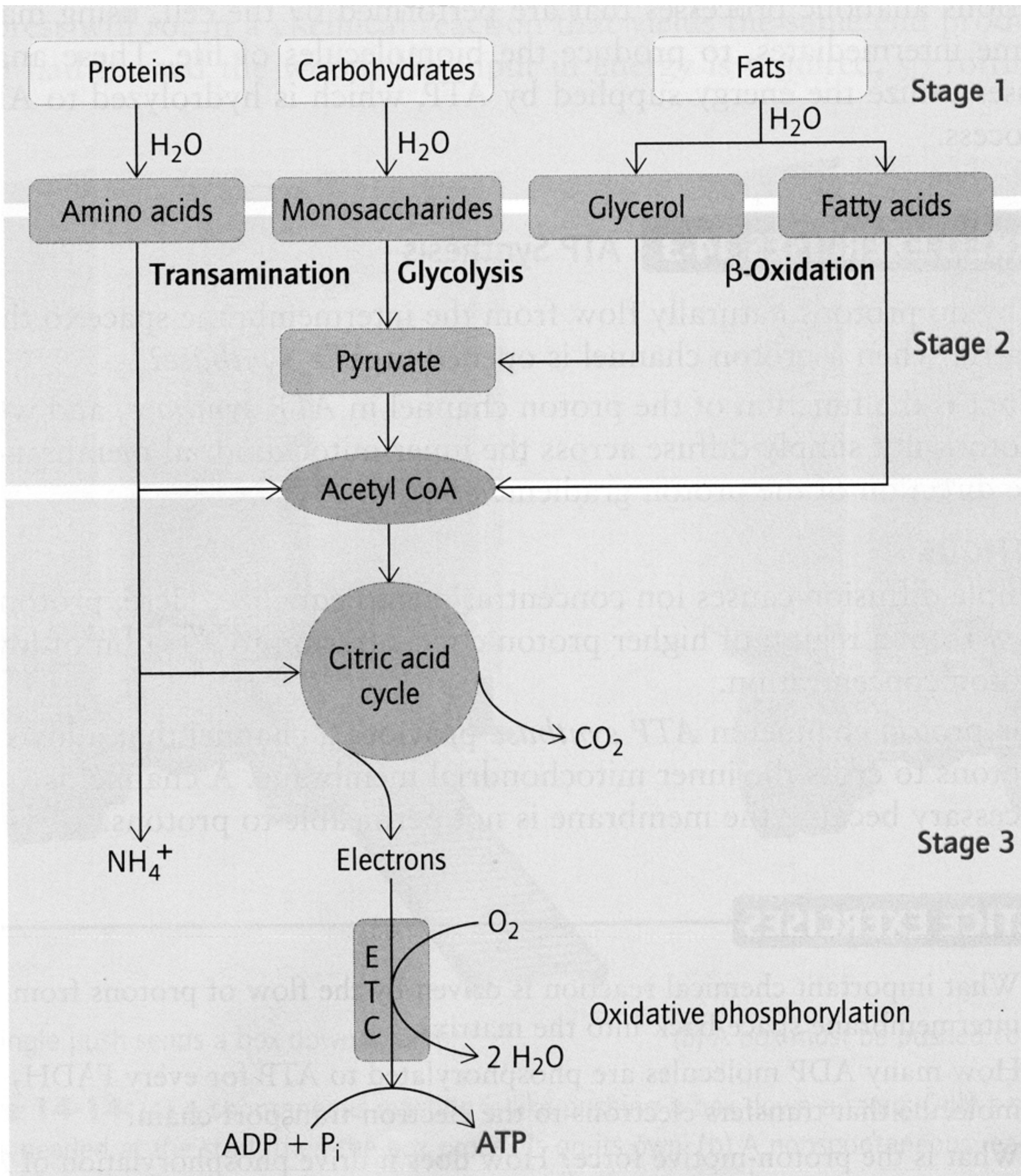
Take notes while watching the following video tutorials to prepare for the "Metabolism Part 2 Activity".

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

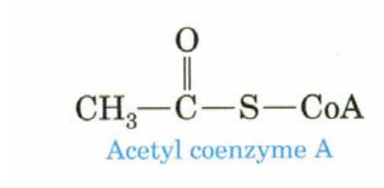
Catabolism – Degradation (oxidative) metabolic reactions that produce energy



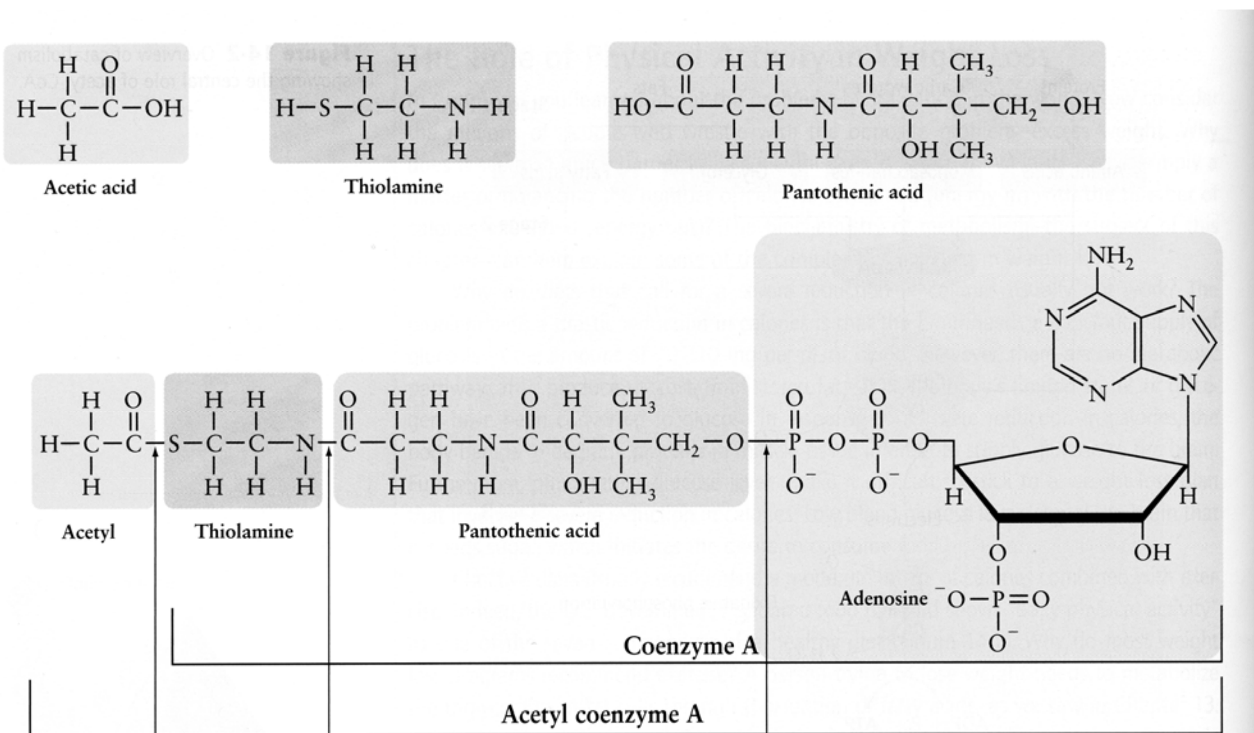
Right before the Citric Acid Cycle

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

$$\text{Pyruvate} + \text{HS-CoA} \xrightarrow{NAD^+ \quad NADH + H^+} \text{Acetyl-CoA} + CO_2$$



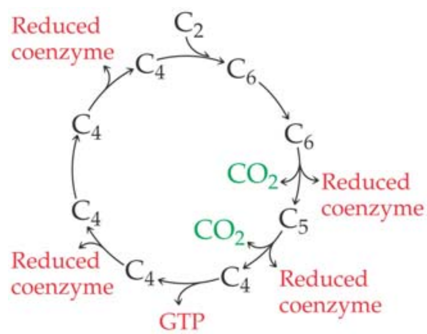
Classify the bonds linking the four compounds together to form acetyl CoA in the diagram below.



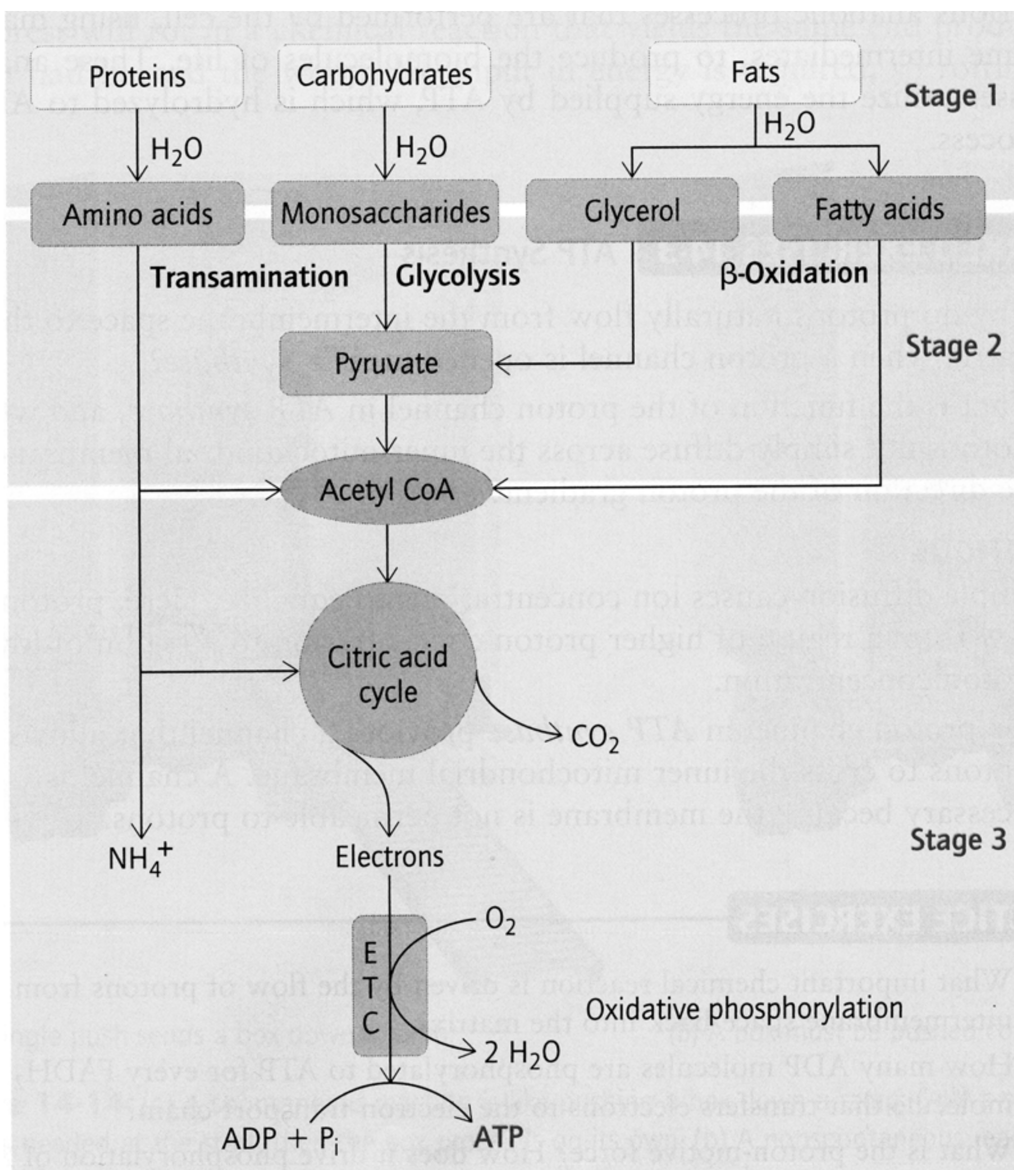
Metabolism and Bioenergetics Part 2: The Citric Acid Cycle

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.

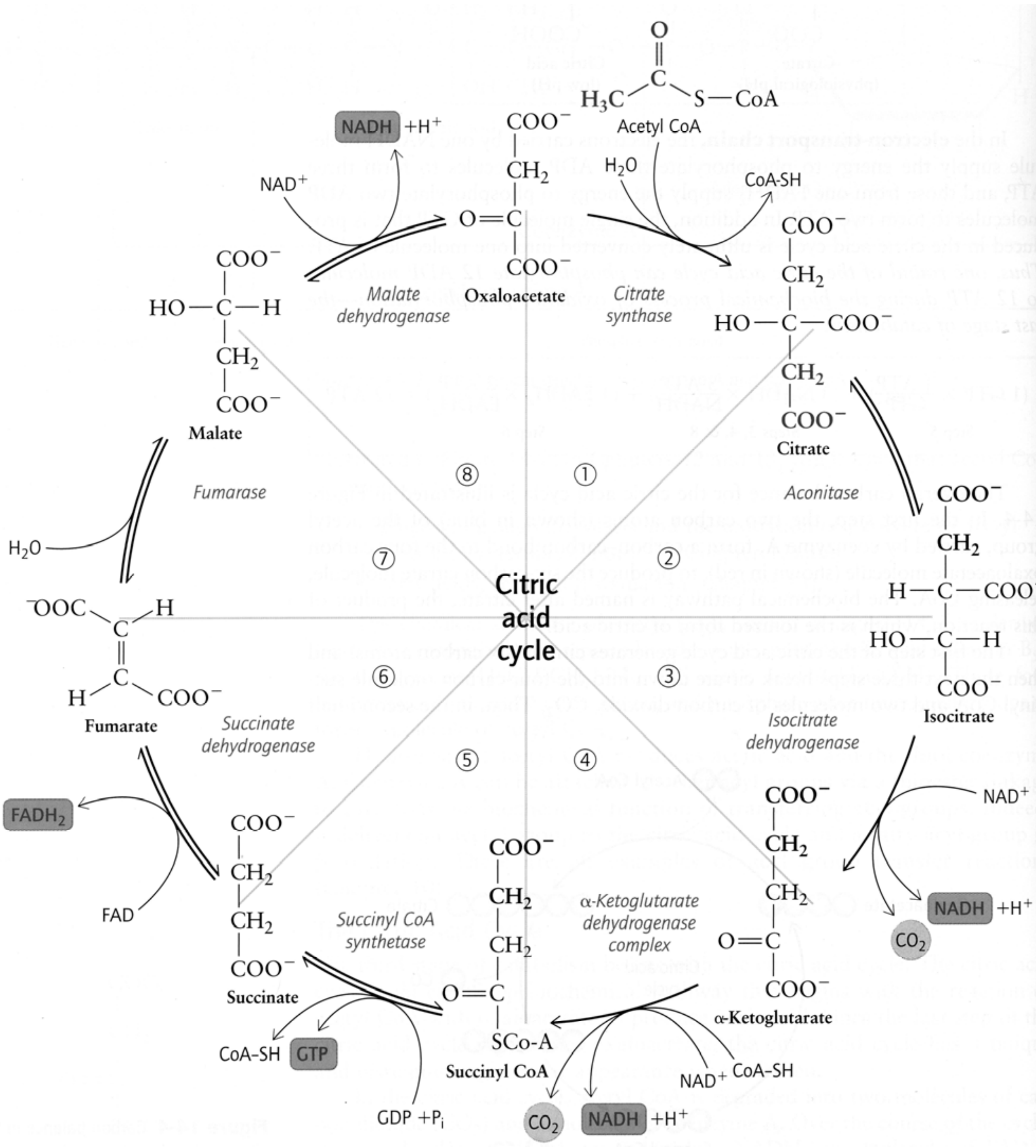


Our body can convert 1 GTP into 1 ATP.



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?

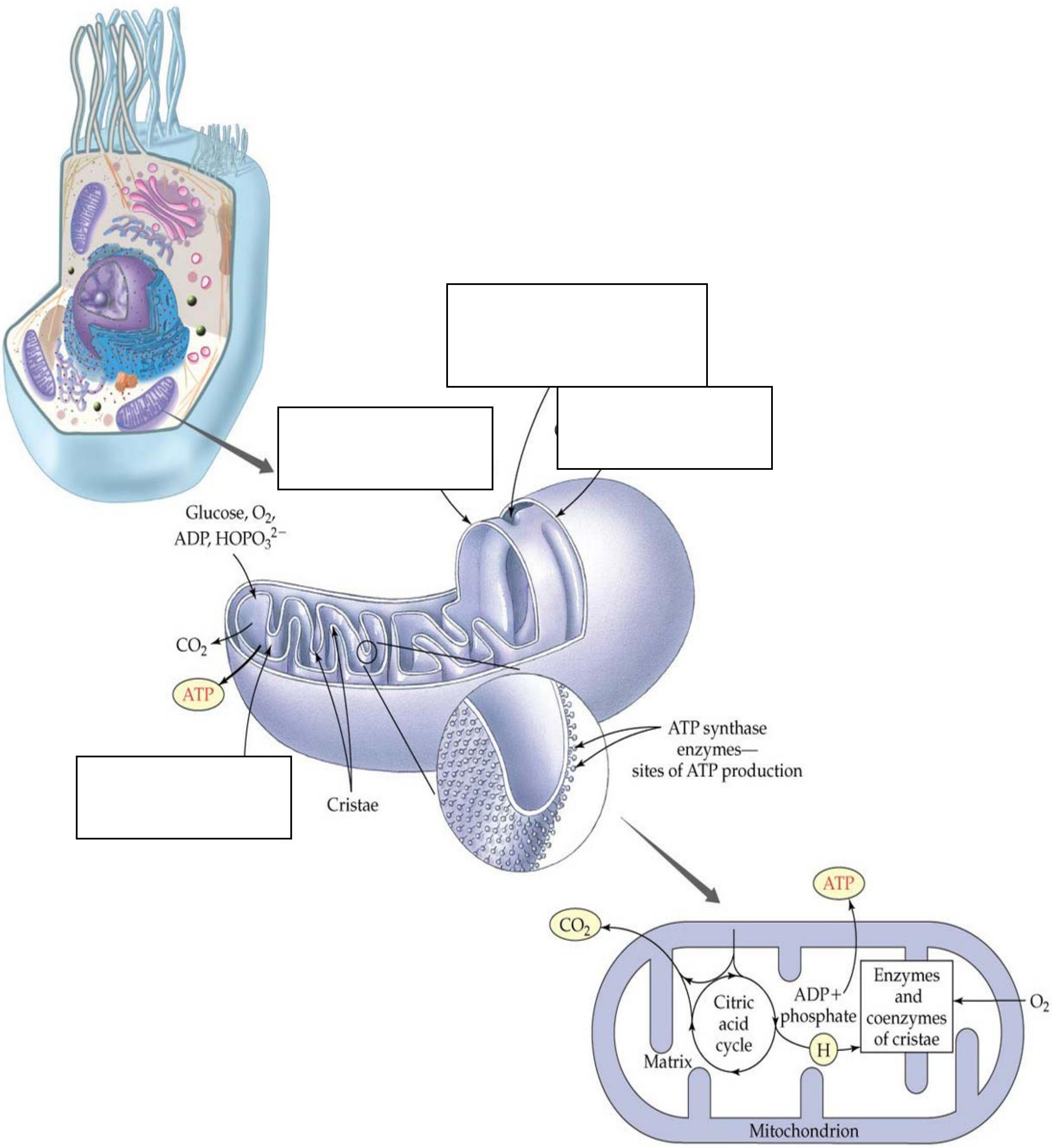
7. Which step(s) require a ligase enzyme?

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

Metabolism and Bioenergetics Part 3:
Electron Transport Chain and Oxidative Phosphorylation

The Mitochondrion

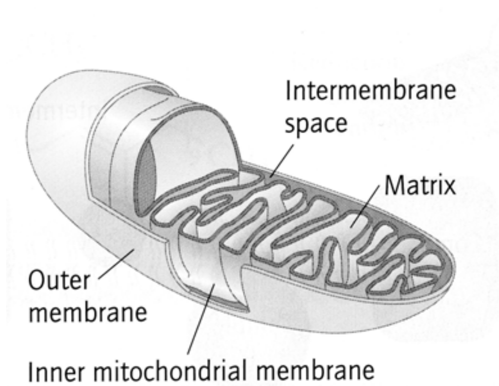
(the place where all of this chemistry is happening inside us.)

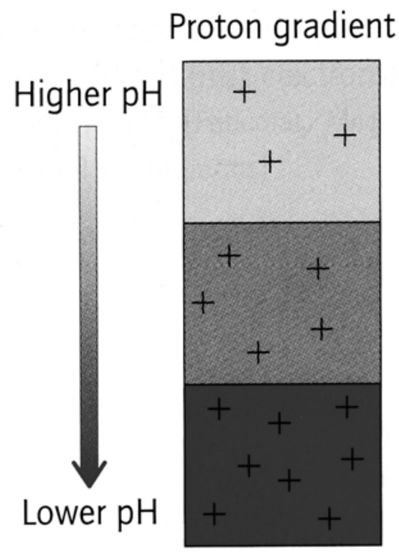


Proton Gradient creates the Proto-motive Force

Ions dialyse through a membrane in the direction that equalizes the concentration of ions. But ions are unable to pass through the inner membrane by simple diffusion creating different proton concentrations on either side of the inner mitochondrial membrane.
The matrix has a lower concentration of protons (lower or higher pH) than the intermembrane space (lower or higher pH).

Label the proton gradient with the terms "matrix" and "intermembrane" to represent what is happening inside the mitochondrion.

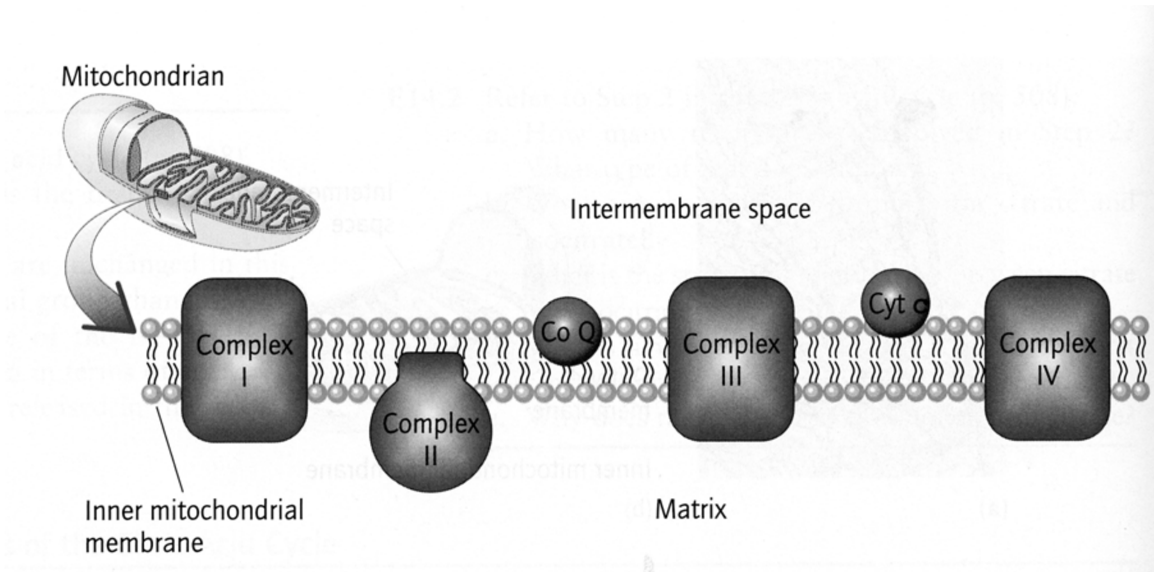




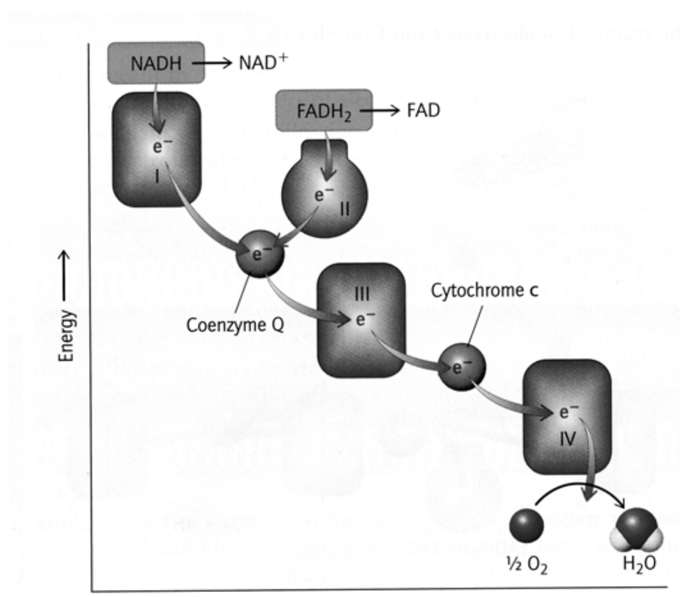
Most of the enzymes involved in the CAC reside in the matrix. The protein complexes involved in oxidative phophorylaton are located along or embedded within the inner membrane. The important enzyme ATP synthase extends from the intermembrane through the inner membrane all the way into the matrix.

The Electron Transport Chain

The ETC takes the electrons from NADH and $FADH_2$ and passes them through a "chain" of cofactors and enzyme complexes resulting in the transfer of 4 electrons and 4 protons (H^+ ions) to O_2 to form H_2O. As the electrons are transferred, the ETC is pumping protons into the intermembrane space. Since the movement of protons is against the proton gradient, the process is referred to as a proton pump. The accumulaton of protons in the intermembrane space represents stored chemical and electrical potential energy called the proton-motive force.



Indicate which complex has the highest e- affinity and which complex has the lowest e- affinity.

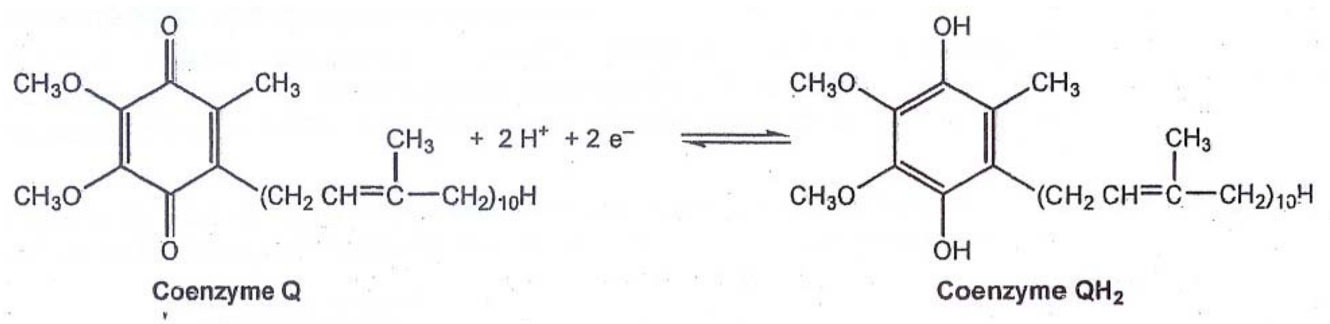


Oxidation-Reduction in the ETC

Electrons are transferred between atoms and molecules through a series of redox reactions that occur at various metal atom centers and organic cofactors such as coenzyme Q.

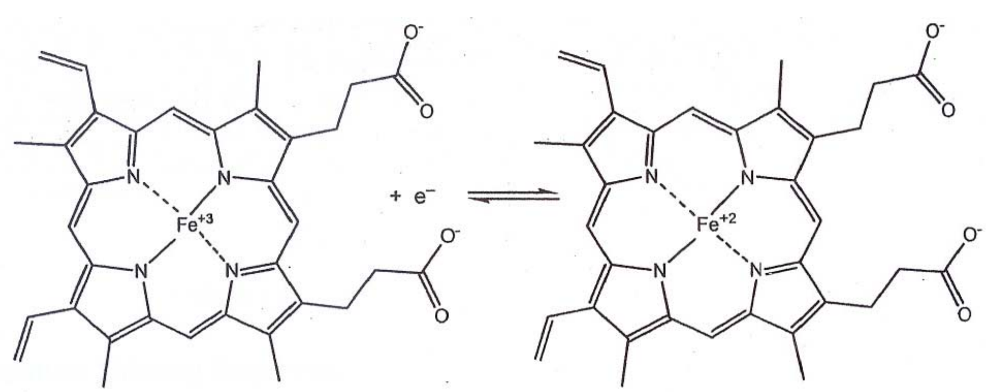
Label the following cofactors as oxidized or reduced.

Coenzyme Q (CoQ), sometimes called ubiquinone, is derived from quinone which is a six carbon cyclic compound with two double bonds and two keto groups attached to a long carbon chain. CoQ is reduced to $CoQH_2$ when the keto groups of quinone accept hydrogen ions and electrons.

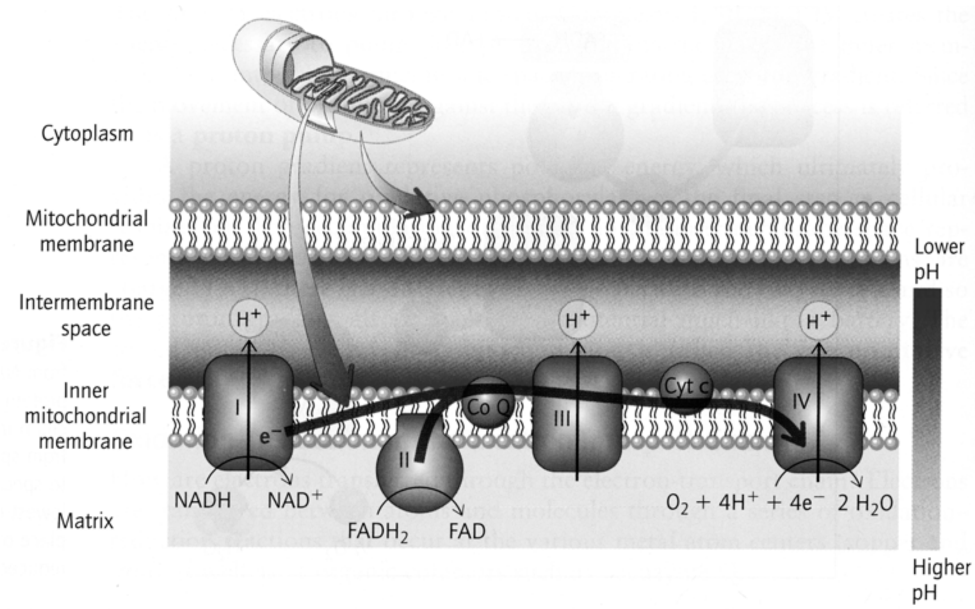


Cytochrome c – Cytochrome c is a protein that contains an iron ion in a heme group. In each cytochrome c, the Fe^{3+} that accepts a single electron to form Fe^{2+} which is oxidized back to Fe^{3+} when the electron is passed on during the next step.

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



ETC – putting it all together



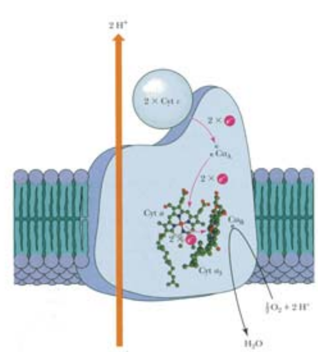
Complex I

Complex II

Complex III

Complex IV

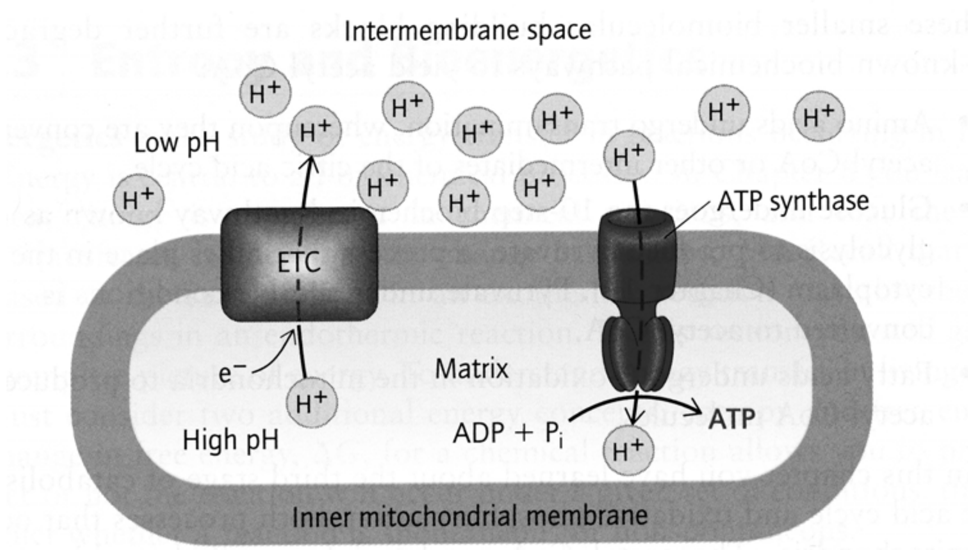
CN⁻ Poisoning & Cytochrome c Oxidase

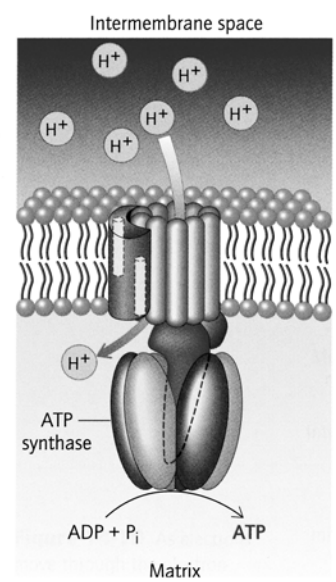


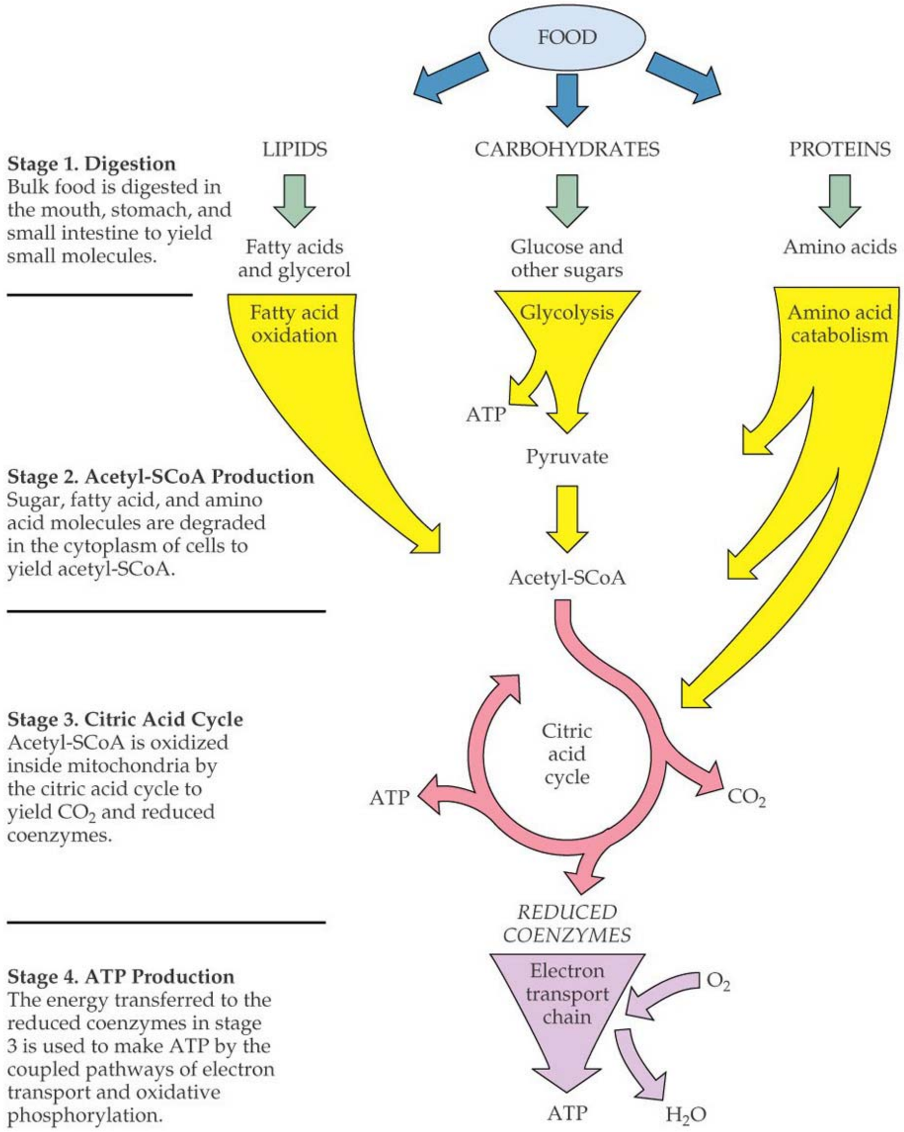
ATP Synthesis

ALL the reactions of the ETC are energetically favorable and "use up" the energy stored in the reduced cofactors. This energy must be saved somehow to make ATP. The energy is saved by using the favorable electron-transport reactions to "pump" protons (H^+ ions) out of the matrix of the inner mitochondrial membrane into the intermembane space.

The "proton gradient" (or "pH gradient") is a high-energy state, 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.






FOOD
LIPIDS
CARBOHYDRATES
PROTEINS
Stage 1. Digestion
Bulk food is digested in the mouth, stomach, and small intestine to yield small molecules.
Fatty acids and glycerol
Glucose and other sugars
Amino acids
Fatty acid oxidation
Glycolysis
Amino acid catabolism
ATP
Pyruvate
Stage 2. Acetyl-SCoA Production
Sugar, fatty acid, and amino acid molecules are degraded in the cytoplasm of cells to yield acetyl-SCoA.
Acetyl-SCoA
Stage 3. Citric Acid Cycle
Acetyl-SCoA is oxidized inside mitochondria by the citric acid cycle to yield CO_2 and reduced coenzymes.
Citric acid cycle
ATP
CO_2
REDUCED COENZYMES
Stage 4. ATP Production
The energy transferred to the reduced coenzymes in stage 3 is used to make ATP by the coupled pathways of electron transport and oxidative phosphorylation.
Electron transport chain
O_2
ATP
H_2O

Energy from Glycolysis

ATP yield from the complete metabolism of one molecule of glucose

Glycolysis of 1 Glucose molecule produces		Net ATP Produced
__________ ATP molecules	⇒	__________
__________ NADH molecules Each NADH molecule can be converted into 3 ATP molecules via the electron transport chain (ETC)	⇒	__________
__________ pyruvate molecules Under aerobic conditions, each pyruvate forms Acetyl-CoA which enters the Citric Acid Cycle. Each molecule of acetyl-CoA leads to the production of 12 ATP molecules.	⇒	__________

The energy of hydrolysis of ATP is 7.3 kcal/mol.

The maximum amount of energy that is released from the oxidation of one mole of glucose is 687 kcal/mol.

If 32 moles of ATP are made per one mole of glucose, how much energy is produced in the cells from the hydrolysis of the 32 moles of ATP?

Can you account for the difference between the maximum amount of energy released from the oxidation of glucose and the energy produced from glucose as ATP?

Energy from β-Oxidation

Energy yield from stearic acid ($CH_3(CH_2)_{16}CO_2H$) catabolism

8 cycles of β-Oxidation	x	5	=	40 ATP
9 acetyl CoA molecules	x	12	=	108 ATP
Activation of stearic acid				- 2 ATP
Total				146 ATP

ATP per carbon atom of 1 molecule of stearic acid

ATP per carbon atom of glucose

How many fatty acids are in one triglyceride?

Note the difference in % explains the nutritional differences.

This spacer page supports 2-sided copying of our Video Tutorial Lecture Outline Packet.