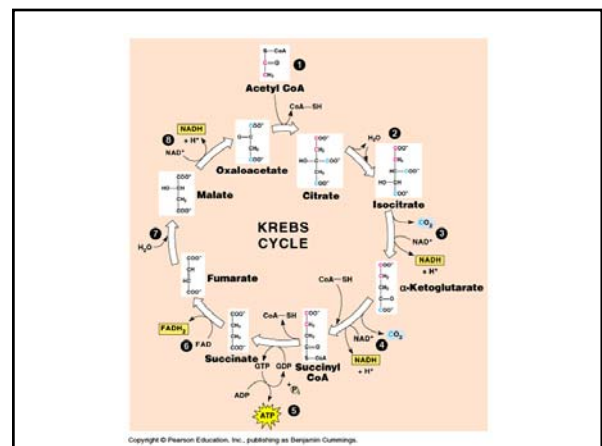
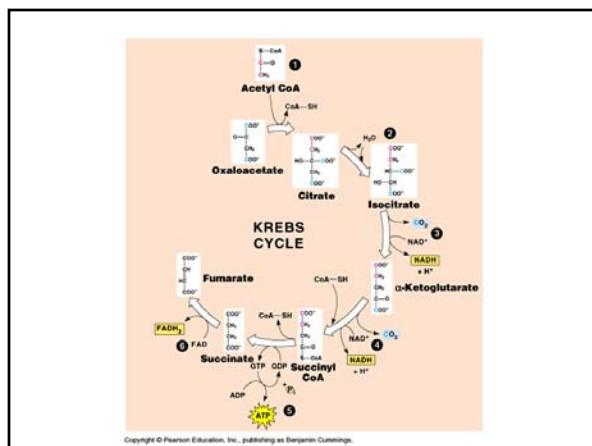
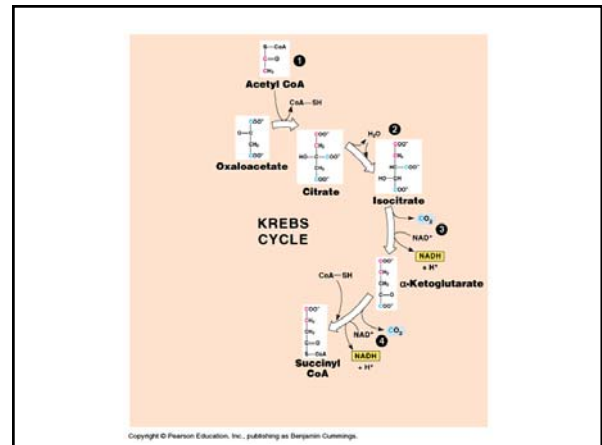
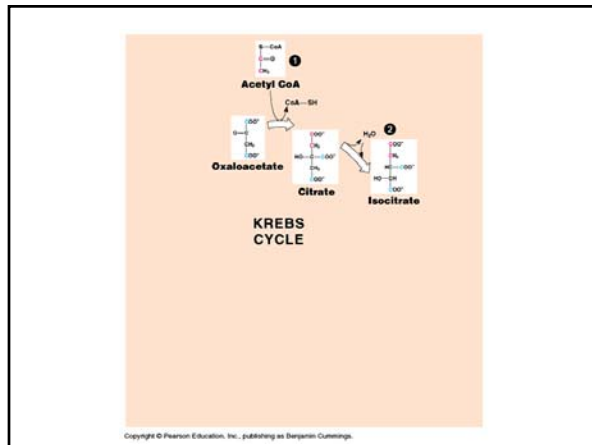
The Krebs cycle completes the oxidation of organic fuel, generating many NADH and FADH_2 molecules

- Occurs in the mitochondrial matrix.

- There are 8 chemical steps, the net result which is to disassemble one two-carbon acetyl CoA into two CO_2 molecules.

- Each step involves a different enzyme.

- In addition to acetyl CoA, ADP, phosphate, NAD^+ , FAD, and oxaloacetic acid are required as reactants.



- The eighth step regenerates oxaloacetic acid. This molecule is required in the beginning.

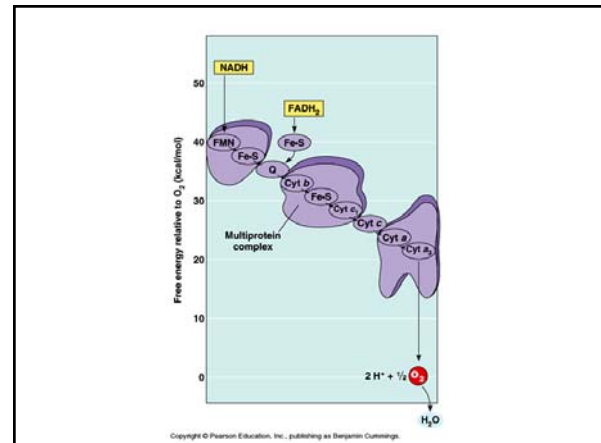
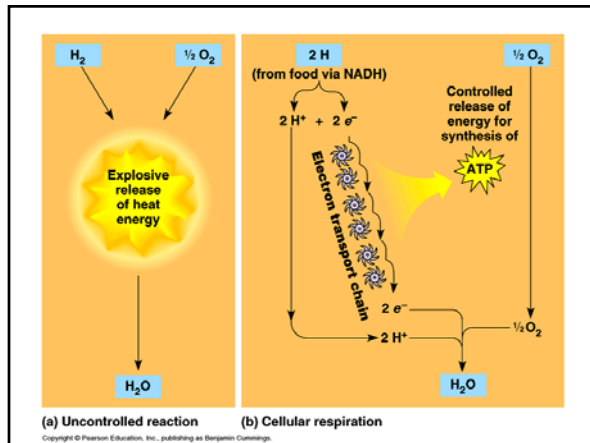
- Coenzyme A is also released at the first step; it goes back to groom more pyruvic acid

Net energy production for the Krebs cycle: 2 ATP (immediately usable), 6 NADH (not immediately usable), and 2 FADH₂ (not immediately usable) for each glucose entering the whole cellular respiration process.

Chemiosmosis powers most ATP production

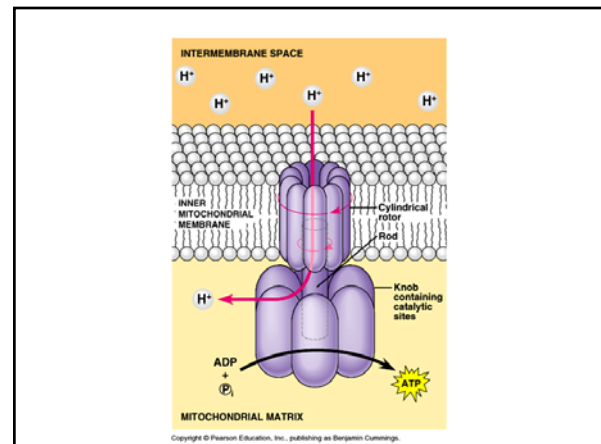
- The electron transport chain is a series of protein complexes built into the cristae (inner mitochondrial membrane).

- Each protein in the chain oscillates between reduced and oxidized states as the energetic electrons from NADH and FADH₂ pass through their region.



- As redox occurs, H⁺ ions are actively transported from inside the cristae to the intermembrane space.

- The resulting H⁺ gradient drives the production of ATP in the matrix, as the H⁺ ions are transported through the ATP synthase.



Net energy production for the electron transport chain:
32 ATP (immediately usable) for each glucose entering the whole cellular respiration process.

- These ATPs are only produced if O_2 is available as a terminal electron acceptor.

Certain poisons interrupt critical events in cellular respiration



- Rotenone** (a plant product commonly used to kill fish and insect pests), cyanide, and carbon monoxide block various parts of ETC.
- The antifungal antibiotic **oligomycin** blocks passage of H^+ ions through ATP synthase molecule.
- “Uncouplers,” such as **dinitrophenol**, cause cristae to leak H^+ ions so that the H^+ gradient is not maintained and chemiosmosis cannot occur.

Review: Each molecule of glucose yields many molecules of ATP

- Glycolysis in cytoplasm yields some ATP in the absence of O_2 but mostly prepares for further steps in the mitochondria that require O_2 .
- The Krebs cycle in the mitochondrial matrix yields some ATP directly but strips out CO_2 producing energy shuttles.
- 3 ATP are produced for every NADH and 2 ATP are produced for each $FADH_2$ introduced to the electron transport chain.

- However, these are maximums. In some cells, ATP is required to shuttle NADH from the cytoplasm into the mitochondrion. Thus the estimate of total ATP generated by aerobic respiration of 1 glucose has a theoretical maximum of **38**.

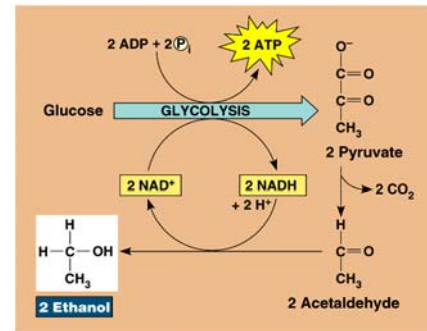
Fermentation is an anaerobic alternative to aerobic respiration

- Fermentation refers to energy-releasing molecular rearrangements in the absence of oxygen.
- The role of fermentation is to recharge NAD^+ so that glycolysis can continue to proceed in the absence of O_2 . In addition, products are produced that are reduced and still energy rich.

- Alcoholic fermentation, characteristic of some yeasts and bacteria, results in one two-carbon ethanol. This product is toxic, and in high concentrations will ultimately kill the cells that produce it.

NOTE: Different strains of yeast are killed by concentrations of up to 20%.

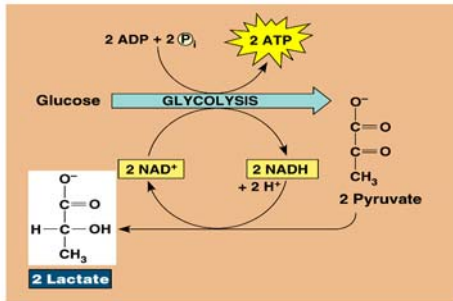




(a) Alcohol fermentation

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•Lactic acid fermentation, characteristic of many organisms, including animals and bacteria, results in one three carbon lactic acid molecule. The accumulation of lactic acid causes muscle fatigue in animals.



(b) Lactic acid fermentation

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•Organisms that can only live in environments that lack oxygen are known as **strict anaerobes**.

•Organisms that can live in environments lacking or containing oxygen are known as **facultative anaerobes**.

Interconnections Between Molecular Breakdown and Synthesis

•Free glucose is not the most common source of fuel in most animal diets, including the human diet. Each of the basic food types can be used as a source of energy.

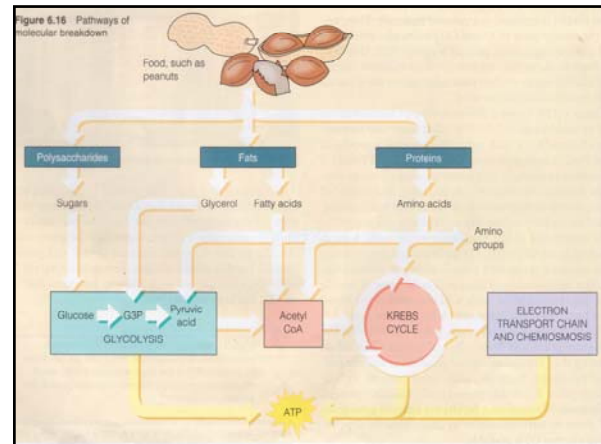
•Carbohydrates such as polysaccharides and glycogen are usually hydrolyzed by digestive enzymes to glucose, which enters glycolysis.

•Proteins must first be digested to their constituent amino acids. The amino acids are then transformed to various compounds, which enter the middle of glycolysis or the Krebs cycle.

•Toxic parts of amino acids are stripped off and eliminated in urine or used to synthesize other compounds.

- Lipids contain almost twice as much energy per unit weight than carbohydrates.

- They must first be digested to glycerol, which enters in the middle of glycolysis, and fatty acids, which are converted to Acetyl CoA and, thus, enter the Krebs cycle.



Food molecules provide raw material for biosynthesis

- Cells and bodies obtain some raw materials directly from the digestion of the macromolecules in food.

- The processes that produce new molecules often appear to be the reverse of the process that breakdown the same class of molecules down.

ATP is required in biosynthetic pathways and produced by degradative pathways.

The fuel for cell respiration ultimately comes from photosynthesis

- Cells of all living things can harvest molecular energy(by cell resp. or fermentation).

- The ability to store molecular energy is not shared by all organisms.