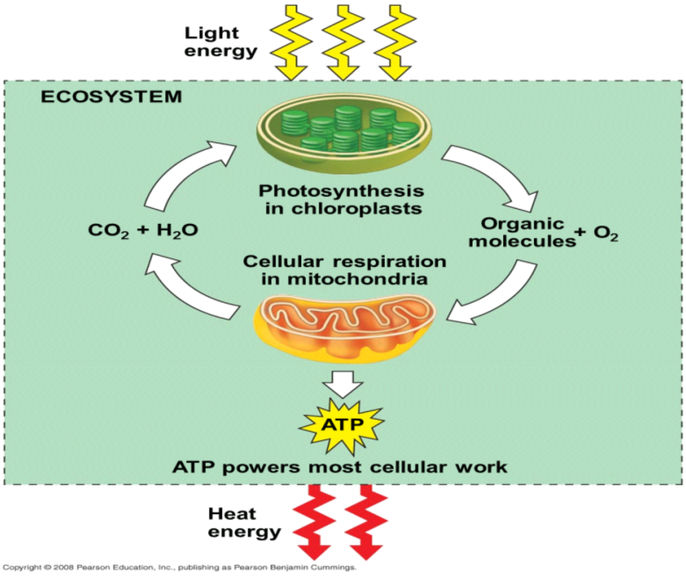
Chapter 9 : cellular respiration and fermentation

Overview: Life is work

- Living cellstransfusions of energy from outside sources to perform their many tasks.
- Some animals such as panda, obtain energy by eating plants and some animals feed on other organisms that eat plant.
- Cells harvest the chemical energy stored in organic molecules and use it to generate ATP, the molecule that drives most cellular work.

Figure 9.2 Energy flow and chemical recycling in ecosystems.



Explanation of figure 9.2

- The energy stored in the organic molecules of food ultimately comes from the sun.
- e nergy flows into an ecosystem as sunlight and leaves as heat ; in contrast , the chemical elements essential to live are recycled.
- Photosynthesis generates oxygen and organic molecules used by the mitochondria of eukaryotes (including plants and algae) as fuel of cellular respiration.
- Respiration breaks this fuel down, generating ATP.
- The waste products of this type of respiration, Carbon dioxide and water, are the row materials for photosynthesis.
- Photosynthesis:
  _ anabolic.
  _ Need ATP
- Cellular respiration:
  _catabolic
  _ make ATP

Concept 9.1: Catabolic pathways yield energy by oxidizing organic fuels

- Metabolic pathways that release stored energy by breaking down complex molecules are called catabolic pathways.
- Electron transfer plays a major role in catabolic path ways .
- Catabolic processes are central to cellular respiration and related pathways.

v Catabolic Pathways and Production of ATP

- The breakdown of organic molecules is exergonic
- Compounds that are participate in exergonic reactions can act the fuel.
- One catabolic process, fermentation, is a partial degradation of sugars or other organic fuel that occurs without the use of oxygen.
- The most prevalent and efficient catabolic pathway is aerobic respiration.
- Aerobic respirationconsumes organic molecules and O_2 and yields ATP.
- Most eukaryotic and many prokaryotes organisms can carry out aerobic respiration.
- Some prokaryotes that live in environments without O_2 use anaerobic respiration.
- Cellular respiration includes both aerobic and anaerobic respiration but is often used to refer to aerobic respiration.
- Food provides the fuel of respiration, and the exhaust is carbon dioxide and water. The overall process can be summarized as follows :
  _ Organic compounds + oxygen ⟶ carbon dioxide (CO2) + water + Energy
- Although carbohydrates , fats , and proteins can all be processed and consumed as fuel , it is helpful to learn the step of cellular respiration by tracking the degradation of the sugar glucose (C6H12O6) :
- $C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$ + Energy (ATP + Heat)
- This break down of glucose is exergonic , having a free energy change of -686 kcal per mole of glucose . (ΔG = -686KCAL/Mol)

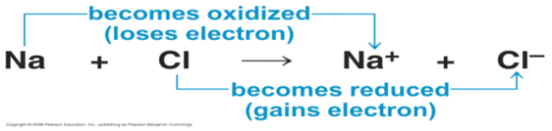
v Redox Reactions: Oxidation and Reduction

- The transfer of electrons during the chemical reaction releases energy stored in organic molecules, and this energy ultimately is used to synthesize ATP.

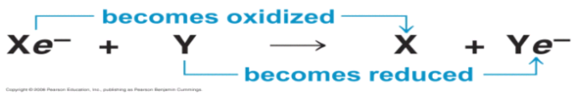
ü *The Principle of Redox*

- In many chemical reaction, there is a transfer of one or more electrons (e-) from one reactant to another.
- These electron transfers are called oxidation-reduction reaction, or redox reaction. In redox reaction; the loss of electrons from one substance is called oxidation , and the additions electrons to another substance is known as reduction.
- In reduction: negatively charged electrons added to an atom reduce the amount of positive charge of that atom.

- Example of redox reaction:



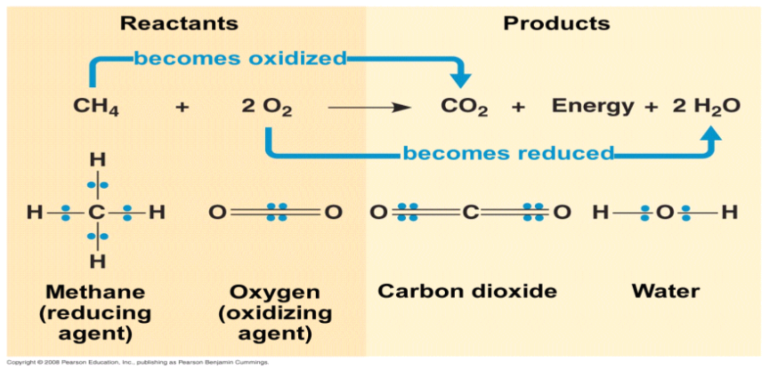
- We could generalize a redox reaction this way:



- Xe-, the electron donor, is called the reducing agent; it reduces Y, which accept the donated electron.
- Substance Y, the electron acceptor, is the oxidizing agent; it oxidizes Xe- by removing its electron.
- Not all redox reaction involve the complete transfer of electrons from one substance to another; some change the degree of electron sharing in covalent bonds.
  _ An example is the reaction between methane and O_2

Figure 9.3 methane combustion as an energy yielding redox reaction.

Fig. 9-3



Explanation of figure 9.3 The reaction releases energy to the surrounding because the electrons lose potential energy when they end up being shared unequally, spending more time near electronegative atoms such as oxygen.

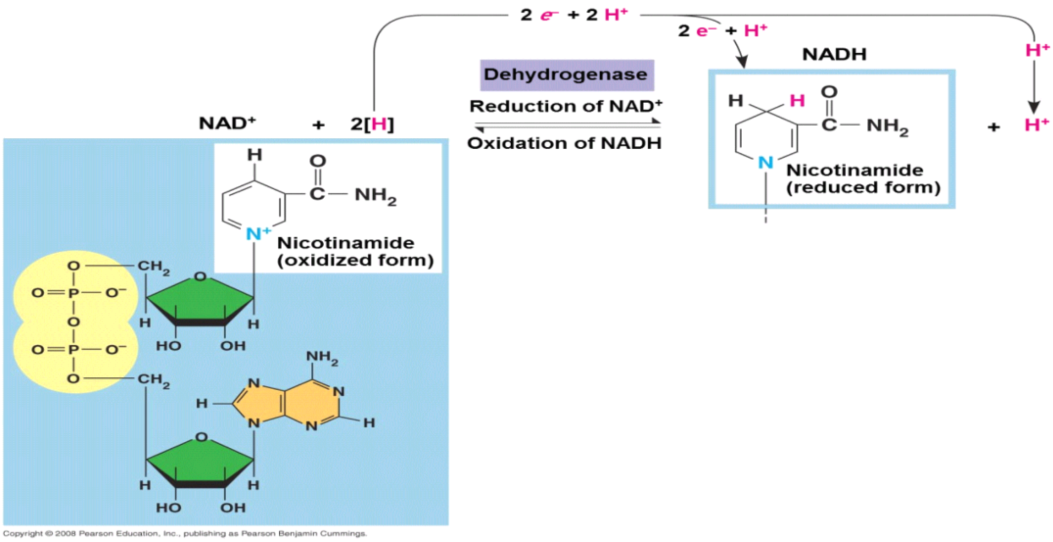
ü *Oxidation of Organic Fuel Molecules During Cellular Respiration*

- During cellular respiration, the fuel (such as glucose) is oxidized, and O_2 is reduced:

ü *Stepwise Energy Harvest via NAD^+ and the Electron Transport Chain*

- If energy is released from the fuel all at once , it cannot be harnessed efficiently for constructive work.
- Cellular respiration dose not oxidize glucose in single explosive step either. Rather, glucose and other organic fuels are broken down in series of steps, each one catalyzed by an enzyme.
- Each electron travels with proton -- thus, as a hydrogen atom.
- The hydrogen atoms are not transferred directly to oxygen , but instead are usually passed first to an electron carrier , a coenzyme called NAD+.
- As an electron acceptor , NAD+ functions as an oxidizing agent during respiration.

Figure 9.4NAD+as an electron shuttle.



Explanation of figure 9.4

- The full name for NAD+, Nicotinamide adenine dinucleotide, describes its structure: The molecule consists of two nucleotides joined together at their phosphate groups.
- nicotinamide is a nitrogenous base, although not one that is present in DNA or RNA .
- the enzymatic transfer of 2 electrons and 1 proton (H+) from an organic molecule in food to NAD+ reduces the NAD+ to NADH; the second proton (H+) is released.

  _Summarization:

  NAD+ + e- → NAD

  NAD+ + H+ → NADH+

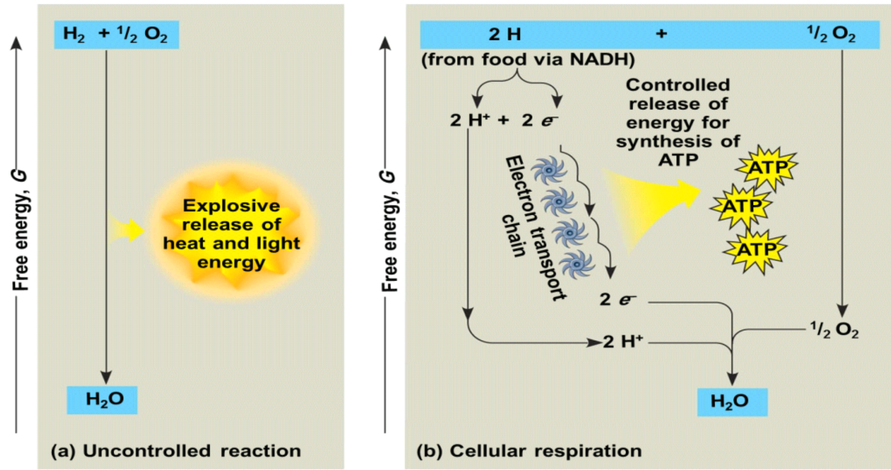
  NADH+ + e- → NADH

  NADH + H+
- most of electrons removed from food are transferred initially to NAD+.
- when the reduction of NAD+ occur , NAD+ in the reactant is the oxidizing agent while (2H) is the reducing agent.

Note:
Another example of 2 electrons and proton transfer to NAD+ with the help of dehydrogenase enzyme:

- Electron lose very little of their potential energy when they are transferred from glucose to NAD+.
- Each NADH molecule formed during respiration represents stored energy that can be tapped to make ATP when the electrons complete their "fall" down an energy gradient from NADH to oxygen.

Figure 9.5 An introduction to electron transport chains.



Explanation of figure 9.5

(a) the one-step exergonic reaction of hydrogen with oxygen to form water releases a large amount of energy in the form of heat and light :an explosion.
(b) in cellular respiration, the same reaction occurs but in stages: an electron transport chain breaks the "fall" of electrons in this reaction into a series of smaller steps and stores some of the released energy in a form that can be used to make ATP. (the rest of the energy is released as heat).also in cellular respiration the hydrogen that reacts with oxygen is derived from organic molecules.

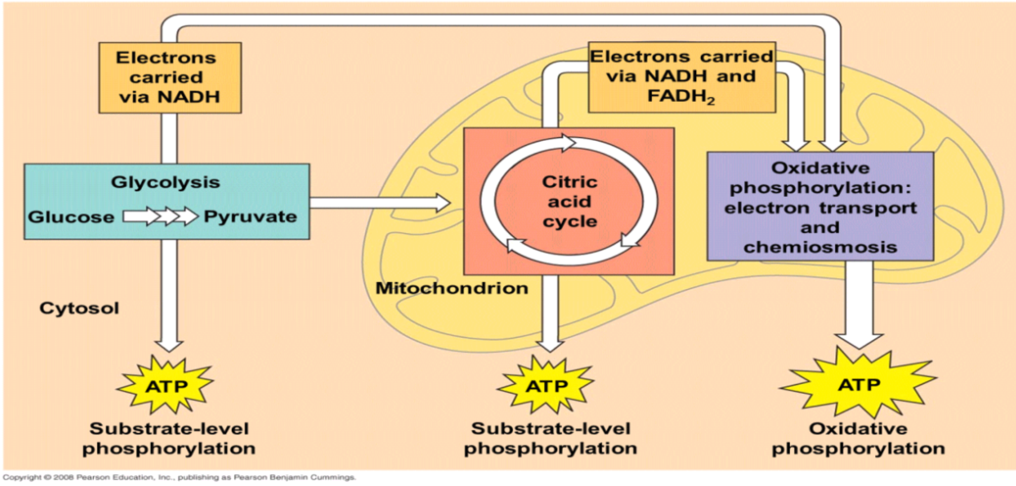
- Electron transfer from NADH to oxygen is an exergonic reaction with a free-energy change of -53 Kcal/mol
- In summary, during cellular respiration, most electrons travel the following "downhill" route: glucose à NADH à electron transport chain à oxygen.

v The stages of cellular respiration : A preview

- the harvesting of energy from glucose by cellular respiration is a cumulative function of three metabolic stages :-
  1-Glycolysis (breaks down glucose into two molecules of pyruvate)

2-The citric acid cycle (completes the breakdown of glucose)
3-Oxidative phosphorylation (accounts for most of the ATP synthesis)

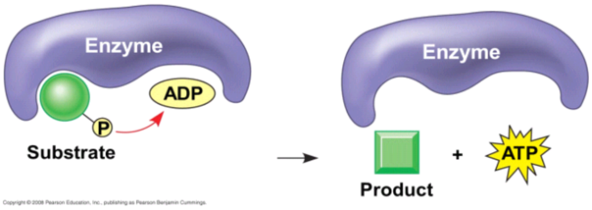
Figure 9.6 an overview of cellular respiration



Explanation of figure 9.6
· Glycolysis and pyruvate oxidation followed by the citric acid cycle are catabolic pathways that break down glucose and other organic fuels. · Glycolysis, which occurs in the cytosol, begins the degradation process by breaking glucose into two molecules of a compound called pyruvate. · In eukaryotes, pyruvate enters the mitochondrion and is oxidized to a compound called acetyl CoA, which enters the citric acid cycle. There, the breakdown of glucose to carbon dioxide is completed.(in prokaryotes, these processes take place in the cytosol) · Some of the steps of Glycolysis and the citric acid cycle are redox reactions in which dehydrogenases transfer electrons from substrates to NAD+, forming NADH. · In the third Stage of respiration, the electron transport chain accepts electrons from the breakdown products of the first two stages via FADH2 and NADH. · During oxidative Phosphorylation, electron transport chains convert the chemical energy to a form used for ATP synthesis in the process called chemiosmosis.

- The process that generates most of the ATP is called oxidative phosphorylation because it is powered by redox reactions.
- Oxidative Phosphorylation accounts for almost 90% of the ATP generated by respiration.
- A smaller amount of ATP is formed directly in a few reactions of glycolysis and the citric acid cycle by a mechanism called substrate-level Phosphorylation.

Figure 9.7 substrate-level Phosphorylation



Explanation of figure 9.7

- ATP formation, some ATP is made by direct transfer of phosphate group from an organic substrate to ADP by an enzyme.(for example in glycolysis)

- The made of ATP synthesis in oxidative Phosphorylation occurs when adding an inorganic phosphate to ADP.

Concept 9.2: Glycolysis harvests chemical energy by oxidizing glucose to pyruvate

- Glycolysis ("splitting of sugar ") breaks down glucose into two molecules of pyruvate
- Glycolysis is exergonic and has two major phases:
  _Energy investment phase
  _Energy payoff phase
- The net energy yield from glycolysis, per glucose molecule is 2ATP plus 2NADH.
- No carbon is release as co2 during Glycolysis.
- Glycolysis occurs whether or not o2 is present , if O2 is present ; the chemical energy stored in pyruvate and NADH can be extracted by pyruvate oxidation and citric acid cycle and oxidative phosphorylation

Figure 9.8 The Energy Input and Output of Glycolysis

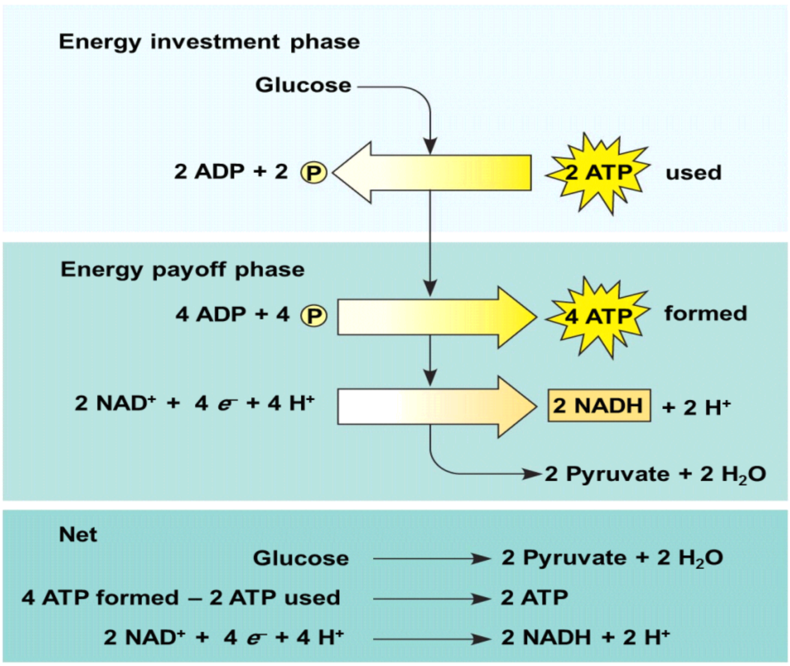
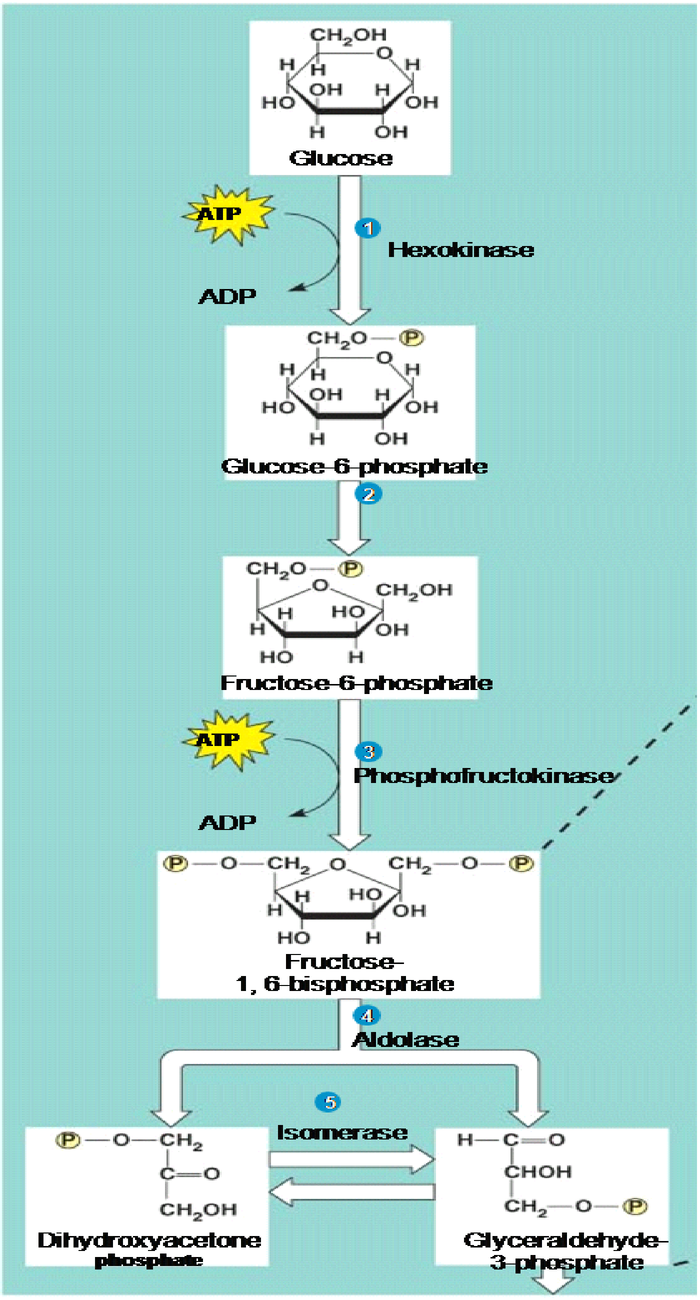


Figure 9.9 : Closer Look at Glycolysis

a) Energy Investment Phase



Explanation of figure 9.9 , step by step

1) Hexokinase transfers a phosphate group from ATP to Glucose , making it more chemically reactive The charge on the phosphate also traps the sugar in the cell.

2) Glucose-6-phosphate is converted to its isomer "Fructose-6-phosphate".

3) Phosphofructokinase Transfer a phosphate group from ATP to the opposite end of the sugar , investing a second molecule of ATP . this is a key step of regulation of glycolysis .

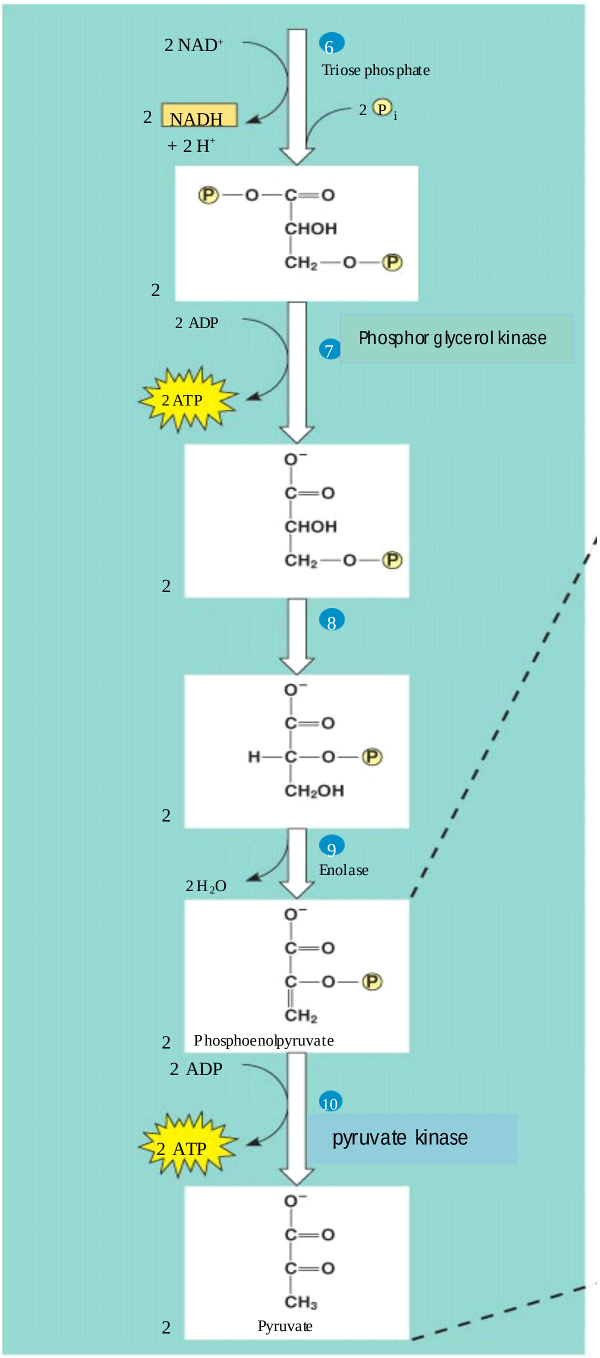
4) Aldolase cleaves the sugar molecule into two different three-carbon sugars (isomers)

5) Isomerase catalyzes the reversible conversion between the two isomers .

- This reaction never reaches equilibrium Glyceraldehyde 3-phosphate is used as the substrate of next reaction step (6) as fast as it forms .

b) Energy Payoff phase

The energy payoff phase occurs after glucose is split into two(three-carbon sugars). thus , the number (2) precedes all molecules in this phase .



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6) Triose phosphate dehydrogenase catalysis two sequential reactions . First : the sugar oxidized by the transfer of electrons to NAD+ forming NADH .
Second: the energy released from this exergonic redox reaction is used to attach a phosphate group to the oxidized substrate , making a product of very high potential energy .

7) The phosphate group added in the previous step is transferred to ADP (substrate level phosphorylation) in an exergonic reaction . this carbonyl group of a sugar has been oxidized to the carboxyl group (__COO-)
Of an organic acid
(3-phosphoglycerate) .

8)Phosphoglyceromutase relocates the remaining phosphate group .

9)Enolase causes a double bond to form in the substrate by extracting a water molecule, yielding phosphoenolpyruvate (PEP) , a compound with a very high potential energy.

10)The phosphate group is transferred from PEP to ADP
(a second example of substrate-level phosphorylation) forming Pyruvate.

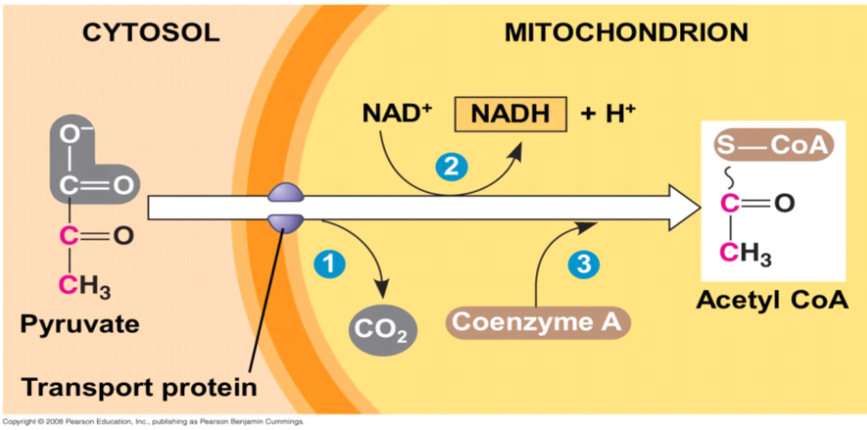
Concept 9.3: The citric acid cycle completes the energy-yielding oxidation of organic molecules

- Glycolysis releases less than a quarter of the chemical energy in glucose that can be released by cells, most of energy remains stockpiled in two molecules of pyruvate.
- If molecular oxygen is present, the pyruvate enters a mitochondrion (in eukaryotic cells) , where the oxidation of glucose is completed . (in prokaryotes cells ,this process occurs in cytosol).

v Oxidation of Pyruvate to acetyl CoA

- Upon entering the mitochondrion via active transport, pyruvate is first converted to a compound called Acetyl CoA .look to next figure

Figure (9.10) oxidation of pyruvate to acetyl CoA, the step before the citric acid cycle.



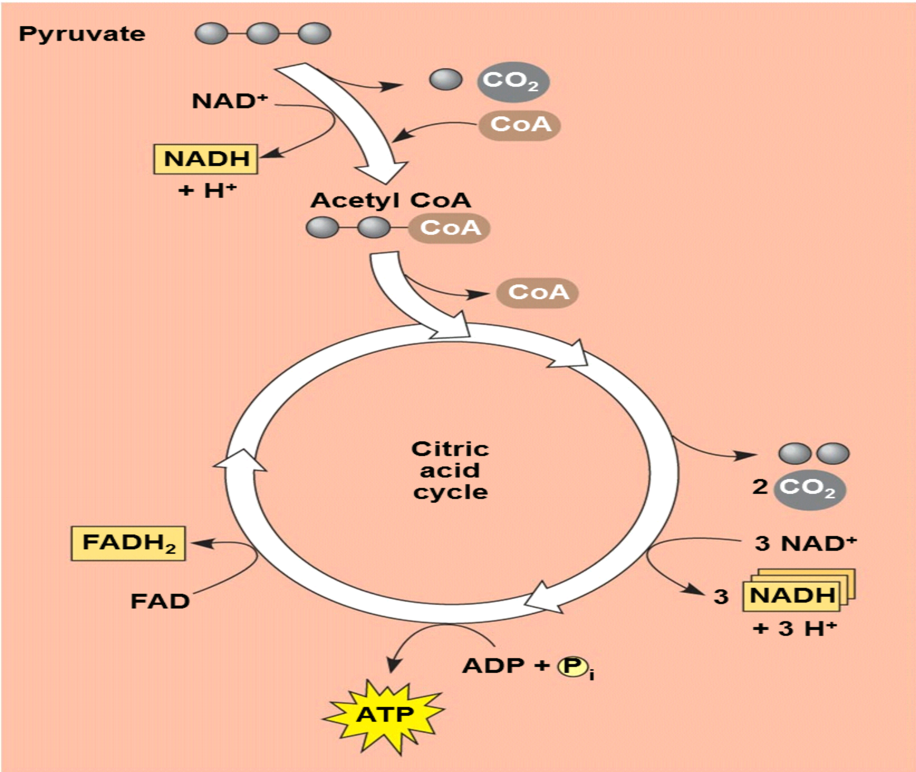
Explanation of figure 9.10

- this step ,linking glycolysis and the citric acid cycle, is carried out by a multienzyme complex that catalyzes three reactions:
  1- Pyruvate Carboxyl Group (__COO-), which is already fully oxidized and thus has a little chemical energy, will be removed and given off as a molecule of CO_2. this CO_2 is released through respiration .
  2- The remaining two carbon fragment is oxidized, forming acetate (CH_3COO^-, ionized form of acetic acid). The extracted electrons are transferred to NAD^+, storing energy in the form of NADH.
  3- Coenzyme A (CoA), a sulfur-containing compound derived from a B vitamin is attached via its sulfur atom to the acetate forming Acetyl CoA.
- The acetyl group of Acetyl CoA will enter the citric acid cycle and the CO_2 molecule will diffuse out of the cell.

V The Citric Acid Cycle

- The citric acid cycle, also called the Krebs cycle, and Tri-carboxyl cycle takes place within the mitochondrial matrix.
- The cycle functions as a metabolic furnace that oxidizes organic fuel derived from pyruvate, generating 1 ATP, 3 NADH, and 1 $FADH_2$ per turn.

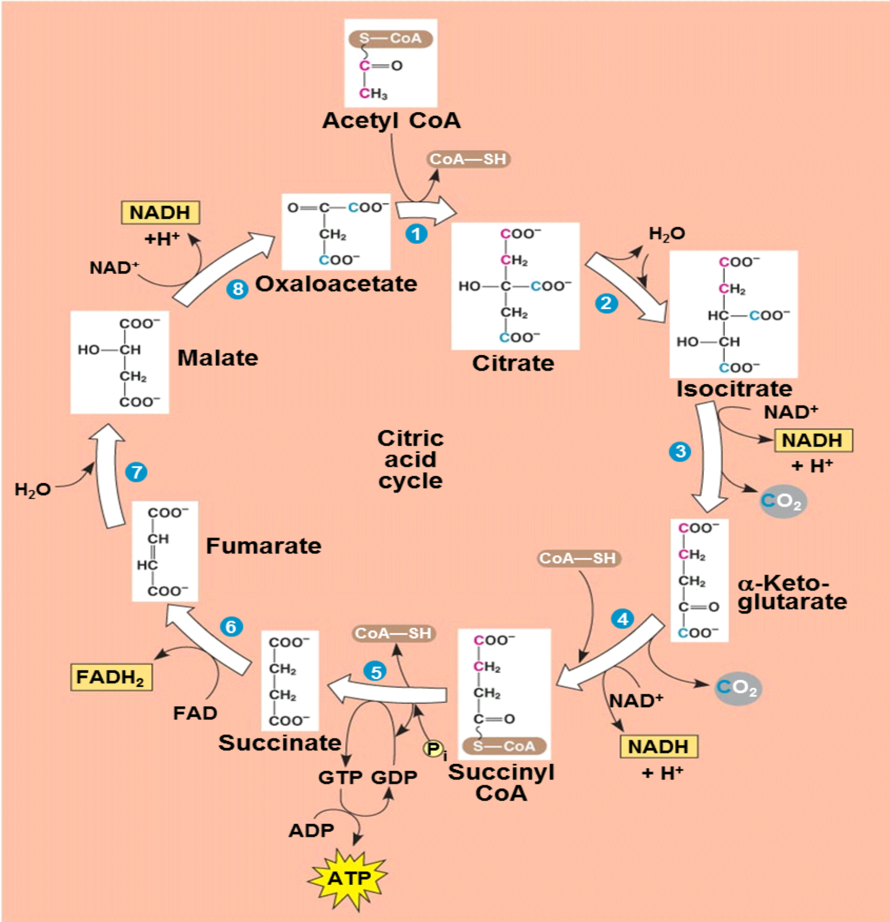
Figure 9.11 An overview of the citric acid cycle.



Note about the figure 9.11
To calculate the yield of a glucose molecule, multiply by 2 ; because each glucose molecule is split during glycolysis into two pyruvate molecules.

- The citric acid cycle has eight steps, each catalyzed by a specific enzyme.
- The acetyl group of acetyl CoA joins the cycle by combining with oxaloacetate, forming citrate(citrate is the ionized form of citric acid , because of this the cycle is named citric acid cycle).
- The next seven steps decompose the citrate back to oxaloacetate, making the process a cycle.

Figure 9.12 A closer look at the citric acid cycle



Explanation of figure 9.12

- Steps:

1- Acetyl CoA adds its two –carbon acetyl group to oxalocetate producing citrate .
2- Citrate is converted to its isomer " isocitrate" by removal of one water molecule and addition of another .
3- Isocitrate is oxidized , reducing NAD^+ to NADH . then the resulting compound loses a CO_2 molecule .
4- Another CO_2 is lost , and the resulting compound is oxidized , reducing NAD^+ to NADH , the remaining molecule is then attached to coenzyme A by an unstable bond.
5- CoA is displaced by a phosphate group, which is transferred to GDP , forming GTP , a molecule with structure and function is similar to ATP ,GTP can also be used as shown , to generate ATP . (in the cell of plants ,bacteria, and some animals tissues step 5 forms an ATP molecule directly).
6- Two hydrogens are transferred to FAD, forming $FADH_2$ and oxidizing succinate .
7- Addition of water molecule rearranges bonds in the substrate.
8- The substrate is oxidized reducing NAD^+ to NADH regenerating oxalocatate.

- Most of the ATP produced by respiration results from oxidative phosphorylation, when the NADH and $FADH_2$ produced by the citric acid cycle rely the electrons extracted from food to the electron transport chain.

Concept 9.4: during oxidative phosphorylation, chemiosmosis couples electron transport to ATP synthesis

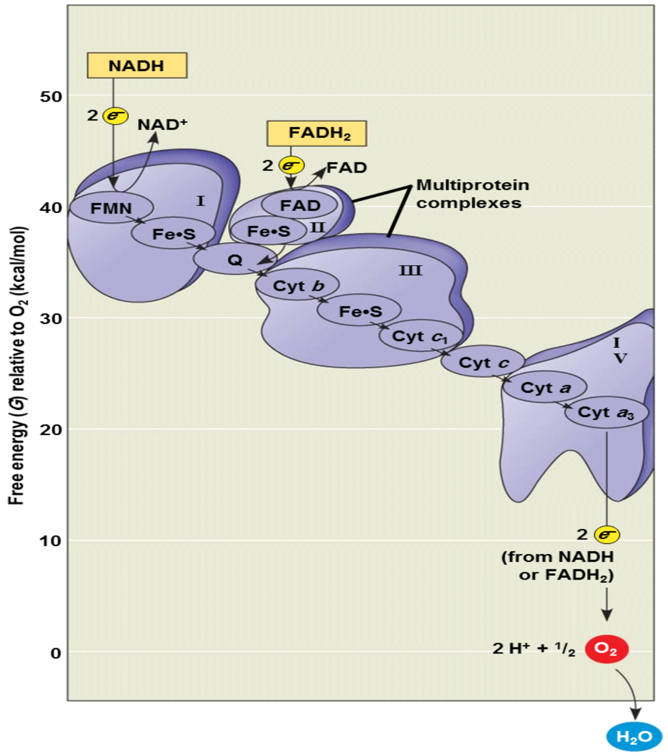
- Following glycolysis and the citric acid cycle, NADH and $FADH_2$ account for most of the energy extracted from food
- These electron escorts link glycolysis and the citric acid cycle to the machinery of oxidative phosphorylation, which uses energy released by the electron transport chain to power ATP synthesis.

v The pathway of electron transport

- The electron transport chain is a collection of molecules embedded in the inner membrane of the mitochondrion in eukaryotic cells. (inprokaryotes, these molecules reside in the plasma membrane).
- Most of the chain's components are proteins, which exist in multiprotein complexes.
- Tightly bound to these proteins are prostheticgroups, nonprotein component essential for the catalytic functions of certain enzymes.
- During electron transport along the chain, electron carries alternate between reduced and oxidized states as they accept and donate electrons.
- Each component of the chain becomes reduced when it accepts electrons from its " uphill "neighbor, which has a lower affinity for electrons (is less electronegative). It then returns to its oxidized form as it passes electrons to its "downhill ", more electronegative neighbor (more affinity for electrons).
- Electrons are transferred from NADH to the first molecule of electron transport chain in complex I.this molecule is flavoprotein, so named because it has aprosthetic group called flavin mononucleotide(FMN).
- In the next redox reaction, the flavoprotein returns to its oxidized form as it passes electrons to an iron-sulfur protein (fe.S in complex I).
- The iron-sulfur protein then passes the electron to a compound called ubiquinone. This electron carrier is a small hydrophobic molecule, the only member of the electron transport chain that is not a protein.
- ubiquinone is individually mobile within the membrane rather than residing in a particular complex .(another name of ubiquinone is coenzyme Q or CoQ)
- Most of the remaining electron transport carriers between ubiquinone and oxygen are proteins called cytochromes, there prosthetic group, called a heme group, has an iron atom that accepts and donates electrons.
- The electron transport chain has several types of cytochromes, each a different protein with a slightly different electron carrying heme group.
- The last cytochrome of the chain,cyt a3, passes its electrons to oxygen "terminal electron acceptor ",which is very electonagative "has very great affinity to electrons ".
- Each oxygen atom also picks up a pair of hydrogen ions from the aqueous solution, forming water.
- Another source of electrons for the transport chain is FADH2, the FADH2 adds its electrons to the electron transport chain from within complex II, at a lower energy level than NADH does.

- Consequently, although NADH and FADH2 each donate an equivalent number of electrons (2) for oxygen reduction, the electron transport chain provides about one-third less energy for ATP synthesis when the electron donor is FADH2 rather than NADH.
- The electron transport chain makes no ATP directly.
- The chain's function is to break the large free-energy drop from food to O_2 into smaller steps that release energy in manageable amounts.

Figure 9.13 free energy change during electron transport.



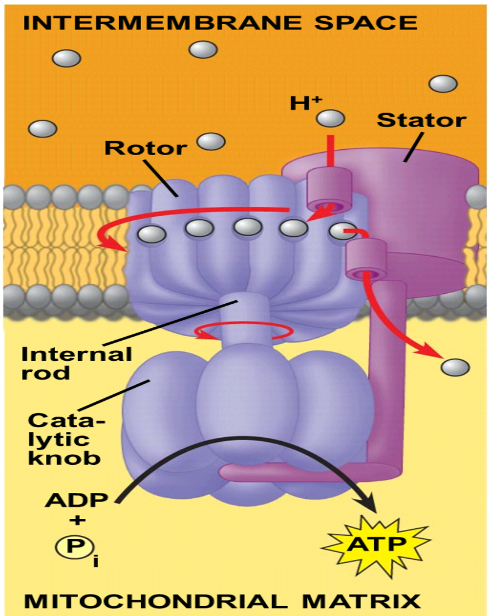
Explanation of figure 9.13

- The figure shows the sequence of electron carries in the electron transport chain and the drop in free energy as electrons travel down the chain.
- The overall energy drop (△G) for electrons traveling from NADH to oxygen is 53 Kcal/mol, but this "fall" is broken up into a series of smaller steps by the electron transport chain.

v Chemiosmosis: The Energy-Coupling Mechanism

- Electron transfer in the electron transport chain causes proteins to pump H^+ from the mitochondrial matrix to the intermembrane space.
- H^+ then moves back across the membrane, passing through channels in ATP synthase.
- Populating the inner membrane of the mitochondrion or the prokaryotic plasma membrane are many copies of a protein complex called ATP synthase, the enzyme that actually makes ATP from ADP and inorganic phosphate.
- ATP synthase works like an ion pump running in reverse.
- ATP synthase uses the exergonic flow of H^+ to drive phosphorylation of ADP.

Figure 9.14 ATP synthase, a molecular mill.



Explanation of figure 9.14

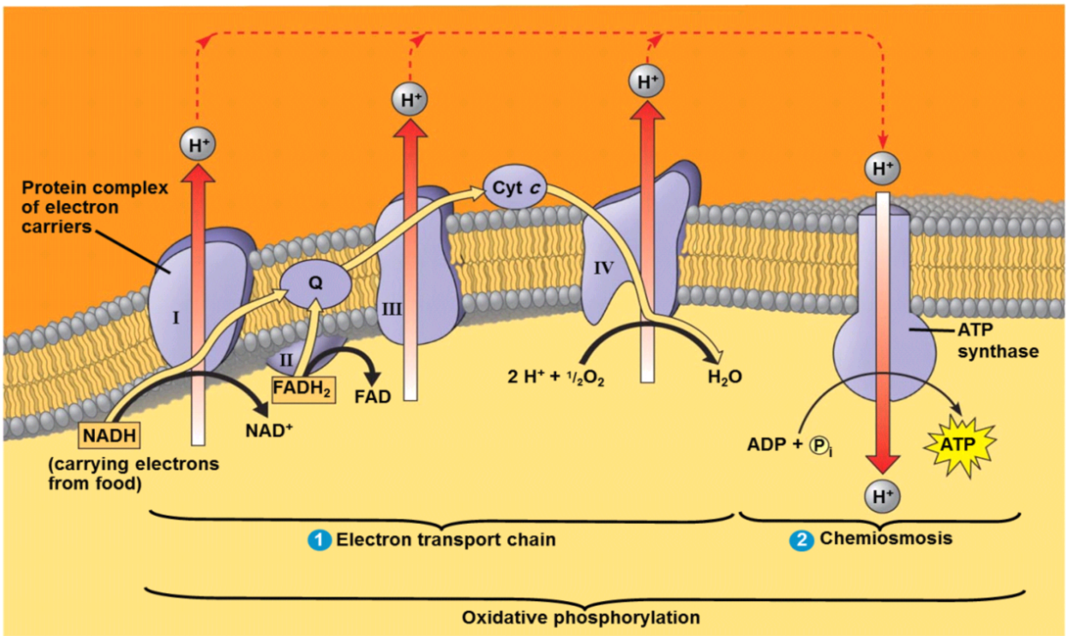
- The ATP synthase protein complex function as a mill, Powered by the flow of hydrogen ions.
- Multiple copies of this complex reside in the mitochondrial and chloroplast membranes of eukaryotes and in the plasma membranes of prokaryotes.
- Each of the four parts of ATP synthase consists of a number of polypeptide subunits.
- Steps:

1) H+ ion s flowing down their gradient enter a half channel in a stator, which is anchored in the membrane.

2) H+ ions move one by one into binding sites within a rotor, changing the shape of each subunit so that the rotor spins within the membrane.
3) Each H+ ion makes one complete turn before leaving the rotor and passing through a second half channel in the stator into the mitochondrial matrix.
4) Spinning of the rotor causes an internal rod to spin as well. This rod extends like a stalk into the knob below it, which is held stationary by a part of the stator.
5) Turning of the rod activates catalytic sites in the knob that produce ATP from ADP and inorganic phosphate group.

- The energy for gradient formation comes from exergonic redox reactions, and ATP synthesis is the work performed.
- The energy stored in a H^+ gradient across a membrane couples the redox reactions of the electron transport chain to ATP synthesis.

Figure 9.15 chemiosmosis couples the electron transport chain into ATP synthesis.



Explanation of figure 9.15

1) NADH and FADH2 shuttle high energy electrons extracted from food during glycolysis and the citric acid cycle into an electron transport chain. The gold arrows trace the transport of electrons, which finally pass the oxygen at the "downhill" end of the chain, forming water. There are two mobile carriers in the electron transport chain, ubiquinone (Q) and cytochrome c (Cyt c), move rapidly, ferrying electrons between the large complexes. As complexes I, III and IV accept and then donate electrons, they pump protons from the mitochondrial matrix into the intermembranespace. (in prokaryotes, protons are pumped outside the plasma membrane).Note that the chain is an energy converter that uses the exergonic flow of electrons from NADH and FADH2 to pump H+across the membrane. Note that FADH2 deposits its electrons via complex II and so results in fewer protons being pumped into the intermembrane space than occurs with NADH. Chemical energy originally harvested from food is transformed into a proton-motive force, a gradient of H+ across the membrane.

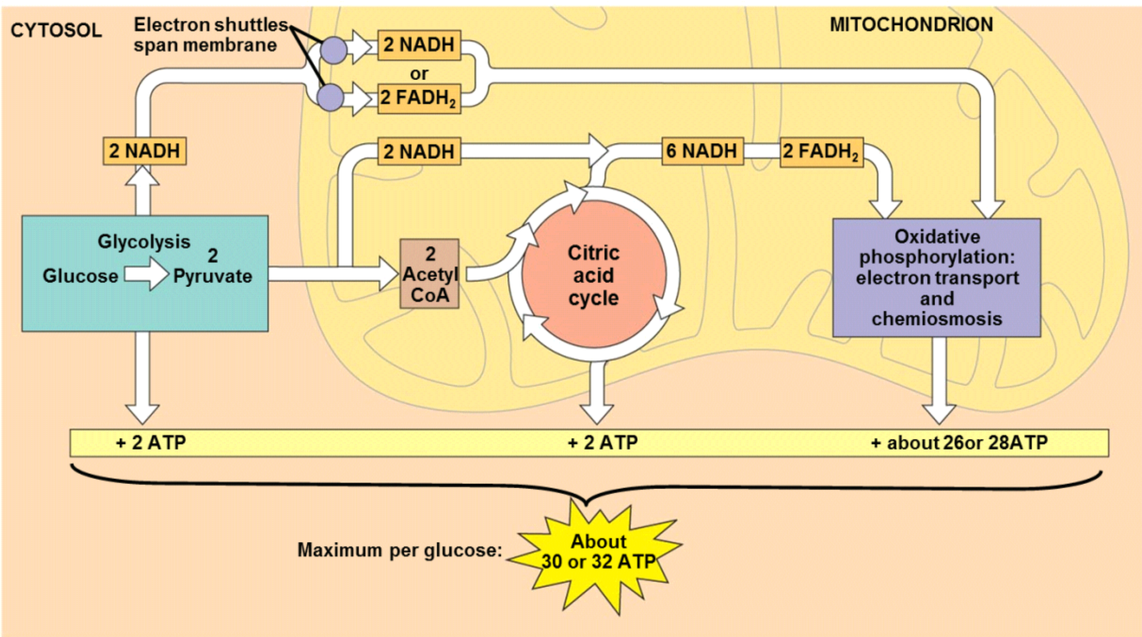
2) During chemiosmosis, the protons flow back down their gradient via ATP synthase, which is built into the membrane nearby. The ATP synthase harnesses the proton-motive force to phosphorylate ADP, forming ATP. Together, electron transport and chemiosmosis make up oxidative phosphorylation.

v An Accounting of ATP Production by Cellular Respiration

- During respiration most energy flows in this sequence: - glucose à NADH à Electron transport chain à proton-motive force à ATP.
- A single molecule of NADH generates enough proton-motive force for the synthesis of 2.5 ATP.
- Since FADH2 electrons enter later in the chain, each molecule of this electron carrier is responsible for transport of only enough H+ for the synthesis of 1.5 ATP.

- The ATP yield varies slightly depending on the type of shuttle used to transport electrons from the cytosol into the mitochondrion.
- The mitochondrial inner membrane is impermeable to NADH, so NADH in the cytosol is segregated from the machinery of oxidative phosphorylation.
- The 2 electron of NADH captured in glycolysis must be conveyed into the mitochondrion by one of several electron shuttle systems. Depending on the kind of shuttle in a particular cell type, the electrons are passed either to NAD+ or to FAD in the mitochondrial matrix.
- If the electrons are passed to FAD, only about 1.5 ATP can result from each NADH that was originally generated in the cytosol.
- If the electrons are passed to mitochondrial NAD+, the yield is about 2.5 ATP per NADH.
- One glucose molecule could generate a maximum of 28 ATP produced by oxidative phosphorylation plus 4 ATP(net) from substrate-level phosphorylation to give a total yield of about 32 ATP (or only about 30 ATP if the less efficient shuttle were functioning).
- Remember that the complete oxidation of a mole of glucose releases 686 Kcal of energy under standard conditions (ΔG= -686 Kcal/mol).
- Phosphorylation of ADP to form ATP stores at least 7.3 Kcal per mole of ATP.
- About 34% of the potential chemical energy in glucose has been transferred to ATP; (the actual percentage is probably higher because ΔG is lower under cellular conditions).The rest of energy stored in glucose is lost at heat.

Figure 9.16 ATP yield per molecule of glucose at each stage of cellular respiration.



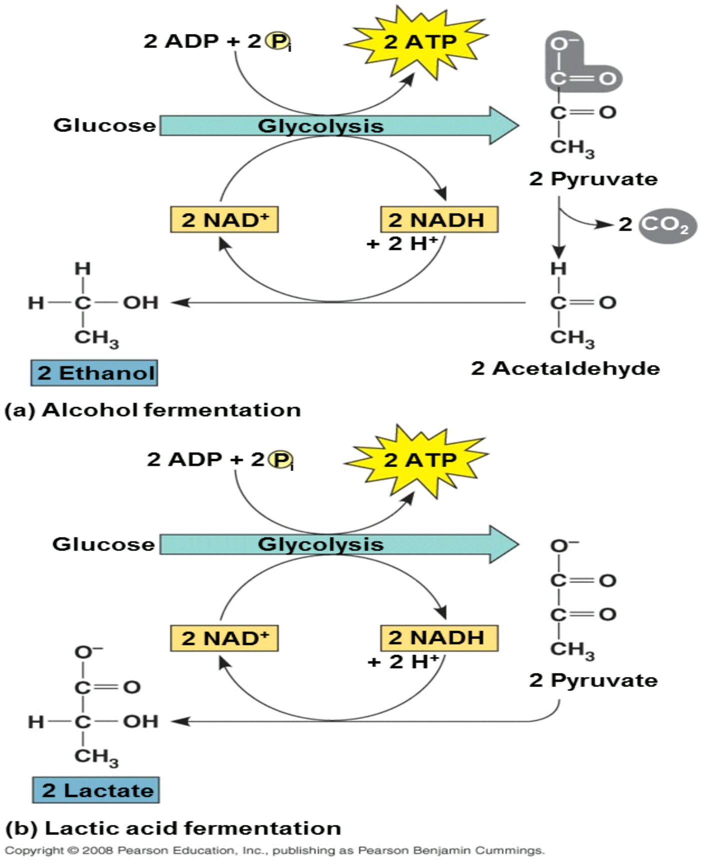
Concept 9.5: Fermentation and anaerobic respiration enable cells to produce ATP without the use of oxygen

- Most cellular respiration requires O_2 to produce ATP
- Glycolysis can produce ATP with or without O_2 (in aerobic or anaerobic conditions)
- In the absence of O_2, glycolysis couples with fermentation or anaerobic respiration to produce ATP
- Anaerobic respiration uses an electron transport chain with an electron acceptor other than O_2, for example sulfateion(SO_4^{-2}) ,and H_2S (hydrogen sulfide) is produced as a by-product rather than water
- Fermentation uses phosphorylation instead of an electron transport chain to generate ATP
- Fermentation is a way of harvesting chemical energy without using either oxygen or any electron transport chain

v Type of Fermentation

- Fermentation consist of glycolysis plus reactions that regenerate NAD^+ by transferring electrons from NADH to pyruvate or derivatives of pyruvate.The NAD^+ can then be reused to oxidize sugar by glycolysis ,which net tow molecules of ATP by substrate level phosphorylation.
- Two common types are alcohol fermentation and lactic acid fermentation.
- In alcohol fermentation, pyruvate is converted to ethanol(ethyl alcohol) in two steps:
  -The first step releases carbon dioxide from the pyruvate, which is converted to the two-carbon compound acetaldehyde.
  -In the second step , acetaldehyde is reduced by NADH to ethanol. This regenerates the supply of NAD^+ needed for the continuation of glycolysis.
- Many bacteria carry out alcohol fermentation.
- Yeast (a fungus) also carries out alcohol fermentation
- Alcohol fermentation by yeast is used in brewing, winemaking, and baking
- During lactic acid fermentation, pyruvate is reduce directly by NADH to form lactic as an end product , with no release of CO_2 . (lactate is the ionized form of lactic acid)
- lactic acid fermentation by certain fungi and bacteria is used in the dairy industry to make cheese and yogurt.
- Human muscle cells make ATP by lactic acid fermentation when oxygen is scare.

Figure 9.17 fermentation



Explanation of figure 9.17

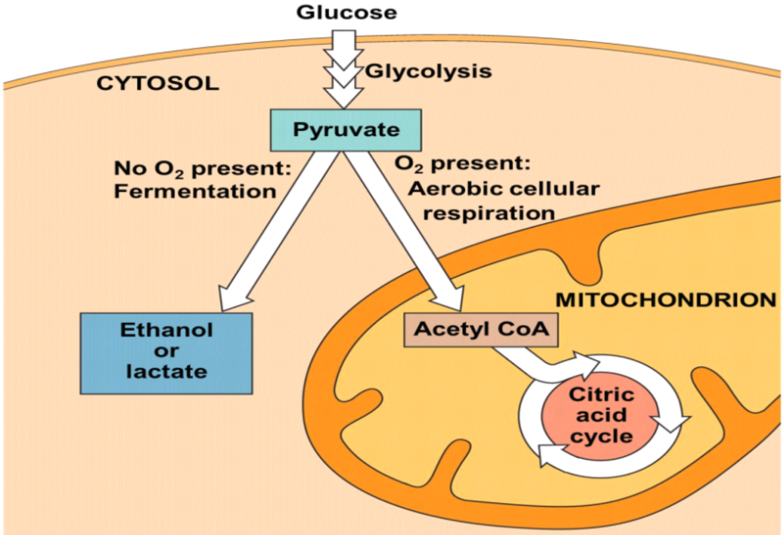
- Pyruvate, the end product of glycolysis ,serves as an electron acceptor for oxidizing NADH back to NAD^+ ,which can then be reused in glycolysis.

Comparing fermentation with Anaerobic and Aerobic respiration

- Fermentation, anaerobic respiration ,and aerobic respiration are three alternative cellular pathways for producing ATP by harvesting chemical energy of food .
- All three use glycolysis to oxidize glucose and other organic fuels to pyruvate,and in all three pathways , NAD^+ is the oxidizing agent that accepts electrons from food during glycolysis .
- A key difference among the three pathways is the contrasting mechanisms for oxidizing NADH back to NAD^+, which is required to sustain glycolysis.
- In fermentation, the final electron acceptor is an organic molecules such as pyruvate (lactic acid fermentation) Or acetaldehyde (alcohol fermentation).
- In aerobic respiration , the final electron acceptor is oxygen; in anaerobic respiration , the final acceptor is another molecule that is electronegative (although invariably less so than oxygen).
- passage of electrons from NADH to the electron transport chain regenerates "recycled" the NAD^+ required for glycolysis .

- aerobic respiration yields up to 16 times as much ATP per glucose molecule as dose fermentation---up to 32 molecules of ATP for respiration ,compared with 2 molecules of ATP for fermentation.
- obligate anaerobic,carry out only fermentation or anaerobic respiration. In fact, these organisms cannot survive in the presence of oxygen
- A few cell types, can carry out only aerobic oxidation of pyruvate, not fermentation.
- Yeast and many bacteria are facultative anaerobes, meaning that they can survive using either fermentation or cellular respiration
- In a facultative anaerobe, pyruvate is a fork in the metabolic road that leads to two alternative catabolic routes

Figure 9.18 pyruvate as a key juncture in catabolism



Explanation of figure 9.18

- In a facultative anaerobic or a muscle cell , which are capable of both aerobic cellular respiration and fermentation,pyruvate is committed to one of those two pathways ,usually depending on whether or not oxygen is present .

v The Evolutionary Significance of Glycolysis

- Glycolysis occurs in nearly all organisms
- G lycolysis probably evolved in ancient prokaryotes before there was oxygen in the atmosphere
- Early prokaryotes may have generated ATP exclusively from glycolysis.
- Glycolysis does not require any of the membrane bounded organelles of the eukaryotic cell.

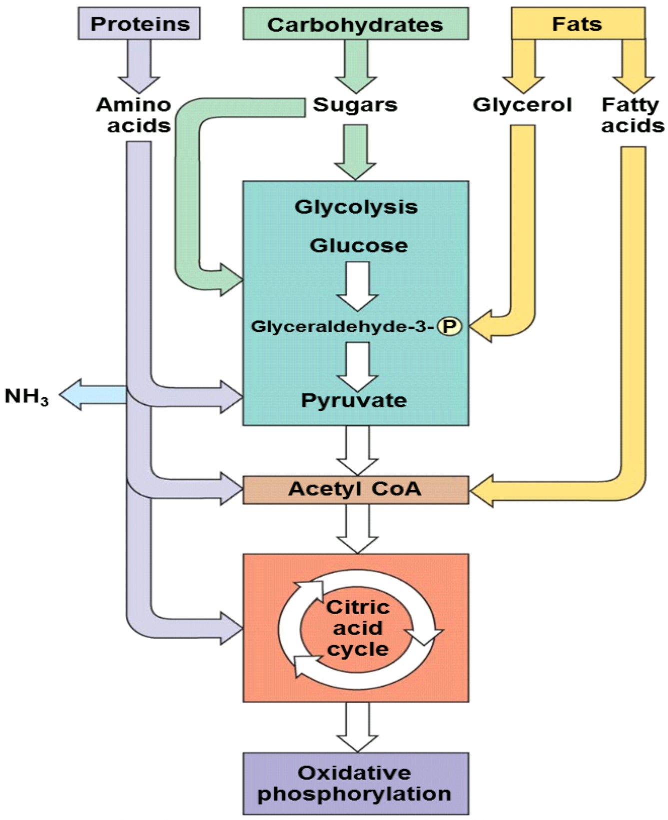
Concept 9.6: Glycolysis and the citric acid cycle connect to many other metabolic pathways

- Glycolysis and the citric acid cycle are major intersections of the cell's catabolic and anabolic (biosynthetic) pathways.

v The Versatility of Catabolism

- Catabolic pathways funnel electrons from many kinds of organic molecules into cellular respiration
- Glycolysis accepts a wide range of carbohydrates
- The digestion of disaccharides, including sucrose, provides glucose and other monosaccharides as fuel of respiration.
- Proteins can also be used for fuel, but first they must be digested to their constituent amino acids. Amino acids presents in excess are converted by enzymes to intermediates of Glycolysis and the citric acid cycle.
- Before amino acids can feed into Glycolysis or the citric acid cycle, their amino groups must be removed, a process called deamination. The nitrogenous refuse is excreted from the animal in the form of ammonia (NH3), urea, or other waste products.
- Fats are digested to glycerol and fatty acids, the glycerol is converted to glyceraldehyde 3-phosphate, an intermediate of Glycolysis.
- Most of the energy of a fat is stored in the fatty acids.
- A metabolic sequence called beta oxidation breaks the fatty acids down to two-carbon fragments, which enter the citric acid cycle as acetyl CoA.
- NADH and FADH2 are also generated during beta oxidation; they can enter the electron transport chain, leading to further ATP production.
- A gram of fat oxidized by respiration produces more than twice as much ATP as a gram of carbohydrate.

Figure 9.19 the catabolism of various molecules from food



Explanation of figure 9.19

- Fats, carbohydrates and proteins enter Glycolysis or the citric acid cycle at various points. Glycolysis and the citric acid cycle are catabolic funnels through which electrons from all kinds of organic molecules flow on their exergonic fall to oxygen.

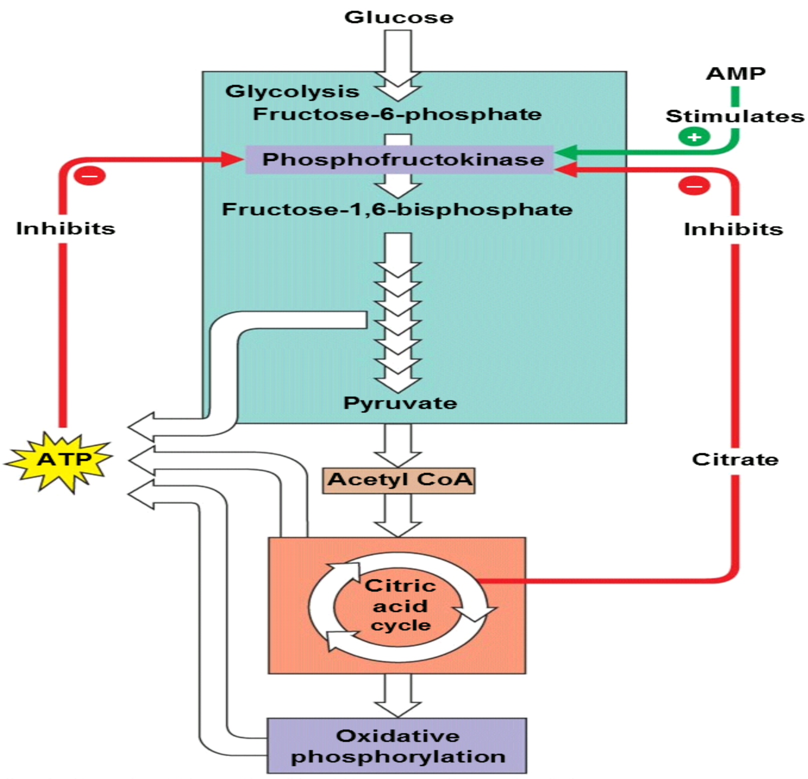
v Biosynthesis (Anabolic pathways)

- Cells need substance "to build other substances "as well as energy.
- Not all the organic molecules of food are destined to be oxidized as fuel to make ATP.
- The body uses small molecules to build other substances
- These small molecules may come directly from food, from glycolysis, or from the citric acid cycle
- Glucose can be made from pyruvate, and fatty acids can be synthesized from acetyl CoA.
- These anabolic , or biosynthetic, pathways do not generate ATP , but instead consume it.
- In addition, Glycolysis and the citric acid cycle function as metabolic interchanged that enable our cells to convert some kinds of molecules to others as we need them. For example, an intermediate compound generated during Glycolysis, dihydroxyacetone phosphate, can be converted to one of the major precursors of fats.

v Regulation of cellular respiration via feedback mechanisms

- Basic principles of supply and demand regulate the metabolic economy,The cell does not waste energy making more of a particular substance than it needs.
- The most common mechanism for this control is feedback inhibition.
- The cell also controls its catabolism, If the cell is working hard and its ATP concentration begins to drop, respiration speeds up, When there is plenty of ATP to meet demand, respiration slows down.

Figure 9.20 the control of cellular respiration



Explanation of figure 9.20

- Allosteric enzymes at certain points in the respiratory pathway respond to inhibitors and activators that help set the pace of Glycolysis and the citric acid cycle.
- Phosphofructokinase, which catalyzes an early step in Glycolysis, is one such enzyme. It is stimulated by AMP (derived from ADP) but is inhibited by ATP and by citrate (first product of the citric acid cycle).
- notice that If citrate accumulates in mitochondria, some of it passes into the cytosol and inhibits phosphofructokinase, so the Glycolysis slows down, and the supply of acetyl groups to the citric acid cycle decreases. if citrate consumption increases; Glycolysis accelerates.
- Notice that by controlling the rate of step.3 in Glycolysis which in it phosphofructokinase enzyme work, the cell can speed up or slow down the entire catabolic process. Phosphofructokinase can thus be considered the pacemaker of respiration.
- This feedback regulation adjusts the rate of respiration as the cell's catabolic and anabolic demands change