Chapter 22

Metabolism & Bioenergetics

Carbohydrates Part 5:
Catabolism Stage 1 (Hydrolysis) & Stage 2 (Glycolysis)

An overview of catabolism

Stage 1 – Hydrolysis

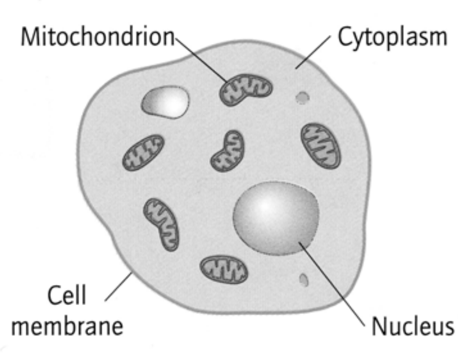
The 1st stage of carbohydrate catabolism is digestion – the breakdown into small molecules for energy production. Digestion begins in the mouth with the physical grinding, softening and mixing of food. Salivary α-amylase catalyzes the hydrolysis of the glycosidic bonds in carbohydrates. α-amylase is denatured in the stomach. Further digestion occurs in the small intestine where additional α-amylase is secreted by the pancreas along with maltase, sucrase and lactase from the mucous lining of the small intestine.

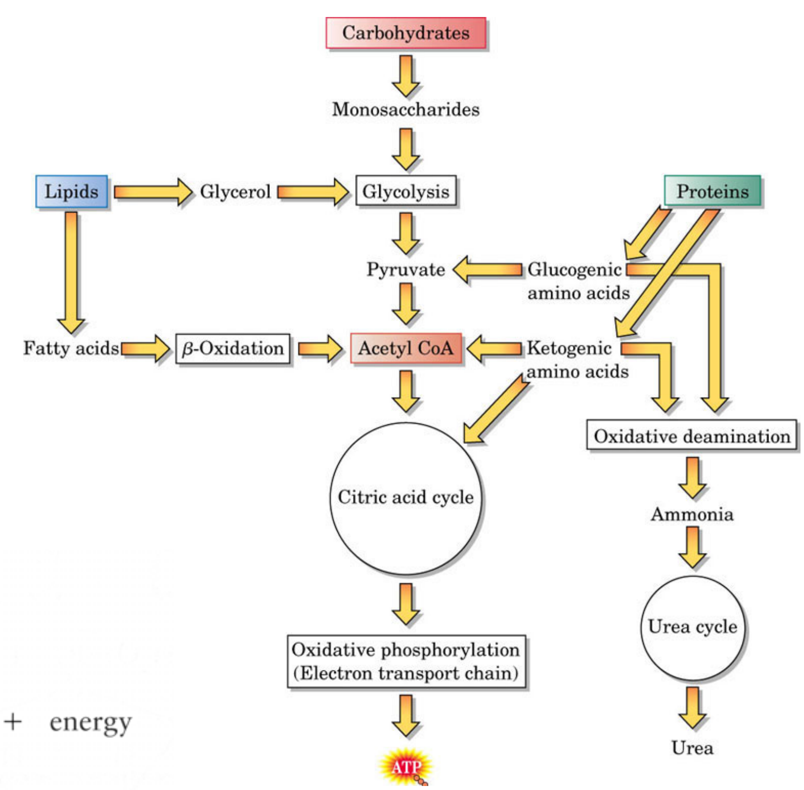
Stage 2 – Glycolysis

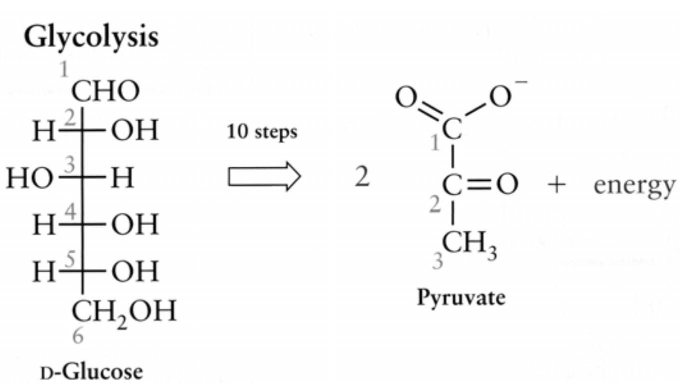
The conversion of glucose to pyruvate.

Stage 3 – Acetyl CoA enters Citric Acid Cycle to produce CO_2 & reduced coenzymes.

The reduced coenzymes transport the electrons to the electron transport chain (ETC) which ultimately reduces O_2 to H_2O and drives the formation of ATP from ADP & P1 in a process known as oxidative phosphorylation.



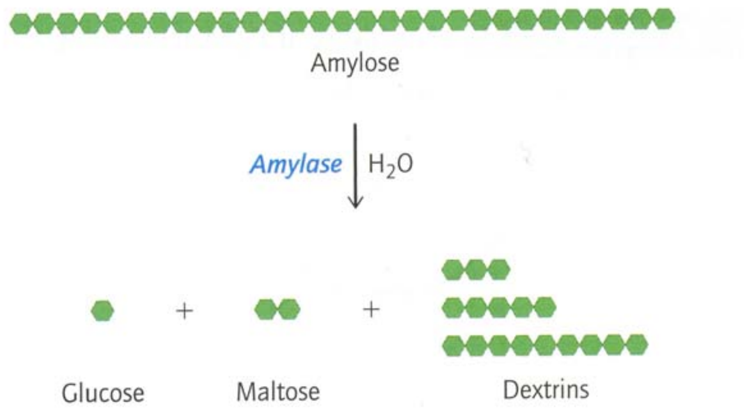




Stage 1

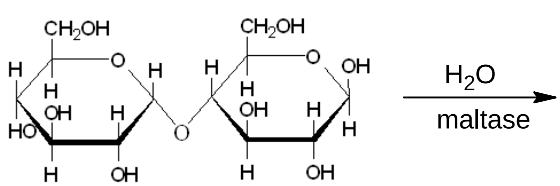
Hydrolysis of polysaccharides (starch, corn syrup & high fructose corn syrup)

breaking the glycosidic bond with water & enzymes



Hydrolysis of Disaccharides

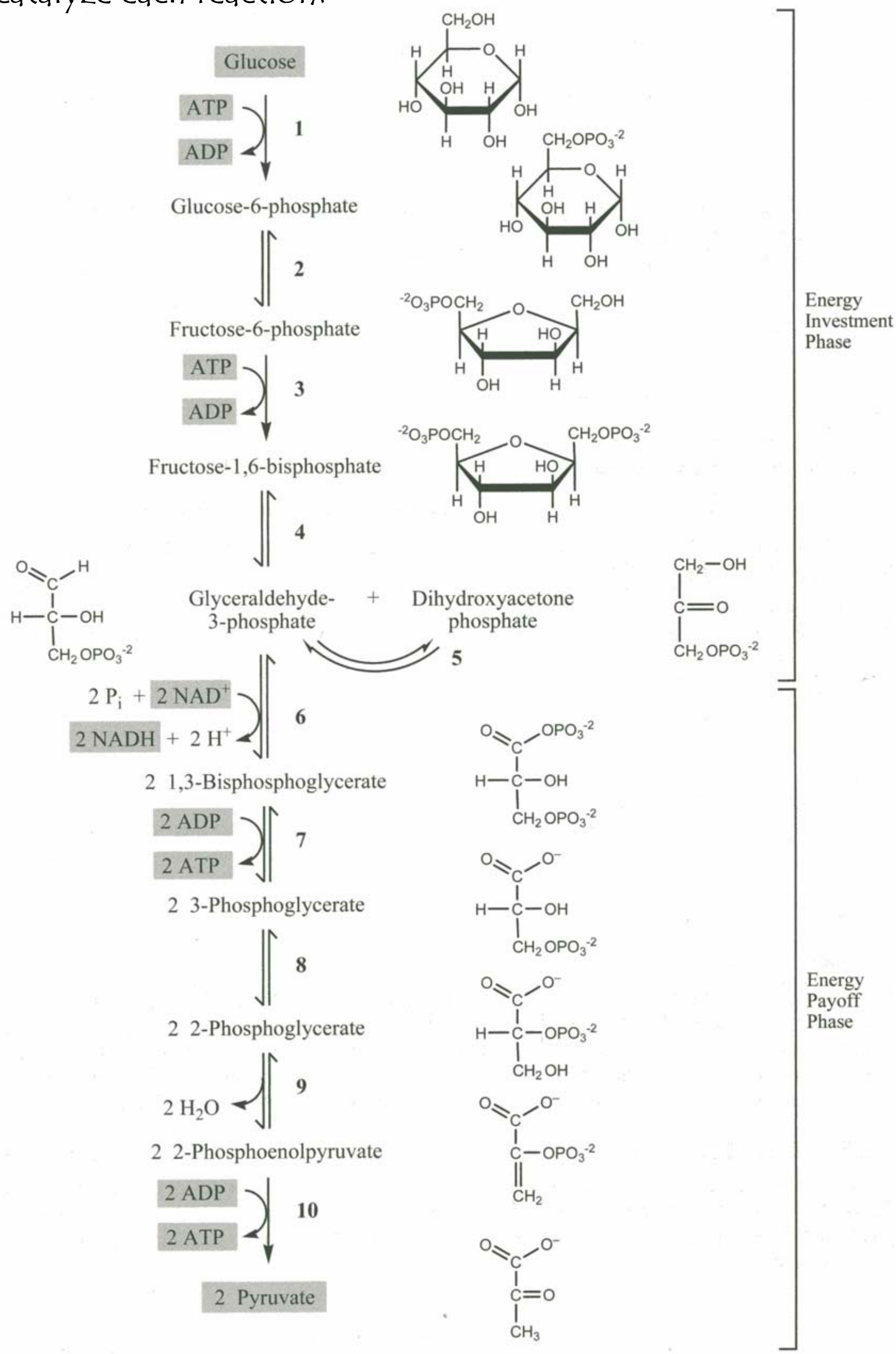
breaking the glycosidic bond with water & enzymes



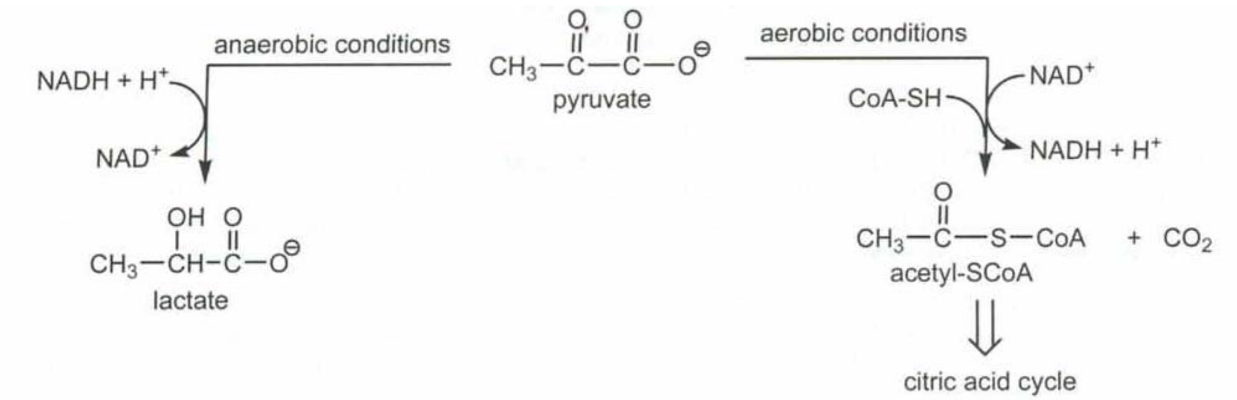
Draw the reaction for sucrose hydrolysis using Haworth projections.
Name the products.

Stage 2 – Glycolysis

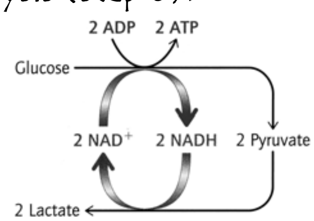
Look through the sequence of reactions in glycolysis and classify the enzymes (Hydrolase, Lyase, Ligase, Transferase, Isomerase, or Oxidoreductase) needed to catalyze each reaction.



Fate of Pyruvate



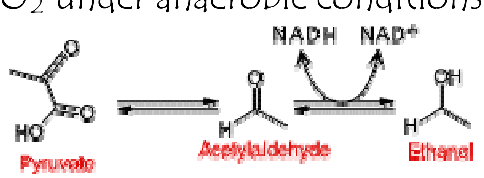
A lack of oxygen will slow down electron transport, causing a build-up of NADH and decreasing the amount of NAD^+ available for glycolysis. If there is no NAD^+, glycolysis cannot continue. The reduction of pyruvate to lactate will generate the NAD^+ needed for glycolysis (step 6).



Tissues with low oxygen content (such as skeletal muscle) rely on anerobic production of ATP by glycolysis.

Some bacteria can convert pyruvate to lactate under anaerobic conditions. The preparation of kimchee, sauerkraut, and yogurt involve these types of bacteria.

Yeast converts pyruvate to ethanol and CO_2 under anaerobic conditions.

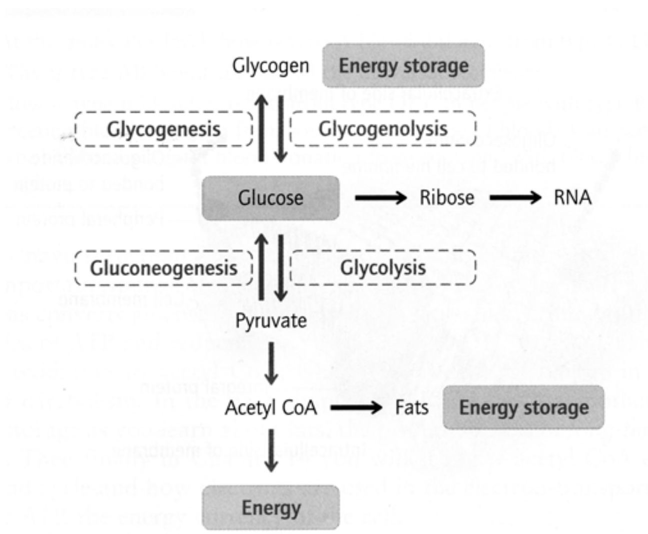


In the mitochondrial matrix, pyruvate is oxidized to form carbon dioxide and an acetyl group (acetyl–CoA).

Pyruvate must diffuse into the mitochondria from the cytosol. It is then transported by a membrane protein across the inner mitochondrial membrane into the matrix.

What happens to the acetyl-CoA?

Carbohydrates Part 6: Other Metabolic roles of Glucose & Ketone Bodies



Glycogenesis: synthesis of glycogen from glucose

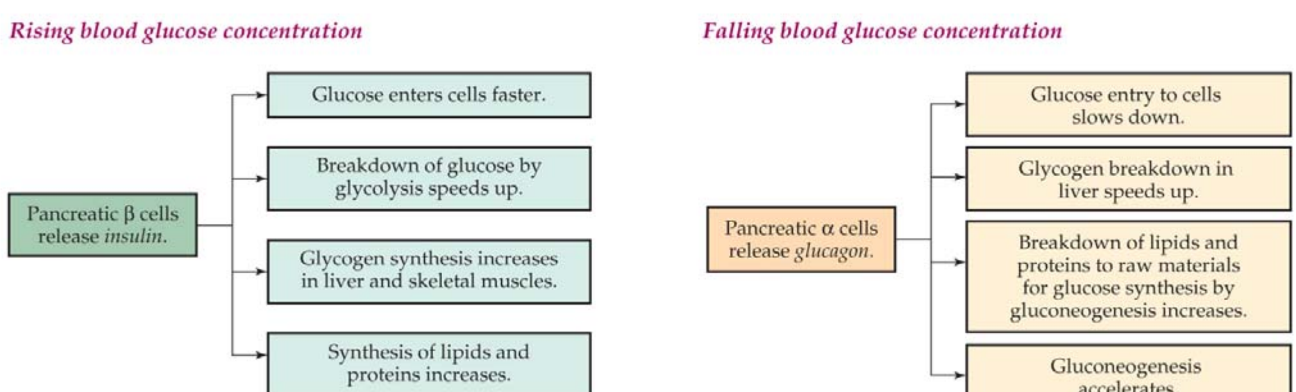
Glycogenolysis: Degradation of glycogen to produce glucose

Gluconeogenesis: Breakdown of proteins; in the liver, formation of glucose from amino acids

Glycolysis: breakdown of glucose to pyruvate

Regulation of Glucose Metabolism and Energy Production

Two hormones secreted by the pancreas play a major role in glucose metabolism.

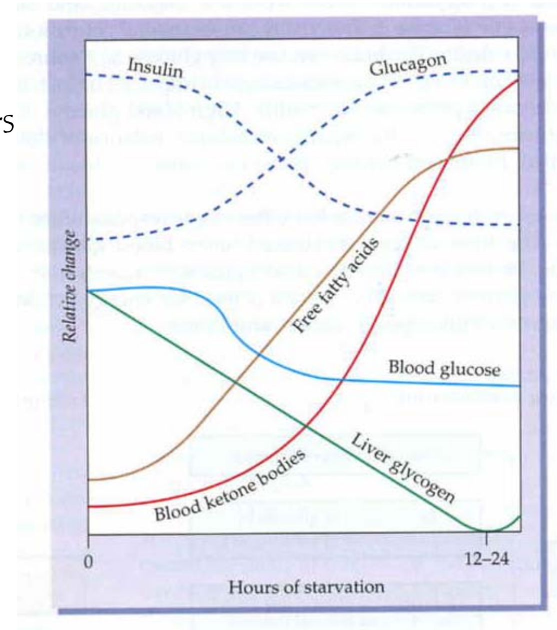


Metabolism during Fasting or Starving

Gradual decline in blood glucose triggers the catabolism of lipids causing a build-up of acetyl CoA.

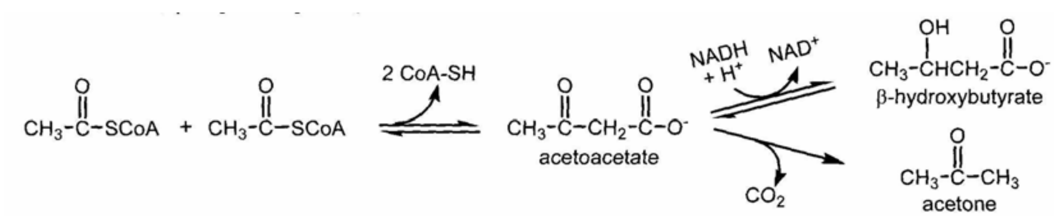
Ketone bodies form from the excess acetyl CoA. (see rxn below)

Brain and other tissues catabolize ketone bodies to produce ATP.



Diabetes Mellitus - glucose cannot be utilized or stored as glycogen because insulin is not secreted or does not function properly, therefore, insufficient amounts of glucose are present in tissues. Liver cells synthesize glucose from non-carbohydrate sources (gluconeogenesis) and break down fat. Acetyl-CoA builds up and ketone bodies accumulate (ketosis). Glucose appears in the urine because it is not undergoing glycolysis.

Formation of Ketone Bodies from Acetyl CoA



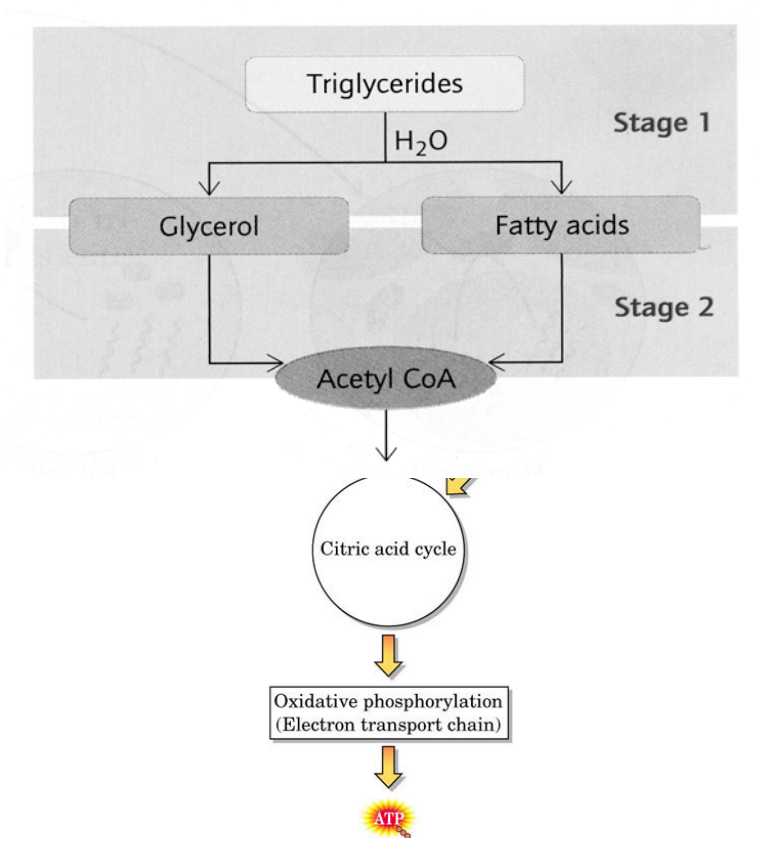
If the concentration of ketone bodies becomes too high, as can happen in diabetics or on a very low carbohydrate diet, a condition called ketoacidosis can result. Since the ketone bodies are not completely metabolized, acetone can diffuse out of the bloodstream into air in the lungs. The acetone can be smelled on the breath. Also, since ketone bodies acetoacetate and β-hydroxybutyrate are acidic, the pH of the blood decreases. This affects the ability of the hemoglobin to carry oxygen – breathing can become difficult. Untreated, ketoacidosis can lead to coma or death.

Lipids Part 7: Fatty Catabolism

Stage 1:

Stage 2:

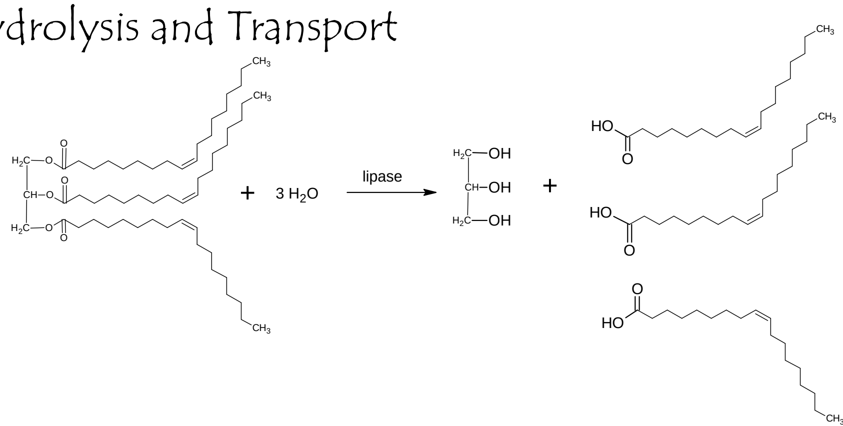
Stage 3:



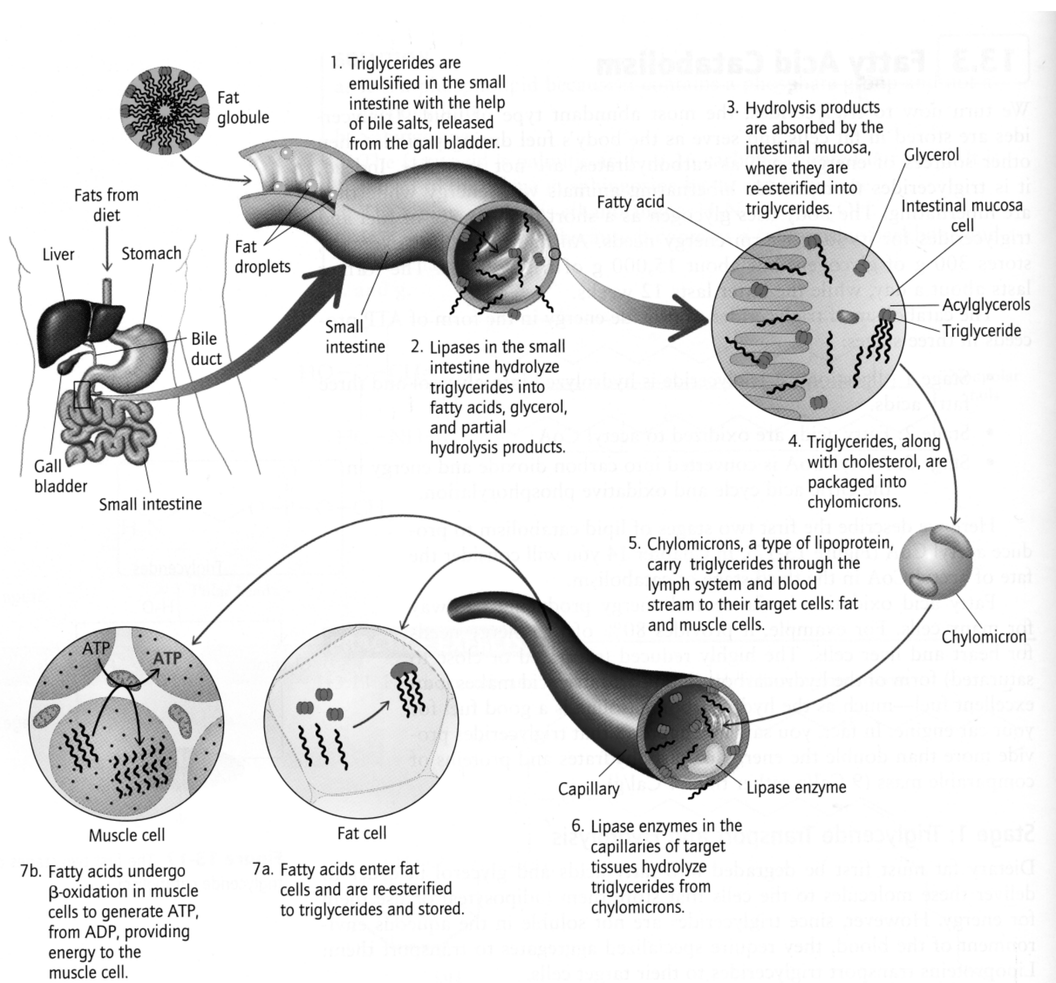
When eaten, fats pass through the mouth unchanged and enter the stomach.

How is this process different than carbohydrates?

Stage 1: Hydrolysis and Transport



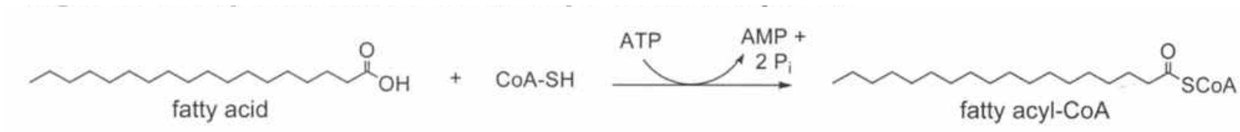
- The bile acids (salts) and phospholipids help emulsify the fatty acids so that the enzymes can breakdown the lipids.
- The hydrophobic lipids are transported by various lipoproteins.
- As the fats are hydrolyzed, the smaller fatty acids and glycerol are water soluble and are absorbed directly through the surface of the villi that line the small intestine.
- Chylomicrons surround the still-insoluble larger fatty acids within the intestine for further hydrolysis by lipases.



Stage 2: Fatty Acid Oxidation

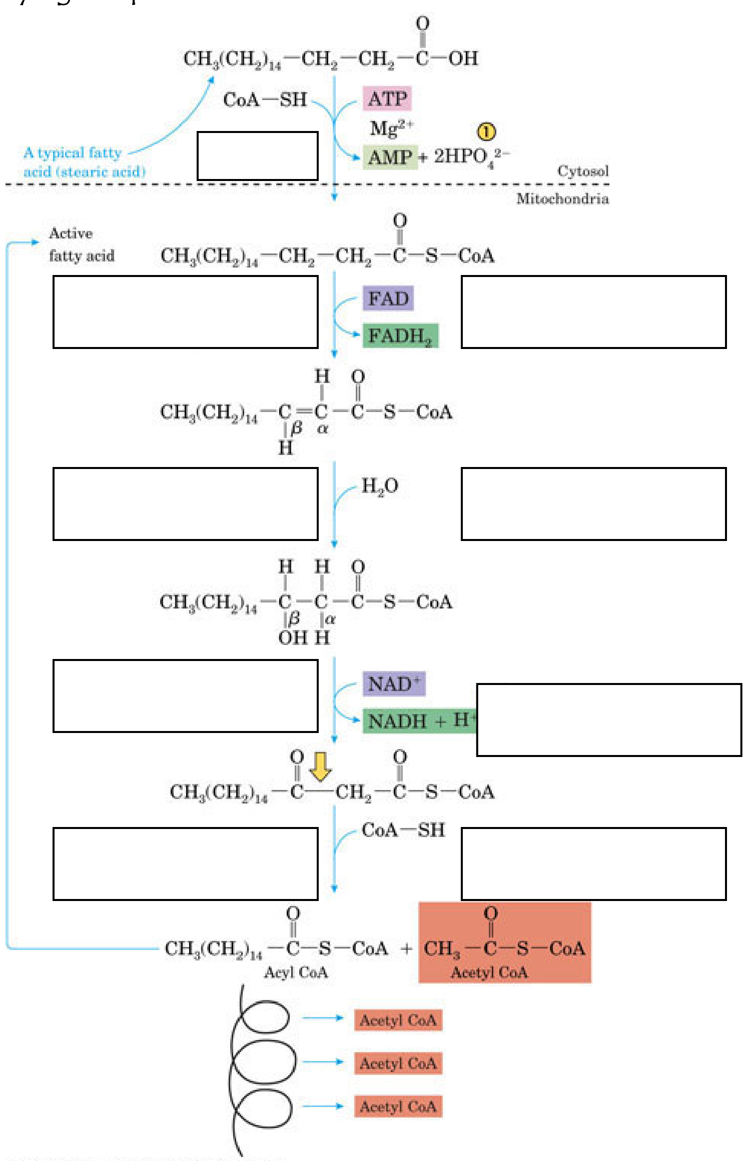
Once a fatty acid enters the cytosol of a cell that needs energy, three successive processes must occur:

1. Activation: The fatty acid is converted to Fatty Acyl-CoA.

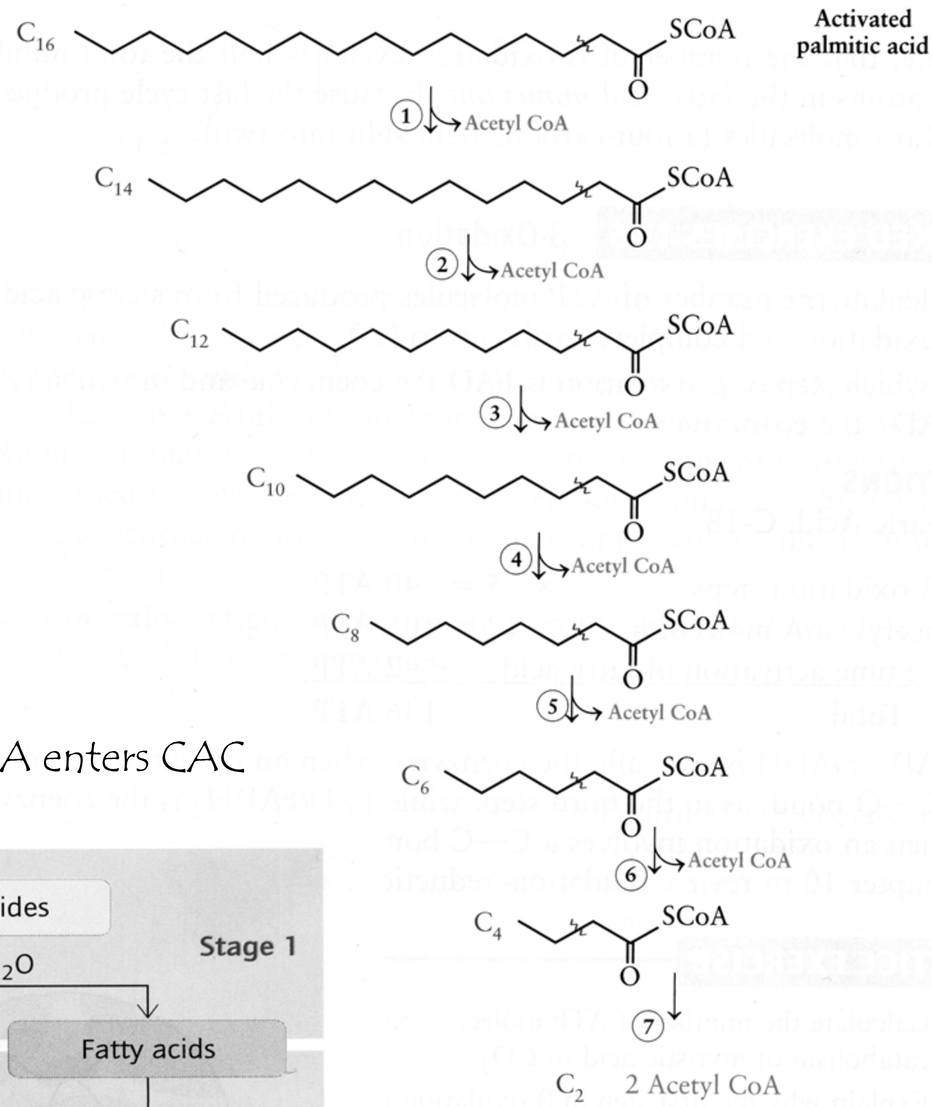


2. Transport: The Fatty Acyl-CoA is transported into the mitochondrial matrix where energy generation will occur.

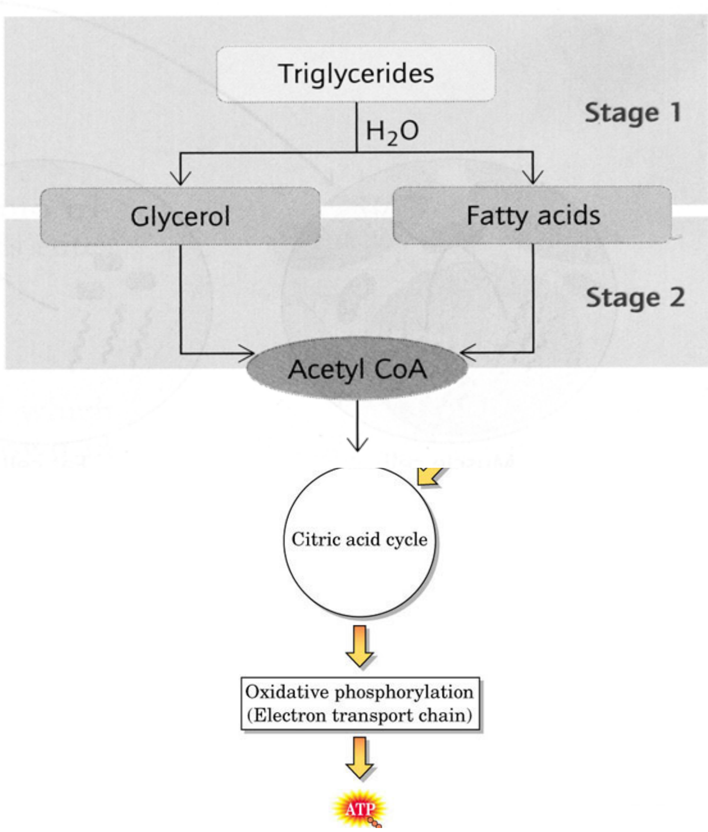
3. β-Oxidation: The Fatty Acyl-CoA is oxidized by enzymes to produce acetyl-CoA and reduced coenzymes. Each repetition of the oxidation cleaves a 2-carbon acetyl group.



Fatty acids undergo repeating cylcles of β-oxidation until the final four-carbon fatty acyl CoA molecule is converted into two acetyl CoA molecules.



Stage 3: Acetyl CoA enters CAC

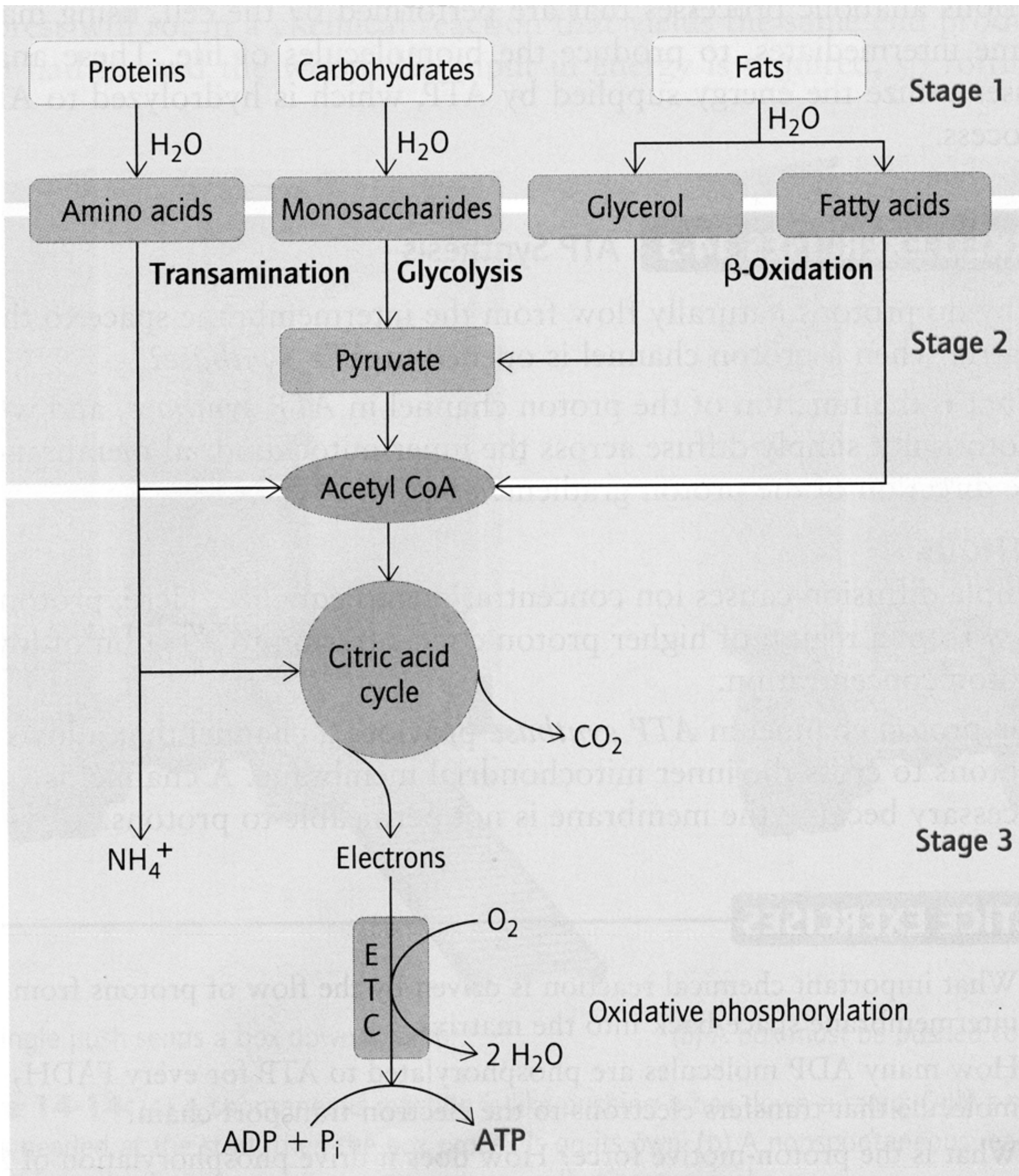


Metabolism and Bioenergetics Part 1: Intro and Acetyl CoA

Metabolism – ALL biochemical reactions involving the use, production & storage of energy

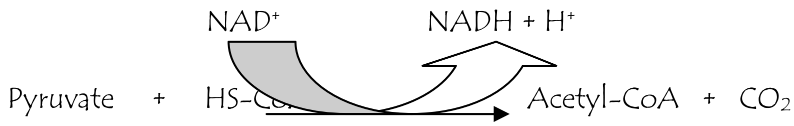
Anabolism – Synthetic (reductive) metabolic reactions that require energy

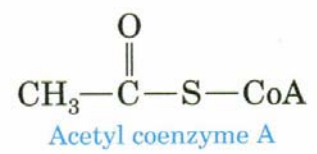
Catabolism – Degradation (oxidative) metabolic reactions that produce energy



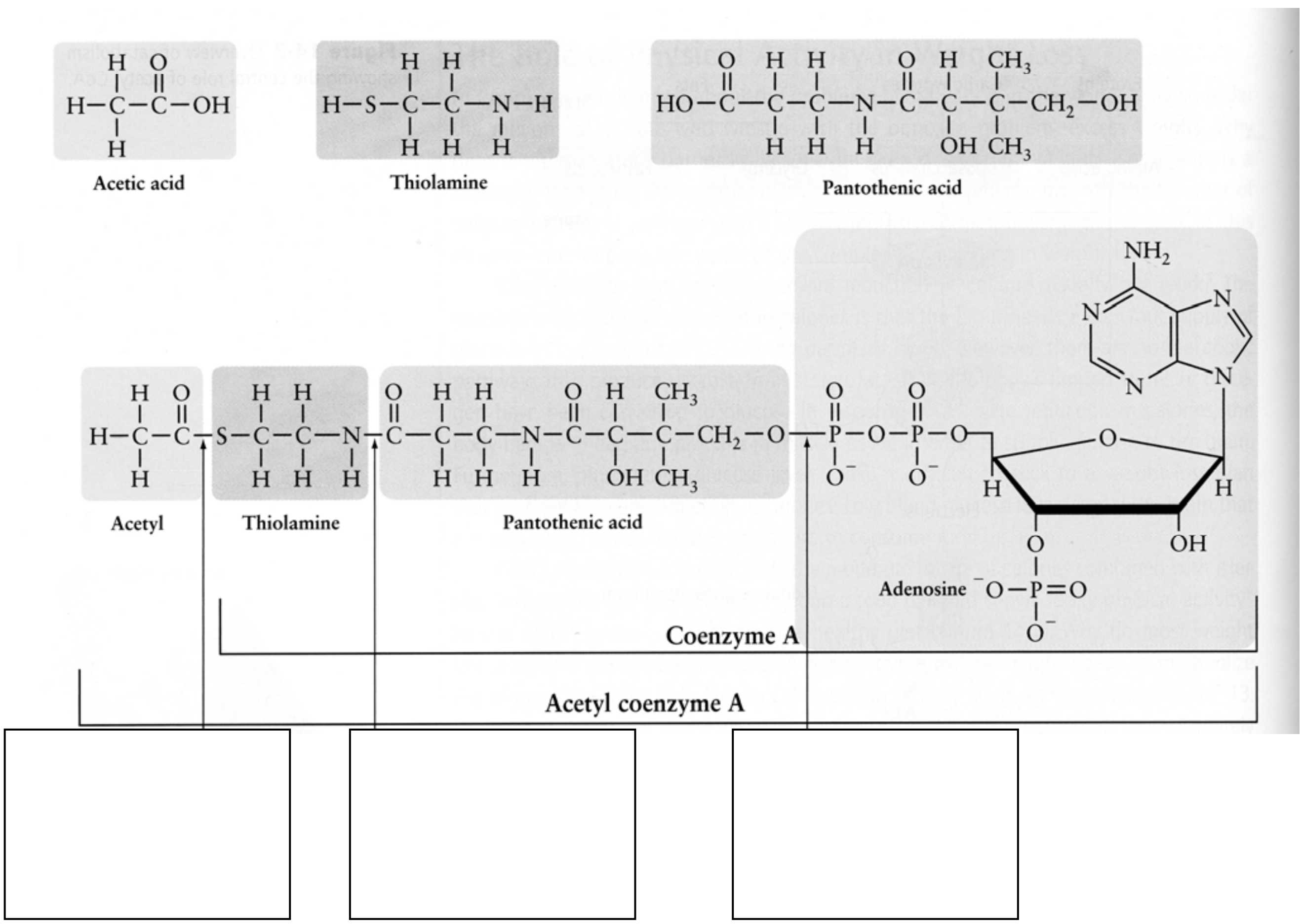
Right before the Citric Acid Cycle

Pyruvate is transported from the outer mitochondrial membrane to the inner mitochondrial membrane where it is converted into acetyl-CoA.





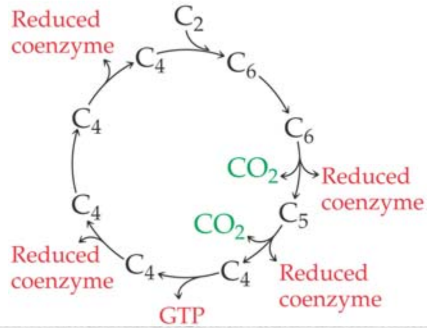
Classify the bonds linking the four compounds together to form acetyl CoA in the diagram below.



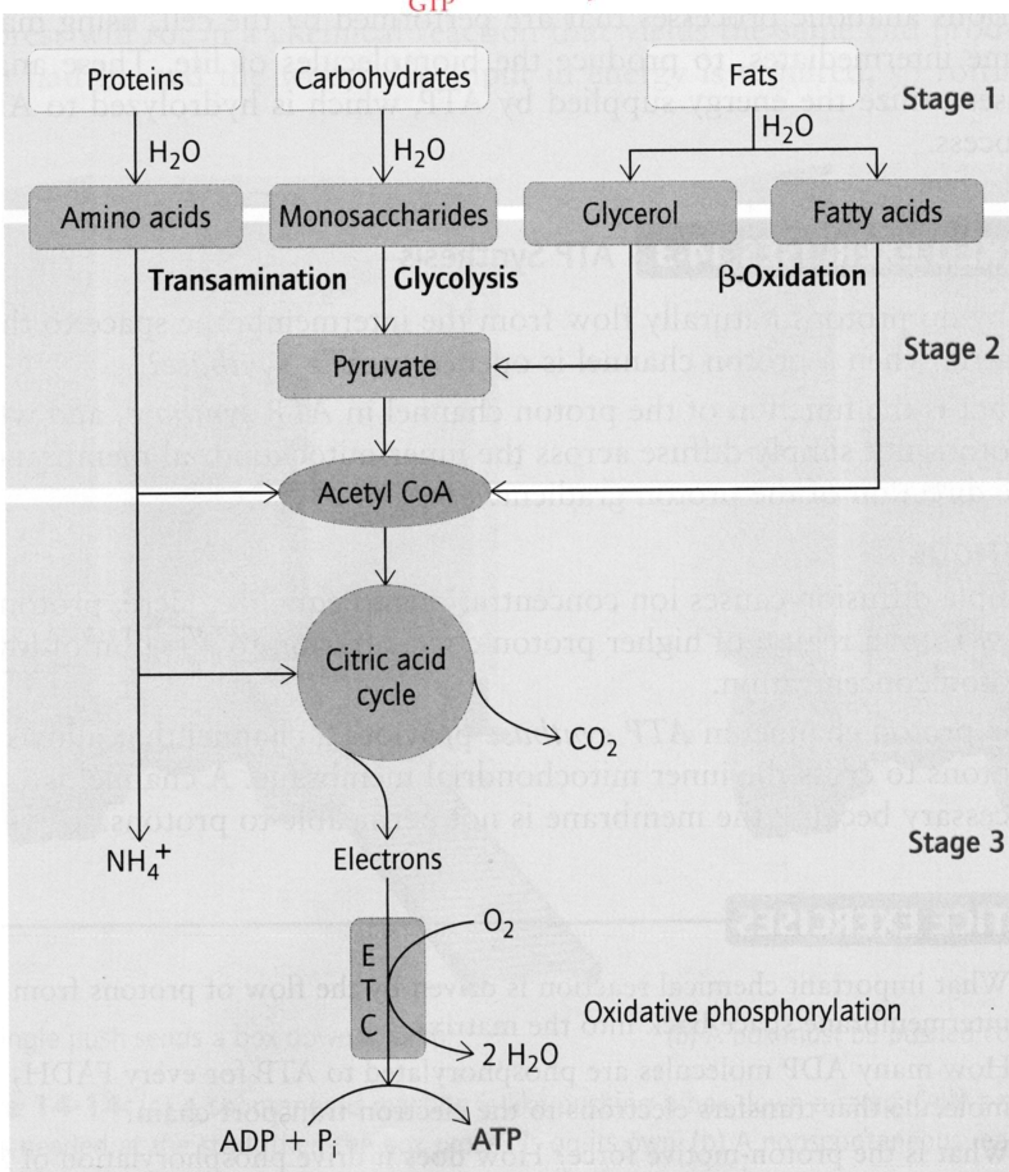
Metabolism and Bioenergetics Part 2: The Citric Acid Cycle

The Citric Acid Cycle (aka CAC and Kreb's cycle)

The series of biochemical reactions that breaks down acetyl groups to create the biochemical energy currency of reduced coenzymes & GTP.

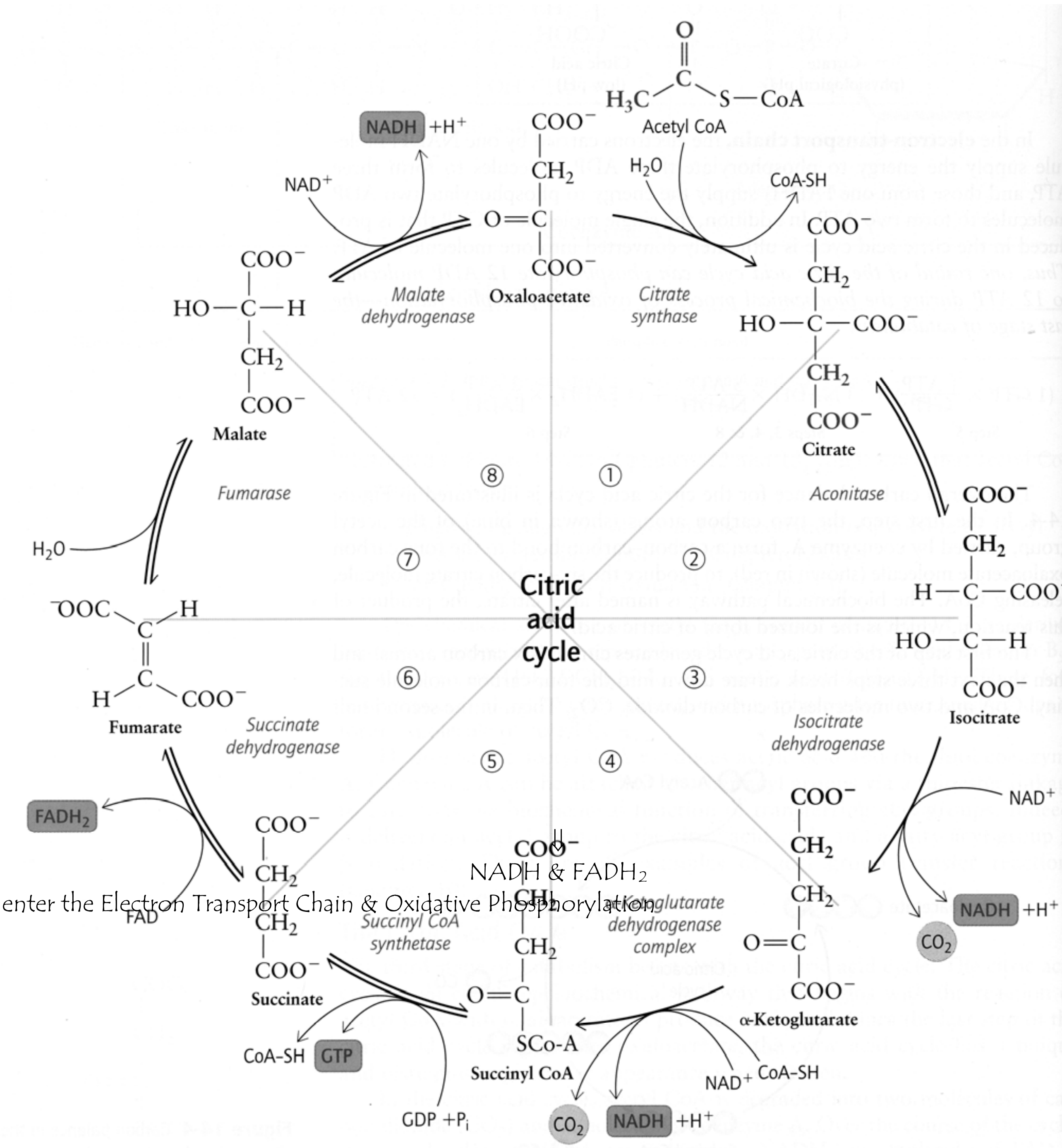


Our body can convert 1 GTP into 1 ATP.



The Citric Acid Cycle in more detail

Circle or Box the changes to the substrates during each step of the cycle.



NADH & FADH$_2$ enter the Electron Transport Chain & Oxidative Phosphorylation

1. What is the substrate of step 4? What is the product of step 3?

2. In each turn of the CAC, 2 molecules of CO_2 are released. In which steps is CO_2 released?

3. In which step of the CAC do two carbons enter the cycle?

4. Which step(s) require an oxidoreductase enzyme?

5. Which step(s) require a lyase enzyme?

6. Which step(s) require a transferase enzyme?

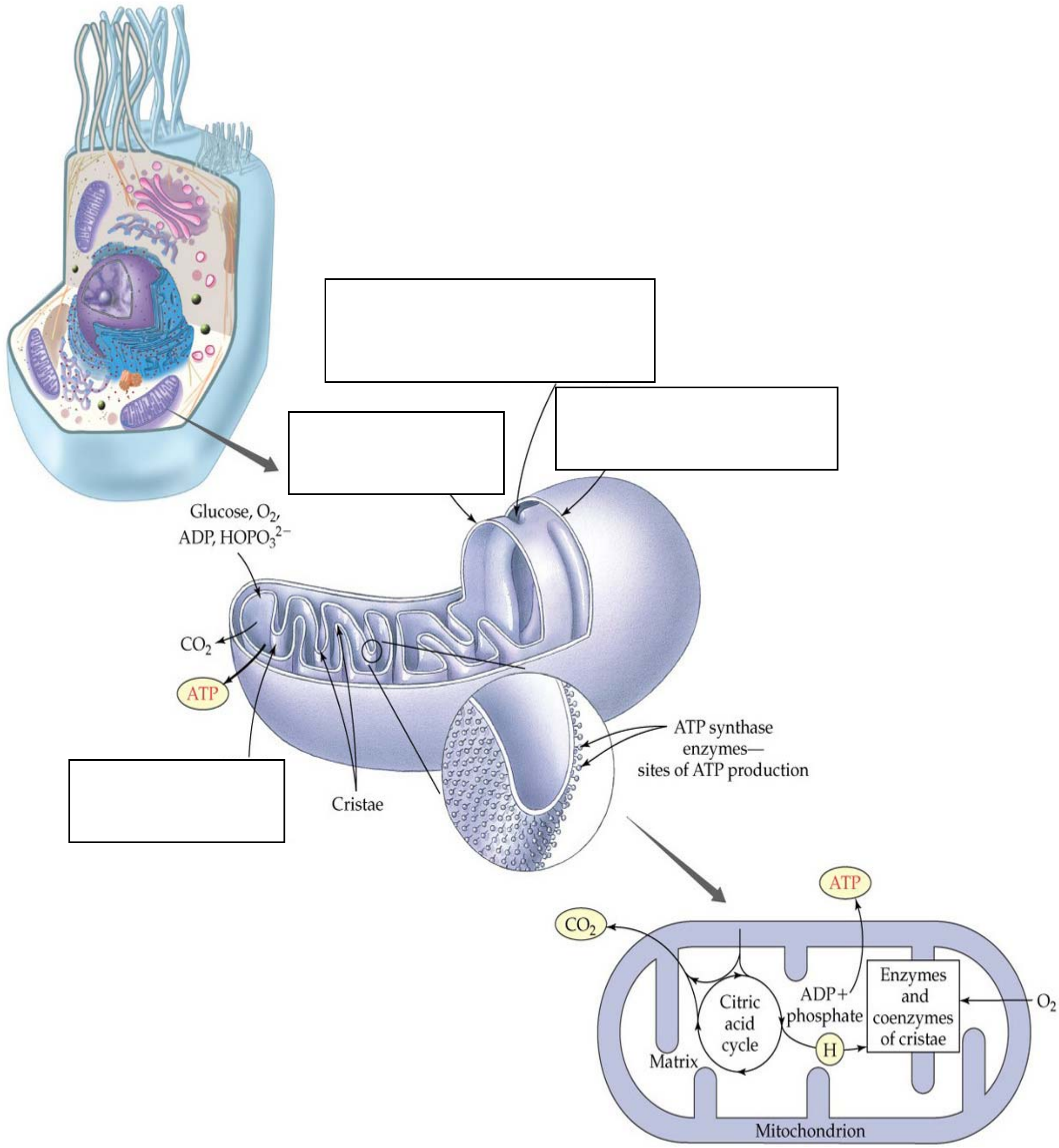
7. Which step(s) require a ligase enzyme?

8. Why is Step 2 needed? Which subsequent step would NOT be possible without Step 2?

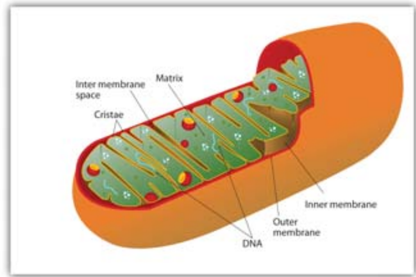
Metabolism & Bioenergetics Part 3: Electron Transport Chain & ATP Production

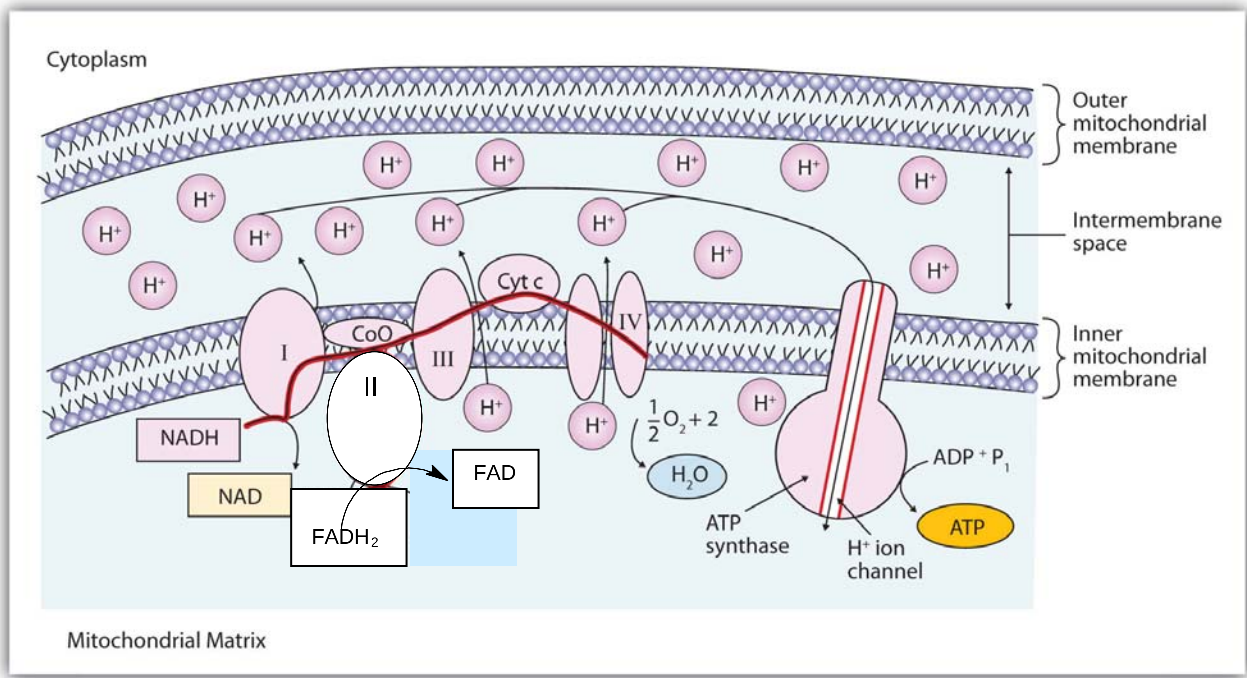
The Mitochondrion

(the place where all of this chemistry is happening inside us.)



The Electron Transport Chain (ETC)





Reduced coenzymes are produced from the CAC in the matrix.

The ETC uses redox reactions to transfer the energy stored in NADH and $FADH_2$ to pump H^+ ions into the inter-membrane space.

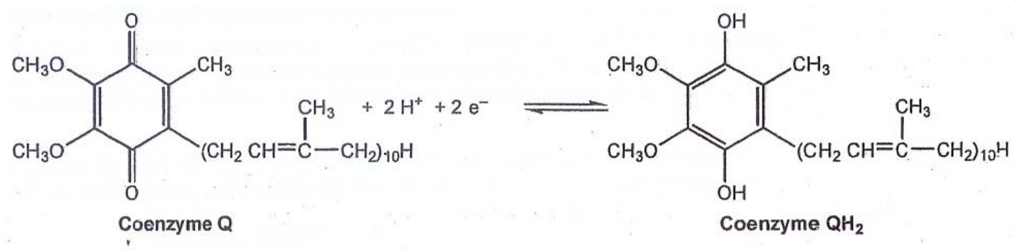
The accumulation of H+ in the inter-membrane space creates stored chemical and electrical potential energy, because the natural tendency is for ions to diffuse from areas of higher concentration to areas of lower concentration. The only way for the protons to reenter the matrix is through an enzyme complex called ATP synthase. So the protons are pumped out of the matrix via the ETC and return providing energy like water turning a waterwheel fueling the attachment of phosphate (Pi) to ADP making ATP. This process is called oxidative phosphorylation because the energy needed to phophorylate ADP to make ATP comes from the oxidative steps of the ETC.

Oxidation-Reduction in the ETC

Complexes I-IV are fixed within the inner membrane of the mitochondrion
A variety of compounds move the electrons from one Complex to another via redox rxns. Some of these compounds are shown below.

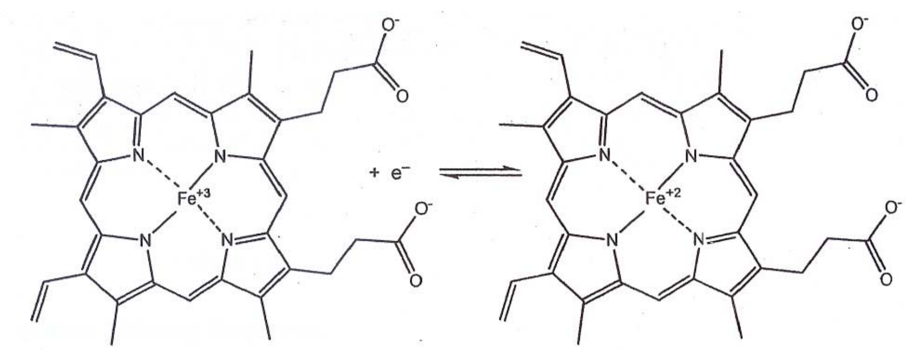
Label the following coenzymes as oxidized or reduced.
Add [H] and [O] to the reaction arrow.

Coenzyme Q (CoQ) is also called ubiquinone.

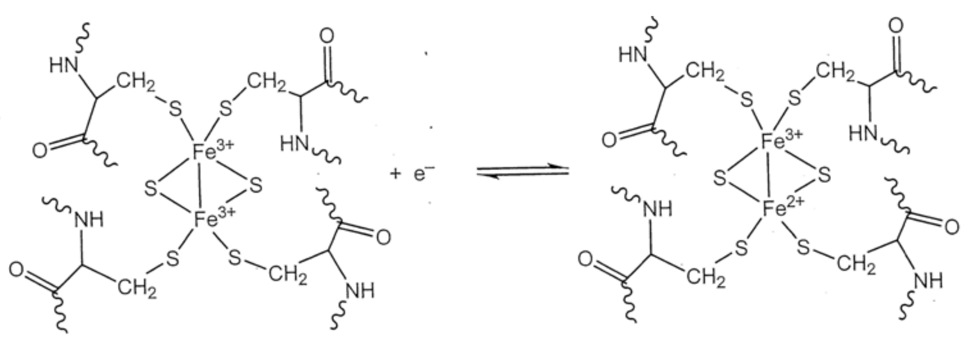


Cytochrome c – a protein that contains an iron ion in a heme group

$$Fe^{3+} + 1e^{-} \rightleftharpoons Fe^{2+}$$

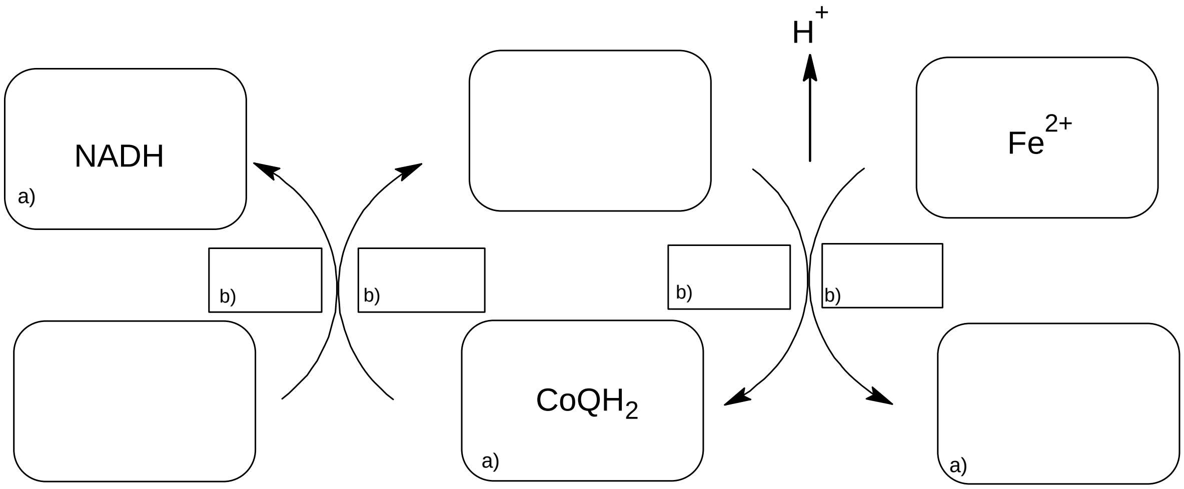


Iron-sulfur proteins - proteins containing iron-sulfur clusters



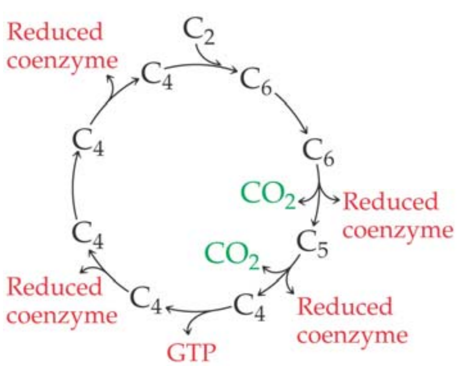
Part of the ETC Redox Pathway for Complex I is shown below.

a) Label the inter-membrane space and matrix.
b) Add the missing elements or ions.
c) Classify each reaction as an "[O] = Oxidation" or "[H] = Reduction".

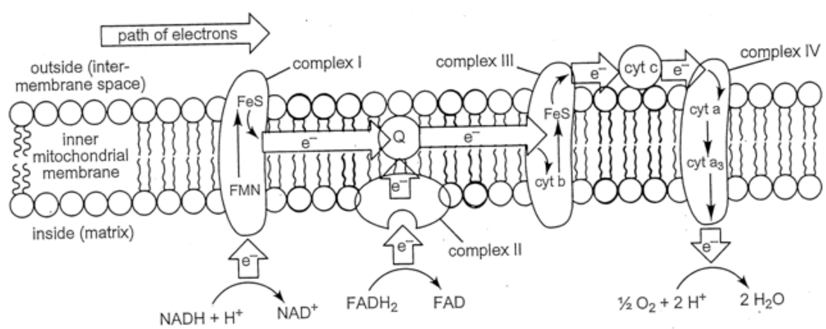


ATP PRODUCTION – Linking the CAC with ETC

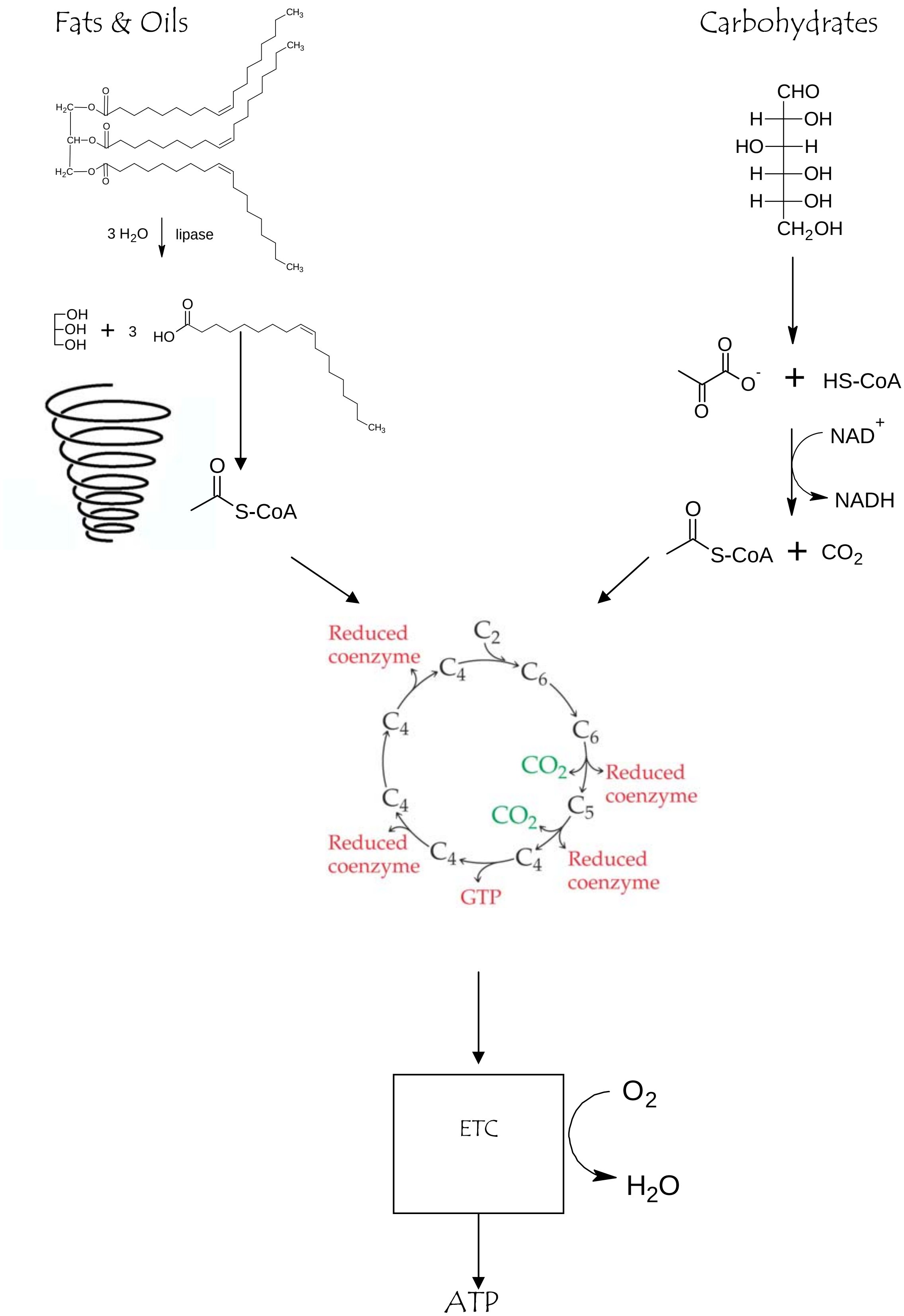
CAC Overview



ETC Overview



Metabolism and Bioenergetics Part 4: Carbohydrates, Fats & ATP



ATP yield from the complete metabolism of one molecule of glucose

1 Glucose molecule produces			ATP Produced
________	ATP from glycolysis	⇒	________
________	NADH from glycolysis	⇒	________
________	NADH from pyruvate oxidation	⇒	________
________	acetyl-SCoA from pyruvate	⇒	________
	Total ATP production	⇒	________

ATP yield from the complete metabolism of one molecule of myristic acid ($CH_3(CH_2)_{12}CO_2H$)

1 Myristic acid produces			ATP Produced
________	$FADH_2$ from β-oxidation	⇒	________
________	NADH from β-oxidation	⇒	________
________	Acetyl-CoA molecules	⇒	________
________	activation of fatty acid	⇒	- ________
	Total ATP production	⇒	________