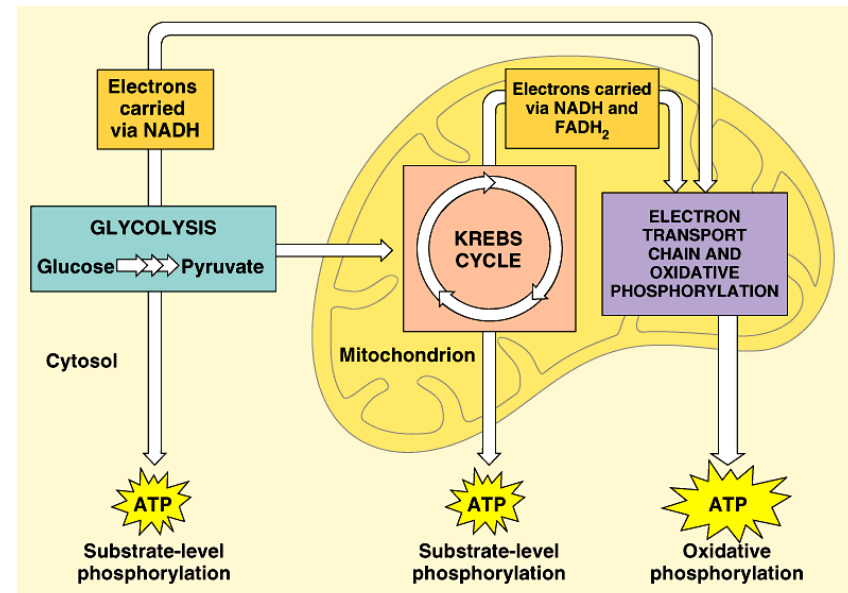


BI107 CHAP 9A

Cellular Respiration

3 Stages of Cellular Respiration

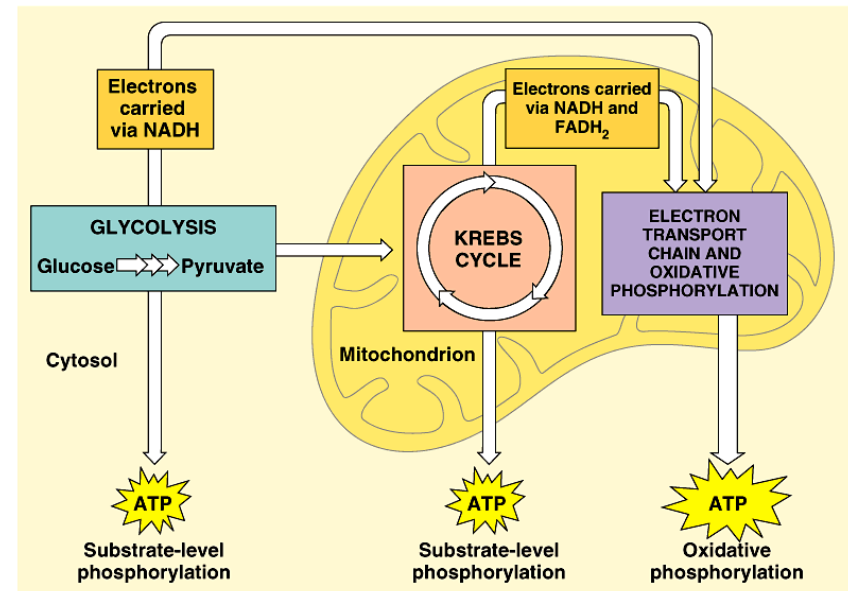
- 3 metabolic stages to cellular respiration –
 - 1) glycolysis
 - 2) Krebs cycle
 - 3) electron transport
- Overview – 1st 2 stages, glycolysis & Krebs cycle, are catabolic pathways decomposing glucose & other organic fuels



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Overview cont.

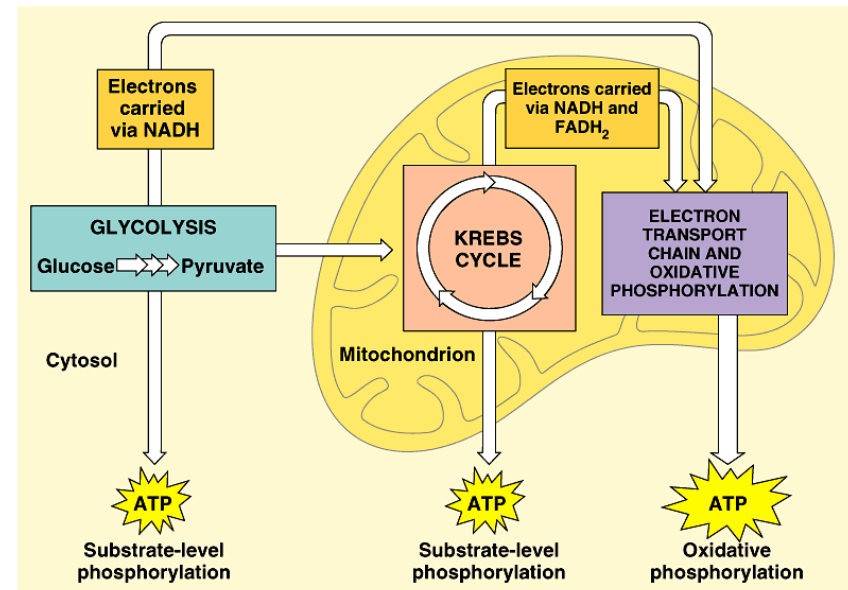
- Glycolysis – occurs in cytoplasm & breaks glucose into 2 molecules of pyruvic acid
- Krebs cycle – occurs in mitochondrial matrix & breaks down a derivative of pyruvic acid to carbon dioxide – so carbon dioxide produced represents fragments of oxidized organic molecules



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Overview cont.

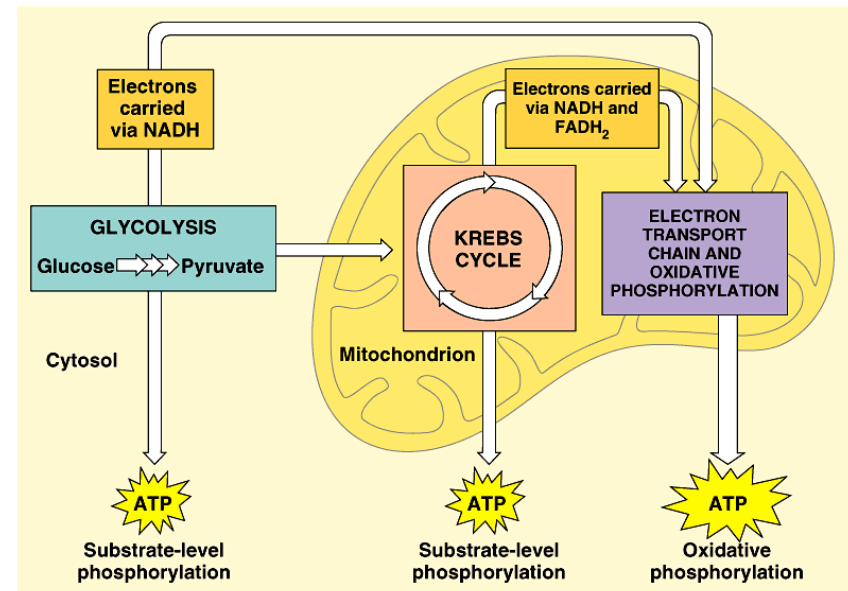
- Some steps of glycolysis & Krebs cycle are redox reactions where dehydrogenase enzymes transfer electrons from substrates to NAD^+ to form NADH



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Overview cont.

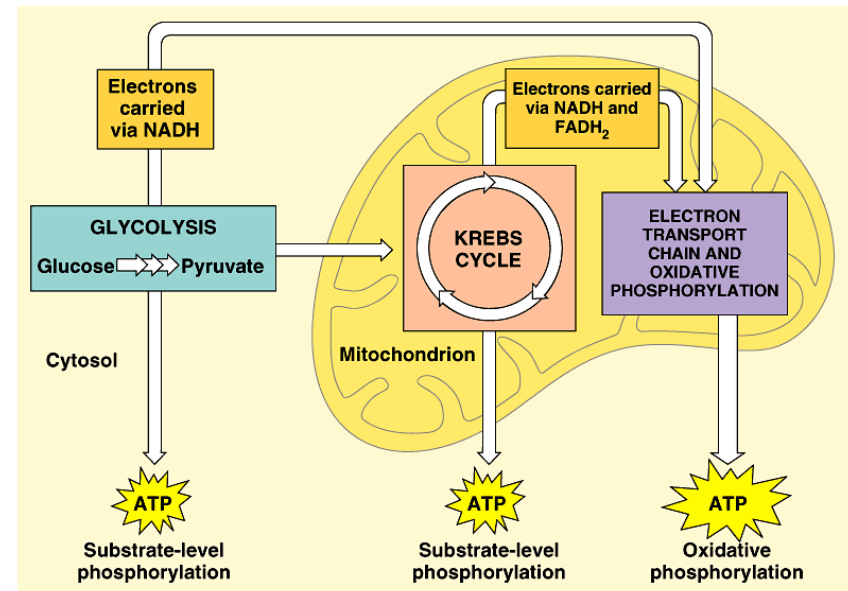
- Electron transport chain accepts electrons from breakdown products of 1st 2 stages (via NADH) & passes electrons from molecule to molecule until at end of chain electrons combine with oxygen to form water
- Energy released at each step stored in a form mitochondria can use to make ATP & process called oxidative phosphorylation since powered by redox reactions that transfer electrons from food to oxygen



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Overview cont.

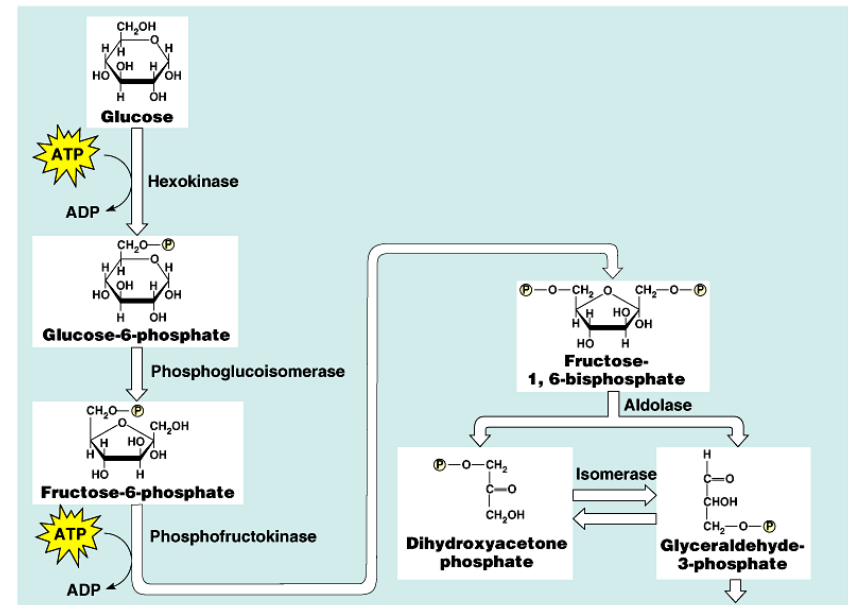
- Electron transport & oxidative phosphorylation occur in inner mitochondrial membrane & produces 90% of ATP generated while 10% of ATP made by substrate level phosphorylation where an enzyme transfers a phosphate group from substrate molecule to ADP to form ATP



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Glycolysis

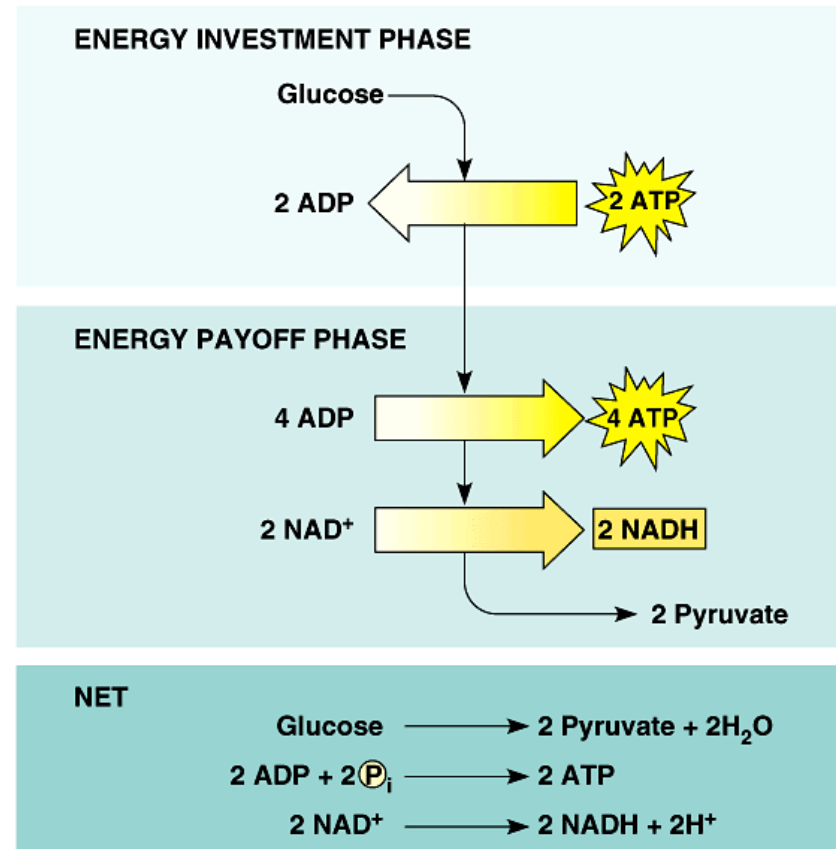
- 6 carbon glucose molecule split into 2 3-carbon sugars which are oxidized & molecules rearranged to form 2 molecules of pyruvate (ionized form of pyruvic acid)
- 10 steps each catalyzed by a specific enzyme



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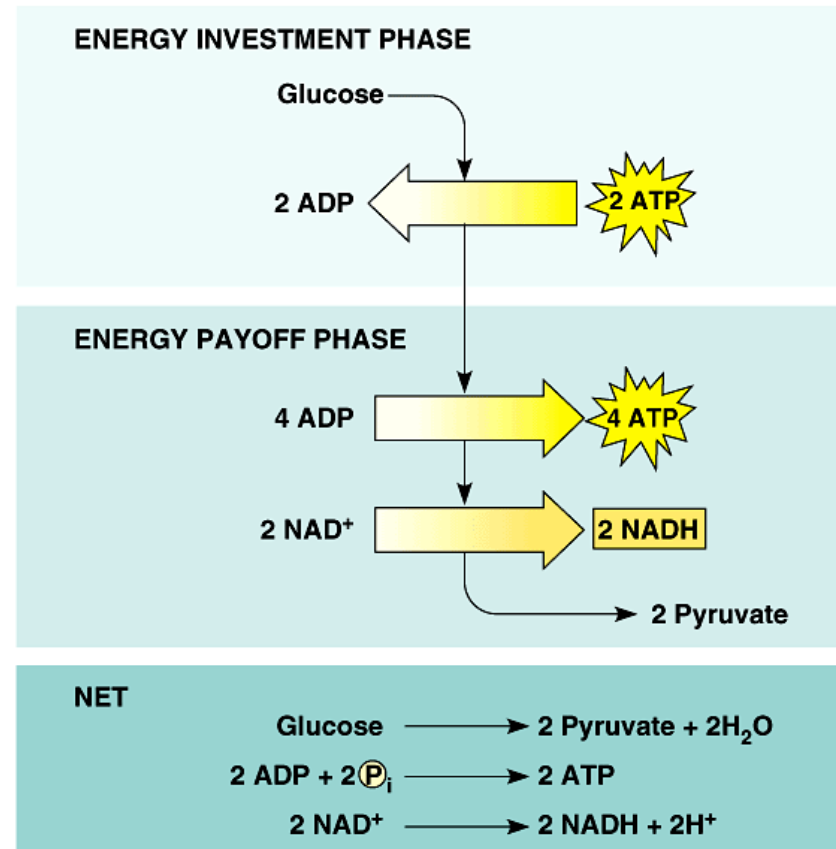
Glycolysis cont.

- Divided into 2 phases – energy investment phase & energy payoff phase
- energy investment phase contains 1st 5 steps – cell uses ATP to phosphorylate food molecules



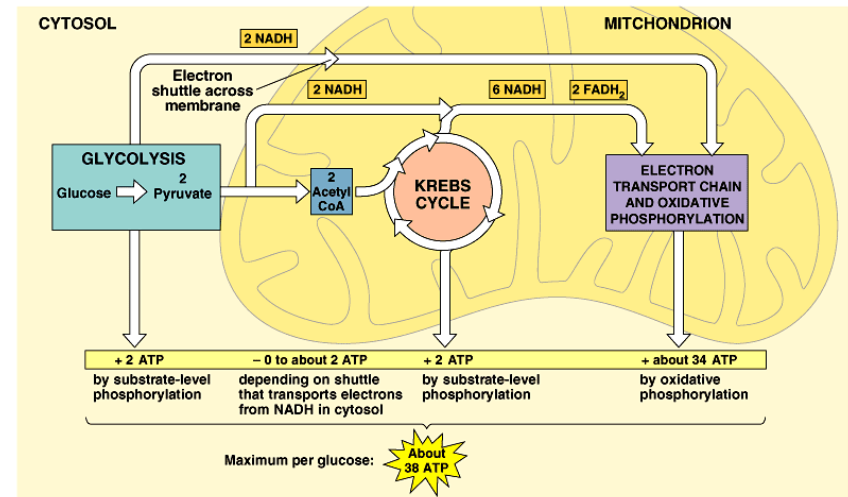
Glycolysis cont.

- During energy payoff phase ATP produced by substrate level phosphorylation & NAD⁺ reduced to NADH by oxidation of food with net energy yield per glucose molecule – 2 ATP & 2 NADH



Glycolysis cont.

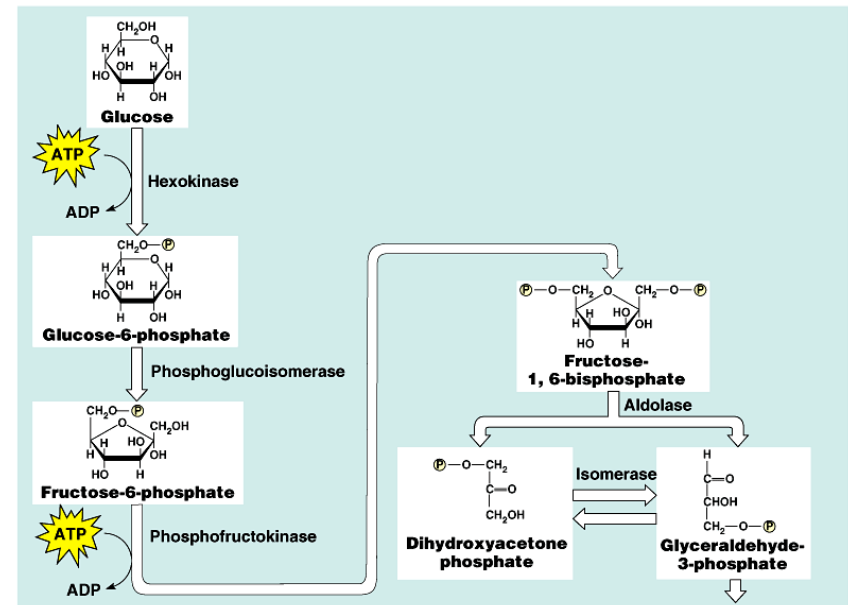
- All carbons originally in glucose now in pyruvic acid & no CO_2 released during glycolysis & no O_2 used so glycolysis occurs whether oxygen is or is not present but if it is present then energy stored in NADH can be converted to ATP by electron transport chain & oxidative phosphorylation & chemical energy in pyruvic acid extracted by Krebs cycle



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Glycolysis cont.

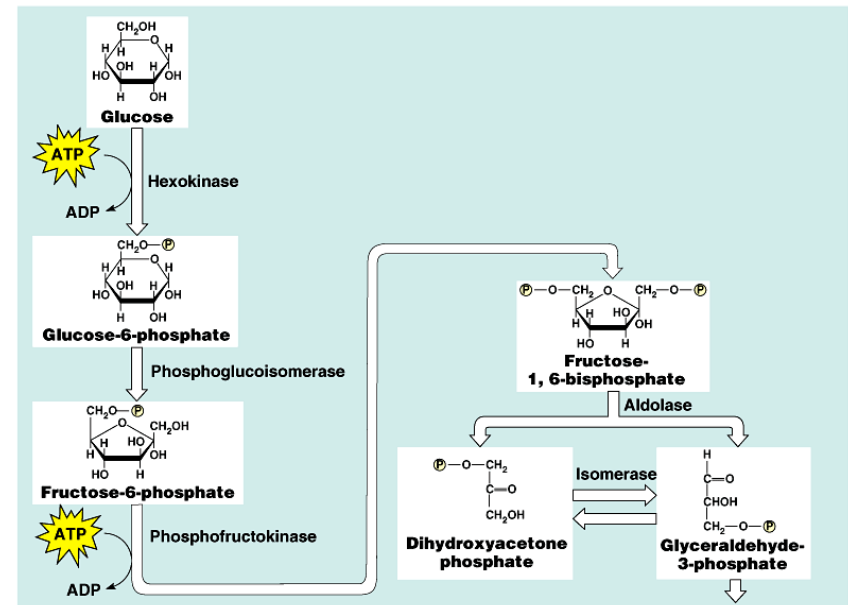
- Glucose enters & is phosphorylated to G-6-P by hexokinase
- G-6-P rearranged to isomer fructose-6-P by phosphoglucose isomerase
- Fructose-6-P gets a 2nd phosphate from ATP due to activity of phosphofructokinase forming fructose-1,6 bisphosphate



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Glycolysis cont.

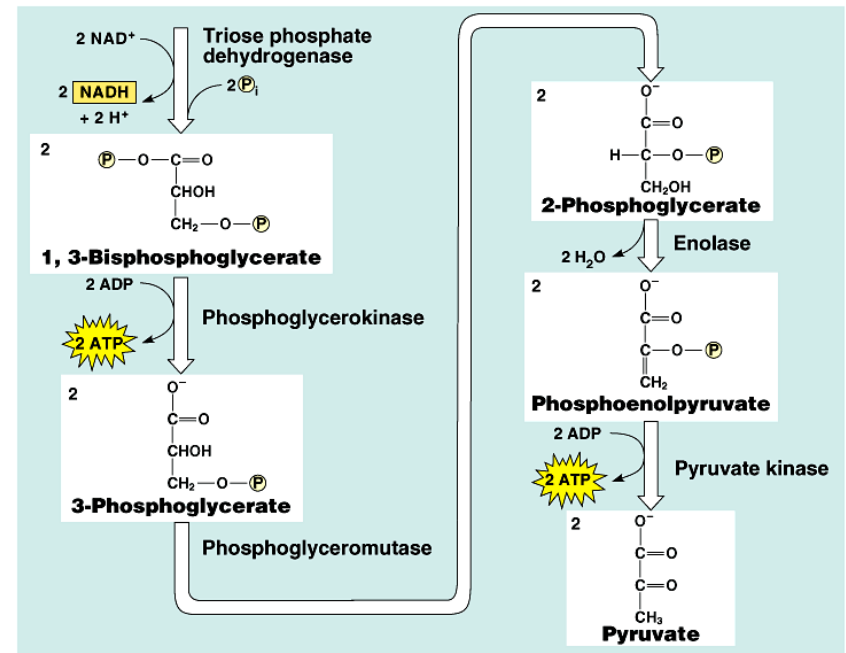
- Fructose 1,6 bisphosphate is cleaved into 2 different 3-carbon sugars: G-3-P and dihydroacetone – P and an isomerase converts reversible interchange



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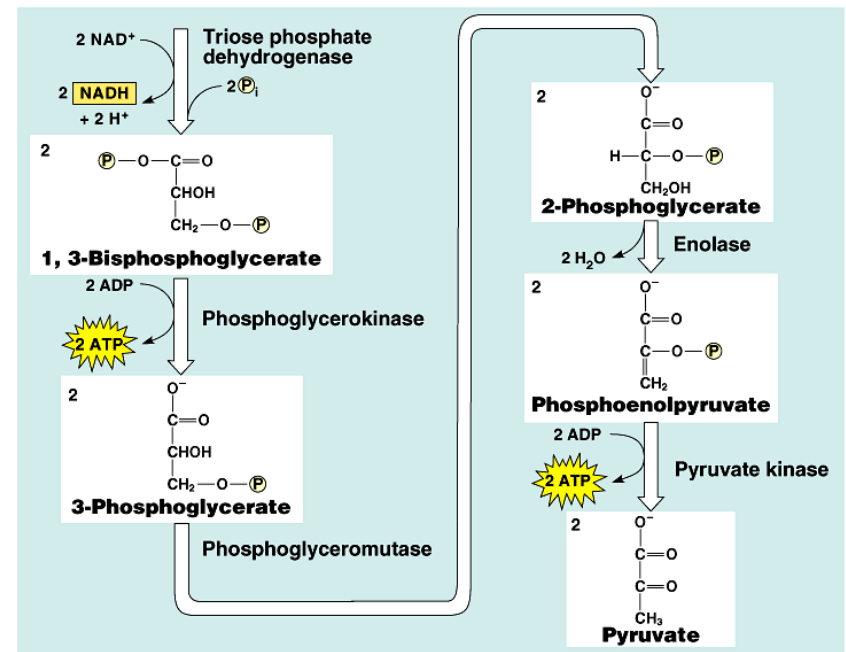
Glycolysis cont.

- In 1st step of energy payoff phase G-3-P removed by next enzyme, triose phosphate dehydrogenase forming 1,3 bisphosphoglycerate which is acted upon by phosphoglycerokinase to form 3-Phosphoglycerate generating ATP in the process



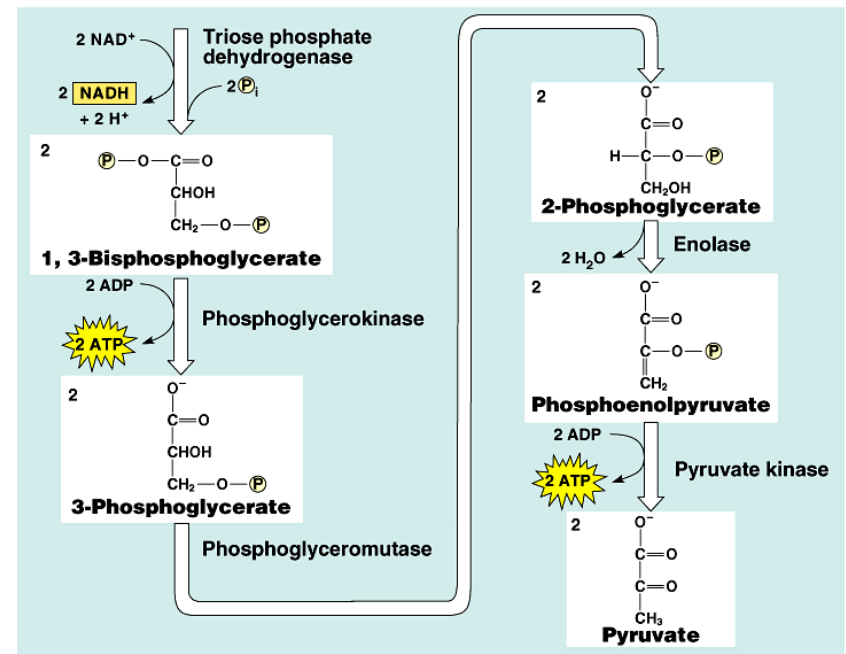
Glycolysis cont.

- Phosphate group rearranged to form 2-phosphoglycerate which is acted on by enolase to form phosphoenolpyruvate which is acted on by pyruvate kinase to form pyruvate with formation of more ATP



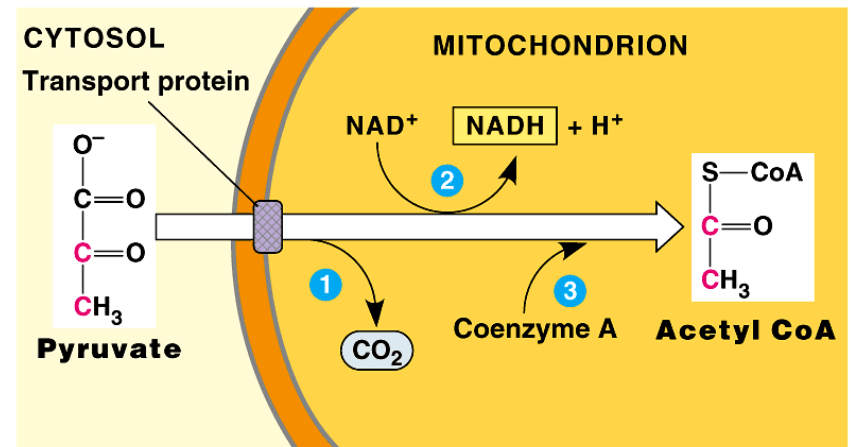
Glycolysis cont.

- Kinase enzymes are involved in ATP formation or use
- Dehydrogenases are used to remove hydrogen ions and form NADH from NAD⁺



Krebs Cycle

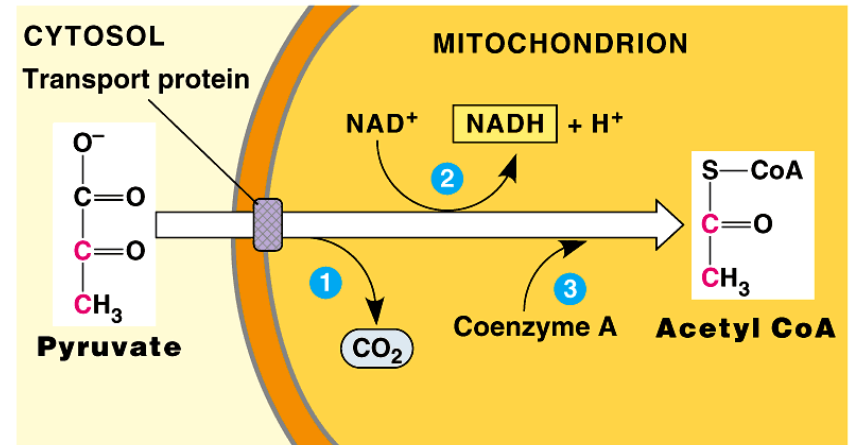
- If molecular oxygen is present the pyruvate, still containing most of the potential energy in the glucose molecule, enters mitochondria where enzymes of Krebs cycle complete the oxidation



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Krebs cycle cont.

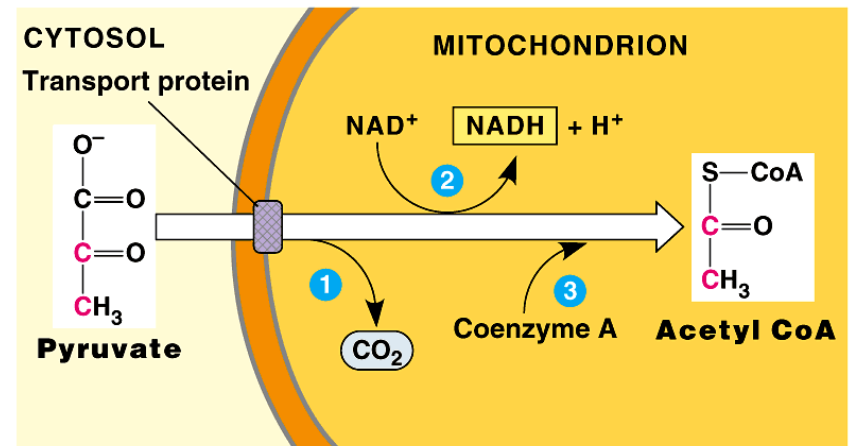
- Pyruvate 1st converted to acetyl coenzyme A or acetyl- CoA
- Takes 3 reactions using a multienzyme complex 1) pyruvate's carboxyl group is fully oxidized & is removed as CO₂. 2) 2 carbon fragment oxidized to form acetate while NADH is formed



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Krebs cycle cont.

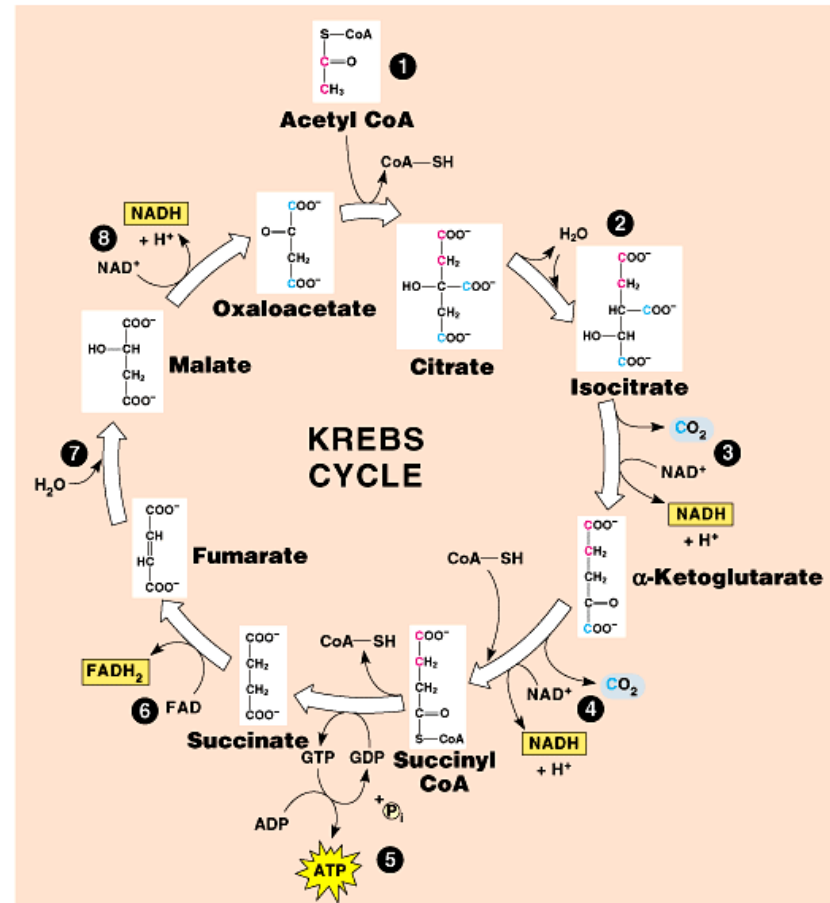
- 3) coenzyme A, a sulfur containing derivative of a B vitamin, is attached to acetate making acetyl group very reactive & acetyl-CoA enters Krebs cycle



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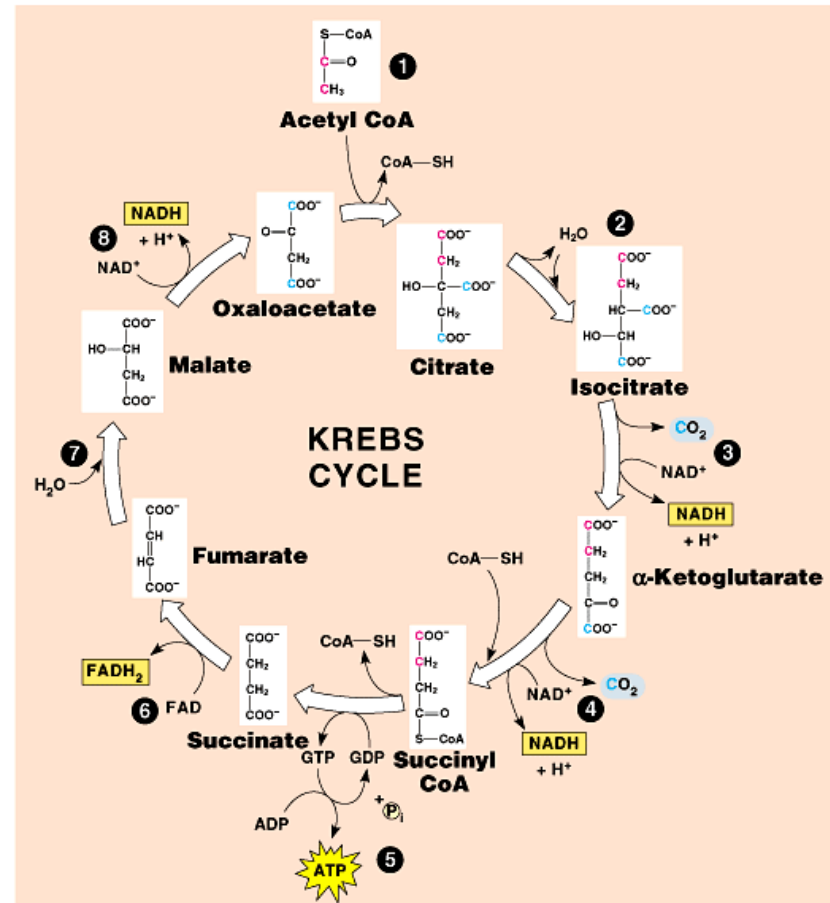
Krebs cycle cont.

- Cycle has 8 steps each catalyzed by a specific enzyme
- For each turn of cycle 2 carbons enter as acetate & 2 different carbons exit as CO_2
- Acetyl CoA 1st joined to oxaloacetate to form citrate then rest of cycle is used to reform oxaloacetate



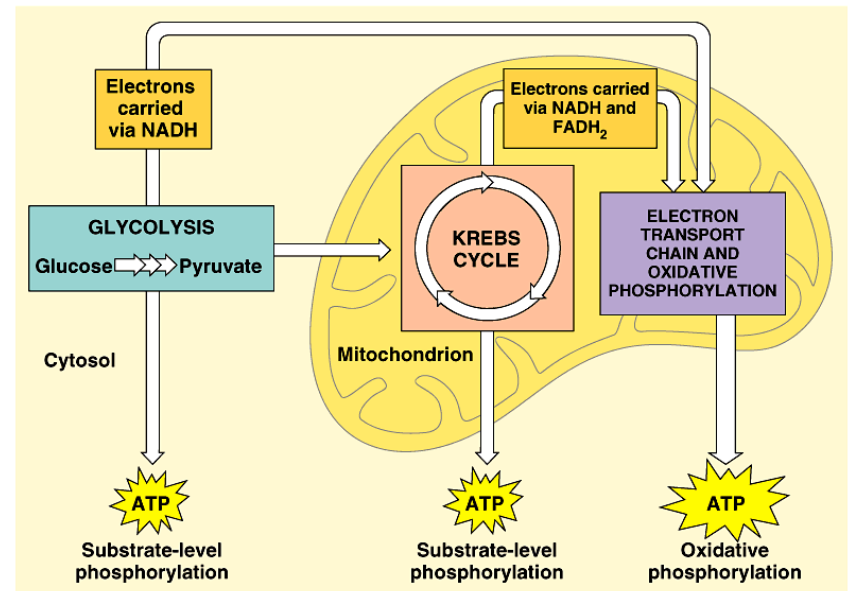
Krebs cycle cont.

- For each acetate that enters the cycle, 3 NAD⁺ are reduced to NADH & in 1 step electrons are transferred to FAD to form FADH₂ – a similar electron carrier
- ATP is formed from GTP by substrate level phosphorylation



Electron transport

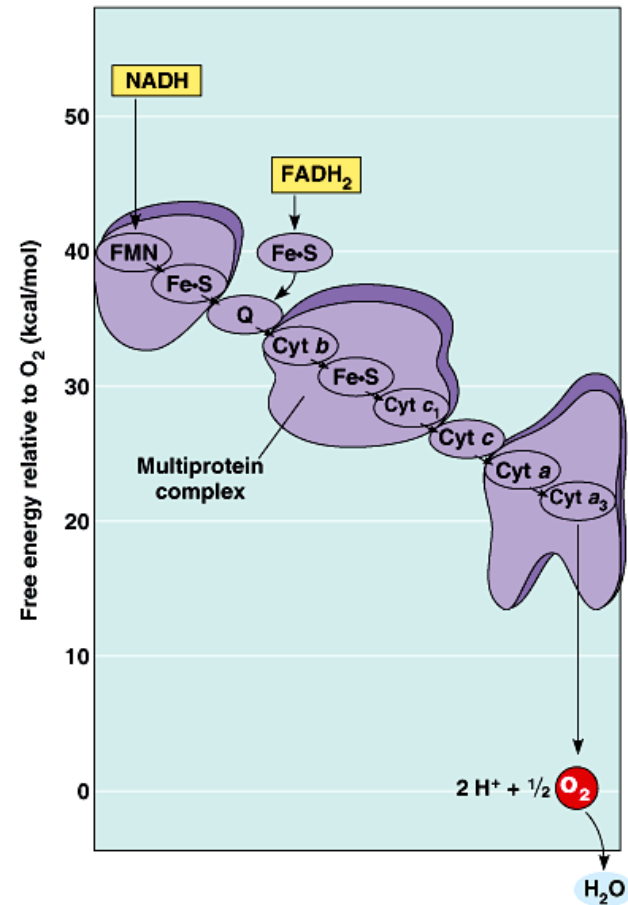
- Only 4 molecules of ATP produced from glycolysis and the Krebs cycle with most of energy extracted from food in the form of high energy electron carriers NADH and FADH₂ which link glycolysis & Krebs cycle to the machinery for oxidative phosphorylation



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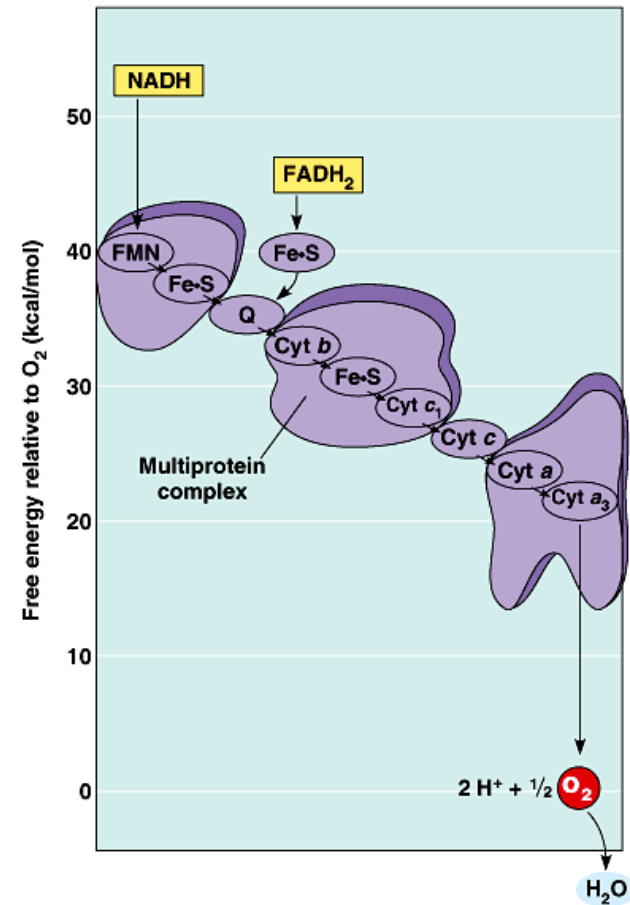
Electron transport – oxidative phosphorylation

- Electron transport is a collection of molecules embedded in the inner mitochondrial membrane with folding of this membrane providing space for thousands of copies of the chain



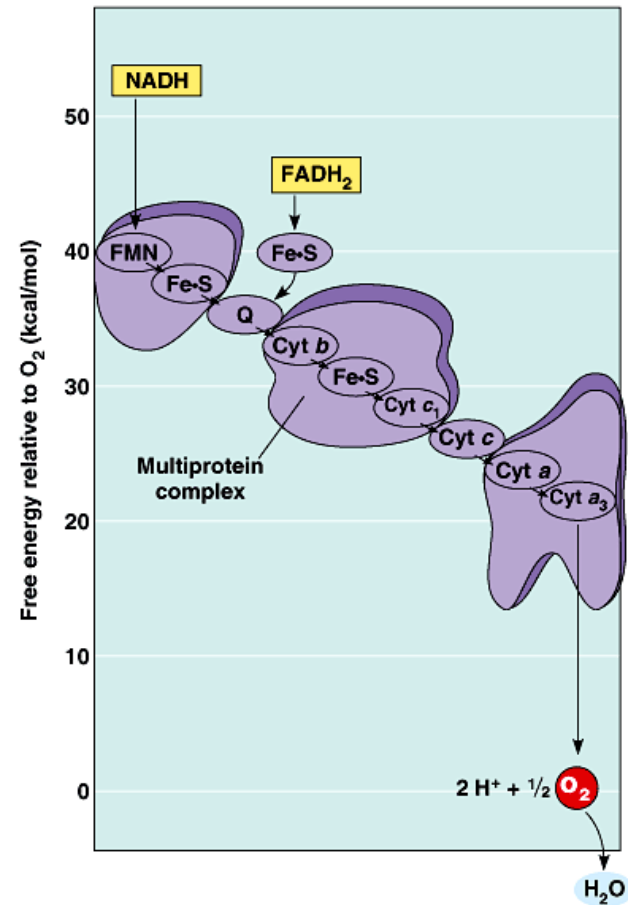
Electron transport – oxidative phosphorylation cont.

- Most components are proteins which have tightly bound prosthetic groups – nonprotein components essential for catalytic function
- During electron transport the prosthetic groups are reduced then oxidized as they accept then donate electrons



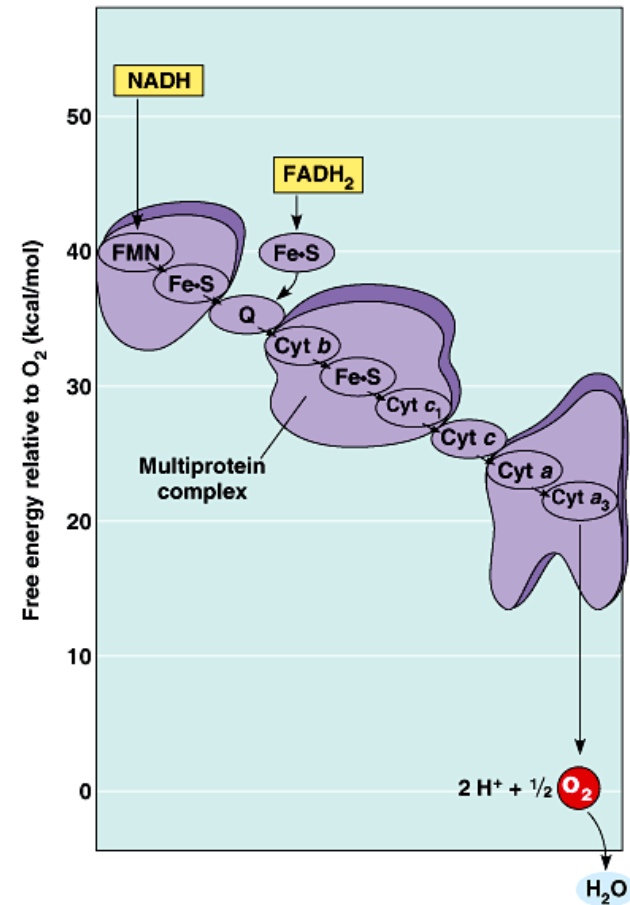
Electron transport – oxidative phosphorylation cont.

- Electrons from NADH transferred to 1st molecule a flavoprotein with a flavin mononucleotide prosthetic group
- Flavoprotein is oxidized as it passes electrons to the 2nd component an iron-sulfur protein which passes electrons to the only lipid component called ubiquinone



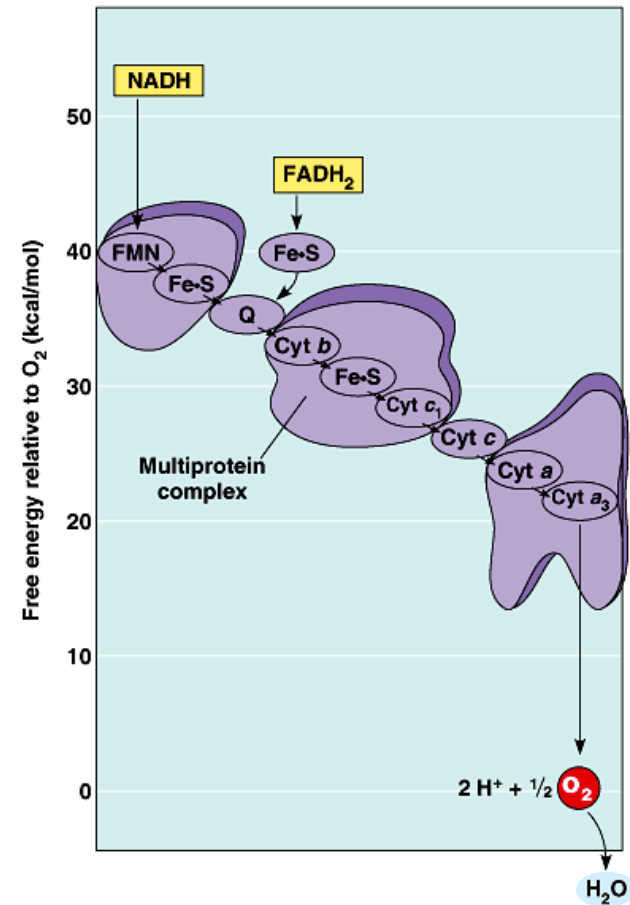
Electron transport – oxidative phosphorylation cont.

- Most of remaining electron carriers are proteins called cytochromes having a heme prosthetic group – 4 organic rings surrounding an iron atom
- Several types of cytochromes are present with the last being cytochrome a_3 which passes the electrons to molecular oxygen



Electron transport – oxidative phosphorylation cont.

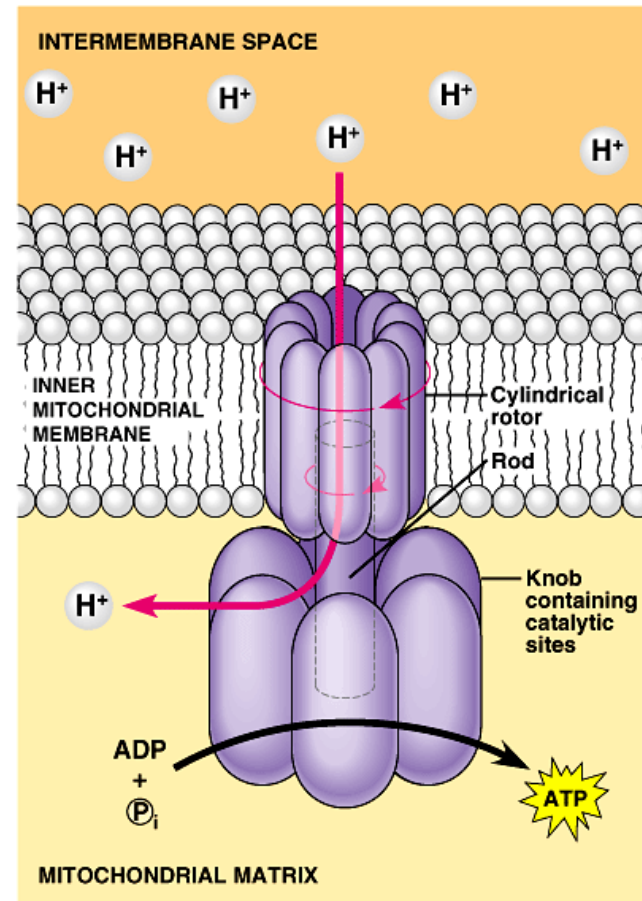
- FADH₂ also passes electrons to the chain but at a lower energy level than NADH providing about 1/3 less energy for ATP synthesis
- Electron transport chain makes no ATP but breaks a large free energy fall into series of small steps that release energy in manageable steps coupling this energy release to ATP synthesis



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Electron transport – oxidative phosphorylation cont.

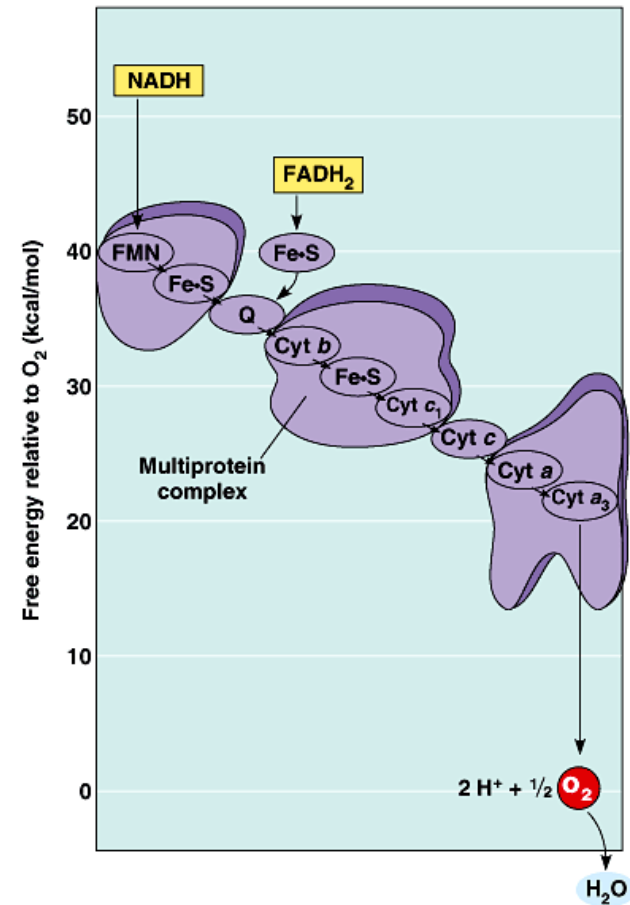
- Coupling of electron transport to ATP synthesis accomplished by mechanism called chemiosmosis
- Inner mitochondrial membrane has many copies of a protein complex called ATP synthase an enzyme which makes ATP from ADP and inorganic phosphate



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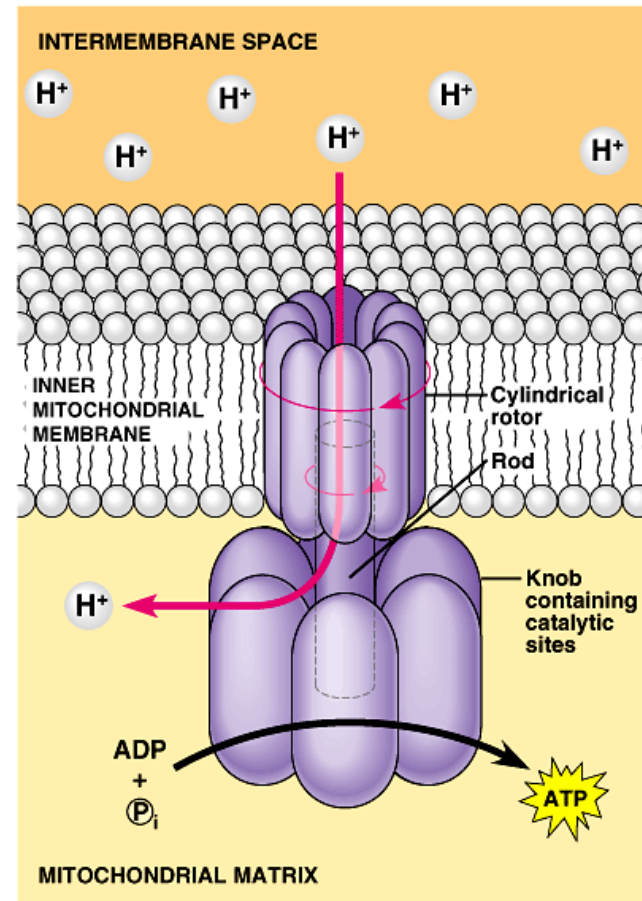
Chemiosmosis & ATP synthase

- ATP synthase acts as an ion pump in reverse using energy of an existing ion gradient to power ATP synthesis
- Ion gradient is a proton (hydrogen ion) gradient across inner mitochondrial membrane generated by energy released during electron transport



Chemiosmosis & ATP synthesis cont.

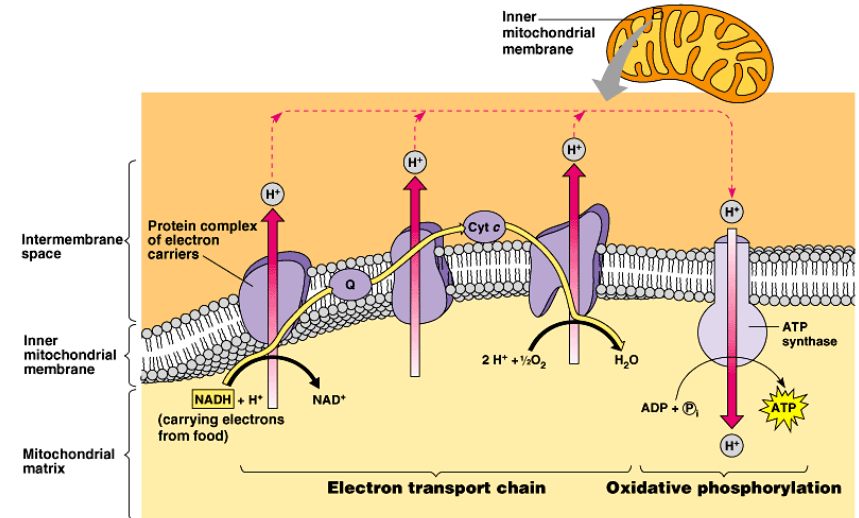
- Electron transport chain is an energy converter using exergonic flow of electrons to pump H^+ across the inner membrane from matrix to inner space but ATP synthase molecules are only place where H^+ can get back across the membrane



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Chemiosmosis & ATP synthesis cont.

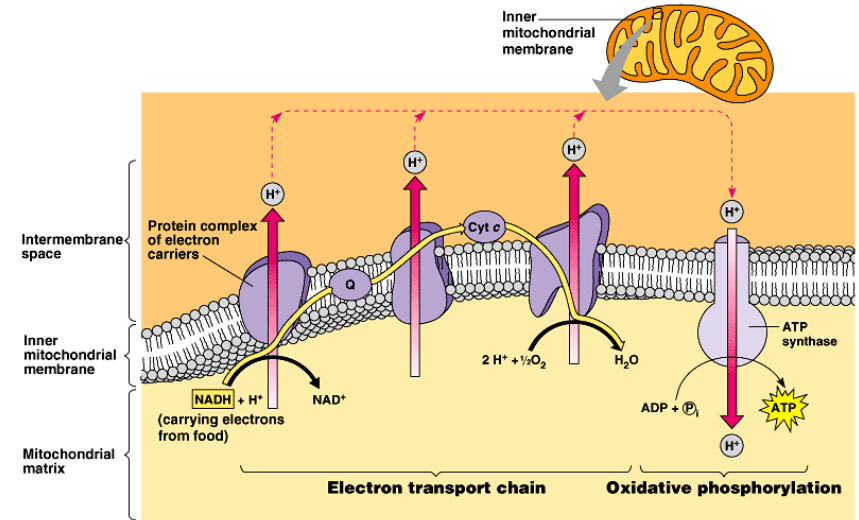
- Hydrogen ions pass through a channel in the ATP synthase protein complex which uses exergonic flow of H^+ to drive oxidative phosphorylation of ADP
- H^+ gradient across a membrane couples redox reactions of electron transport to ATP synthesis by mechanism called chemiosmosis



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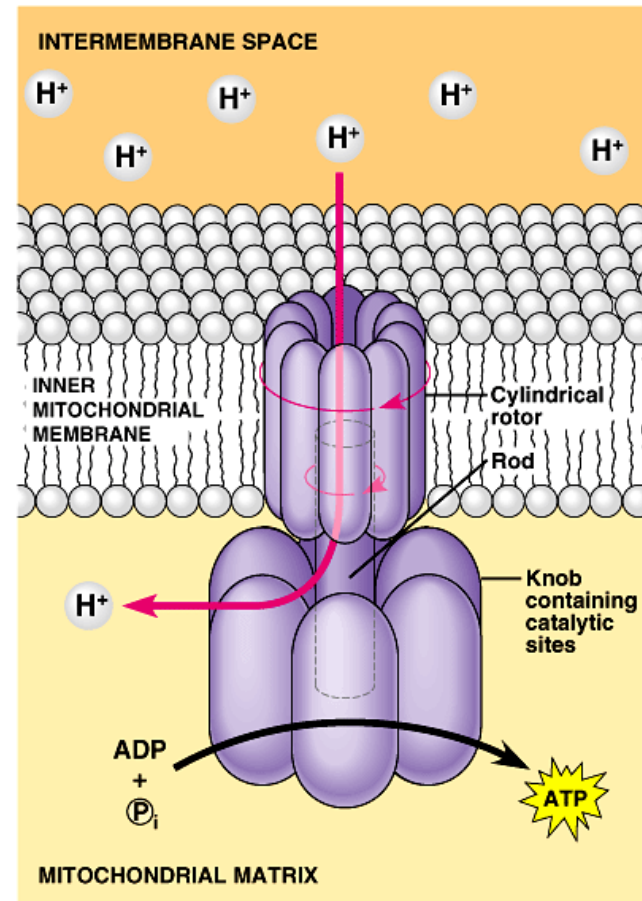
Chemiosmosis & ATP synthesis cont.

- At certain points along the chain electron transfers cause H^+ to be taken across the membrane & the resulting H^+ gradient is called a proton motive force



Chemiosmosis & ATP synthesis cont.

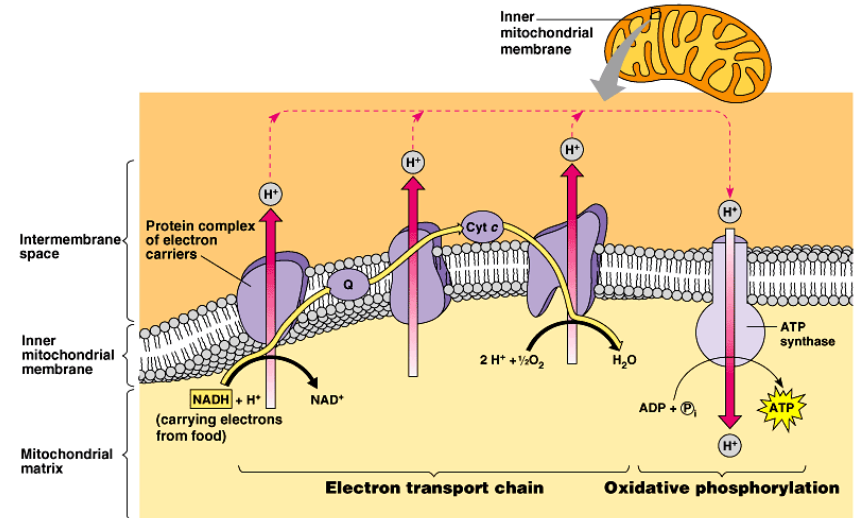
- ATP synthase has 3 main parts – cylindrical rotor in mitochondrial membrane, knob protruding into matrix & internal rod connecting the two
- Flow of H^+ down the gradient causes rotor & rod to spin which causes conformational changes in knob activating catalytic sites for combination of ADP and P_i to form ATP



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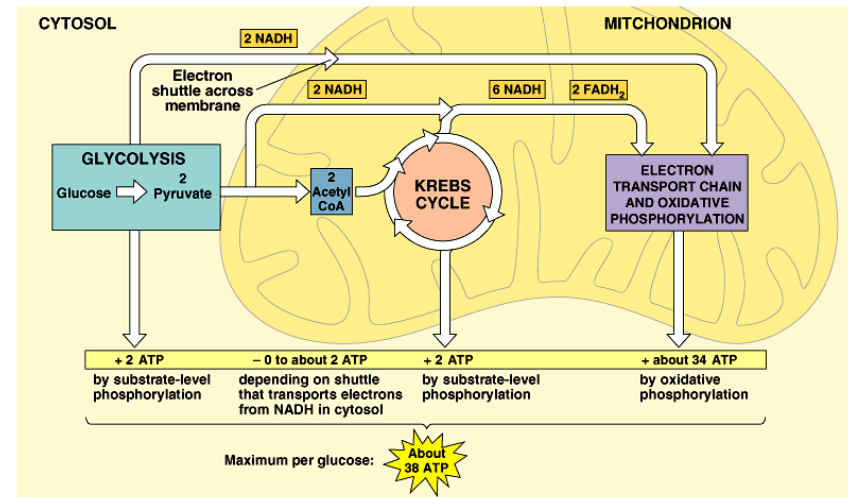
Chemiosmosis cont.

- Same mechanism used in chloroplasts to generate ATP and in prokaryotes to make ATP, pump nutrients & wastes across membrane & rotate flagella



Cellular respiration – review

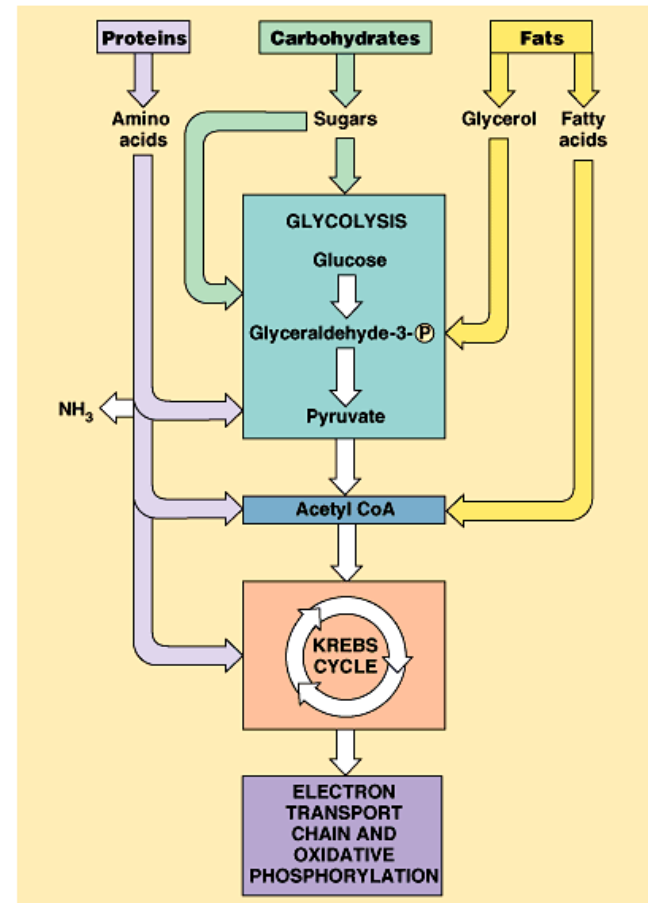
- Yield of ATP per glucose varies somewhat because NADH made in glycolysis is not able to enter mitochondria so several shuttle systems exist to get the electrons in with some of the shuttles requiring ATP expenditure & some shuttles use FAD not NADH & FADH₂ enters the electron transport chain at a lower energy level



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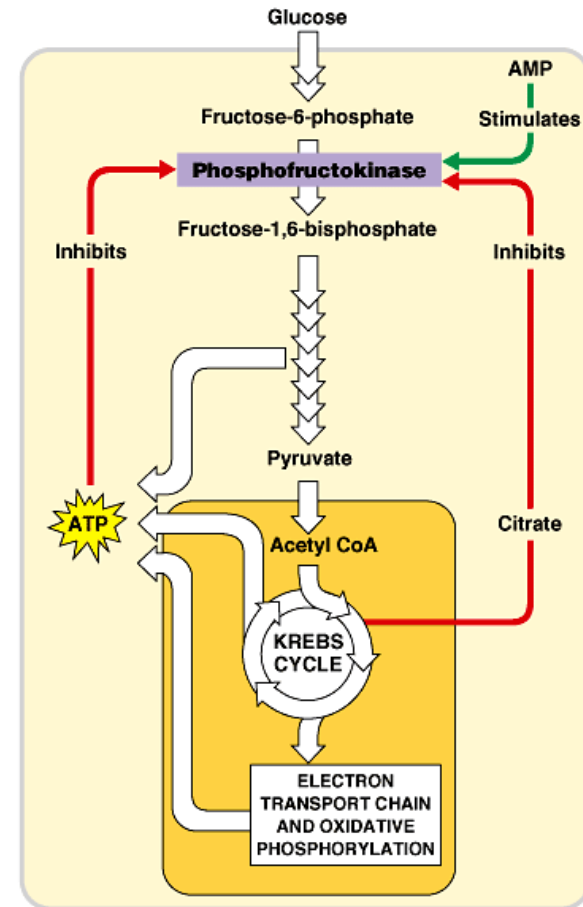
Cellular respiration is versatile

- Glycolysis & Krebs cycle can accept many different molecules for ATP production – carbohydrates, fats (beta oxidation of fatty acids) & proteins after NH_2 group removed by deamination



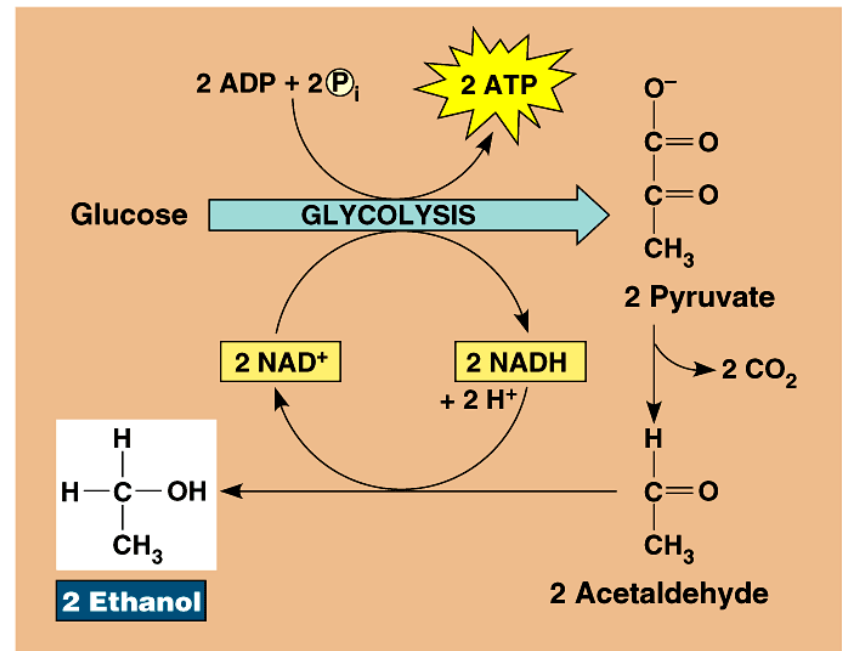
Cellular respiration – feedback control

- Cell controls metabolic pathways by using feedback inhibition
- One control point is phosphofructokinase which is inhibited by ATP from 3 parts of cellular respiration and by citrate from Krebs cycle but stimulated by AMP



Fermentation

- Fermentation allows some cells to produce ATP without oxygen
- Fermentation is an extension of glycolysis that generates ATP by substrate level phosphorylation as long as have enough NAD^+ to accept electrons during glycolysis & NAD^+ is generated by passing electrons to pyruvate

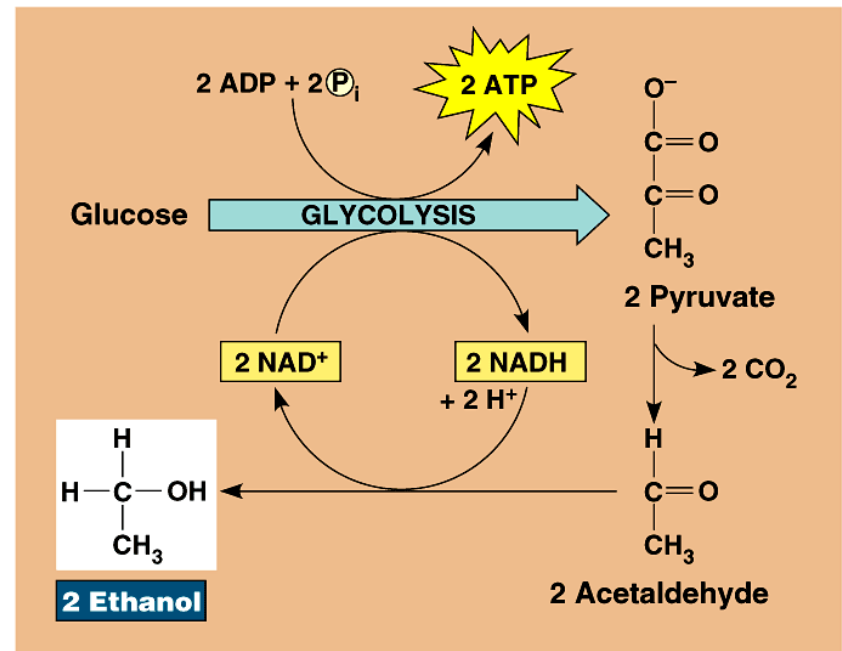


(a) Alcohol fermentation

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Alcohol fermentation

- Pyruvate is converted to ethanol in 2 steps with the release of CO_2 during the 1st step
- Yeast & many bacteria can carry out alcohol fermentation

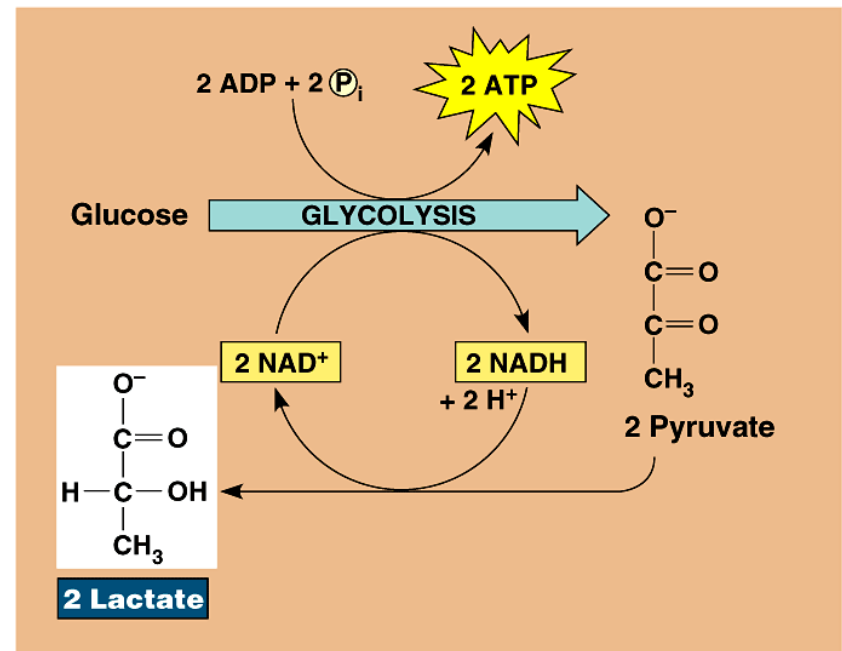


(a) Alcohol fermentation

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Lactic acid fermentation

- Pyruvate directly reduced by NADH to form lactate with no release of CO₂
- Process used in making cheese & yogurt
- Human muscle generates lactate during strenuous exercise



(b) Lactic acid fermentation

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Facultative Anaerobes

- Some bacteria & yeasts can use either fermentation or respiration to make ATP & are called facultative anaerobes
- In these organisms pyruvate is an important metabolic fork leading to 2 alternative catabolic pathways

