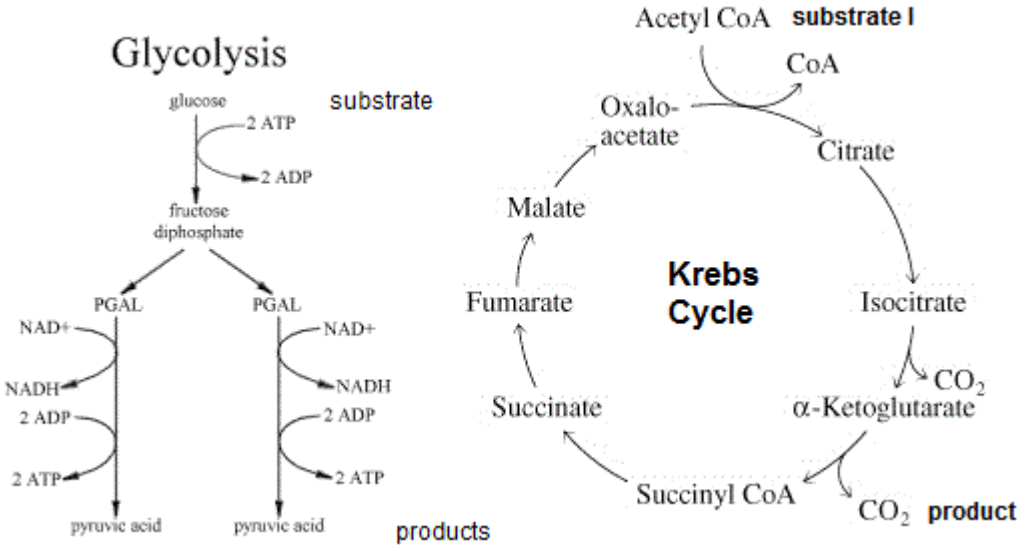
Topic 8.1 - Metabolism

Understandings:

∑ - Metabolic pathways consist of chains and cycles of enzyme-catalysed reactions.

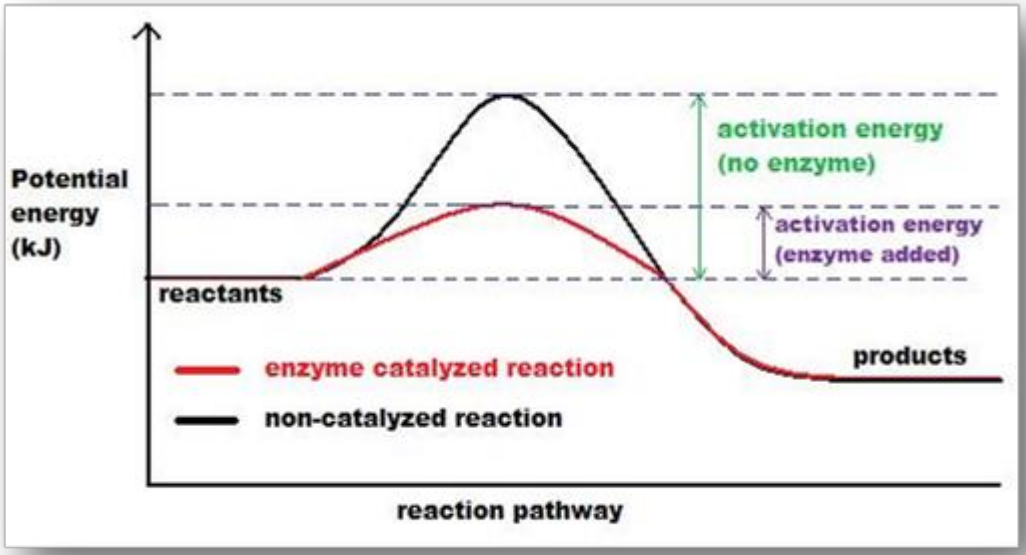
- Metabolism – the chemical reactions that occur in organisms in order for them to maintain life, such as the synthesis of ATP during cellular respiration.
- In metabolic pathways, enzymes catalyse each reaction along the pathway
- Some of these pathways are anabolic, which is building up of organic molecules (easy to remember as anabolic steroids help build muscle)
- The other pathways are catabolic, which means breaking down of large organic molecules into smaller ones (example – hydrolysis reactions during digestion)
- Some of these metabolic reactions are cycles (i.e. Krebs Cycle) and some are linear chains (i.e. Glycolysis)



∑ - Enzymes lower the activation energy of the chemical reactions that they catalyse.

- Activation energy is the energy that must be overcome in order for a chemical reaction to occur.
- Activation energy more specifically can be defined as the energy needed to weaken and break the chemical bonds of the substrate.
- Enzymes work by lowering the activation energy needed for the reaction to occur.
- When a substrate binds to the active site on the enzyme, the enzyme changes its conformational shape, thus altering the shape of the active site.
- Changing its shape destabilizes the bonds of the bound substrate.
- Thus less energy is required for the reaction to take place.
- These reactions therefore occur faster and more substrates can be converted into more products (rate of reaction increases dramatically).

Diagram of Exothermic reaction



∑ - Enzyme inhibitors can be competitive or non-competitive.

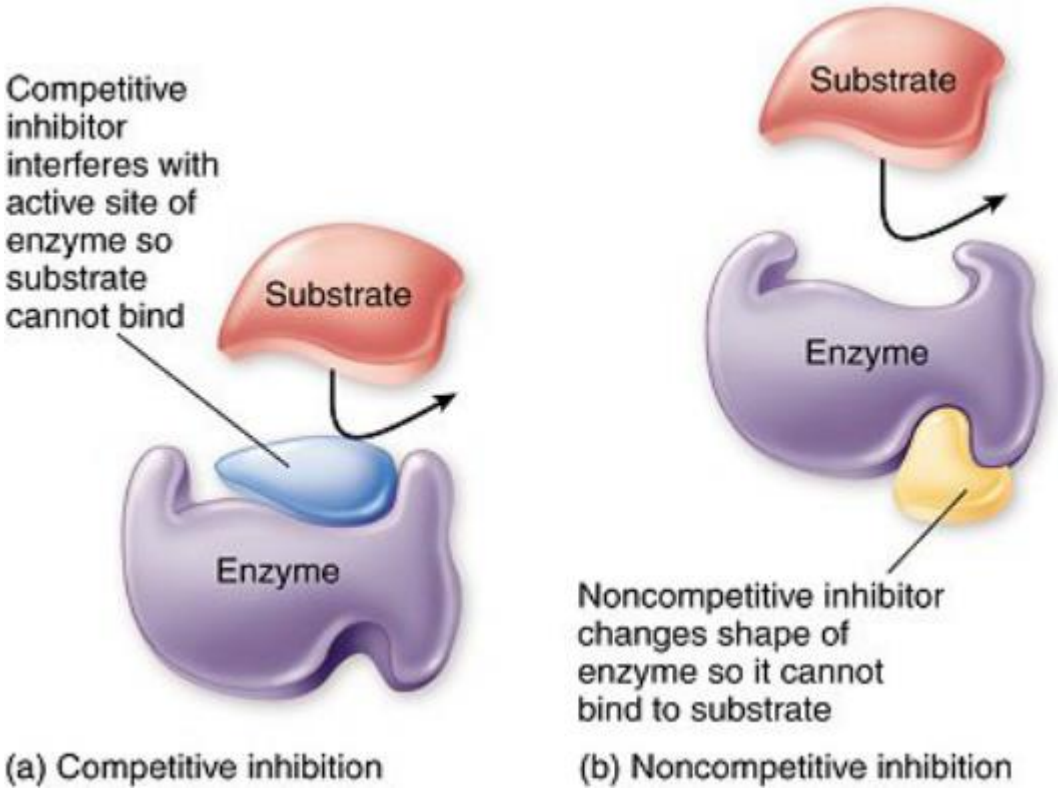
- Enzyme inhibition occurs when molecules bind to enzymes and decreases their activity.
- Two types of enzyme inhibition are competitive and non-competitive inhibition.

Competitive Inhibition

- Competitive inhibition occurs when a molecule that is structurally similar to the substrate competes directly with substrate for access to the active site, thus decreasing the number of times a substrate interacts with an enzyme.
- The inhibitor essentially blocks the substrate from binding to the enzyme.
- Since there is less enzyme/substrate interactions, the chemical reaction rate decreases.
- Competitive inhibition is usually reversible but can be irreversible in some cases.
- Competitive inhibition can be overcome by sufficiently increasing the concentrations of substrate, thereby out-competing the inhibitor.
- An example of completive inhibition is when **ethanol** is introduced to compete with and inhibit the oxidization of **methanol**. If someone accidently drinks methanol they can become blind and actually die depending on the amount. As methanol is oxidized to form formaldehyde and formic acid, these products can attack the optic nerve. Ethanol is introduced which competes with methanol for the active site on the **enzyme alcohol dehydrogenase**. The by-products of ethanol are much less toxic.
- Another example is the competitive inhibition of the enzyme **Succinate dehydrogenase** by **malonate,** during the conversion of **succinate to fumarate**.

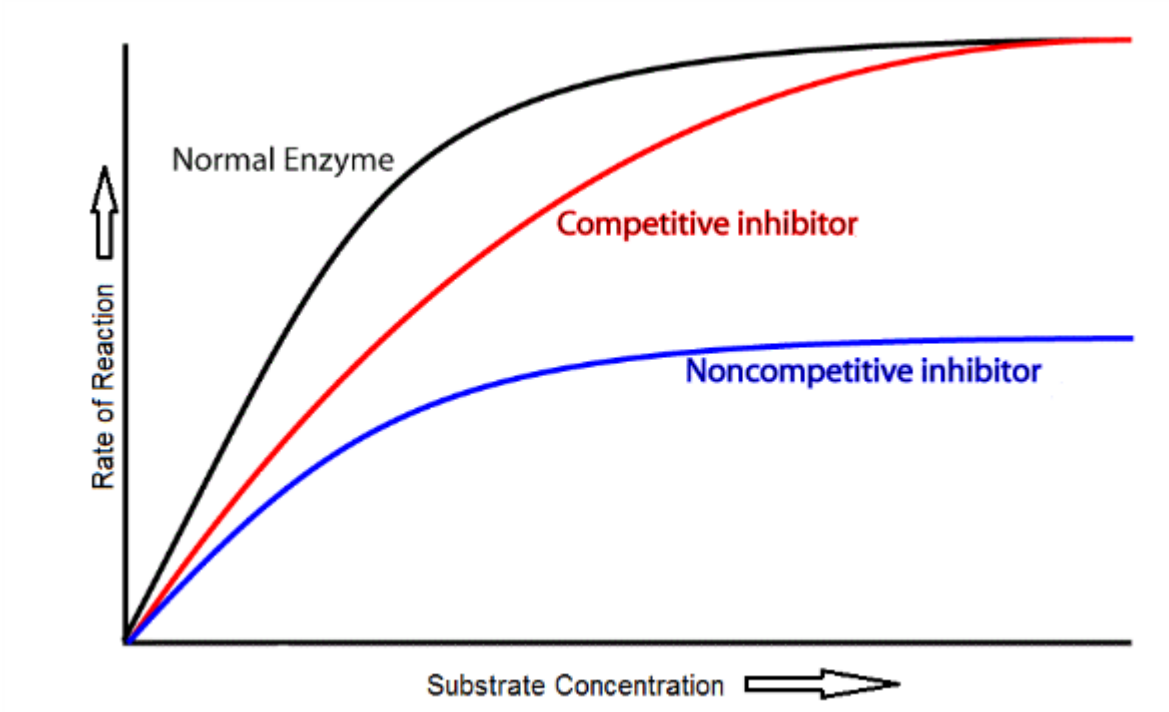
Non-Competitive Inhibition

- Non-competitive inhibition occurs when an inhibitor does not compete for the active site with the substrate, but instead binds to a separate site on the enzyme.
- When non-competitive inhibitor binds to the enzyme at the alternative site, it changes the conformational shape of the enzyme and thus the active site, so that the substrate can no longer bind to the enzyme for a reaction to occur.
- Non-competitive inhibition is also called allosteric inhibition and the site where the inhibitor binds is called the allosteric site.
- Non-competitive inhibition is usually reversible.
- Since the inhibitor binds to a site other than the active site, increasing the concentration of the substrate will not speed up the reaction or reduce the effect of the inhibitor.
- An example of non-competitive inhibition is when ATP acts as an allosteric inhibitor in the conversion of glycogen to glucose phosphate in a metabolic pathway.
- ATP binds to the enzyme Glycogen phosphorylase that catalyzes this reaction
- This prevents the over production of ATP and glucose if it is not needed.
- Other examples include heavy metals such as Ag^{+}, Hg^{2+} and Pb^{2+}.



http://www.tokresource.org

β - Skill: Distinguishing different types of inhibition from graphs at specified substrate concentration.

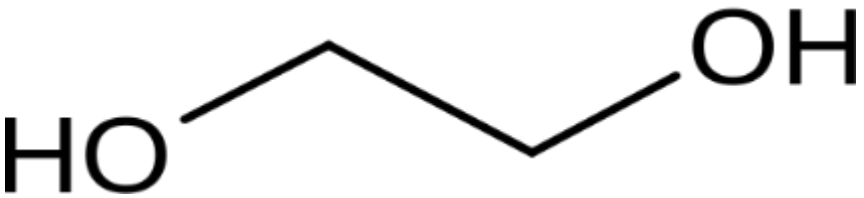


β - Many enzyme inhibitors have been used in medicine.

For example ethanol has been used to act as a competitive inhibitor for antifreeze poisoning.

Fomepizole, which is an inhibitor of alcohol dehydrogenase, has also been used for antifreeze poisoning.

- The main ingredient in antifreeze is called ethylene glycol



- Ethylene glycol is a toxic, colourless and odorless liquid with a sweet taste that is sometimes consumed by children and animals
- Symptoms include feelings of intoxication and nausea, followed by vomiting, hyperventilation, acidosis and acute kidney failure.
- Treatment must start as soon as possible to prevent kidney failure, which can be fatal

Competitive Inhibition

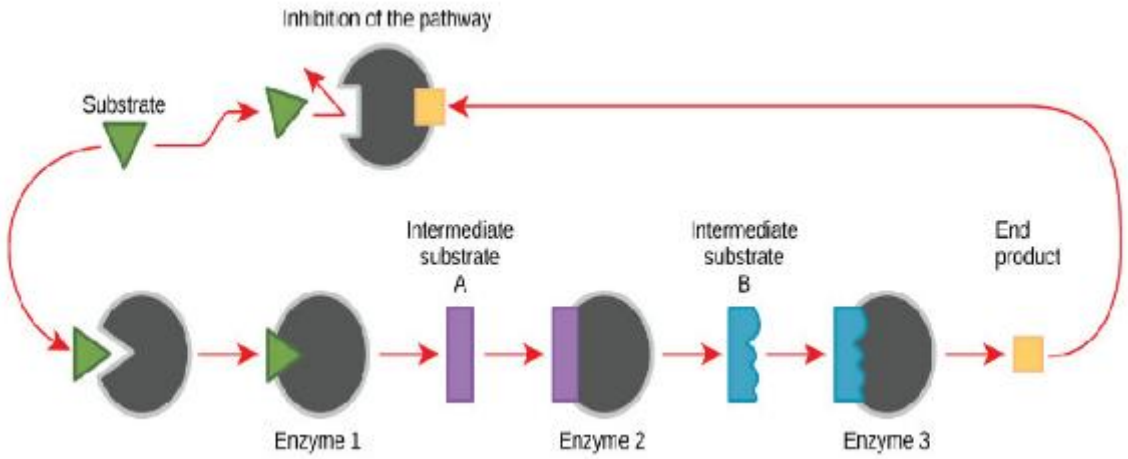
- Ethanol is used as treatment to block the enzyme responsible for metabolizing ethylene glycol into glycolic acid and oxalic acid (these two molecules are more toxic that the original molecule)
- Ethanol acts by competing with ethylene glycol for the active site of alcohol dehydrogenase, the first enzyme in the degradation pathway. Because ethanol has a much higher affinity for the alcohol dehydrogenase, about a 100-times greater affinity, it successfully blocks the breakdown of ethylene glycol into glycoaldehyde, which prevents the further degradation into its dangerous metabolites such as oxalic acid.
- Since the oxalic acid isn't formed, kidney damage is avoided and the ethylene glycol is excreted in the urine

Non-Competitive Inhibition

- Fomepizole is a strong inhibitor that also blocks the formation of the destructive metabolites of ethylene glycol and the approved antidote by the US Food and drug Administration
- Fomepizole binds to the allosteric site of the enzyme which changes the conformational shape of the enzyme
- The ethylene glycol can no longer bind to the active site
- Since this is non-competitive dosage adjustments and blood monitoring do not have to be performed as with ethanol treatment (ethanol treatments require frequent blood ethanol measurements and dosage adjustments to maintain therapeutic ethanol concentrations as the ethanol is broken down)
- A disadvantage is that Fomepizole is expensive

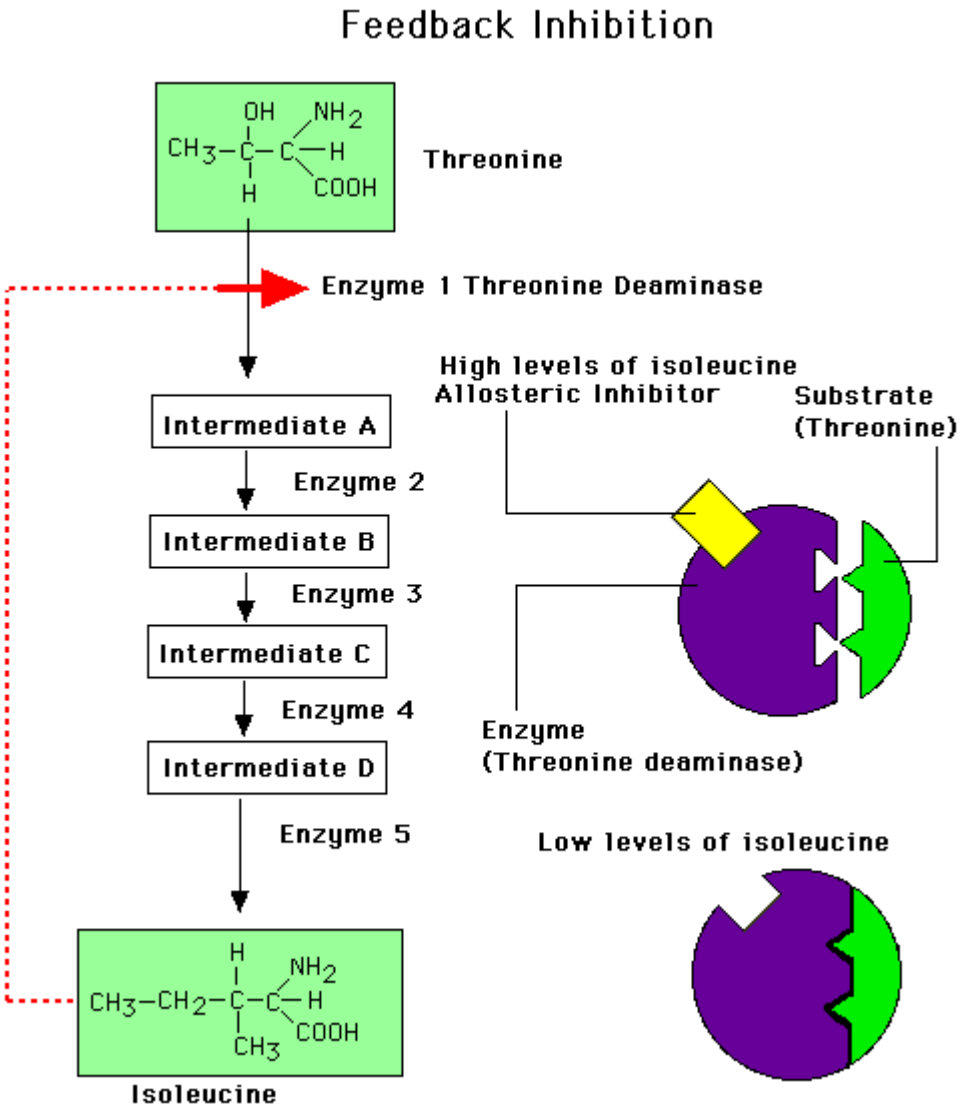
∑ - Metabolic pathways can be controlled by end-product inhibition.

- Allosteric or non-competitive inhibition plays an important role in controlling metabolic pathways.
- When a metabolic pathway is producing a specific product the product will alsoact as an inhibitor to this metabolic pathway.
- End-product inhibition prevents the cell from over producing products that it does not need, thereby preventing the cell from creating waste or using valuable energy resources.
- If a cell is creating a specific product through a metabolic pathway and it makes too much of this product, this product will actually inhibit the first enzyme in the metabolic pathway, thus stopping the metabolic pathway from producing more unneeded product.
- An example of allosteric inhibition can be the same example as the one described above. When too much ATP is produced, ATP acts as an allosteric inhibitor in the conversion of glycogen to glucose phosphate. ATP binds to the enzyme that catalyzes this reaction thus preventing the over production of ATP.
- As the end-product is used up, the metabolic pathway starts again as the first enzyme is reactivated.



Applications and skills:

<u>β - Application</u>: End-product inhibition of the pathway that converts threonine to isoleucine.



http://www.uic.edu/classes/bios/bios100/lectures/feedback-inh.gif

β - Application: Use of databases to identify potential new anti-malarial drugs.

- Malaria is a disease caused by the protist ***Plasmodium falciparum***
- The increased resistance of the pathogen ***P. falciparum*** to anti-malarial drugs such as chloroquine and the increasing global efforts to eradicate malaria have driven the need to produce new anti-malarial drugs
- P. falciparum strain 3D7 has been sequenced by scientists and is used to test chemicals for new possible medication
- One specific study tested over 300,000 chemicals against a chloroquine-sensitive 3D7 strain and a chloroquine-resistant K1 strain to determine if any of these chemicals inhibited metabolism
- The results showed that 19 new chemicals inhibited the enzymes normally targeted by anti-malarial drugs and 15 chemicals that bound to a total of 61 different malarial proteins.
- This research provides starting points to produce possible new ant-malarial drugs

β - Skill: Calculating and plotting rates of reaction from raw experimental results.

Catalase is an enzyme found in the cells of many tissues of living organisms. It speeds up a reaction which breaks down hydrogen peroxide, a toxic chemical, into 2 harmless substances--water and oxygen.

The chemical reaction is as follows: $2H_2O_2 \rightarrow 2H_2O + O_2$

This reaction is important to cells because hydrogen peroxide (H_2O_2) is produced as a byproduct of many normal cellular reactions. If the cells did not break down the hydrogen peroxide, they would be poisoned and die. In this lab, you will study the catalase found in liver cells. The following data has been recorded from the breakdown of hydrogen peroxide by beef liver over a 10 minute time period.

Time (s) after 1 g of Beef liver added	0	60	120	180	240	300	360	420	480	540	600
Mass (g) of the remaining solution	45.23	44.41	43.60	42.85	42.16	41.52	40.89	40.31	39.82	39.10	38.95

Please fill in the following table and calculate the rate of reaction at each time interval.

Time (s) after 1 g of Beef liver added	0	60	120	180	240	300	360	420	480	540	600
Mass (g) decrease											
Mass (mg) decrease											
Rate of mass decrease (mg s^{-1})											

Please show one sample calculation for the rate of mass decrease over time.

Please graph your change in mass over your change in time to show the rate (write in the proper labels on the axis, including units.

Calculate the overall rate of reaction for the 600 second time period.

What do you notice as the time increases?

Why do you think this is the case?

*****Do the data-based questions on page 378 and 379*****

Guidance:

Enzyme inhibition should be studied using one specific example for competitive and non-competitive inhibition

Theory of Knowledge:

Many metabolic pathways have been described following a series of carefully controlled and repeated experiments. To what degree can looking at component parts give us knowledge of the whole

http://www.theguardian.com/science/punctuated-equilibrium/2010/oct/11/3

http://scienceofwholeness.com/the-whole-is-greater-than-the-sum-of-its-parts/

http://www.cienciasinseso.com/en/the-whole-is-greater-than-the-sum-of-its-parts/

8.2 Cell Respiration

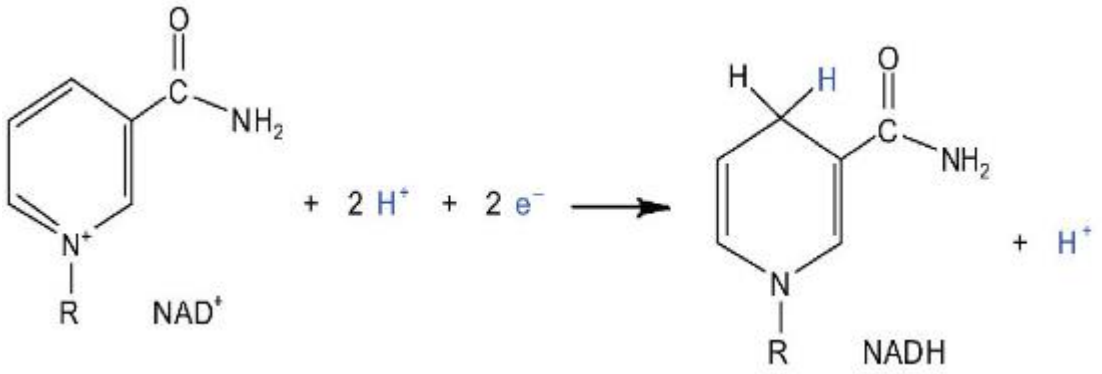
Nature of Science: Paradigm shift—the chemiosmotic theory led to a paradigm shift in the field of bioenergetics. (2.3)

∑ - Understandings:

∑ - Cell respiration involves the oxidation and reduction of electron carriers.

- **Oxidation** involves the *loss* of electrons from an element through the gain of oxygen or the loss of hydrogen.
- **Reduction** involves the *gain* of electrons through the addition of hydrogen or the *loss* of an oxygen molecule.
- These reactions are called Redox reactions (reduction-oxidation) which are chemical reactions in which atoms have their oxidation number changed.
- For example the oxidation of carbon to form CO_2 and the reduction of carbon by the addition of hydrogen to yield methane (CH_4).

- Electron carriers are specific substances that accept and give up electrons
- The main electron carrier in cellular respiration is NAD (nicotinamide adenine dinucleotide)
- During respiration NAD which actually exists as NAD^+ accepts 2 electrons and a proton (H^+) from the molecule being oxidized (like pyruvate) to form NADH with one extra H^+ leftover as a product. The reaction is illustrated below.



- After the electron carriers are reduced they transport their electrons and hydrogens to the ETC, where the opposite reaction occurs (oxidation)

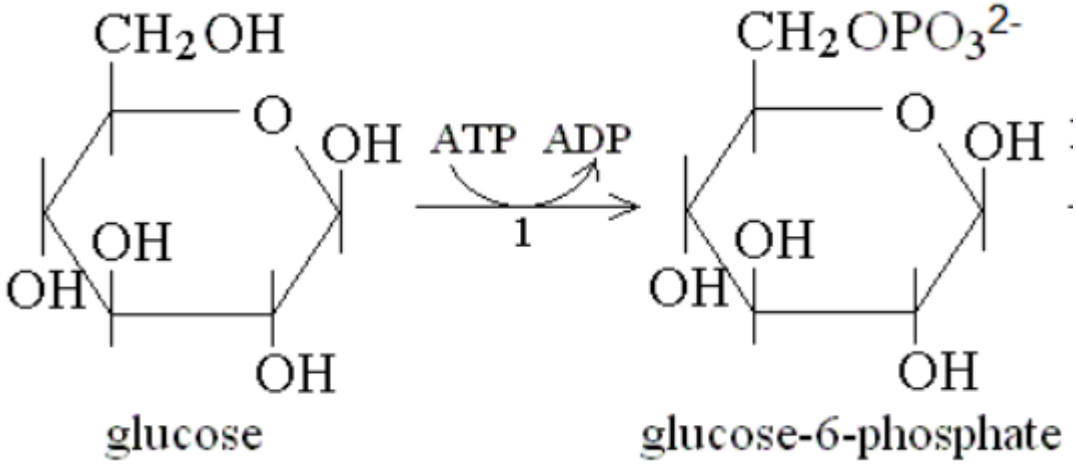
$$2\,H_2O \rightarrow O_2 + 4\,H^+ + 4\,e^- \qquad (\Delta E_0 = -1.23\ V)$$

- So when NADH is oxidized it donates the electrons and protons to an electron carrier (complex I) in the inner mitochondrial membrane made from conjugated proteins (Fe-S core)
- This carrier is therefore reduced and will be re-oxidized as it passes the electrons down the ETC

∑ **- Phosphorylation of molecules makes them less stable.**

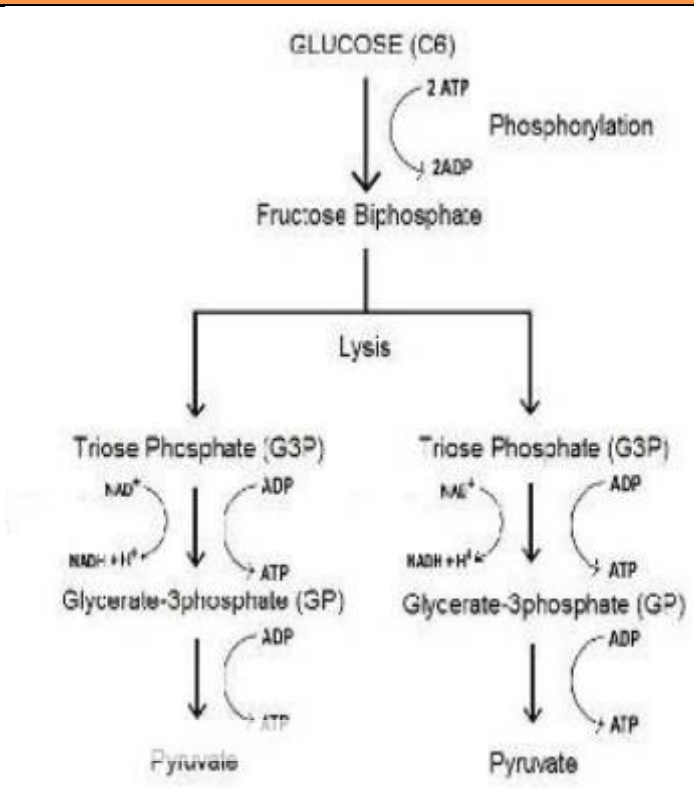
- Phosphorylation occurs when a phosphate (PO_4^{3-}) molecule is added to an organic molecule to make the molecule less stable and more likely to react
- Phosphorylation basically activates the molecule and is an endergonic reaction
- The removal of the phosphate through hydrolysis is an exergonic reaction
- The reactions are coupled together, so one molecule releases the phosphate and one accepts the phosphate molecule, and are spontaneous

<u>Example</u> – Phosphorylation of Glucose to Glucose-6-phosphate, coupled with the hydrolysis of ATP to ADP.



∑ - In glycolysis, glucose is converted to pyruvate in the cytoplasm.

∑ - Glycolysis gives a small net gain of ATP without the use of oxygen.

Glycolysis	Diagram
In the first stage of glycolysis, 2 ATP molecules are used to phosphorylate glucose (add phosphates) through a process calledphosphorylation	
Immediately following the phosphorylation Fructose Biphosphate splits into 2 G3P molecules (lysis)	
The 2 G3P molecules formed from the split are then oxidated by the removal of hydrogen atomsto form NADH + H^+	
A phosphate is added to the G3P's to briefly form 3 carbon molecules with 2 phosphate groups. Next,one phosphate is removed from each to form ATP and glycerate-3-phospahte (GP)	
In the final stages of glycolysis one more phosphate is removed from each GP to form 2 ATP molecules and 2 pyruvates	

- Glycolysis occurs in the cytoplasm.

- One hexose sugar (glucose) is converted into two three-carbon compounds(**pyruvate**) **with a net gain of 2 ATP** (2 ATP molecules are used to start the process) and 2 NADH + H^+.

Glycolysis Video: https://www.youtube.com/watch?v=hDq1rhUkV-g

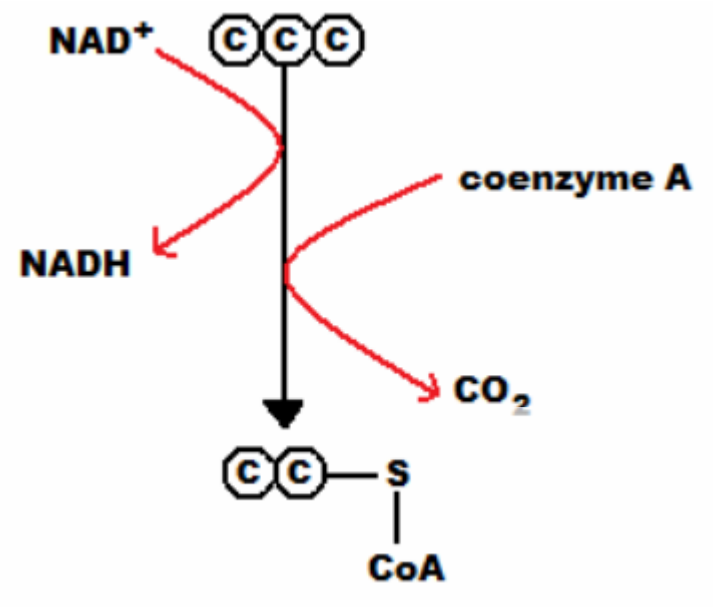
∑ - In aerobic cell respiration pyruvate is decarboxylated and oxidized, and converted into acetyl compound and attached to coenzyme A to form acetyl coenzyme A in the link reaction.

Decarboxylation is a chemical reaction that removes a carboxyl group and releases carbon dioxide (CO_2).

Oxidation is the *loss* of electrons or an *increase* in oxidation state by a molecule, atom, or ion. Pyruvate is oxidized by the by the removal of pairs of hydrogen atoms (with their electrons), which are passed on the NAD^+ and FAD

Link Reaction

- Two pyruvate molecules enter the matrix of the mitochondria and are decarboxylated to form two acetyl groups (removal of carbon as CO2).
- The acetyl group is oxidized and NAD^+ is reduced to form NADH.
- Each acetyl group combines with CoA (enzyme) producing 2 Acetyl Coenzyme A molecules.
- These products enter the Krebs cycle.



- The above **link reaction** occurs twice per glucose molecule (2 pyruvate --> 2 Acetyl CoA)

∑ - In the Krebs cycle, the oxidation of acetyl groups is coupled to the reduction of hydrogen carriers, liberating carbon dioxide.

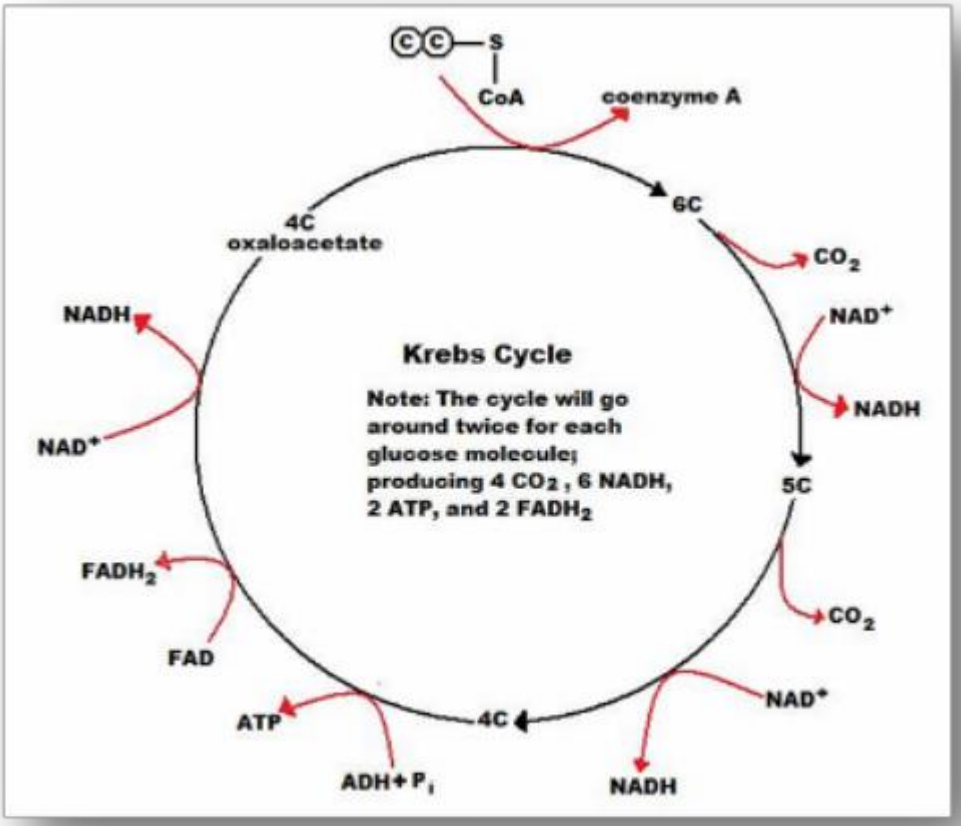
β - Skill: Analysis of diagrams of the pathways of aerobic respiration to deduce where decarboxylation and oxidation reactions occur

Krebs Cycle

Each acetyl group enters the Krebs cycle, therefore there are two rotations of the Krebs cycle per glucose molecule. There are two decarboxylations and four oxidations per cycle

- Acetyl Co A is a two carbon molecule that transfers the acetyl group to the four carbon molecule oxaloacetate to form the six-carbon compound citrate (6C).
- CoA is released, free to pick up another acetyl group.
- Citrate is decarboxylated (released as carbon dioxide) and CO_2 is excreted as a waste product with the CO_2 from link reaction.
- Citrate is also oxidized and NAD^+ is reduced to form NADH.
- The C5 molecule formed is further oxidized and decarboxylated to form another CO_2 molecule (excreted as waste) and another NADH.
- At this point all the carbons from the original pyruvate molecule have been released as CO_2.
- The C4 molecule undergoes changes to regenerate the original oxaloacetate (C4) molecule, further producing a NADH, a $FADH_2$ and an ATP through a series of redox reactions.
- ATP is produced directly through a reaction called substrate-level phosphorylation.
- The products produced by the Krebs cycle are used in electron transport chain to make ATP.
- Final products for one glucose molecule: 2 ATP, 6 NADH, 2 $FADH_2$ and 4 CO_2(excreted).

Diagram Krebs Cycle



Good video on all respiration: https://www.youtube.com/watch?v=Fcu_8URp4Ac

∑ - Energy released by oxidation reactions is carried to the cristae of the mitochondria by reduced NAD and FAD.

- As shown above during the redox reactions, energy released from the oxidation of the acetyl groups is transferred to electron carriers NAD and FAD to form NADH and FADH2
- This energy is carried by these two molecules to the cristae of the mitochondria
- The energy transferred is used to create ATP through a process called oxidative phosphorylation

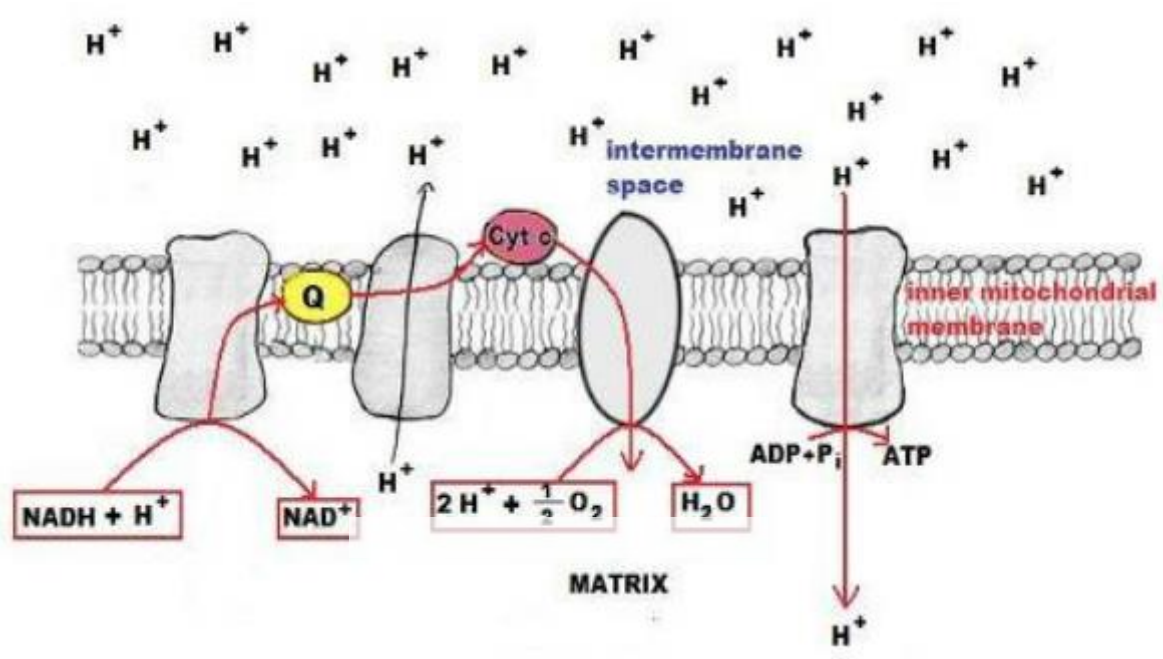
∑ - Transfer of electrons between carriers in the electron transport chain in the membrane of the cristae is coupled to proton pumping.

∑ - In chemiosmosis protons diffuse through ATP synthase to generate ATP.

Electron Transport Chain and Chemiosmosis

- The chain is a series of electron carriers located in the inner membrane of mitochondria that pass electrons from one carrier to the next down an energy gradient.
- NADH supplies 2 electrons to the first carrier in the chain (reforming NAD^+). These electrons move along the chain of electron carriers giving up energyeach time they pass from one carrier to the next.
- $FADH_2$ is also oxidized (forms FAD) releases its electrons a little later into the electron transport chain.
- Energy is released as the electrons are passed along the carrier proteins.
- This energy is used to pump H^+ ions across the inner mitochondrial membrane from the matrix to the intermembrane space.
- This accumulation of H^+ ions in the intermembrane space creates an H^+concentration gradient.
- Protons (H^+) flow back from the intermembrane space to the matrix throughspecial protein channels located in the inner mitochondrial membrane calledATP synthase.
- As the protons pass across the membrane, they release energy, which is usedby the ATP synthase to produce ATP through a phosphorylation reaction.
- This process is called oxidative phosphorylation because oxygen is **the final electron acceptor** and the energy released by **reducing oxygen to water** is used to phosphorylate ADP and generate ATP.
- For each glucose molecule, about 32 molecules of ATP are produced.

Diagram ETC



Crash Course: https://www.youtube.com/watch?v=00jbG_cfGuQ

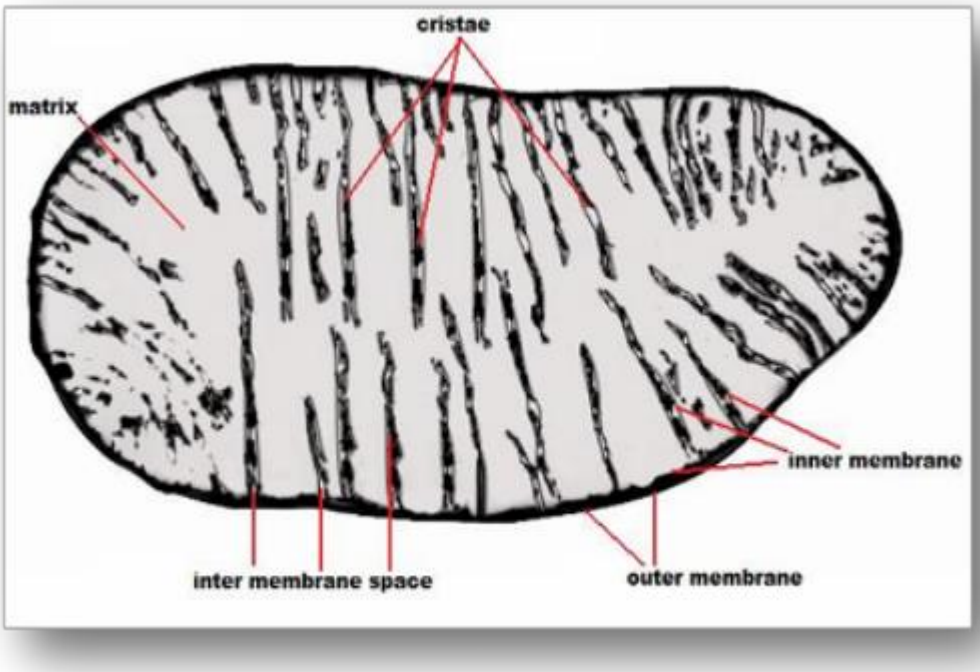
∑ - Oxygen is needed to bind with the free protons to maintain the hydrogen gradient, resulting in the formation of water.

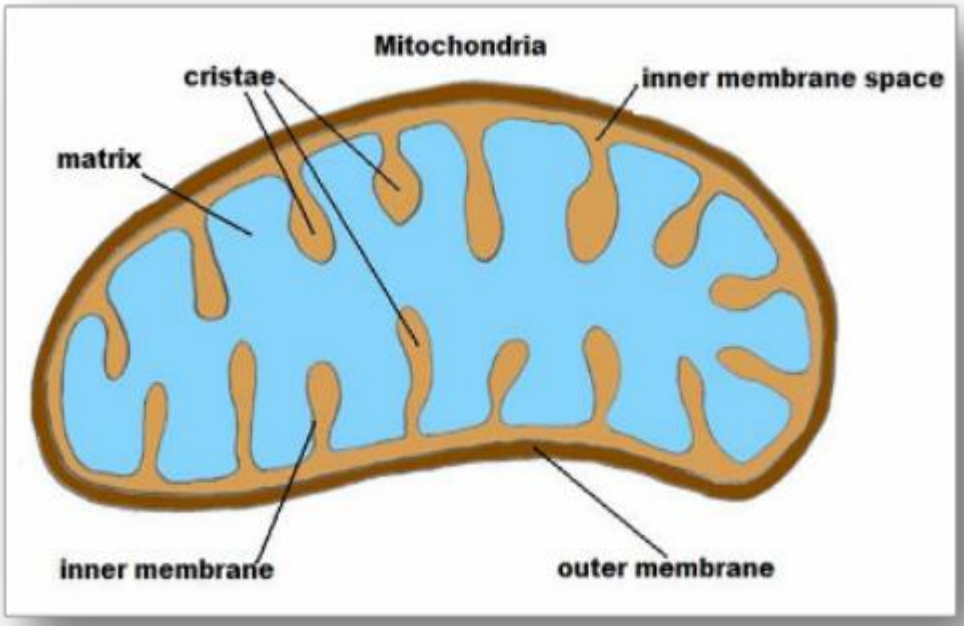
Role of Oxygen

- At the end of the ETC, electrons are given to oxygen. Oxygen accepts hydrogen ions and forms water (known as the terminal acceptor).
- If oxygen is not available, electron flow along the ETC stops and NADH + H^+cannot be reconverted to NAD^+.
- Supplies of NAD^+ in the mitochondrion run out and the link reaction and Krebs cycle cannot continue.
- Glycolysis can continue because conversion of pyruvate into lactate or ethanol and carbon dioxide produces as much NAD^+ as is used in glycolysis.
- Therefore oxygen is necessary for aerobic respiration to take place.
- Also, by using up the hydrogen to form water, the proton gradient across the inner mitochondrial membrane is maintained.

∑ - The structure of the mitochondrion is adapted to the function it performs.

β - Skill: Annotation of a diagram of a mitochondrion to indicate the adaptations to its function.





Structure	Function
Outer mitochondrial membrane	Separates the contents of the mitochondria from the rest of the cell creating a separate compartment specialized for the biochemical reactions of aerobic respiration
Inner mitochondrial membrane	Contains the ETC and the ATP synthase for oxidative phosphorylation reactions. The cristae membrane is highly folded to increase the surface area for these reactions
Intermembrane space	The volume of the space is small to allow proton build-up to create a concentration gradient in order to create ATP through oxidative phosphorylation as the protons flow back into the matrix through ATP synthase
Matrix	Contains enzymes necessary for the reactions that take place; the Krebs cycle and the link reaction
Semi-autonomous organelle	Can grow and reproduce by itself with the resources from the rest of the cell

*****Do the data-based questions on page 387*****

Theory of knowledge:

- Peter Mitchell's chemiosmotic theory encountered years of opposition before it was finally accepted. For what reasons does falsification not always result in an immediate acceptance of new theories or a paradigm shift?
- Article - http://www.esalq.usp.br/lepse/imgs/conteudo_thumb/mitchell-lecture.pdf

Applications and skills:

β - Application: Electron tomography used to produce images of active mitochondria.

Read the article on page 388 and do the questions at the bottom of the page

Guidance:

*****The names of the intermediate compounds in glycolysis and the Krebs cycle are not required*****

8.3 Photosynthesis

Nature of science: Developments in scientific research follow improvements in apparatus—sources of 14C and autoradiography enabled Calvin to elucidate the pathways of carbon fixation

Interesting video from Cosmos on Photosynthesis - 5:40-11:00 min
https://www.youtube.com/watch?v=QLhApXP326A

∑ - Understandings:

∑ - Light-dependent reactions take place in the intermembrane space of the thylakoids.

- The chloroplast has an outer membrane and an inner membrane
- The inner membrane encloses the interconnected membranes called the thylakoid membranes
- Chlorophyll molecules are grouped together into photosystems contained within the thylakoid membranes.
- The area within these thylakoid membranes is called the thylakoid space and this is where the light-dependent reactions take place

∑ - Reduced NADP and ATP are produced in the light-dependent reactions.

- This process is the first stage of photosynthesis in which light energy is converted into chemical energy (NADPH and ATP). These products will be used in the light independent stage.

∑ - Absorption of light by photosystems generates excited electrons.

- Chlorophyll molecules are grouped together into photosystems contained within the thylakoid membranes.
- **Chlorophyll a** within the photosystem II (PS II) absorbs a photon of light (most efficient at 680 nm).
- This photon of light excites an electron from the chlorophyll a molecule to a higher energy state.
- The chlorophyll is now in a photoactivated state.
- The excited electron is released by the oxidized Chlorophyll a molecule to the primary electron acceptor in photosystem II.
- This electron acceptor is called plastoquinone (PQ)
- PQ accepts two exited electrons and transfers these electrons along a series of electron carriers in the thylakoid membrane
- Photosystem II can repeat this process to produce a second reduced PQ molecule (total of 4e- are used to produce 2 reduced PQ molecules)

∑ - Photolysis of water generates electrons for use in the light-dependent reactions.

- The lost electrons are **replaced** by the **splitting of water** through a process called **photolysis**. During this reaction **oxygen is produced** and released as a **by-product**.

$$2\,H_2O \rightarrow O_2 + 4\,H^+ + 4\,e^- \qquad (\Delta E_o =$$

∑ - Transfer of excited electrons occurs between carriers in thylakoid membranes.

- The electron then moves along a series of electron carriers through a series of redox reactions from photosystem II (PSII) to photosystem I (PSI)
- Electron Carriers: (plastoquinone (PQ) --> cytochrome complex b6f --> lastocyanin --> PS I).

∑ - Excited electrons from Photosystem II are used to contribute to generate a proton gradient.

- As electrons move down the electron transport chain they lose energy. This**energy is used to pump H^+ (protons)** across the **thylakoid membrane** into the **thylakoid space**.
- This creates an **H^+ concentration gradient** and the potential energy needed, that will drive chemiosmosis and **produce ATP** from ADP during**photophosphorylation** (similar to oxidative phosphorylation in mitochondria)

- The photolysis of water also helps create the proton gradient as H^+ is produced when water is split (shown above)

∑ - ATP synthase in thylakoids generates ATP using the proton gradient.

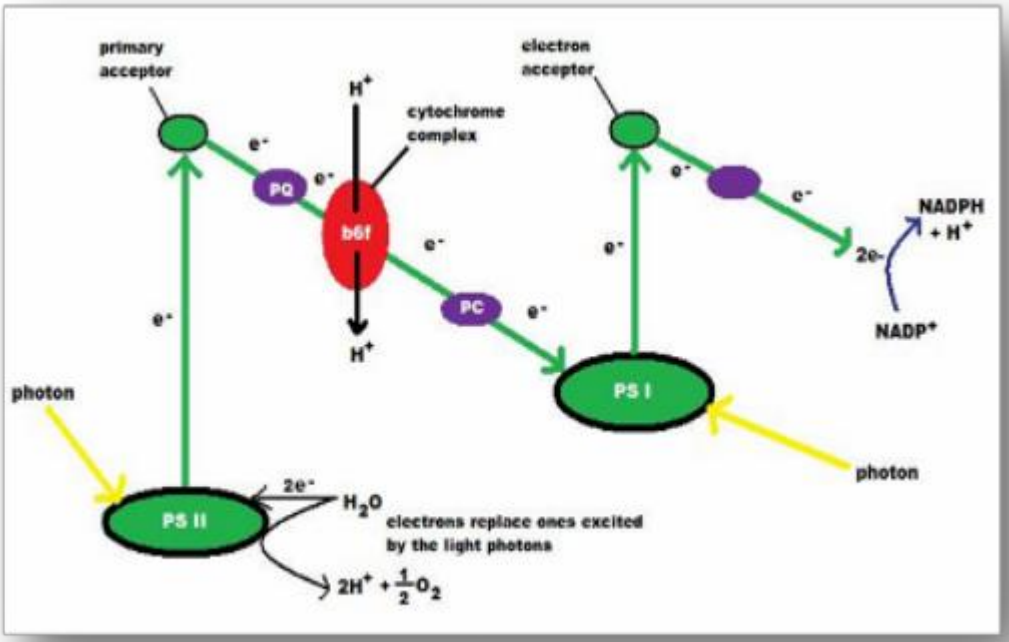
- The production of ATP from ADP and phosphate using energy derived from light is called **photophosphorylation.**
- Photophosphorylation occurs on the thylakoid membrane of the chloroplasts.
- As electrons pass along the electron transport chain between PS II and PS I, the electrons release energy that is used to **pump protons from the stroma into the thylakoid space**.
- This builds up the concentration of H^+ within the thylakoid space **creating a proton concentration gradient.**
- **Protons** will **flow** across the membrane from the **thylakoid space to the stroma**, through **ATP synthase** following the concentration gradient.
- As the protons flow through ATP synthase, the **energy released** from the **flow of protons** is used to **combine ADP and inorganic phosphate to form ATP**(photophosphorylation).
- This whole process of producing ATP is called **chemiosmosis.**

Website animation: http://highered.mcgraw-hill.com/olc/dl/120072/bio13.swf

∑ - Excited electrons from Photosystem I are used to reduce NADP.

- A photon of light strikes photosystem I, re-exciting the electron to a higher energy state (**photoactivation**)
- This electron is passed along a second electron transport chain (includes ferredoxin) until it is accepted by the final electron carrier $NADP^+$.
- A second electron that follows the same path is also accepted by $NADP^+$.
- These electrons reduce **$NADP^+$ to form NADPH ($NADP^+ + 2e^- + H^+$ --> NADPH).**
- This reaction is catalyzed by an enzyme called NADP reductase
- Since the electrons are not returned to photosystem II, this path for making ATP is called non-cyclic photophosphorylation.
- New electrons are passed to **PSI from PSII** through a carrier called plastocyanin
- If $NADP^+$ runs out and it cannot accept the excited electron from photosystem I, electrons return to the electron transport chain (PQ) where they can reflow back to PS I thus pumping more protons into the thylakoid space; producing more ATP.
- This is called **cyclic photophosphorylation.**

Diagram of the Light Dependent Reaction



Website animation: http://highered.mcgraw-hill.com/olc/dl/120072/bio12.swf

∑ - Light-independent reactions take place in the stroma.

- The light-independent reactions use the products produced by the light dependent reactions and CO_2 to produce glucose.
- The light-independent reactions take place in the stroma.
- The stroma contains enzymes necessary for the light-independent reactions (Calvin Cycle)
- 6 CO_2 are required to create one 6 carbon sugar molecule.

∑ - In the light-independent reactions a carboxylase catalyses the carboxylation of ribulose bisphosphate.

- One CO_2 molecule enters the Calvin cycle and combines with a 5 carbon molecule called Ribulose bisphosphate (RuBP) to temporarily form a 6C molecule.
- This reaction is catalyzed by the enzyme RuBP carboxylase (rubisco).
- This immediately breaks down into two 3C molecules called **glycerate-3-phosphate (GP).**

∑ - Glycerate 3-phosphate is reduced to triose phosphate using reduced NADP and ATP.

- The two glycerate-3-phosphate molecules are reduced by adding hydrogen from two NADPH using the energy from the breakdown of 2 ATP into 2 ADP and 2 Pi.

- This creates two molecules called triose phosphate (TP).
- Five more molecules of CO2 enter the Calvin cycle producing 10 more TP molecules (total of 12 triose phosphate (TP) molecules are produced by 6 $CO_2$and 6 turns of the Calvin cycle).

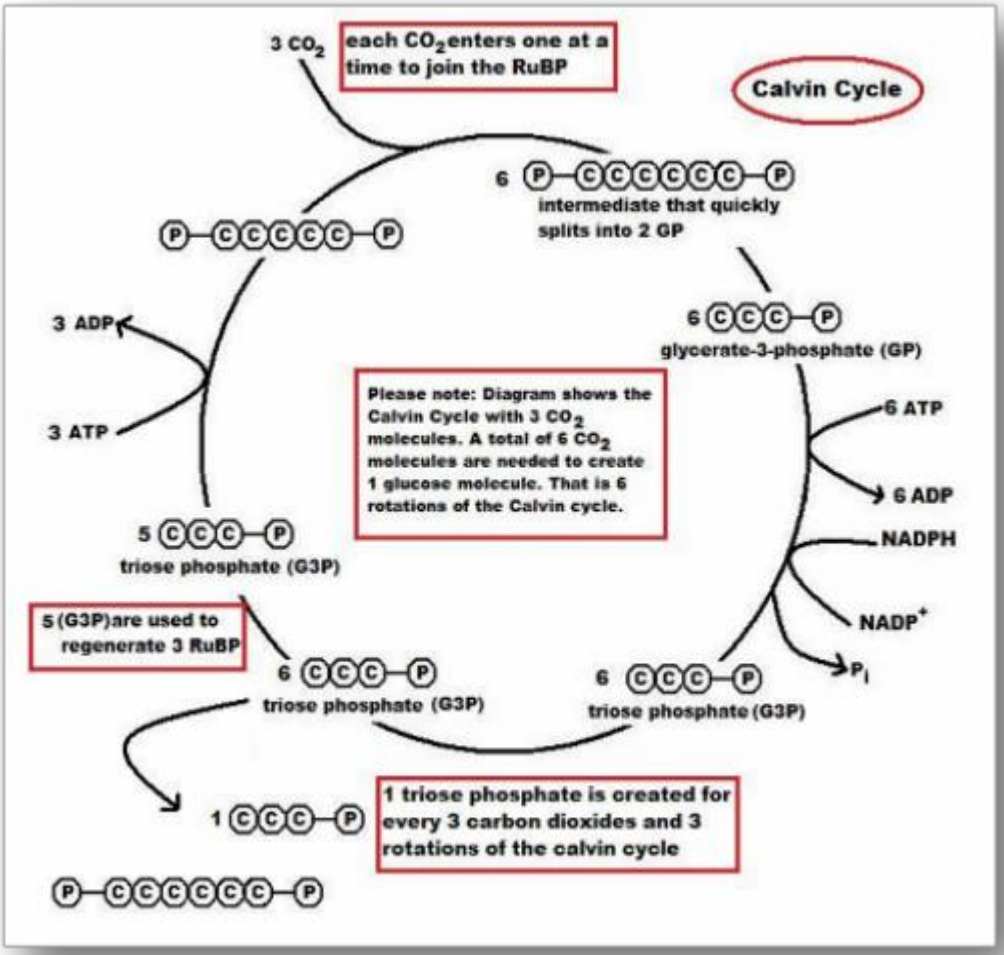
∑ **- Triose phosphate is used to regenerate RuBP and produce carbohydrates.**

∑ **- Ribulose bisphosphate is reformed using ATP.**

- Two TP molecules are used to produce one six carbon glucose phosphate molecule, which can eventually be combined with other glucose phosphate to form starch.
- The other ten TP (3C) molecules are used to regenerate six RuBP (5C) using 6 ATP molecules for energy.
- So for every 6 triose phosphate molecules produced, 5 of these triose (3C) sugars are used to reform 3 RuBP (5C) molecules using 3 ATP molecules The one remaining triose phosphate forms half a glucose phosphate

Crash Course Photosynthesis: https://www.youtube.com/watch?v=sQK3Yr4Sc_k

Diagram of Light Independent Reaction (Calvin cycle)



*****Do data-based questions on page 396*****

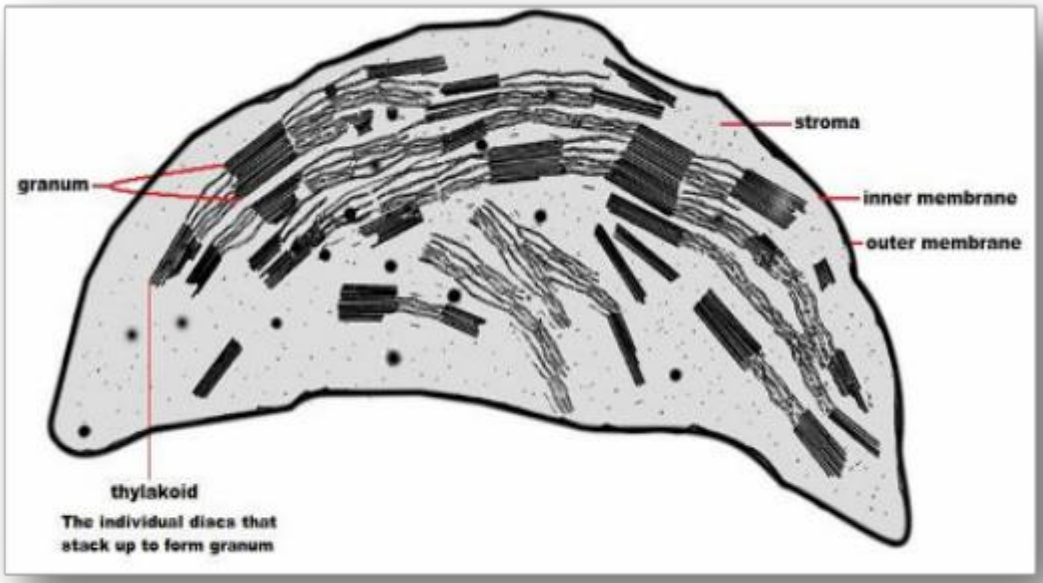
∑ - The structure of the chloroplast is adapted to its function in photosynthesis.

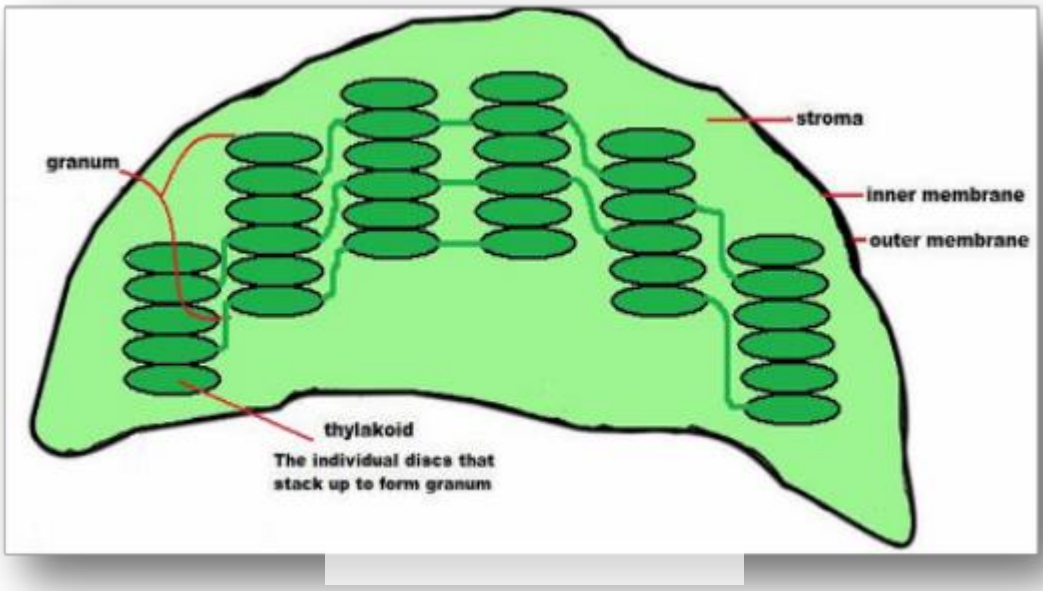
Structure	Function
Thylakoid membrane – large surface area from the extensive membrane	Increased SA allows for greater absorption of light by the photosystems in the membrane
Stroma – cytosol-like fluid filled region contains many enzymes	Allows for the concentration of enzymes necessary for the Calvin cycle to occur
Thylakoid space – small space within the thylakoids	Small space allows for the accumulation of protons to create a concentration gradient necessary for chemiosmosis to occur

β - Application: Calvin's experiment to elucidate the carboxylation of RuBP

- Read through the experiment details and do the questions on age 397

β - Skill: Annotation of a diagram to indicate the adaptations of a chloroplast to its function.





*****Do data-based questions on page 398*****

Theory of knowledge:

The lollipop experiment used to work out the biochemical details of the Calvin cycle shows considerable creativity. To what extent is the creation of an elegant protocol similar to the creation of a work of art?

Utilization:

The Global Artificial Photosynthesis (GAP) project aims to create an artificial “leaf” within the next decade. An electronic version of the leaf that creates oxygen and hydrogen from water and sunlight has already been invented and will be developed for use in the next decade.

Aim 6: Hill´s method demonstrating electron transfer in chloroplasts by observing DCPIP reduction, immobilization of a culture of an alga such as Scenedesmus in alginate beads and measurement of the rate of photosynthesis by monitoring their effect on hydrogencarbonate indicator are all possible experiments.