Topic 2 - Molecular Biology

2.1 Molecules to metabolism

Understandings: ∑

∑ - Molecular biology explains living processes in terms of the chemical substances involved.

- Involves the explaining of biological processes from the structures of the molecules and how they interact with each other
- There are many molecules important to living organisms including water, carbohydrates, lipids, proteins and nucleic acids
- Proteins are one of the most varied macromolecules, performing many cellular functions, including catalyzing metabolic reactions (enzymes)
- The relationship between genes and proteins is important as well
- Molecular biologists break down biochemical processes into their component parts (reductionism)
- When they look at the sum of all these reactions as a whole, they can study theemergent properties of that system

Applications and skills: β

β - Application: Urea as an example of a compound that is produced by living organisms but can also be artificially synthesized.

- Video on how the synthesis of urea was discovered

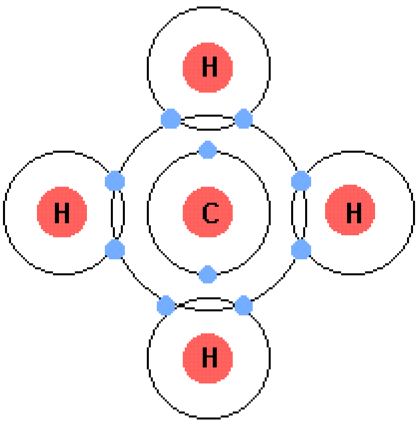
http://science.howstuffworks.com/life/27866-100-greatest-discoveries-synthesis-of-urea-video.htm

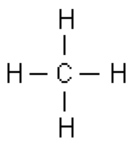
- Urea is a component of urine which is produced when there is an excess of amino acids in the body; way to secrete nitrogen
- A series of enzyme catalyzed reactions produce urea in the liver, where it is transported by the blood to the kidney, where it is filtered out and excreted in the urine.
- Urea can be produced artificially through different chemical reactions; however, the product is the same.
- Urea is mainly used as a nitrogen source in fertilizers

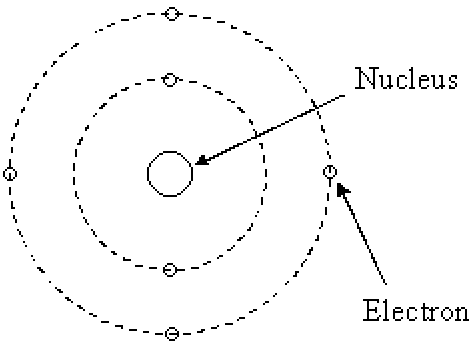
  Read the following article http://humantouchofchemistry.com/urea-and-the-beginnings-of-organic-chemistry.htm . In groups of 3-4 discuss the "Falsification of Vitalism", with respect to the synthesis of artificial urea. After you have discussed this concept in small groups, come back together for a class discussion on your findings and opinions.

∑ - Carbon atoms can form four covalent bonds allowing a diversity of stable compounds to exist.

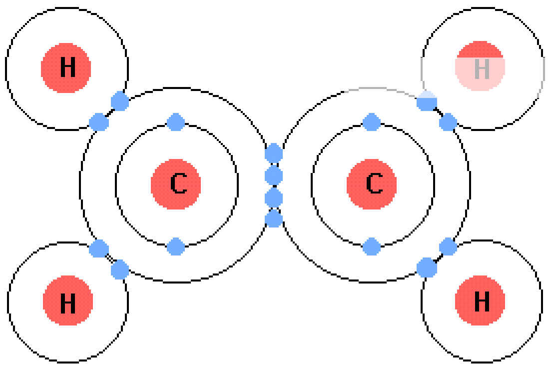
- Carbon has a few unique bonding properties - the most important of which is its ability to form long chains of carbon. No other element can bond like carbon does.
- The reason carbon can do this is that carbon-carbon bonds are extremely strong. This allows carbon to make up many of the basic building blocks of life (fats, sugars, etc).
- Since carbon-carbon bonds are strong and stable, carbon can form an almost infinite number of compounds
- In fact, there are more known carbon-containing compounds than all the compounds of the other chemical elements combined except those of hydrogen (because almost all organic compounds contain hydrogen too).
- Carbon can also form rings eg. glucose
- The simplest form of an organic molecule is the hydrocarbon—a large family of organic molecules that are composed of hydrogen atoms bonded to a chain of carbon atoms. Eg. Methane
- All bonding in hydrocarbons is covalent
- Covalent Bonds are chemical bonds formed by the sharing of a pair of electronsbetween atoms. The nuclei of two different atoms are attracting the same electrons.
- Carbon can form single, double and triple bonds

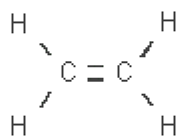






Carbon has 4 valance electrons in it's outer shell.





∑ - Life is based on carbon compounds including carbohydrates, lipids, proteins and nucleic acids.

Carbohydrates

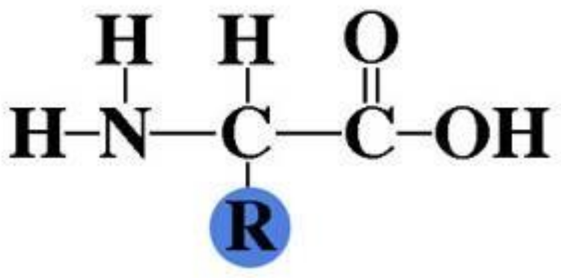
- Carbohydrates are composed of carbon, hydrogen and oxygen
- The general formula for carbohydrates is **$(CH_2O)n$.**
- Many carbohydrates are used for energy or structural purposes

Lipids

- Lipids are compounds that are insoluble in water but soluble in nonpolar solvents.
- Some lipids function in long-term energy storage. Animal fat is a lipid that has six times more energy per gram than carbohydrates.
- Lipids are also an important component of cell membranes.
- Some examples of lipids are ***triglycerides, steroids, waxes and phospholipids***
- Animal fats (saturated) are solid at room temperature and plant fats (unsaturated) are liquid at room temperature

Proteins

- Proteins are composed of one or more chains of amino acids
- All proteins are composed of carbon, hydrogen, oxygen and nitrogen
- Proteins are distinguished by their "R" groups. Some of these also contain sulphur

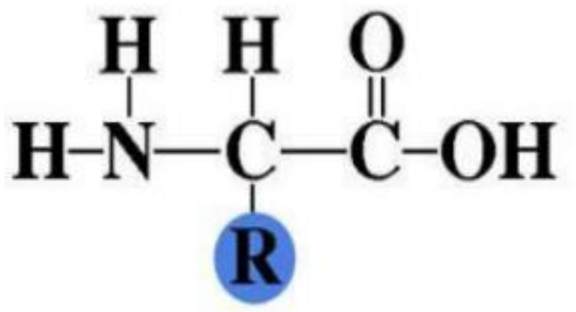
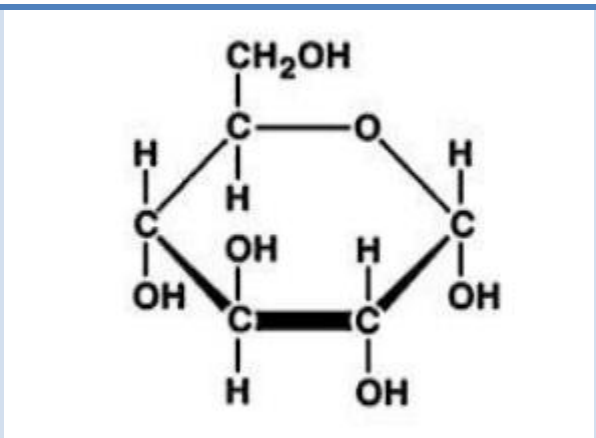


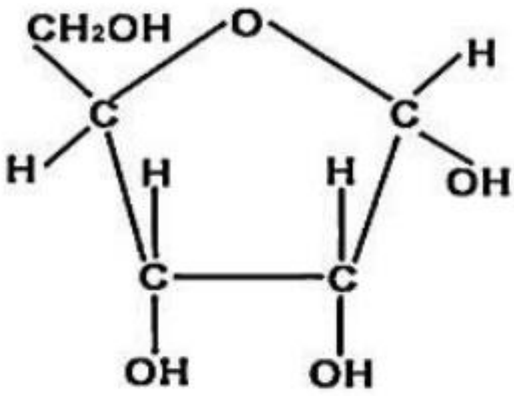
Generalized amino acid

Nucleic Acids

- Nucleic acids are composed of smaller units called nucleotides, which are linked together to form a larger molecule (nucleic acid).
- Each nucleotide contains a base, a sugar, and a phosphate group. The sugar is deoxyribose (DNA) or ribose (RNA). The bases of DNA are ***adenine, guanine, cytosine, and thymine***. **Uracil** substitutes for Thymine in RNA
- They are made from carbon, hydrogen, oxygen, nitrogen and phosphorus

✓ **Skill: Drawing molecular diagrams of glucose, ribose, a saturated fatty acid and a generalized amino acid.**

Amino Acid • Composed of an amine (NH2) group, a carboxyl (COOH) group, and an R group. • 20 amino acids exist that compose all proteins • Each amino acid differs because the R groups are different	
Glucose • Is a reducing sugar that contains $C_6H_{12}O_6$ • Most commonly found in a ringed structure and is the main product formed by photosynthesis • Energy molecule used in aerobic respiration • Monomer of starch, glycogen, and cellulose	

<table>
<tr>
<td>Ribose
Pentose (5 carbon) sugar of RNA and RUBP (Calvin cycle)
$C_5H_{10}O_5$
Differs from Deoxyribose (sugar in DNA) because it has an extra –OH group on the 2nd carbon of the ring</td>
<td colspan="2"></td>
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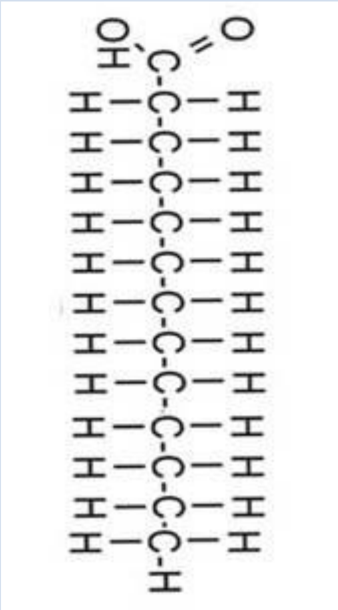
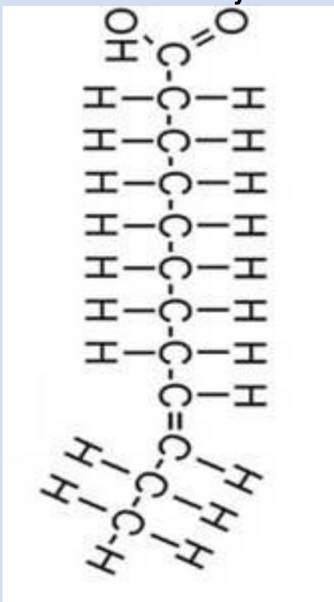
<tr>
<td>Fatty Acids
Main component of triglycerides and phospholipids
Fatty acids are non-polar and therefore hydrophobic
Chains consist of covalently bonded carbon with hydrogen
Saturated FA's are all single bonds and are therefore saturated with hydrogen.
Unsaturated FA's contain a double bond or double bonds.</td>
<td>Saturated Fatty Acid
</td>
<td>Unsaturated Fatty Acid
</td>
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✓ **£ - Skill: Identification of biochemicals such as sugars, lipids or amino acids from molecular diagrams.**

- The generalized formula for carbohydrates is **CH_2O**. All carbohydrate contain C, H and O
- Proteins also contain C,H, O but **they all have N**. Some proteins also contain **S** in their **R-groups**

- Lipids contain C, H and O as well, but in different ratios and **much less O then carbohydrates.**

∑ - Metabolism is the web of all the enzyme-catalysed reactions in a cell or organism.

- Metabolism is the set of life-sustaining chemical reactions within the cells of living organisms.
- These reactions are catalyzed by enzymes and allow organisms to grow and reproduce, maintain their structures, and respond to their environments.
- Many of these reactions occur in the cytoplasm, but some are extracellular including digestion and the transport of substances into and between different cells
- The word metabolism can refer to the sum of all chemical reactions that occur in living organisms

∑ - Anabolism is the synthesis of complex molecules from simpler molecules including the formation of macromolecules from monomers by condensation reactions.

- Metabolism is divided into two components; anabolism (building large molecules from smaller ones) and catabolism (breaking down of large molecules into their component parts)
- Anabolic reactions require energy as you are building large molecules from small ones (takes energy to build things)
- Some anabolic processes are protein synthesis, DNA synthesis and replication, photosynthesis, and building complex carbohydrates, such as cellulose, starch and glycogen
- If you can't remember which one is which, think anabolic steroids are used to build muscles in athletes and body builders and catapults are used to break down walls in wars

∑ - Catabolism is the breakdown of complex molecules into simpler molecules including the hydrolysis of macromolecules into monomers.

- Catabolism are reactions that break down larger molecules into smaller ones or their component parts
- Catabolic reactions release energy (sometimes captured in the form of ATP)
- Some examples of catabolic reactions are digestion of food, cellular respiration, and break down of carbon compounds by decomposers
- Think of "catapults" used to break down enemy walls during wars

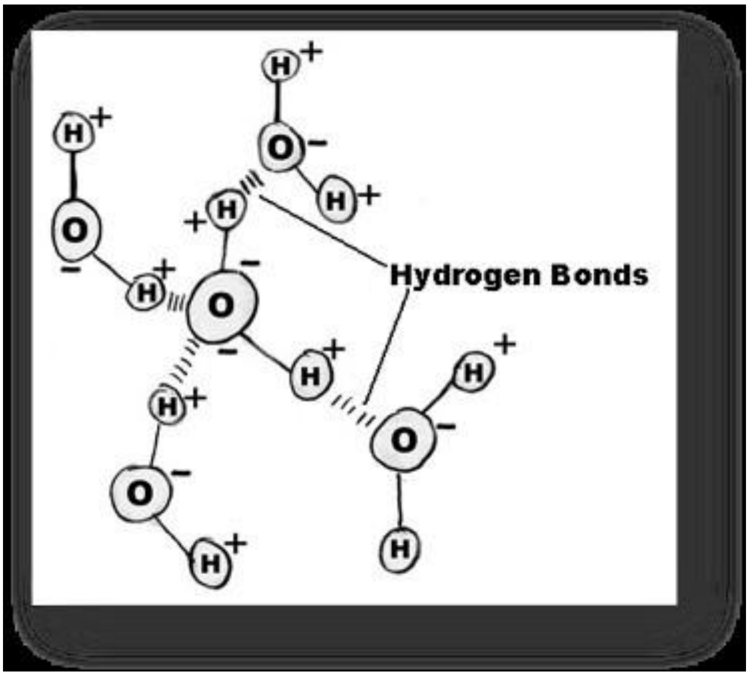
**Note these reactions are condensation and hydrolysis which are outlined **

2.2 Water

Understandings: ∑

∑ - Water molecules are polar and hydrogen bonds form between them.

- A water molecule consists of an oxygen atom covalently bound to two hydrogen atoms
- Since O is more electronegative than H, an unequal sharing of electrons occurs
- This creates a polar covalent bond, with H having a partial positive charge and O having a partial negative charge
- Water is also bent so the positive charge exists more or less on one side and the negative charge from the O exists on the opposite side
- The partial +ve charge is attracted to the partial –ve charge creating an intermolecular attraction between the water molecules called a "Hydrogen bond."
- H-bonds are the strongest of the intermolecular bonding, but is still considered a weak bond; however since there are so many H_2O molecules they give water its unique properties and make it essential to life on this planet



∑ - Hydrogen bonding and dipolarity explain the cohesive, adhesive, thermal and solvent properties of water.

Thermal Property

- Water has a high specific heat capacity (amount of energy needed to raise temperature of a substance by a certain temperature level). Basically, water can absorb a lot of heat and give off a lot of heat without drastically changing the temperature of water.
- Water's high specific heat capacity results from the extensive hydrogen bonding between the water molecules.
- Water also has a high latent heat of vaporization which means it takes a lot of heat to evaporate water from a liquid to a vapor. This is very important as a cooling mechanism for humans. As we sweat, the water droplets absorb heat from our skin causing the water to evaporate and our bodies to cool down.

Interesting Documentary on the ICEMAN: Man who can control his core body temperature
https://www.youtube.com/watch?v=VaMjhwFE1Zw

Cohesive Properties

- Water is a polar molecule, with a negative oxygen end and a positive hydrogen end.

- Hydrogen bonds that exist between water molecules create a high level of attraction linking water molecules together. This attraction between two of the same molecules is calledcohesion.
- These cohesive forces allow water to move up vascular tissue in plants against gravity. It also creates surface tension on water that allows some organisms to walk on water.

Adhesive Properties

- Not only does water bind strongly to itself, it also forms H-bonds with other polar molecules. This is called adhesion.
- This is an important property in transpiration as well, as water adheres to the cellulose in the walls of the xylem vessels
- As water is evaporated from the stomata, the adhesion can help the water move up through the xylem

Solvent Properties

- Water is known as the "universal solvent" because of its ability to dissolve many substances because of its polarity.
- Water is able to dissolve other polar molecules such as many carbohydrates, proteins and DNA; and positively and negatively charged ions such as Na^+.
- This is essential because it allows water to act as a transport medium (blood and cytoplasm) of important molecules in biological organisms.

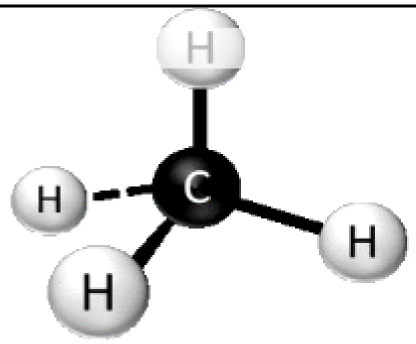
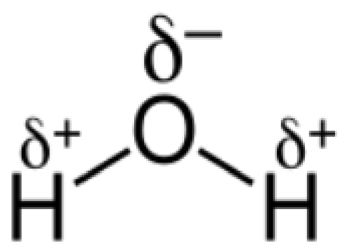
∑ - Substances can be hydrophilic or hydrophobic.

- Essentially hydrophilic means "water loving"
- Any substances that dissolves in water including charged ions such as Na^+ or polar molecules such as glucose and fructose are hydrophilic. Molecules that are attracted to water likephospholipid heads are also hydrophilic
- Hydrophobic molecules are kind of "water fearing" but basically, these are non-polar, insoluble in water or non-charged substances, such as lipids

✓ **Lab Activity – Water stations to demonstrate the different properties of water. Click here to download**

β - Applications and skills:

β - Application: Comparison of the thermal properties of water with those of methane.

Methane's formula is CH_4	Water's formula is H_2O
	

Non-polar	Polar
Single covalent bonds	Single covalent bonds
Since water is polar it has stronger intermolecular attraction (H-bonds) and therefore has a much greater specific heat capacity, latent heat of vaporization, melting point and boiling point	
SHC = 2.2 J per g per°C	4.2 J per g per°C
LH of V = 760 J/g	2257 j/g
BP = -160 ° C	100 °C
MP = -182 ° C	0 °C

β - Application: Use of water as a coolant in sweat.

- Water is essential to living organisms.
- Water has a high latent heat of vaporization which means it takes a lot of heat to evaporate water from a liquid to a vapor.
- This is very important as a cooling mechanism for living organisms. As humans sweat, thewater droplets absorb heat from the blood flowing under our skin causing the water to evaporate and our blood to cool down. This will in turn cool our whole body down.
- This cooling is controlled by negative feedback through receptors in the hypothalamus
    - If the body is overheated, receptors in the hypothalamus sense this and stimulate the sweat glands to secrete sweat
    - Some reptiles such as crocodiles cool by opening their mouths (gaping). Dogs also pant which causes water to evaporate from their upper respiratory tract.

β - Application: Modes of transport of glucose, amino acids, cholesterol, fats, oxygen and sodium chloride in blood in relation to their solubility in water.

- Blood transport many different substances to different parts of the body using a variety of methods
- Water is critical both as a solvent in which many of the body's solutes dissolve
- Due to its polarity water is a great solvent of other polar molecules and ions. This is vital because it allows water to act as a transport medium (blood and cytoplasm) of important molecules in biological organisms.
- NaCl is an ionic compound that is very soluble in water. Na+ and Cl- dissolve and are carried in the blood plasma
- Glucose is polar and is soluble in water and is therefore transported in the plasma
- Amino acids have both a negative and a positive charge, but their “R” groups vary, therefore they can be hydrophilic or hydrophobic. They are all soluble enough to be carried in the plasma
- Fats are nonpolar and therefore insoluble in water. They are transported in a single layer sphere of phospholipids called a lipoprotein complex. The hydrophilic heads face outwards towards the water in the plasma and the tails face inwards towards the fats. Proteins are also embedded in the phospholipid layer.
- Finally, cholesterol, which is mostly hydrophobic because it is a lipid, are also transported inside the lipoprotein complex with the small hydrophilic end facing the phospholipid heads

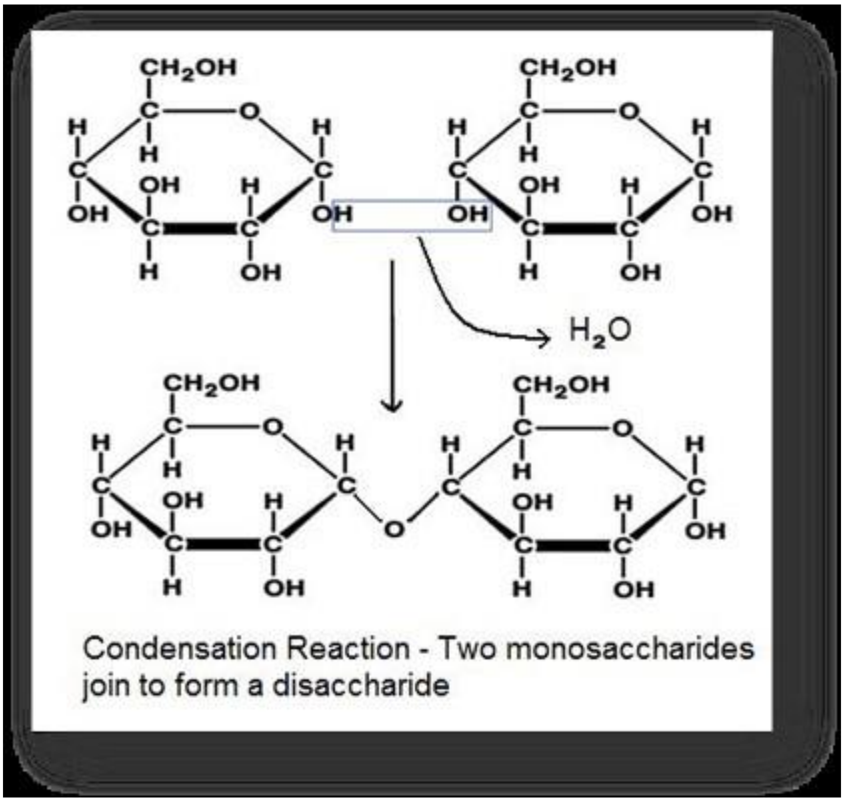
2.3 Carbohydrates and lipids

∑ - Understandings:

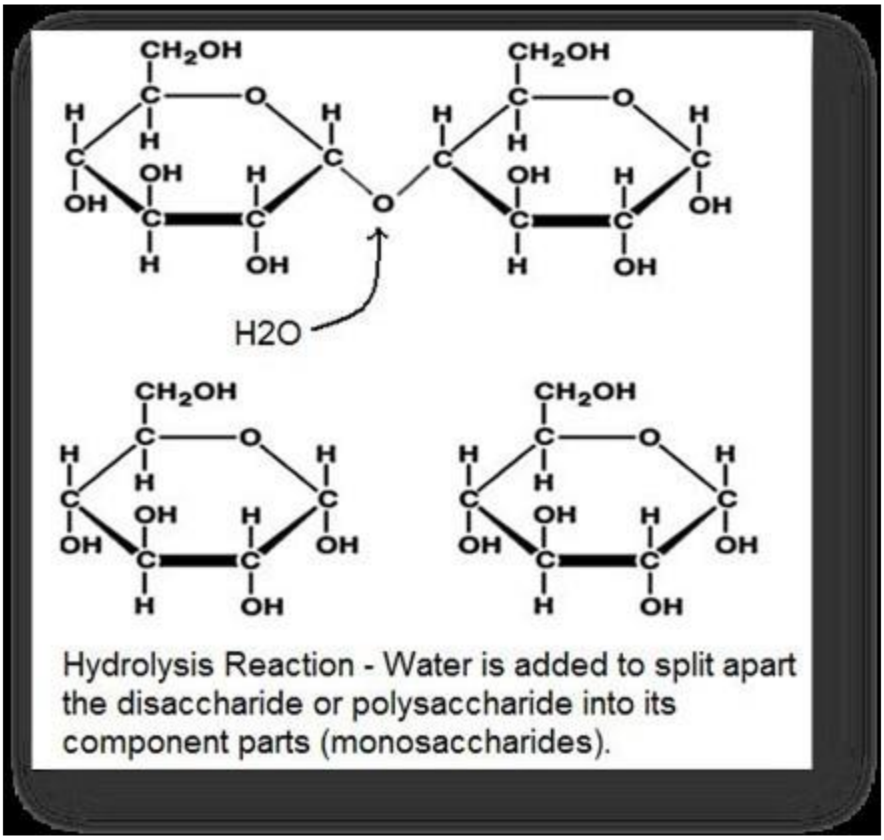
∑ - Monosaccharide monomers are linked together by condensation reactions to form disaccharides and polysaccharide polymers.

Monosaccharides	glucose	Energy molecule used in aerobic respiration
	galactose	Nutritive sweetener in foods
	fructose	Fruit sugar
Disaccharides	maltose	Malt sugar found in barley, consists of 2 glucose molecules
	lactose	Sugar found in milk
	sucrose	Transport sugar found in plants because of its solubility
Polysaccharides	starch	Storage carbohydrate in plants
	glycogen	Storage carbohydrate in animals
	cellulose	Main component in plant cell walls

- When two monomers combine together they form a dimer. When many monomers combine together they form a polymer.
- Condensation Reactions: The building of large macromolecules (polymers) by the removal of water molecules when monomers combine. Each time two monomers combine, one water is removed.
- For example: Glucose is a monosaccharide that is used to build up large storage molecules (polysaccharides) in plants and animals. In plants, many glucose molecules combine through condensation reactions to form the polysaccharide starch. In animals, glucose molecules are combined to form the polysaccharide glycogen through condensation reactions.



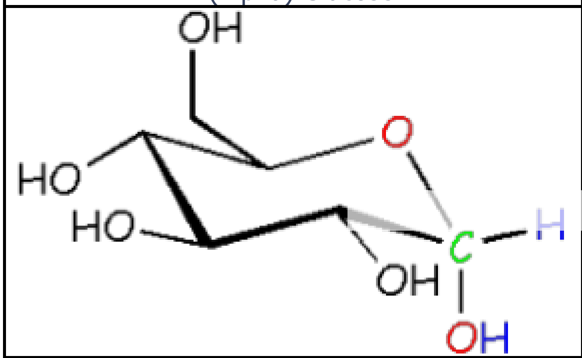
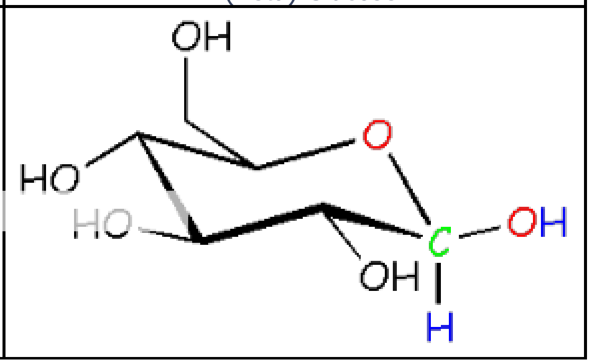
- When a plant or an animal needs to use energy stored in polysaccharide molecules, the opposite reaction to condensation takes place. This break down of larger polysaccharides into smaller monosaccharides through the addition of water is called hydrolysis (water split or separate).
- Starch and glycogen are broken down by the addition of water into glucose molecules (the energy molecule used in aerobic respiration).
- In lipids the polymer is called a triglyceride.
- Hydrolysis of a triglyceride uses water to break apart the lipid into glycerol (C3H5(OH)3 and 3 fatty acids.



β - Applications and skills:

β - Application: Structure and function of cellulose and starch in plants and glycogen in humans.

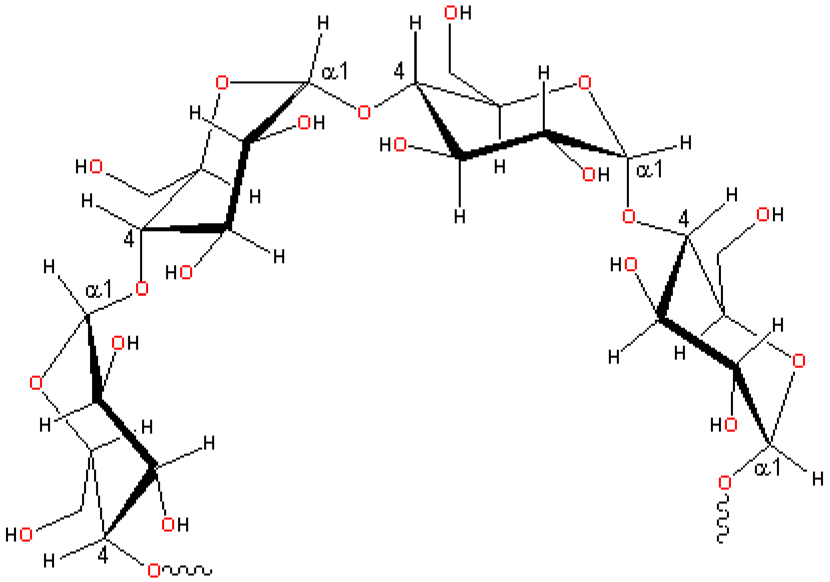
- Polysaccharides are long chains of monosaccharides held together with glycosidic linkages made by condensation reactions
- Starch, cellulose and glycogen are all polysaccharides that are made from long chains of glucose; however, they differ in their structure and the type of glucose, which leads to different functions

A (Alpha) Glucose	B (Beta) Glucose
	

http://www.pslc.ws/macrog/kidsmac/starlose.htm

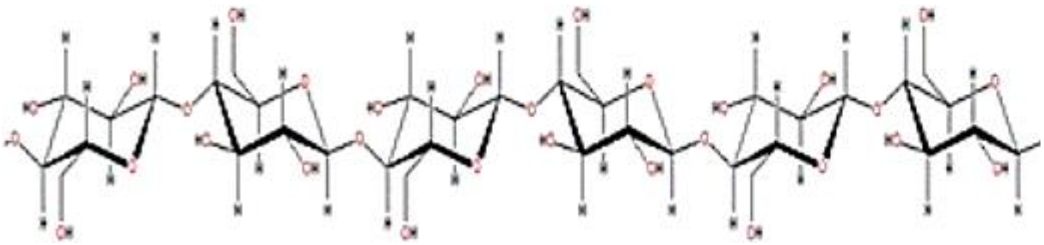
- Starch consists of two types of molecules, amylose which linear and amylopectin which is branched

- Since the bonds in starch are α-glucose, the –OH groups from the glucose molecules are always pointed down, causing starch to have a curved appearance. This makes starch a good molecule for storing glucose in plants.



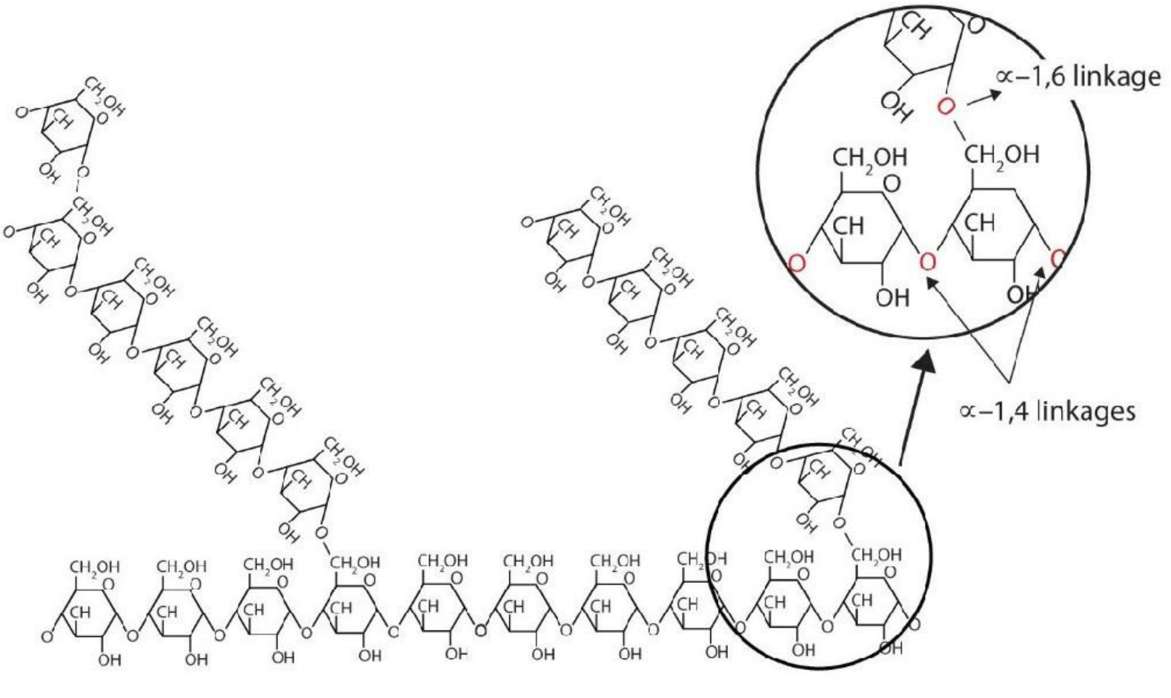
http://www.pslc.ws/macrog/kidsmac/starlose.htm

- Even though glucose is hydrophilic, starch is too large to be soluble in water at room temperature
- Cellulose are unbranched straight chains of β (beta) glucose molecules, held together with glycosidic bonds
- Since the –OH groups point out in opposite directions and every other β glucose is flipped 180 degrees, cellulose forms a nice straight chain
- These straight chains also allow cellulose to form bundles linked by H-bonds
- This is essential for cellulose's function, which is to provide strength for cell walls in plant cells (high tensile strength)
- Notice the up and down alternating glycosidic bonds between the glucose molecules



http://www.pslc.ws/macrog/kidsmac/starlose.htm

- Glycogen – Is a multi-branched energy storage polysaccharide for animals
- Glycogen consists of many α (alpha) glucose molecules linked by glycosidic bonds
- It is highly branched, making the molecule more compact and a perfect molecule for energy storage
- It is stored in the liver and some muscles of humans

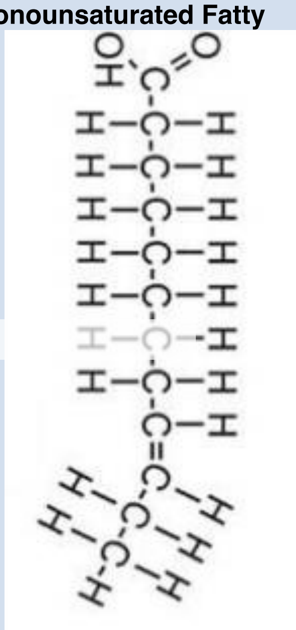


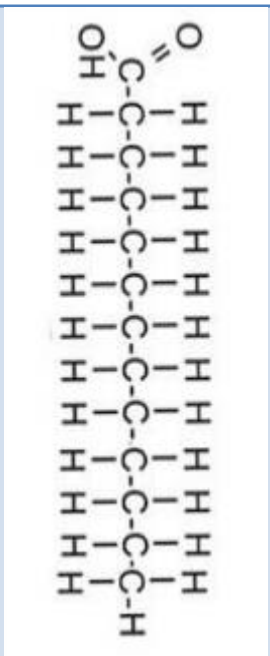
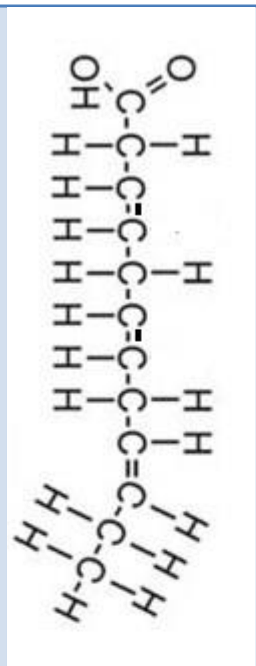
- http://2012books.lardbucket.org/books/introduction-to-chemistry-general-organic-and-biological/s19-07-polysaccharides.html

✓ **Skill: Use of molecular visualization software to compare cellulose, starch and glycogen.**

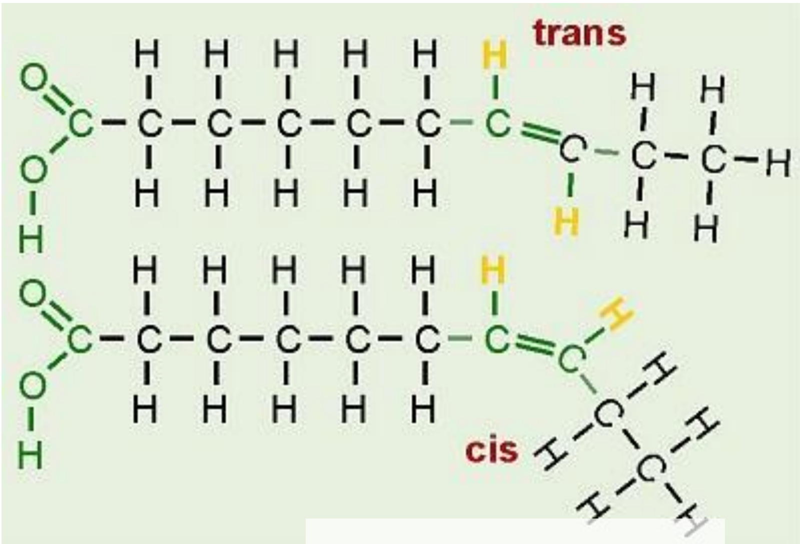
- Use the following link to analyze and compare the above polysaccharides.
- http://biomodel.uah.es/en/model3/polisac.htm
- Method to manipulate the molecules with the mouse is on the bottom right corner of the webpage

∑ - Fatty acids can be saturated, monounsaturated or polyunsaturated.

Fatty Acids Main component of triglycerides and phospholipids Fatty acids are non-polar and therefore hydrophobic Chains consist of covalently bonded carbon with hydrogen Saturated FA's are all single bonds and are	**Saturated Fatty Acid**	**Monounsaturated Fatty Acid** 	**Polyunsaturated Fatty acid**

therefore saturated with hydrogen. Unsaturated FA's contain a double bond or double bonds.			

∑ **- Unsaturated fatty acids can be cis or trans isomers.**



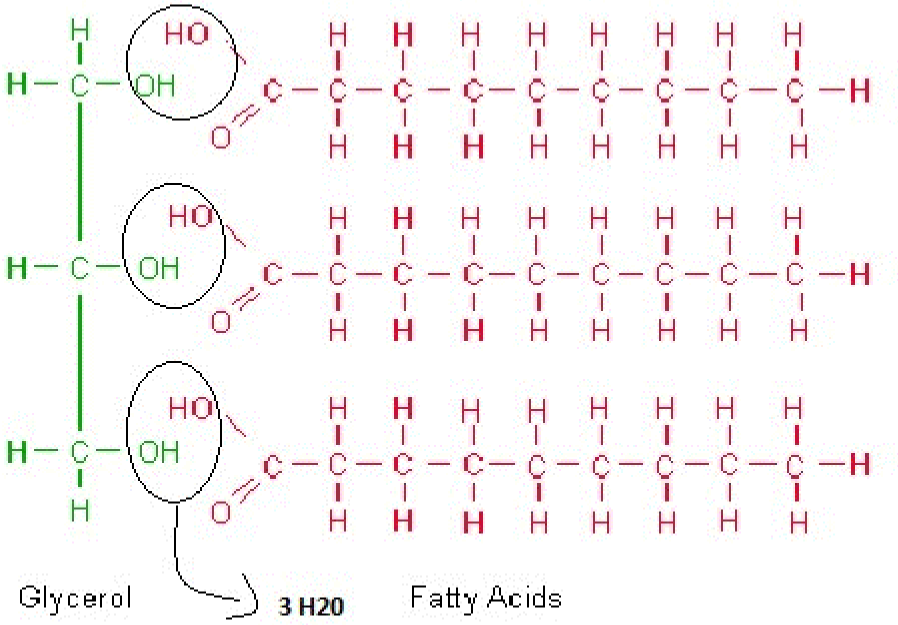
http://homepage.smc.edu/wissmann_paul/humanbiology/lipids.html

- If the hydrogen atoms are on the same side of the double bond then the isomer is "cis" (yellow H above) and if the hydrogens are on opposite side of the double bond then the isomer is "trans"
- "cis" fatty acids have a kink at the double bonds, causing the fatty acids to pack more loosely, lowering the melting point and making them liquid at room temperature

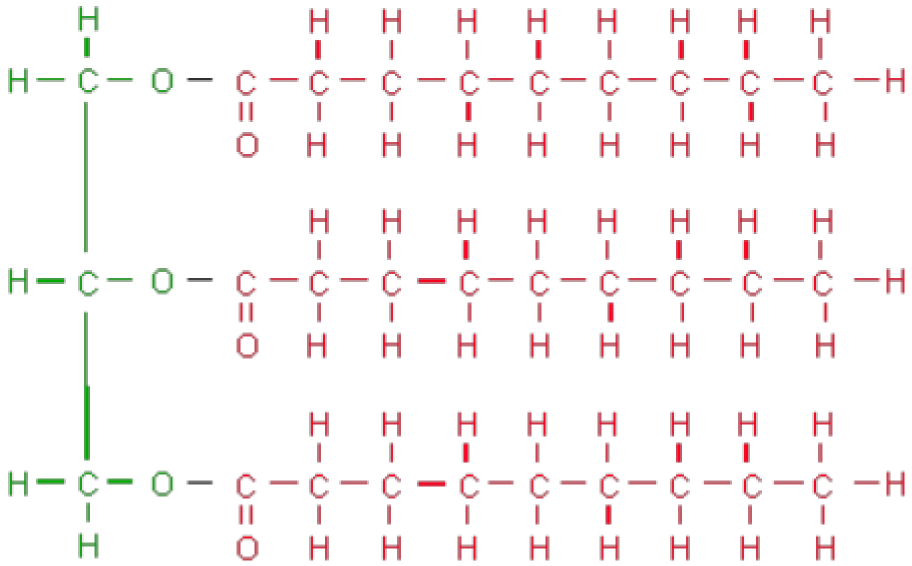
- "trans" fatty acids do not have the kink at the double bond, can pack more tightly, have a higher melting point and are solid at room temperature.
- Trans fats are partial hydrogenated oils found in some processed foods like margarine. They can cause health risks for humans.

∑ - Triglycerides are formed by condensation from three fatty acids and one glycerol.

- Fatty acids have a long hydrocarbon (carbon and hydrogen) chain with a carboxyl (acid) group. The chains usually contain 16 to 18 carbons.
- Glycerol contains 3 carbons and 3 hydroxyl groups. It reacts with 3 fatty acids to form a triglyceride or fat molecule through a condensation reaction, which gives off 3 water molecules and forms and ester bond



Triglyceride or Fat



- http://www.hhmi.org/biointeractive/molecular-structure-fat
- Check out the interactive video on the molecular structure of fats

β - 1) Application: Scientific evidence for health risks of trans fats and saturated fatty acids.
β - 2) Application: Evaluation of evidence and the methods used to obtain the evidence for health claims made about lipids

- <u>***Use the following links and your text to write a two page analysis on the above two applications. Make sure you have a clear understanding of what trans fats and saturated fatty acids are and how they affect our bodies. Critically analyze the evidence for health risks and the methods used to obtain the evidence ***</u>

- http://www.webmd.com/diet/features/trans-fats-science-and-risks
- http://www.dairynutrition.ca/scientific-evidence/experts-summaries/new-evidence-reveals-that-saturated-fat-does-not-increase-the-risk-of-cardiovascular-disease
- http://www.dairynutrition.ca/scientific-evidence/cardiovascular-disease/the-facts-on-natural-trans-fats-and-cardiovascular-disease
- http://www.cdc.gov/nutrition/everyone/basics/fat/transfat.html
- http://www.efsa.europa.eu/en/press/news/nda040831.htm
- http://www.npr.org/sections/thesalt/2015/10/26/451211964/bad-day-for-bacon-processed-red-meats-cause-cancer-says-who

β - Application: Lipids are more suitable for long-term energy storage in humans than carbohydrates.
<u>Energy Storage</u>

- One's body requires energy to function, more specifically each cell relies on a source of energy to drive the chemical reactions involved in metabolism, growth and other physiological functions
- Both carbohydrates and lipids (triglycerides) are a major source of energy in animals.
- Fats contain about twice as much energy as carbohydrates. Each gram of carbohydrates stores about 4 calories of energy, whereas each gram of lipid stores about 9 calories.
- Therefore, lipids serve as a more compact way to store energy, since it contains more energy per gram than carbohydrates. As a result, your body tends to use fat to store energy over long periods of time and uses carbohydrates to store energy short-term.
- Glycogen (carb storage) can be quickly into glucose for energy.
- Triglycerides (fats) contain a glycerol and 3 fatty acids and is stored mainly in the body's adipose tissue

- Fats also provide thermal insulation, protection for organs (shock absorber) and hormones

✓ **Skill: Determination of body mass index by calculation or use of a nomogram.**

- http://www.gpscbc.ca/system/files/36-BMI%20Nomogram.pdf
- Use the nomogram on the following quick reference guide from Health Canada to calculate your family members BMI. Ask your parents' permission if they are willing to share the data.

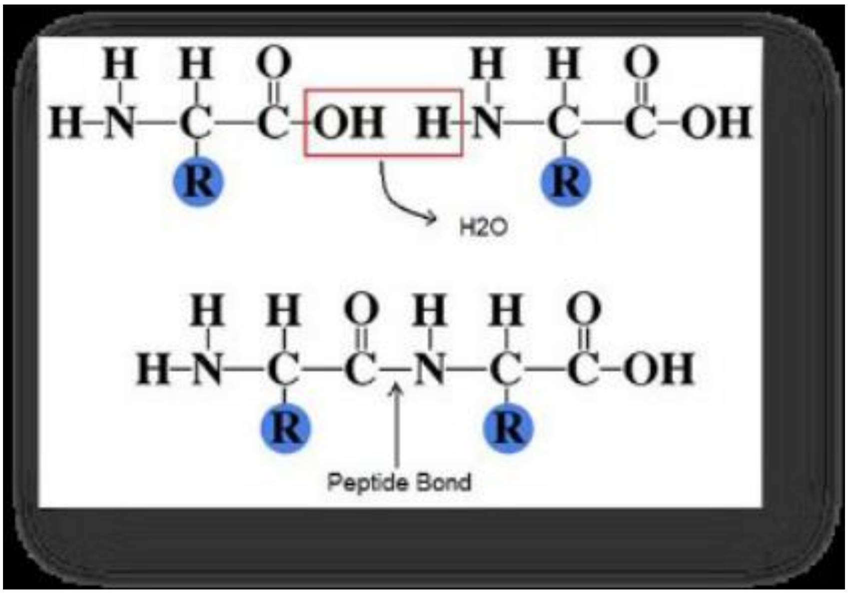
2.4 Proteins

∑ - Understandings:

∑ - Amino acids are linked together by condensation to form polypeptides.

- Amino acids are then combined to create large polypeptides through condensation reactions which produce many molecules of water (i.e. polypeptides - Hemoglobin and Insulin).

✓ **Skill: Drawing molecular diagrams to show the formation of a peptide bond.**

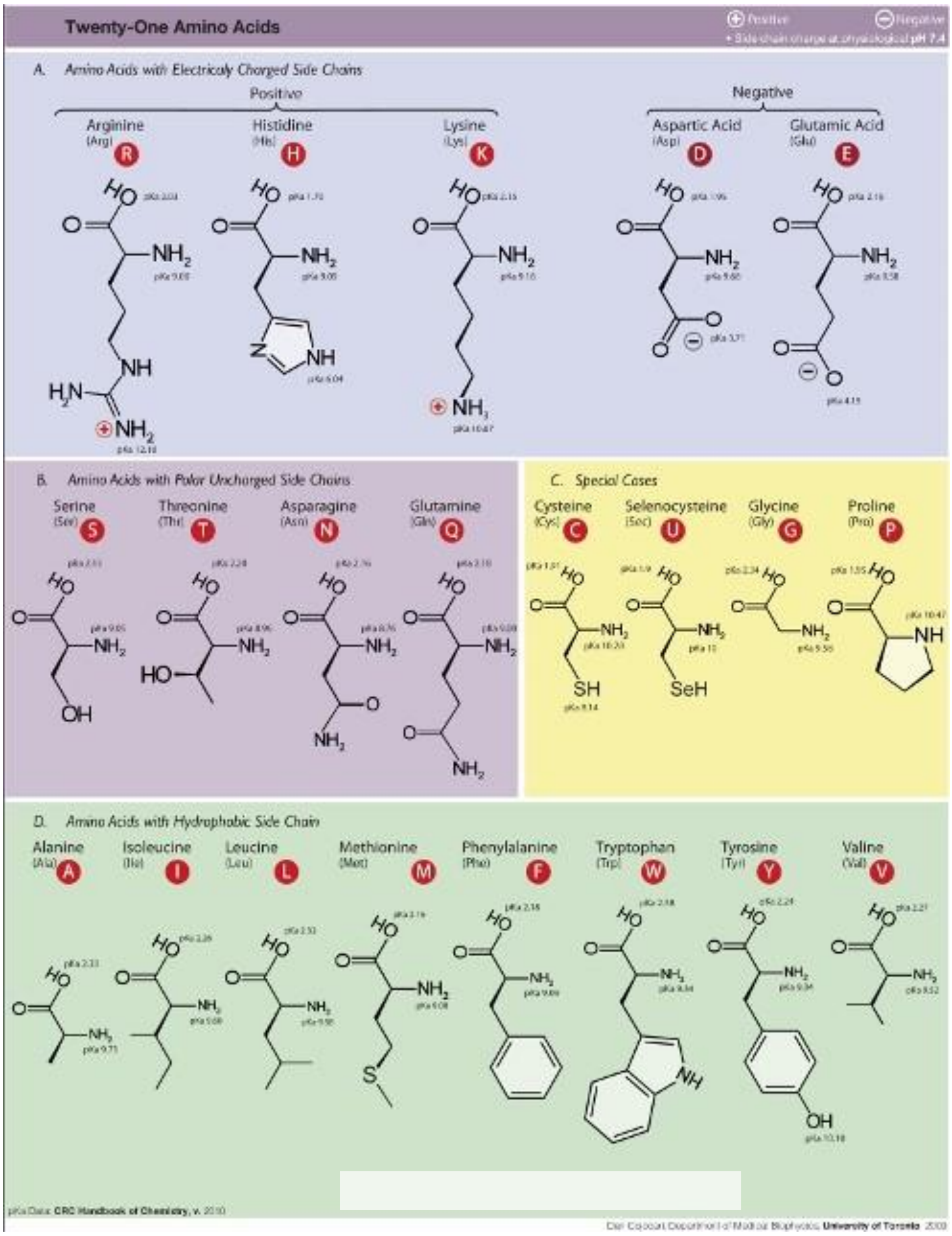


- Basic dipeptide shown above. Students should practice drawing with a variety of different amino acids (different "R" groups)
- Every peptide bond should be between the NH2 (amine group) and the COOH (carboxyl group). One H comes from the NH_2 and an –OH group comes from the –COOH group to produce H2O
- Condensation reaction

∑ - There are 20 different amino acids in polypeptides synthesized on ribosomes.

- Twenty different amino acids are used by the ribosomes to create polypeptides in our body

- They all contain an amine (NH2) group, a carboxyl (-COOH) group which combine to form the peptide bond and a “R” group
- The different “R” groups are what makes the amino acids different and allow the proteins to form a wide array of structures and functions
- Some are charged or polar, hence they are hydrophilic
- Some are not charged and are non-polar, hence they are hydrophobic



http://en.wikipedia.org/wiki/Protein_%28nutrient%29#mediaviewer/File:Amino_acids.png

∑ - Amino acids can be linked together in any sequence giving a huge range of possible polypeptides.

- Ribosomes link amino acids together forming a peptide bond according the mRNA sequence copied from the gene or genes (DNA) for a particular polypeptide

- Since there are 20 amino acids, an enormous variety of polypeptides can be produced
- Basically the number of different polypeptides that can be produced is 20^n, where 20 represents the number of amino acids that can be used and n represents the number of AA's in a particular polypeptide.
- So if a protein has 200 AA's, the number of different combinations would be 20^{200}, which is an astronomically large number. Some proteins can be in the thousands or tens of thousand

∑ - The amino acid sequence of polypeptides is coded for by genes.

- The sequence of amino acid in polypeptides is coded by the base sequence in an organism's genes
- Each 3 bases codes for 1 amino acid in a polypeptide
- So if a polypeptide is 300 amino acids in length, 900 bases actually code for that polypeptide (not including the 3 base pairs that code for the stop codon). Also, the genes are actually longer as they contain non-coding regions that don't code for the polypeptide.
- The actual coding region is called the reading frame

∑ - A protein may consist of a single polypeptide or more than one polypeptide linked together.

- Some proteins consist of a single polypeptide, while some contain more than one polypeptide
- Hemoglobin for example has 4 linked polypeptides, which are folded into a globular protein to carry oxygen in the blood
- Collagen consists of 3 polypeptides wound together like a rope (structural protein in tendons)
- Keratin consists of 2 polypeptides twisted into a double helix (structural protein in hair and fingernails). Insulin also has two polypeptides
- Glucagon consists of only 1 alpha helix polypeptide. Glucagon breaks down glycogen into glucose when the body needs sugar for energy

∑ - The amino acid sequence determines the three-dimensional conformation of a protein.

- There are 4 levels of proteins, primary, secondary, tertiary and quaternary
- How a protein twists and folds to form secondary and tertiary structures is determined by the primary sequence of amino acids
- Secondary structures for fibrous proteins such as collagen and keratin are determined by repeating sequences in the amino acid sequence. They are formed by the interactions between the amine and carboxyl groups
- Tertiary structures which form globular proteins are still determined by the original amino acid sequence. They form from interactions between the different "R" groups causing them to fold to create an active protein

∑ - Living organisms synthesize many different proteins with a wide range of functions.

Protein Functions	Examples
Enzymes - catalyze biochemical reactions by lowering the activation energy needed for the reaction to take place	Pepsin – breaks down protein in the stomach Amylase – breaks down starch in the mouth and small intestine
Hormones – chemical messengers that help	Insulin – regulates glucose metabolism by

coordinate certain regulatory activities	controlling blood sugar concentration
Structural Proteins – fibrous proteins provide support and structure within the body	Collagen – main protein in connective tissues such as tendons and ligaments
Transport Proteins – move molecules from one place to another around the body	Hemoglobin – transports oxygen throughout the blood system
Muscle Contractions	Acctin and myosin – used in contraction of muscle in location and transport
Cytoskeletons	Tubulin – subunit of microtubules in the spindle to pull apart chromosomes and give animal cells their shape
Receptors	Binding sites in the membrane for hormones, neurotransmitters and light in the retina
Immunity	Antibodies – for defence against pathogens

∑ - Every individual has a unique proteome.

- A proteome is all of the different kinds of proteins produced by a genome, cell, tissue or organism at a certain time.
- This is completed by extracting mixtures of proteins and using gel electrophoresis with antibodies specific to those proteins with florescent markers
- Proteomes vary in different cells (different cells make different proteins) and at different times within the same cell (cell activity varies)
- Proteomes vary between different individuals because of not only cell activity but slight variations in amino acid sequences
- Within species there are strong similarities between proteomes

Applications and skills:

β - Application: Rubisco, insulin, immunoglobulins, rhodopsin, collagen and spider silk as examples of the range of protein functions.

Rubisco	- Catalyzes the reaction in the Calvin cycle that fixes CO_2 into organic carbon to be used by living organisms to produce the carbon compounds need for life. - Full name is ribulose bisphosphate carboxylase - It is one of the most abundant and important enzyme in the world
Insulin	- hormone produced by the beta cells of the pancreas that reduces the blood glucose levels by promoting the absorption of glucose from the blood to the skeletal muscles and tissue - Insulin binds reversibly to receptors in the cell membrane to

	promote uptake
Immunoglobulins	- these are also known as "antibodies" - They are Y shaped proteins produced by the plasma B cells to identify and neutralize foreign pathogens like bacteria and viruses - they act as markers to identify these pathogens for destruction by large white blood cells called Phagocytes - each antibody is specific for a specific pathogen
Rhodopsin	- rhodopsin is a biological pigment in the photoreceptor cells of the retina - rhodopsin consists of a retinal molecule surrounded by an opsin polypeptide - When the retinal absorbs light through the eye, it changes it's shape and the shape of the opsin. This sends a nerve impulse through the optic nerve to the brain - essential in low light
Collagen	- main structure molecule in various connective tissues such as skin, blood vessels and ligaments - They are fibrous rope-like proteins made from 3 polypeptides Most abundant protein in the body (about ¼ of all the proteins)
Spider silk	- spider silk consists of many different types with different functions Eg. dragline silk is stronger than steel and tougher than Kevlar used in bulletproof vests) - used in the spokes of a web and when a spider suspends itself - very extensible and resistant to breaking

β - Application: Denaturation of proteins by heat or by deviation of pH from the optimum. (studied in further detail in enzyme section)

- Tertiary or 3D structure of proteins is held together by bonds between the "R" groups
- Heat causes proteins to denature because vibrations caused by the KE break the intermolecular bonds or interactions
- Different proteins can tolerate different temperatures. Most of the proteins in the humans work best at body temperature, but some organisms like bacteria in hydrothermal vents or volcanic hot springs can tolerate extreme temperatures without denaturing (Thermus aquaticus – optimal temperature is 80 Celsius
- Different pH's away from a proteins optimal pH can also cause denaturation
- Alkaline or acidic solutions can break the ionic bonds between R groups causing the protein to lose its 3D shape
- Pepsin – Enzyme in the stomach works best at about 1.5 pH but will denature as the pH gets higher

2.5 Enzymes

∑ - Understandings:

∑ - Enzymes have an active site to which specific substrates bind.

- **Active site**: The area or the pocket on the enzyme where the substrate binds.
- **Enzyme:** Proteins that catalyze chemical reactions (increase the rate by lowering the activation energy)
- Each enzyme catalyzes a specific reaction for a **specific substrate**
- Enzymes are not used up during the chemical reactions

- Enzymes are very specific, because both the enzyme and the substrate possess specific complementary shapes that fit into one another.
- The binding of the substrate to the enzyme causes the chemical bonds of the substrate to weaken.
- This eventually causes the reactions that take place that form the products.
- After the products are released, the enzyme can bind to another substrate, because enzymes are not used up in these chemical reactions.

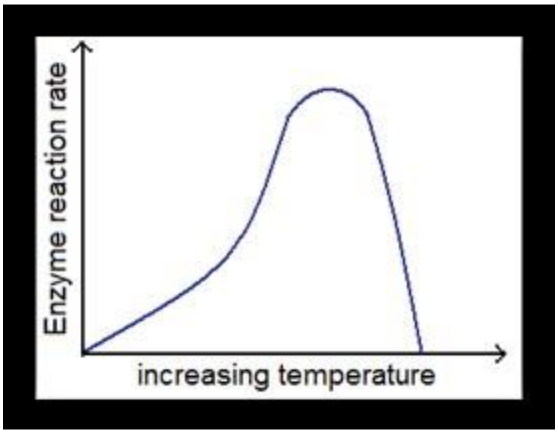
∑ - Enzyme catalysis involves molecular motion and the collision of substrates with the active site.

- When a substrate comes close to the active site of the enzyme, it can collide and bind to the active site of the enzyme
- Since the substrate is dissolved in water around the enzyme, the substrates and enzymes are in continuous motion
- The direction and movement is constantly changing and is random
- Collisions occur at random between the substrate and enzyme
- Successful reactions only occur if the substrate and the active site of the enzyme are correctly aligned and the collide with sufficient KE

∑ - Temperature, pH and substrate concentration affect the rate of activity of enzymes.

<u>Temperature</u>

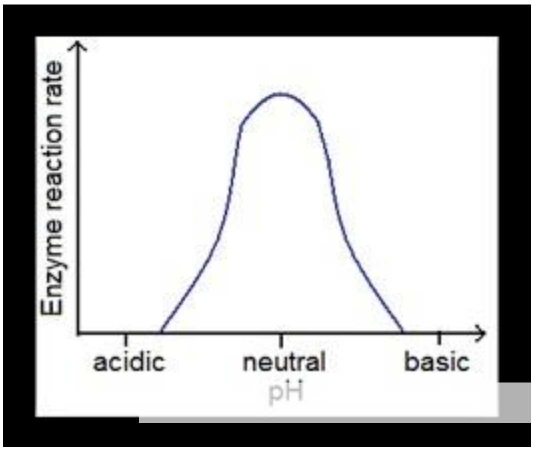
- When heat is added to a liquid the particles speed up, thus giving them more kinetic energy.
- In a liquid that contains substrates and enzymes, the increase in kinetic energy will cause more collisions between substrates and enzymes thereby increasing enzyme activity and reaction rates.
- However, as temperature increases and becomes too high, the bonds of the enzyme begin to vibrate and eventually break.
- This causes the enzyme to lose its 3D shape, including the shape of the active site.
- When the enzyme loses its shape and can no longer catalyze reactions, the enzyme is said to be denatured.
- When the enzymes in solution become denatured, the reaction rate decreases dramatically.
- Enzyme denaturation is usually permanent.



- The optimum rate of reaction is when the graph reaches the top of the curve which is around 40ºC for most enzymes.

pH:

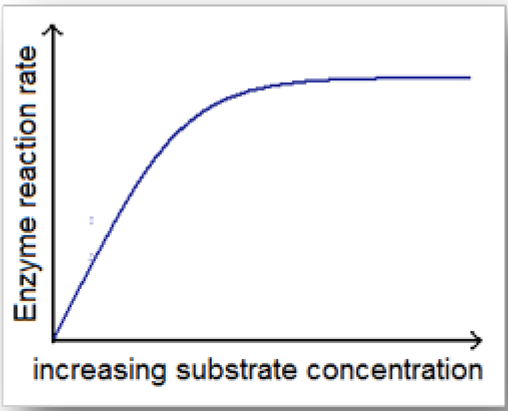
- pH is dependent on the number of H^+ ions compared to the number of OH- ions.
- When a solution has a high number of H^+ ions the solution it is said to have a low pH (acid). If a solution has a high number of OH^- ions the solution is said to have a high pH (base).
- Enzymes have an optimum pH at which they work the best.
- When deviations occur away from this optimum pH, the enzyme's activity or reaction rate decreases.
- When the pH moves too far away from the enzyme's optimum pH, the enzyme will lose its shape and denature, drastically decreasing enzyme activity.
- For example, the optimum pH for the enzyme pepsin is around 2-3. If the pH increases to 5 or 6, the enzyme loses its ability to catalyze reactions (breakdown of proteins in the stomach).
- Most enzymes have an optimum pH close to neutral (7) pH.



Substrate Concentration

- With a fixed amount of enzymes, as substrate concentration increases, the rate of reaction will increase, because more collisions between enzymes and substrates will occur.
- However, as substrate level increases, more and more enzyme active sites are being filled.

- At a certain substrate concentration, all active sites on the enzymes are being used or are filled.
- At this point the reaction rate levels off and remains constant.
- Adding more substrate to the reaction will not increase the reaction rate. Reaction rate can only be increased with addition of more enzymes.



∑ - Enzymes can be denatured.

- Denaturation is a structural change in a protein (usually enzymes) that results in the loss (usually permanent) of its biological properties. When an enzyme denatures, the bonds that hold together its three dimensional shape begin to vibrate and eventually break. This causes the enzyme to unfold and lose its shape, thereby eliminating the enzyme's ability to catalyze reactions.

∑ - Immobilized enzymes are widely used in industry.

- More than 500 enzymes are now used for commercial purposes
- The majority of these enzymes used in industry are immobilized; meaning they are attached to another material (such as glass) or grouped together (in a calcium alginate gel)
- The benefits of using immobilized enzymes are as follows

1. Convenience – only small amounts of proteins dissolve in the reactions leaving only solvent and the products. This means the enzymes and products can be easily separated
2. Economics – The immobilized enzymes can be easily removed and recycled from the solution, saving money. Eg. Particular useful in the removal of lactase in the production of Lactose Free Milk.
3. Stability – Immobilized enzymes generally have a greater thermal and chemical stability than the soluble form of the enzyme

4. Reaction rate is faster because substrates can be exposed to a higher concentration of enzymes

∑ - Applications and skills:

∑ - Application: Methods of production of lactose-free milk and its advantages.

- Lactose is a disaccharide sugar present in milk composed of monosaccharides glucose and galactose.
- Lactase is the enzyme that breaks down lactose into its two monosaccharides.
- Humans are born with the ability to digest milk (lactase produced) but as we grow older, most humans lose the ability to produce lactase in significant amounts.
- If the lactose is broken down in milk before it is consumed, people that are lactose intolerant can drink the milk.
- Some types of yeasts produce lactase.
- Biotechnology companies can culture these yeasts and remove the lactase.
- Milk is treated with lactase before distribution, allowing lactose intolerant people to consume milk and milk products.

✓ **Skill: Design of experiments to test the effect of temperature, pH and substrate concentration on the activity of enzymes.**

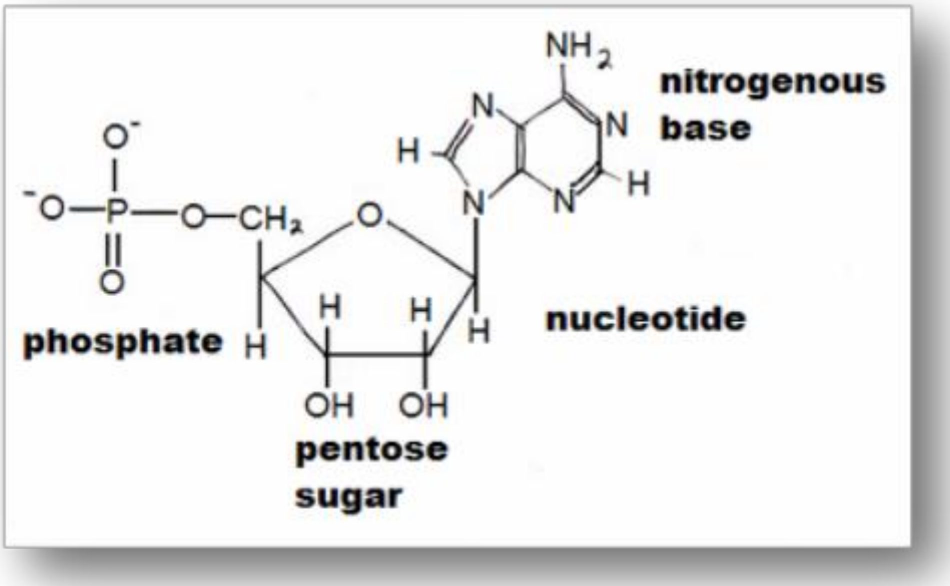
✓ **Skill: Experimental investigation of a factor affecting enzyme activity. (Practical 3)**

LAB: Students can be given a choice to investigate a factor (pH, temperature, substrate or enzyme concentrations) that affects enzyme activity. Students should come up with their testing and recording methods. Use of data loggers such as pressure sensors, pH sensors or colorimeters can be used to satisfy ICT requirements.

2.6 Structure of DNA and RNA

Understandings:

∑ - The nucleic acids DNA and RNA are polymers of nucleotides.



- Nucleotides are the monomers of the polymer DNA.
- DNA nucleotides are made up of 3 components; a phosphate group (PO4-3), a pentose sugar, and a nitrogenous base.
- The phosphate, sugar and base are linked by covalent bonds
- In DNA and RNA each nucleotide is linked to the next nucleotide between the phosphate of one and the pentose sugar of the other nucleotide

∑ - DNA differs from RNA in the number of strands present, the base composition and the type of pentose.

DNA	RNA
Sugar is **deoxyribose** (carbon 2 - no oxygen attached)	Sugar is **ribose** (carbon 2 has an –OH attached)
Nitrogenous bases are guanine, adenine, cytosine and ***thymine***	Nitrogenous bases are guanine, adenine, cytosine and ***uracil***
Double-stranded molecule	**Single-stranded** molecule

∑ - DNA is a double helix made of two antiparallel strands of nucleotides linked by hydrogen bonding between complementary base pairs.

- DNA is double stranded and shaped like a ladder, with the sides of the ladder made out of repeating phosphate and deoxyribose sugar molecules covalently bonded together. The two strands are antiparallel to each other.

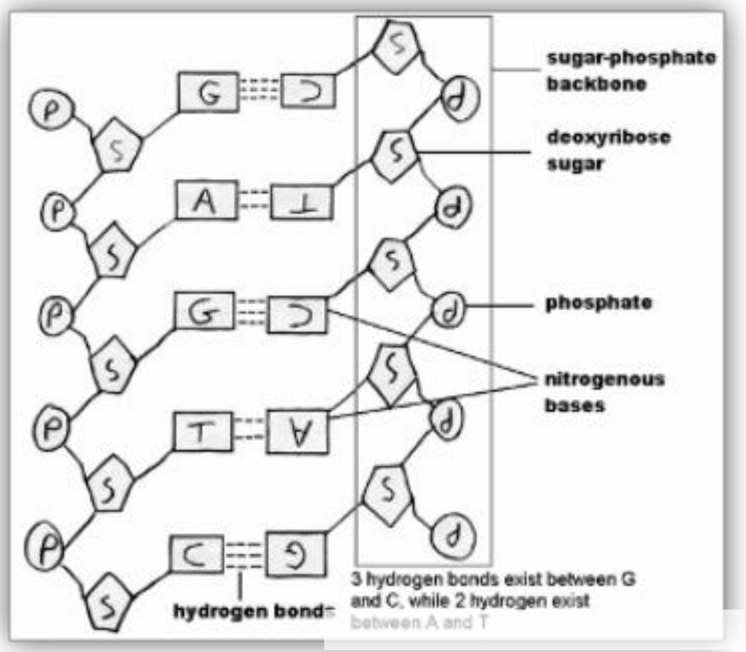
- The rungs of the ladder contain two nitrogenous bases (one from each strand) that are bonded together by hydrogen bonds.
- The nitrogenous bases match up according the Chargaff's Rules in which adenine always bonds to thymine, and guanine always bonds with cytosine. These bonds are hydrogen bonds.
- These base pairs, A-T and G-C, are considered to be complimentary.
- Guanine and cytosine are held together by 3 hydrogen bonds.
- Adenine and thymine are held together by 2 hydrogen bonds.

β - Applications and skills:
β - Application: Crick and Watson's elucidation of the structure of DNA using model making.

- Go to http://www.dnai.org/a/index.html and click on Finding the Structure.
- Then click on the menu button players
- Watch the interviews for Erwin Chargoff, Rosalind Franklin and Watson and Crick
- Write a one page summary on how Watson and Crick used models to discover the structure of DNA

✓ **Skill: Drawing simple diagrams of the structure of single nucleotides of DNA and RNA, using circles, pentagons and rectangles to represent phosphates, pentoses and bases.**

Draw and label your own simple structure of DNA using circles for phosphates, pentagons for pentose sugar and rectangles for bases.



2.7 DNA replication, transcription and translation

Understandings:

∑ - The replication of DNA is semi-conservative and depends on complementary base pairing.

- Complementary base pairing ensures two identical DNA strands are formed after replication is complete.
- In replication, the original strands are used as templates, allowing complementary bases to be added according to base pairing rules.
- DNA replication is semi-conservative, meaning the new DNA that is createdconsists of one old strand (template) and one new strand (synthesized strand).
- The significance of complimentary base pairing means that the two daughter cells have the exact same DNA genome as the parent cell.
- Gene sequences (if no mutations occur) are therefore successfully passed on from generation to generation.
- Adenine is always matched with thymine with two hydrogen bonds and guanine is always matched with cytosine with three hydrogen bonds.

ü **Skill: Analysis of Meselson and Stahl's results to obtain support for the theory of semi-conservative replication of DNA.**

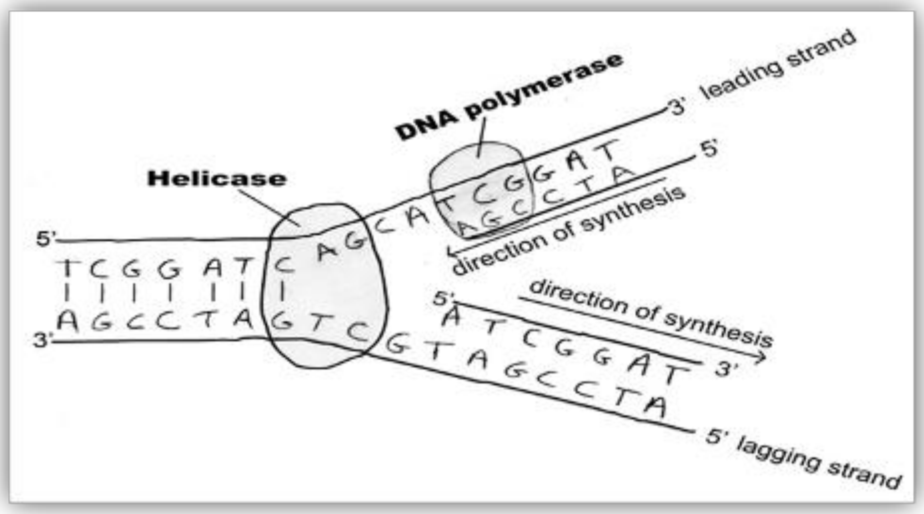
Read through the article for Obtaining evidence for the theory of semi-conservative replication and complete the data based question on the Analysis of Meselson and Stahl's results on page 113- and 114

∑ - Helicase unwinds the double helix and separates the two strands by breaking hydrogen bonds.

- The DNA strand is unwound and separated by an enzyme called helicase.
- The separation is completed by breaking the hydrogen bonds between the base pairs
- Energy from ATP is required for Helicase to move along the DNA and break the bonds

∑ - DNA polymerase links nucleotides together to form a new strand, using the pre-existing strand as a template.

- Free nucleotides found in the nucleus are added to the strands of DNA by an enzyme called DNA polymerase.
- DNA polymerase brings the nucleotide into position so a hydrogen bond can form between the base pairs
- A covalent bond is formed between the phosphate on the free nucleotide and the sugar on the existing chain
- Nucleotides are added to complimentary bases on the DNA template strands according base-pairing rules (adenine pairs with thymine and guanine pairs with cytosine).
- Bases are added in one direction on one strand and are added in the opposite direction on the other strand.
- Very few mistakes occur
- The newly formed DNA strands rewind to form a double-helix spiral staircase shape once again.



β - Applications and skills:

β -Application: Use of Taq DNA polymerase to produce multiple copies of DNA rapidly by the polymerase chain reaction (PCR).

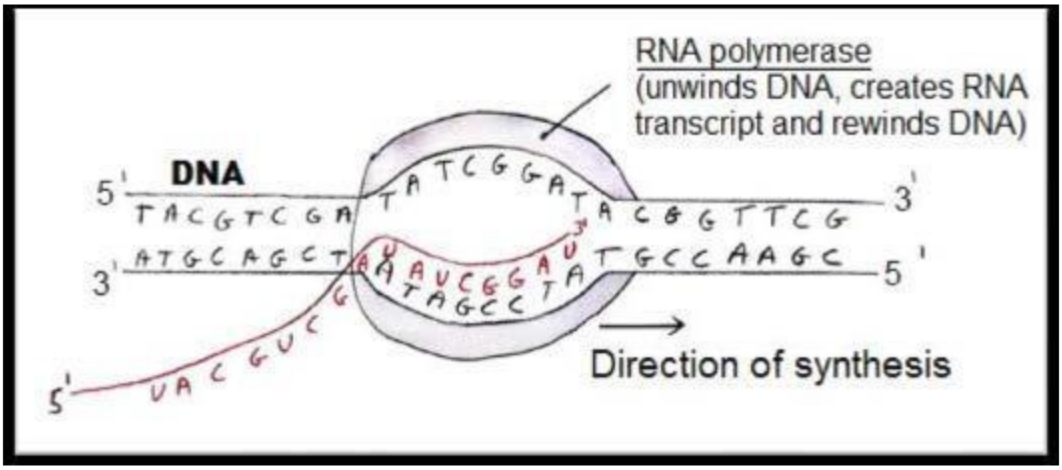
- Go to http://www.dnalc.org/resources/animations/pcr.html
- Click on **Amplification** to start the animation
- Follow the animation and write down the steps involved in PCR
- PCR (polymerase chain reaction) is a laboratory technique that takes a single or few copies of DNA and amplifies them to generate millions or more copies of a particular DNA sequence.
- When you collect DNA from different sources such as sperm samples or small drops of blood, there are usually very little usable cells to collect DNA.
- Therefore, PCR is used to create enough DNA to be analyzed for investigations such as forensics or custody cases.
- Once large quantities of the DNA have been created, other methods such asgel electrophoresis is used to analyze the DNA.

∑ - Transcription is the synthesis of mRNA copied from the DNA base sequences by RNA polymerase.

- Genes contained within a specific region of DNA code for a specific protein.
- Protein synthesis occurs outside the nucleus on the ribosomes. Therefore a molecule needs to be synthesized that will relay the DNA code to allow the specific protein to be made correctly.
- Transcription is the formation of an mRNA strand that is complementary to the DNA strand contained within the gene.
- Transcription begins when the area of DNA that contains the gene is unwound by RNA polymerase
- RNA nucleotides found in the nucleus are added to the template strand of the DNA by the enzyme RNA polymerase according to base-pairing rules.
- RNA polymerase also creates covalent bonds between the nucleotides of the mRNA strand.

- The mRNA strand contains the nitrogenous base uracil instead of thymine.
- Once the gene has been transcribed, the mRNA strand falls off and exits the nucleus through the nuclear pore. It is then transported to the ribosomes for protein synthesis.
- The DNA strand with the same base sequence as the mRNA is the called the sense (coding) strand and the other is called the antisense (template) strand

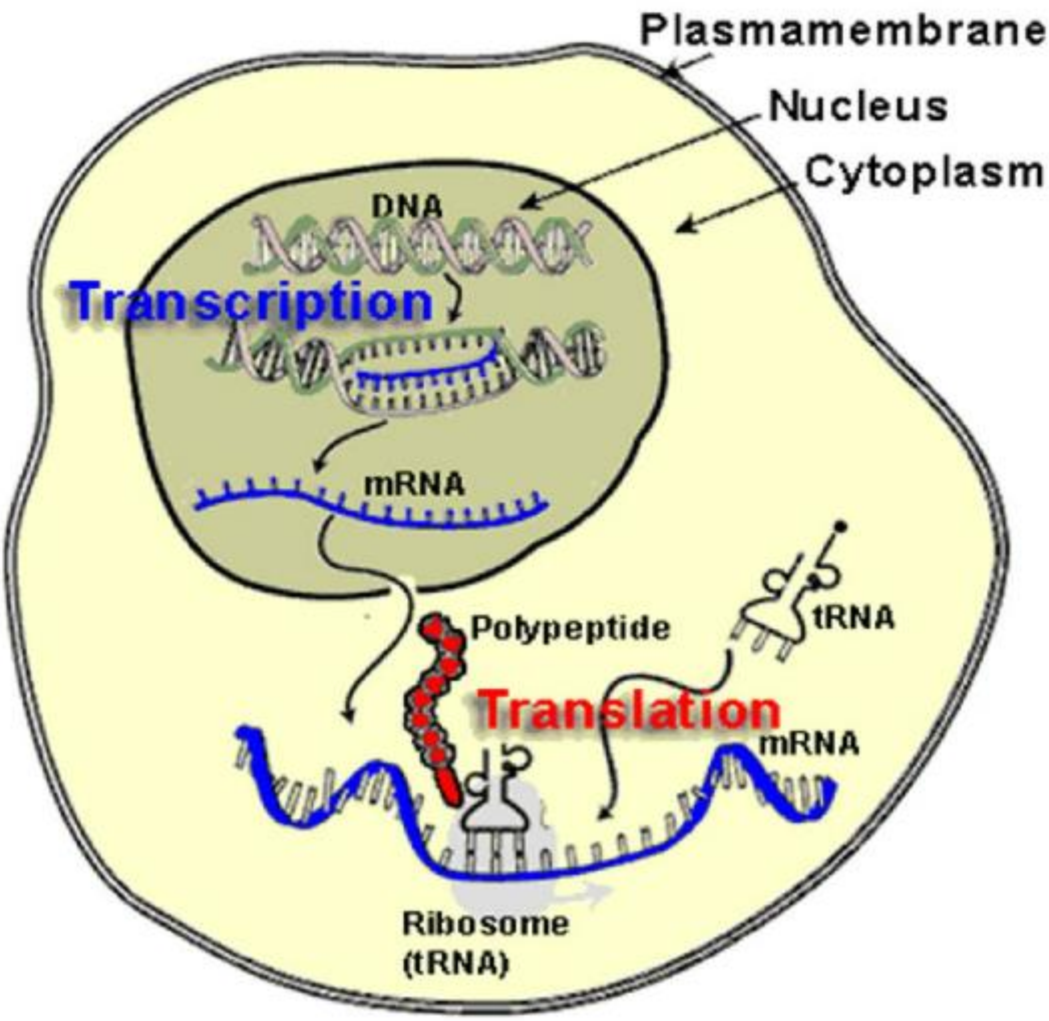
http://www.johnkyrk.com/DNAtranscription.html **Good animation**



Good Video on transcription and translation https://www.youtube.com/watch?v=28mgfg8nRT4

∑- Translation is the synthesis of polypeptides on ribosomes.

- Translation is the synthesis of polypeptides with a specific amino acid sequence that is determined by the base sequence on the mRNA molecule
- That base sequence is determined by the specific gene
- Translation takes place at the ribosomes in the cytoplasm or on the rough ER
- The ribosomes consist of a large and a small subunit
- Ribosomes are made of rRNA and protein



∑ - The amino acid sequence of polypeptides is determined by mRNA according to the genetic code.

- Messenger RNA (mRNA) carries the information from the specific gene to the ribosomes in order to create the correct polypeptide
- The mRNA that is created is specific for that polypeptide only

∑ - Codons of three bases on mRNA correspond to one amino acid in a polypeptide.

- The mRNA strand created in transcription consists of triplet bases calledcodons.
- Each triplet codon on the mRNA codes for a specific amino acid.
- The protein synthesized is made up of a series of amino acids coded for by the mRNA strand which is a complimentary copy of the gene contained in the DNA.
- All the different combinations of bases that make up the 64 triplet codons can code for one of the 20 amino acids.
- However 3 triplets, UAA, UAG, and UGA do not code for amino acids and are called stop codons.

- The mRNA codon AUG, codes for the amino acid Methionine and is called the START codon because it signals the start of translation.
- The genetic code is considered “degenerate” because more than one triplet codon can code for a specific amino acid.

✓ **Skill: Use a table of the genetic code to deduce which codon(s) corresponds to which amino acid.**

✓ **Skill: Use a table of mRNA codons and their corresponding amino acids to deduce the sequence of amino acids coded by a short mRNA strand of known base sequence.**

✓ **Skill: Deducing the DNA base sequence for the mRNA strand.**

Codons in mRNA

First Base	Second Base								Third Base
	U		C		A		G		
U	UUU	Phenylalanine	UCU	Serine	UAU	Tyrosine	UGU	Cysteine	U
	UUC	Phenylalanine	UCC	Serine	UAC	Tyrosine	UGC	Cysteine	C
	UUA	Leucine	UCA	Serine	UAA	Stop	UGA	Stop	A
	UUG	Leucine	UCG	Serine	UAG	Stop	UGG	Tryptophan	G
C	CUU	Leucine	CCU	Proline	CAU	Histidine	CGU	Arginine	U
	CUC	Leucine	CCC	Proline	CAC	Histidine	CGC	Arginine	C
	CUA	Leucine	CCA	Proline	CAA	Glutamine	CGA	Arginine	A
	CUG	Leucine	CCG	Proline	CAG	Glutamine	CGG	Arginine	G
A	AUU	Isoleucine	ACU	Threonine	AAU	Asparagine	AGU	Serine	U
	AUC	Isoleucine	ACC	Threonine	AAC	Asparagine	AGC	Serine	C
	AUA	Isoleucine	ACA	Threonine	AAA	Lysine	AGA	Arginine	A
	AUG	Methionine or start	ACG	Threonine	AAG	Lysine	AGG	Arginine	G
G	GUU	Valine	GCU	Alanine	GAU	Aspartic Acid	GGU	Glycine	U
	GUC	Valine	GCC	Alanine	GAC	Aspartic Acid	GGC	Glycine	C
	GUA	Valine	GCA	Alanine	GAA	Glutamic Acid	GGA	Glycine	A
	GUG	Valine	GCG	Alanine	GAG	Glutamic Acid	GGG	Glycine	G

http://scshstechnology.pbworks.com/f/7b.jpg

Use the DNA strand below to transcribe a strand of mRNA and then identify the correct amino acids in the polypeptide strand.

Template Strand GCC TAC TCG CCT TTT AAA GCT AGT ACT GGG CGC

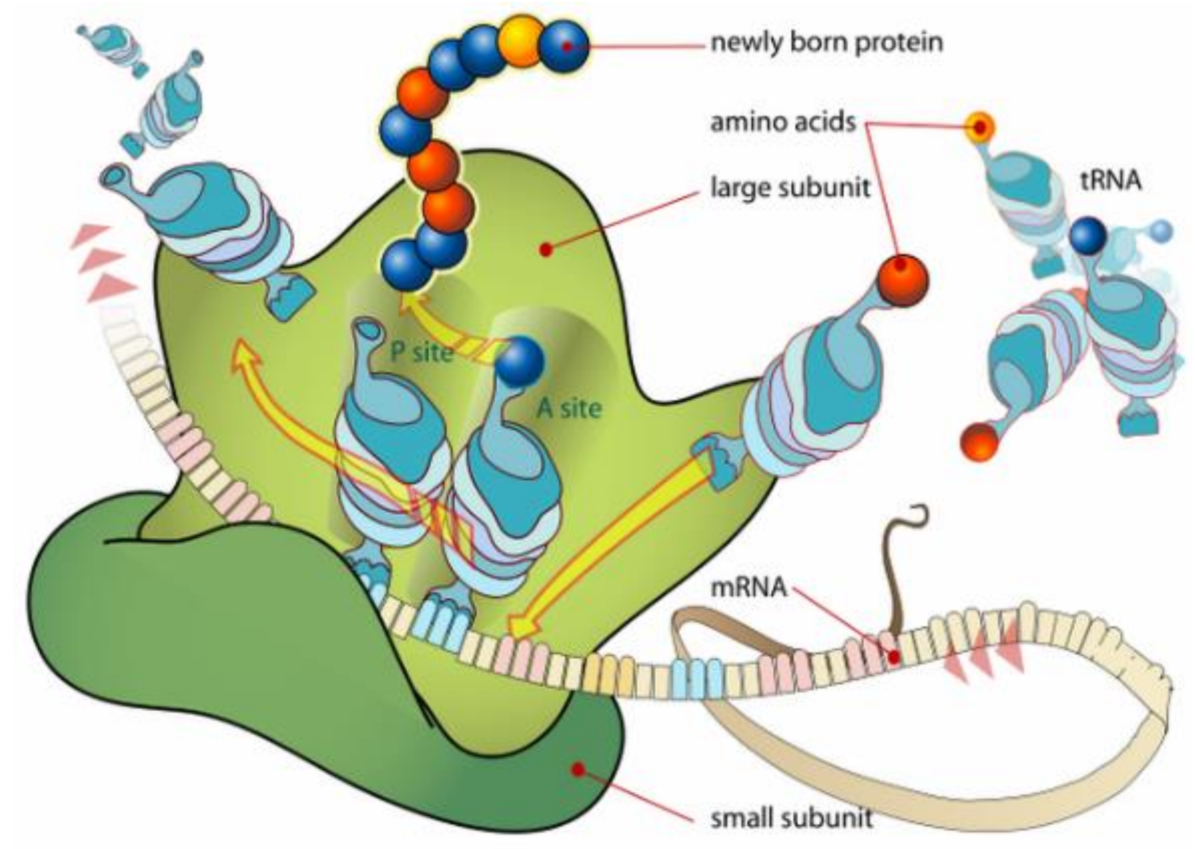
Coding Strand CGG ATG AGC GGA AAA TTT CGA TCA TGA CCC GCG

Amino Acids ____

Also complete the Decoding base sequences in your text.

∑ - Translation depends on complementary base pairing between codons on mRNA and anticodons on tRNA.

- Process where amino acids are combined to form proteins (polypeptides).
- mRNA has a sequence of codons (3 base pairs) that specifies the AA sequence of the polypeptide
- tRNA have an anticodon that matches and binds to their complementary codon carrying the AA corresponding to that codon
- rRNA binding site for the mRNA and tRNA and catalyzes the reaction to put together the polypeptide
- After transcription occurs the transcribed mRNA moves out from the nucleus through the nuclear pore into the cytoplasm and binds to the ribosome unit either in the cytoplasm or attached to the rough ER
- mRNA binds to the small subunit of the ribosome with its first two codonscontained within the binding sites of the ribosome.
- The first codon is called the start codon (AUG) which codes for methionine.
- The corresponding tRNA attaches to the mRNA bringing the amino acid methionine to the ribosome to start the polypeptide chain.
- While still attached, a second tRNA attaches to the mRNA at the second binding site on the ribosome, carrying the amino acid that corresponds to the mRNA codon.
- The two amino acids are combined by a condensation reaction, forming acovalent dipeptide bond.
- The bond between the first amino acid and the tRNA that carried it to the ribosome is broken by an enzyme.
- The ribosome slides along the mRNA, moving down one codon releasing the tRNA back into the cytoplasm so it can go pick up another amino acid (in this case methionine).
- Another tRNA moves into the empty site bringing the next amino acid that corresponds to the mRNA codon.
- Again, the amino acid is attached to the polypeptide and the previous tRNA is released back into the cytoplasm as the ribosome moves along the mRNA.
- This process continues until 1 of the 3 stop codons (UAA, UGA, and UAG) is reached. These tRNA have no attached amino acid.
- Finally, when the ribosome moves along the mRNA, the polypeptide will fall off and be released into the cytoplasm.



Watch the following animation on translation.http://highered.mheducation.com/sites/0072943696/student_view0/chapter3/animation__protein_synthesis__quiz_3_.html

β - Application: Production of human insulin in bacteria as an example of the universality of the genetic code allowing gene transfer between species.

- A gene produces a certain polypeptide in an organism.
- Since the genetic code is universal, when a gene is removed from one species and transferred to another the sequence of amino acids in the polypeptide produced remains unchanged.
- Animal insulin has been used for the treatment of diabetics for many years; however, some people develop an allergic reaction to the animal insulin
- Since 1982, human insulin created by the pancreas has been produced usinggene transfer techniques with E. coli bacteria
- Gene transfer is taking one gene from an organism and inserting it into another organism.
- First, mRNA that codes for insulin produced in the pancreatic cells isextracted.
- The enzyme reverse transcriptase is mixed with the mRNA. This enzymeproduces a strand of coding DNA called cDNA.
- Plasmids are small circles of DNA found in bacteria cells. These plasmids are cut with a restriction enzyme, leaving sticky ends to which the cDNA can attach.
- DNA ligase is used to seal the nicks between the cDNA and the plasmid.

- Linking sequences are added to the cDNA allowing them to be inserted into the plasmid.
- The bacterial plasmid carrying the insulin gene is now inserted into plasmid free bacterial cell such as e.coli bacteria (with plasmid removed). This is known as the host cell.
- These insulin producing bacterial cells will now reproduce rapidly during fermentation, creating millions of insulin producing bacteria cells.
- Finally, the insulin produced is extracted from the cell and purified to be used by diabetics.

Watch the video on the production of insulin and genetic engineeringhttps://www.youtube.com/watch?v=zlqD4UWCuws

2.8 Cell respiration

∑ - Understandings:

∑ - Cell respiration is the controlled release of energy from organic compounds to produce ATP.

- Organic compounds from the food we eat such as glucose contain stored energy within their covalent bonds.
- All living organisms carry out cell respiration in order to convert stored energy into a form that can be used by the cell.
- When organic molecules are broken down, the energy formed is eventually stored in a high energy molecule called **ATP**.
- Cell respiration is the controlled release of energy from organic compounds in cells to produce ATP.

∑ - ATP from cell respiration is immediately available as a source of energy in the cell.

- Energy for all types of cellular processes is immediately supplied by ATP
- The main types of cellular activity include synthesizing large molecules (eg. DNA, RNA and protein), pumping ions across membranes by active transport, and moving things around the cell, such as vesicles and chromosomes. Muscle contractions also use ATP.
- Energy is released by spitting **ATP -> ADP + Pi**

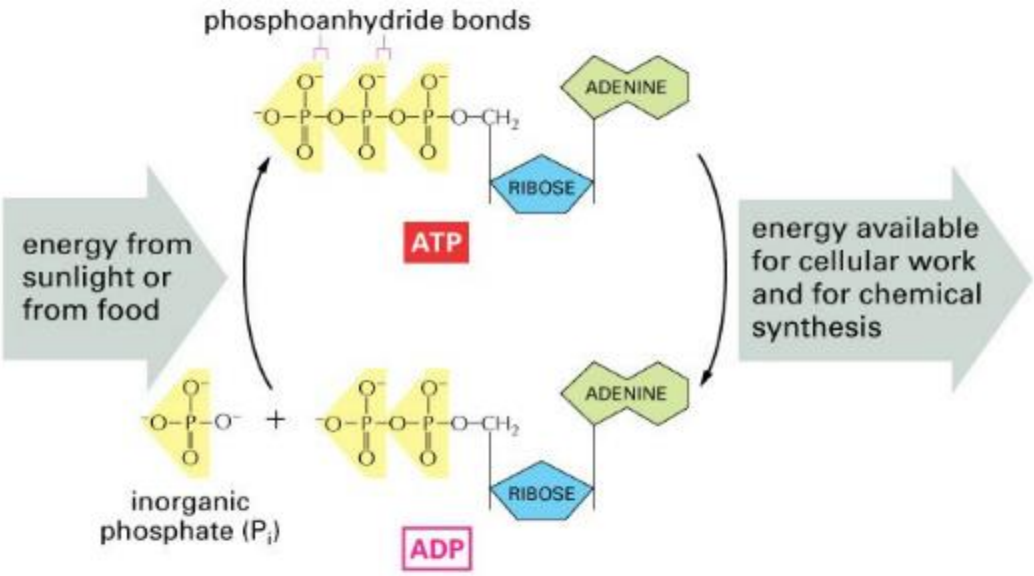


Figure 3-32 Essential Cell Biology, 2/e. (© 2004 Garland Science)

http://www.accessexcellence.org/RC/VL/GG/ecb/ATP_ADP.php

∑ - Anaerobic cell respiration gives a small yield of ATP from glucose.

- Glucose (6C) is broken down into 2 pyruvate (3C) in the cytoplasm by the process ofglycolysis.
- There is a net gain of 2 ATP molecules.
- Glycolysis does not require oxygen.
- Anaerobic respiration (without oxygen) occurs in the cytoplasm.
- During glycolysis, glucose is converted into pyruvate with a net gain of 2 ATP.
- After glucose is converted to pyruvate, if no oxygen is available, pyruvate is further convertedinto lactate or ethanol depending on the organism.
- When no oxygen is available, humans convert pyruvate into lactate (lactic acid) with no further gain of ATP.
- No CO_2 is produced, because like pyruvate, lactate is also a 3 carbon molecule.
- In yeast and plants, pyruvate is converted into ethanol (2C) and carbon dioxide with no further yield of ATP.
- Ethanol and CO2 are excreted as waste products.

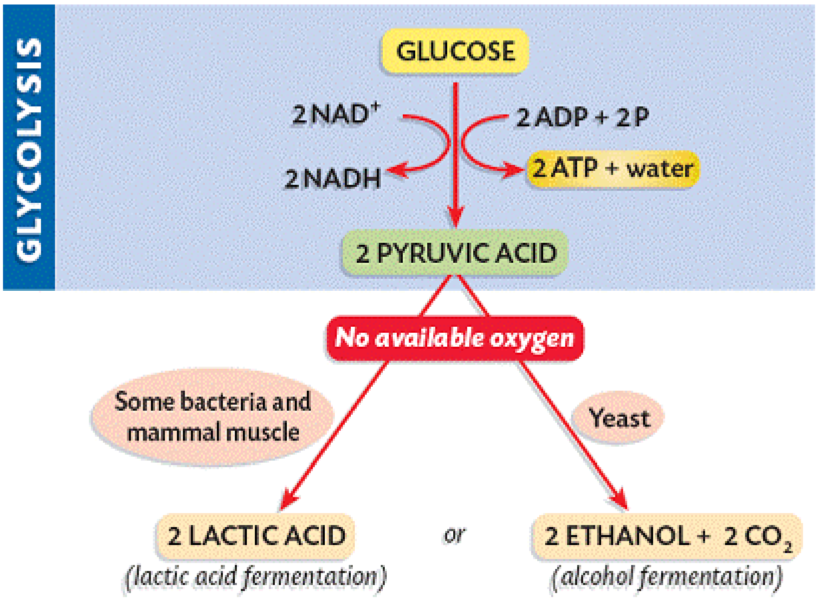
β - **Applications and skills:**

β **- Application: Use of anaerobic cell respiration in yeasts to produce ethanol and carbon dioxide in baking.**

Read through "Yeast and its uses" on page 124-125 and answer the data based questions on page 125.

β - **Application: Lactate production in humans when anaerobic respiration is used to maximize the power of muscle contractions.**

Watch https://www.youtube.com/watch?v=cDC29iBxb3w. Discusses anaerobic respiration in humans.



http://leavingbio.net/respiration-(higher%20level).htm

∑ - **Aerobic cell respiration requires oxygen and gives a large yield of ATP from glucose.**

- Aerobic respiration also begins with glycolysis which produces 2 pyruvate molecules per glucose.
- Aerobic respiration occurs in the mitochondria.
- Aerobic respiration is much more efficient than anaerobic respiration as the glucose molecule is fully oxidized.
- The products created in the redox reactions of the Kreb's cycle, plus oxygen (terminal electron acceptor) will produce large quantities of ATP though oxidative phosphorylation (phosphate added to ADP to form ATP) in the ETC, with water being released.
- Overall in aerobic respiration glucose + oxygen will produce carbon dioxide + water with a large yield of ATP
- About 32-34 molecules of ATP are produced by aerobic respiration, while in anaerobic respiration, only 2 ATP molecules are produced

Do data based questions on page 128

✓ **Skill: Analysis of results from experiments involving measurement of respiration rates in germinating seeds or invertebrates using a respirometer.**

Lab Practical – Using a respirometer to measure rate of respiration in germinating peas

2.9 Photosynthesis

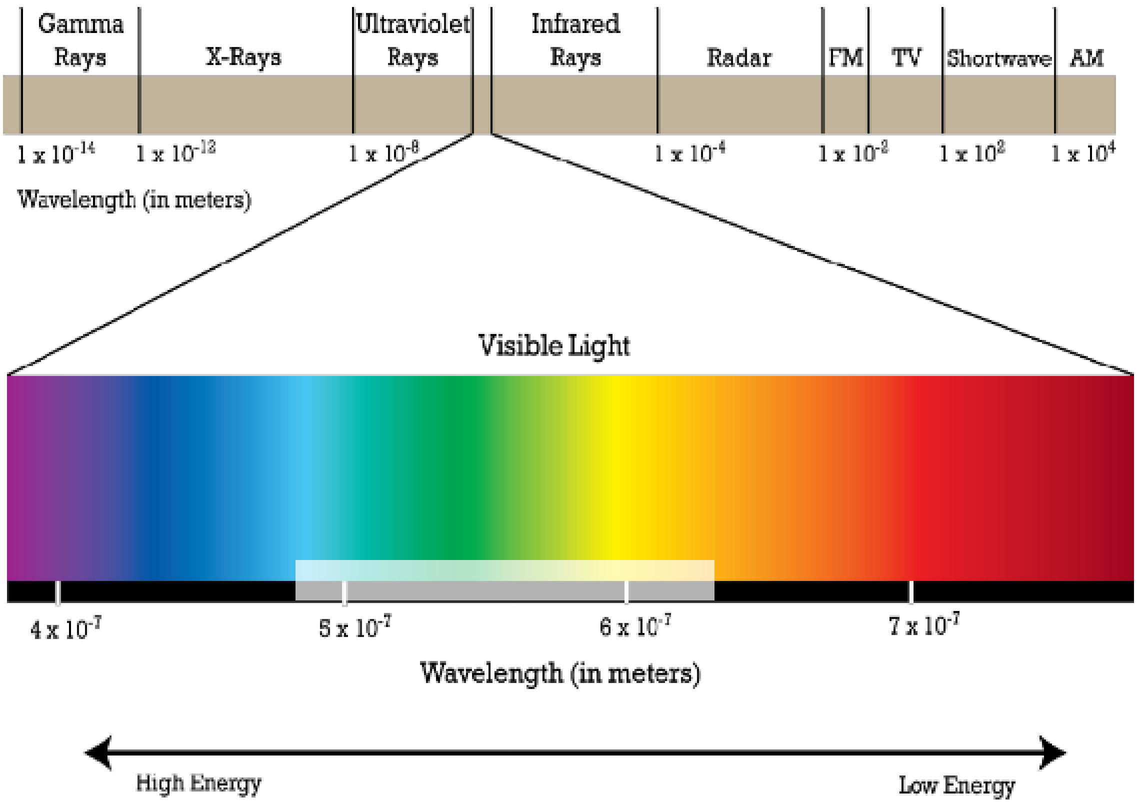
∑ - Understandings:

∑ -Photosynthesis is the production of carbon compounds in cells using light energy.

- Living organisms require complex carbon compounds to carry out life processes and build the structures in their cells
- Photosynthesis involves the conversion of light energy into chemical energy (carbohydrates, lipids, protein and nucleic acids).
- Chloroplasts absorb light energy from the sun and convert this energy into chemical energy (glucose) to be used by the organisms for energy.

∑ - Visible light has a range of wavelengths with violet the shortest wavelength and red the longest.

- Light from the sun is composed of a range of wavelengths.
- The visible spectrum is the portion of the electromagnetic spectrum that is visible to or can be detected by the human eye.
- Electromagnetic radiation in this range of wavelengths (380 to 750 nm) is called visible light.
- All these wavelengths together form white light, with violet/blue colors having shorter wavelengths (more energy) and red colors having longer wavelengths (less energy).



http://www.pion.cz/en/article/electromagnetic-spectrum

∑ - Chlorophyll absorbs red and blue light most effectively and reflects green light more than other colours.

- Sunlight is a mixture of different wavelengths of visible light, which we see as colors.
- The two main colors of light that are absorbed by chlorophyll are red and blue light.
- The main color that is reflected is green light, which is why most leaves look green.

∑ - Oxygen is produced in photosynthesis from the photolysis of water.

- Photolysis is one of the first and most important steps in the light dependent reactions of photosynthesis
- Two water (H2O) molecules are split by photons of light to produce 4 e- + $4H^+$ + O_2

∑ - Energy is needed to produce carbohydrates and other carbon compounds from carbon dioxide.

- Plants convert inorganic CO_2 into organic carbohydrates through the process of photosynthesis
- Carbon dioxide + Water --> CH_2O (carbohydrates) + oxygen
- Energy is required for this reaction to occur
- Light energy from the sun is used and converted into chemical energy
- The reactions are generally endothermic

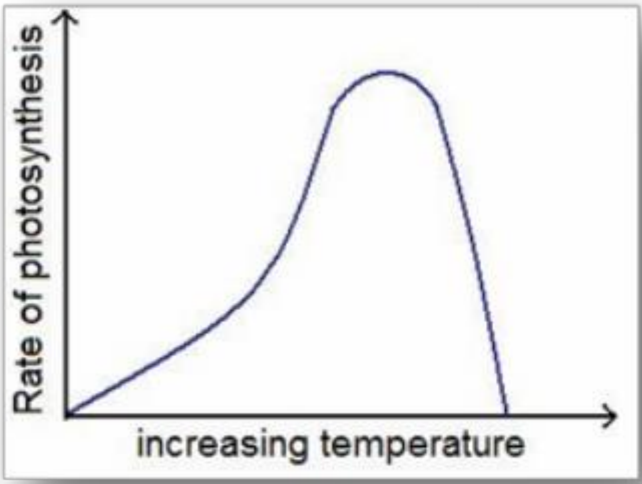
∑ - Temperature, light intensity and carbon dioxide concentration are possible limiting factors on the rate of photosynthesis.

- Light intensity, CO_2 concentration and temperature can all be limiting factors for the rate of photosynthesis
- If any of these factors is below their optimal level, they can be limiting; however, only one of these factors can be limiting at one time
- This is usually the factor that is the furthest away from its optimal level
- This is the only factor that can increase the rate of photosynthesis
- As this factor gets closer to its optimal level, the limiting factor can change to one of the other factors

Temperature

- At low temperatures the rate of photosynthesis is very low.
- Because photosynthesis requires enzymes, as the temperature increases the amount of kinetic energy in the reactants increases, thereby increasing the rate of photosynthesis.
- This rate increases until an optimum temperature is reached. In plants this optimum temperature is usually between 25º and 35º C.
- After the optimum temperature is reached, the rate of photosynthesis drops dramatically, because the temperature can cause the enzymes to denature (lose their shape and active site)

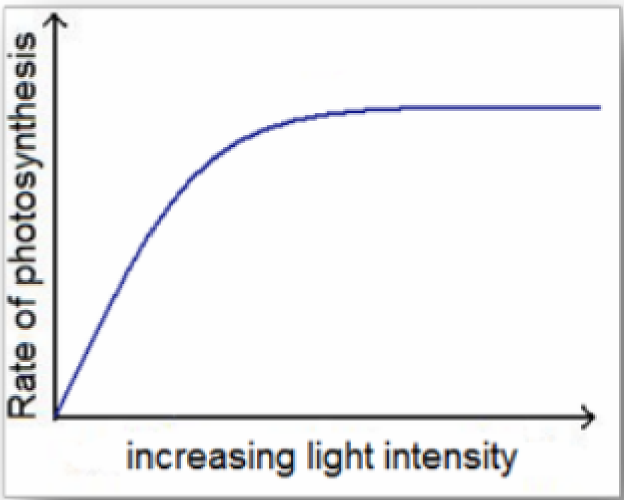
The graph of photosynthesis rate vs. temperature is very similar to the enzyme/temperature graph.



Light Intensity

- Light is used to produce ATP and split water by photolysis to form H^+ ions and oxygen.
- As light intensity increases the rate of photosynthesis also increases.
- At low light intensities, an increase in light causes a drastic increase in the rate of photosynthesis.
- As light intensity increases the rate of photosynthesis begins to level off and becomes constant.
- As light intensity increases further there is no change in the rate of photosynthesis as enzymes are working at their maximum rate.

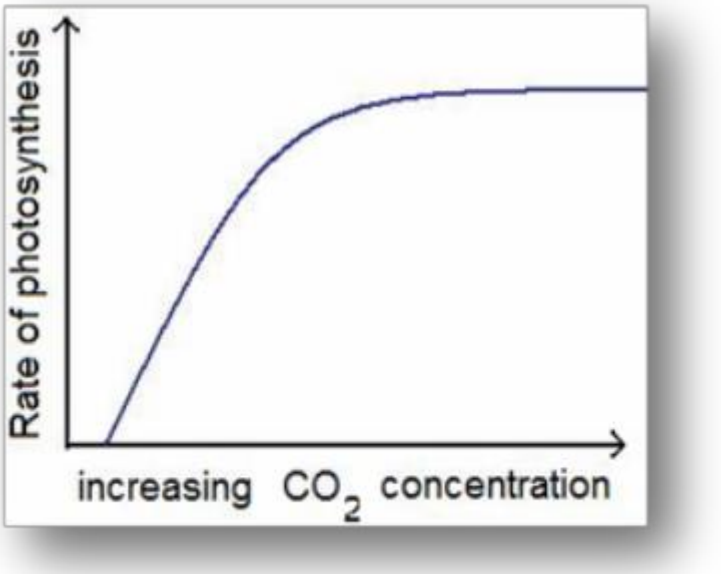
-



Carbon Dioxide Concentration

- CO_2 is the essential molecule in the formation of organic molecules.

- At low CO_2 concentrations, an increase in the amount of CO_2 will increase the rate of photosynthesis. At very low levels, no photosynthesis will take place
- As the CO_2 concentration increases, the rate of photosynthesis begins to plateau.
- At high levels of CO_2 concentration, the rate of photosynthesis remains constant unless light intensity is increased to create more ATP or temperature is increased to provide more kinetic energy.



*** Do the data based questions on page 134***

Applications and skills:

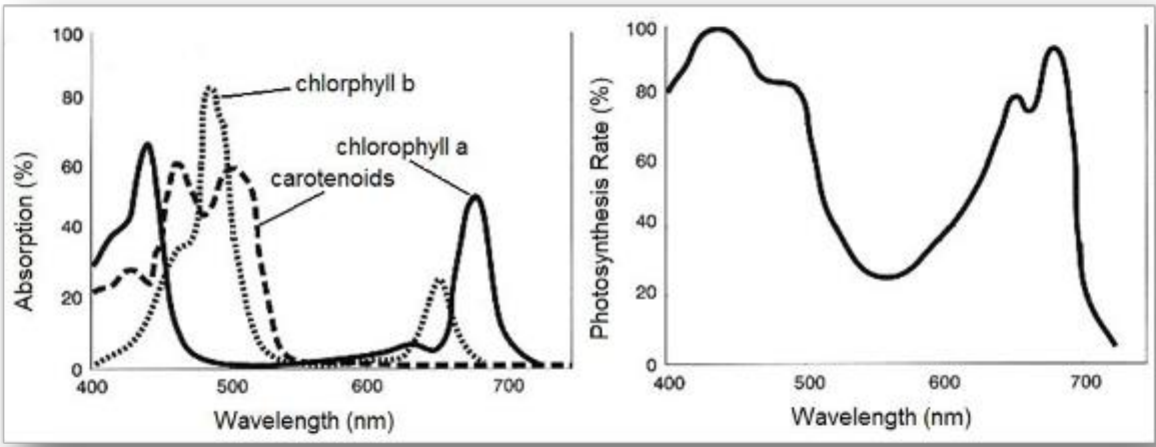
∑ - Changes to the Earth's atmosphere, oceans and rock deposition due to photosynthesis.

- Early bacterial life introduced oxygen to the atmosphere about 3.5 billion years ago.
- As the first free oxygen was released through photosynthesis by cyanobacteria, it was initially soaked up by iron dissolved in the oceans and formed red coloured iron oxide, which settled to the ocean floor.
- Over time, distinctive sedimentary rocks called banded iron formations were created by these iron oxide deposits. Once the iron in the oceans was used up, the iron oxide stopped being deposited and oxygen was able to start building up in the atmosphere about 2.4 billion years ago.
- This was known as the "Great Oxidation Event"
- The oxygen remained at about 2% until about 700 mya. Then there was then a significant rise in oxygen until it reached about 20%.
- This lead to a huge increase in species as multicellular organisms evolved

✓ Skill: Drawing an absorption spectrum for chlorophyll and an action spectrum for photosynthesis.

- The electromagnetic spectrum consists of the entire range of electromagnetic radiation.

- The part of the spectrum that is involved in photosynthesis is called the visible light spectrum.
- An action spectrum is the rate of a photosynthesis plotted against wavelength of light. It shows which wavelength of light is most effectively used during photosynthesis.
- The highest rates of photosynthesis occur at red and blue wavelengths.
- The absorption spectrum shows the % of light absorbed by the photosynthetic pigments in chloroplasts at each different wavelength.
- The graphs are very similar because photosynthesis occurs when light is absorbed by the chlorophyll pigments; therefore the wavelengths that have greatest rates of absorption will also have high rates of photosynthesis.
- Green wavelength of light is reflected and therefore has a very low % absorption level on the absorption spectra (this is why most leaves are green).



✓ **Skill: Design of experiments to investigate the effect of limiting factors on photosynthesis.**

✓ **Skill: Separation of photosynthetic pigments by chromatograph. (Practical 4)**

These would be two separate practicals. You could use the first investigation to carry out a full lab in preparation for the internal assessment.

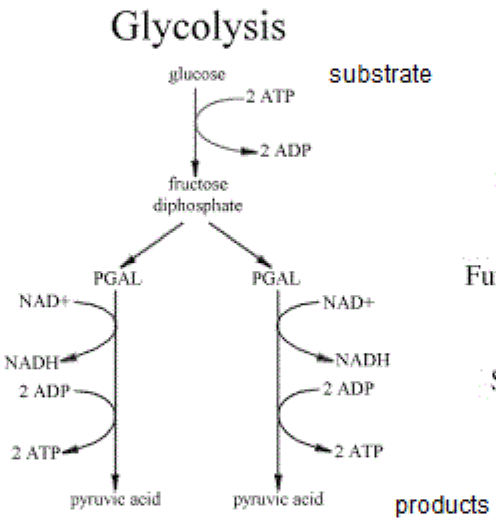
Topic 8.1 - Metabolism

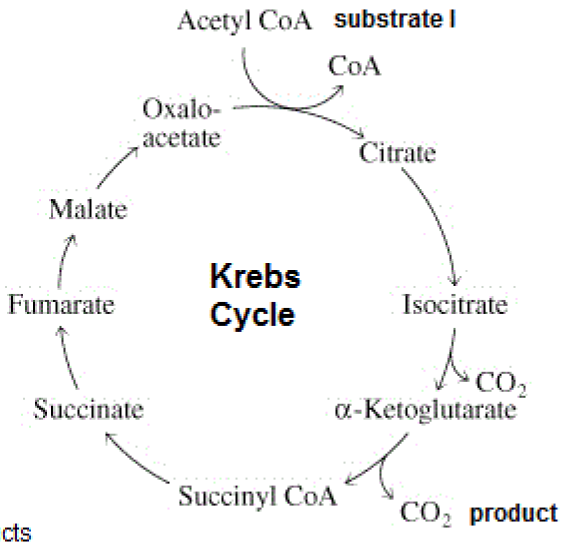
Understandings:

∑ - 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)

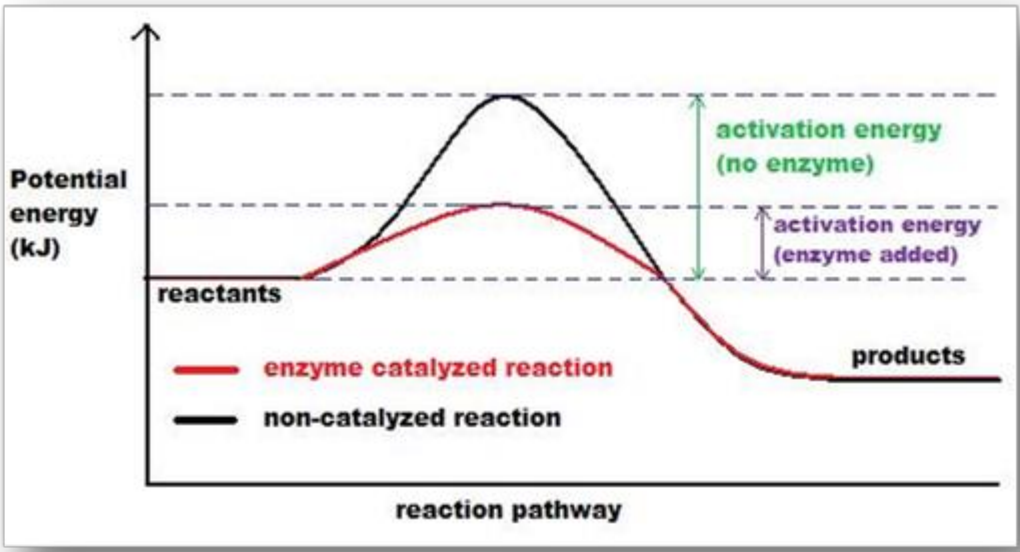




∑ - Enzymes lower the activation energy of the chemical reactions that they catalyse.

- Activation energy is the <u>energy that must be overcome</u> in order <u>for a chemical reaction to occur</u>.
- Activation energy more specifically can be defined as the <u>energy needed to weaken and break the chemical bonds of the substrate.</u>
- <u>Enzymes</u> work by <u>lowering the activation</u> energy needed for the reaction to occur.
- When a substrate binds to the active site on the enzyme, the <u>enzyme changes its conformational</u> <u>shape</u>, thus altering the shape of the active site.
- <u>Changing its shape destabilizes the bonds</u> of the bound <u>substrate</u>.
- Thus <u>less energy is required</u> 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.

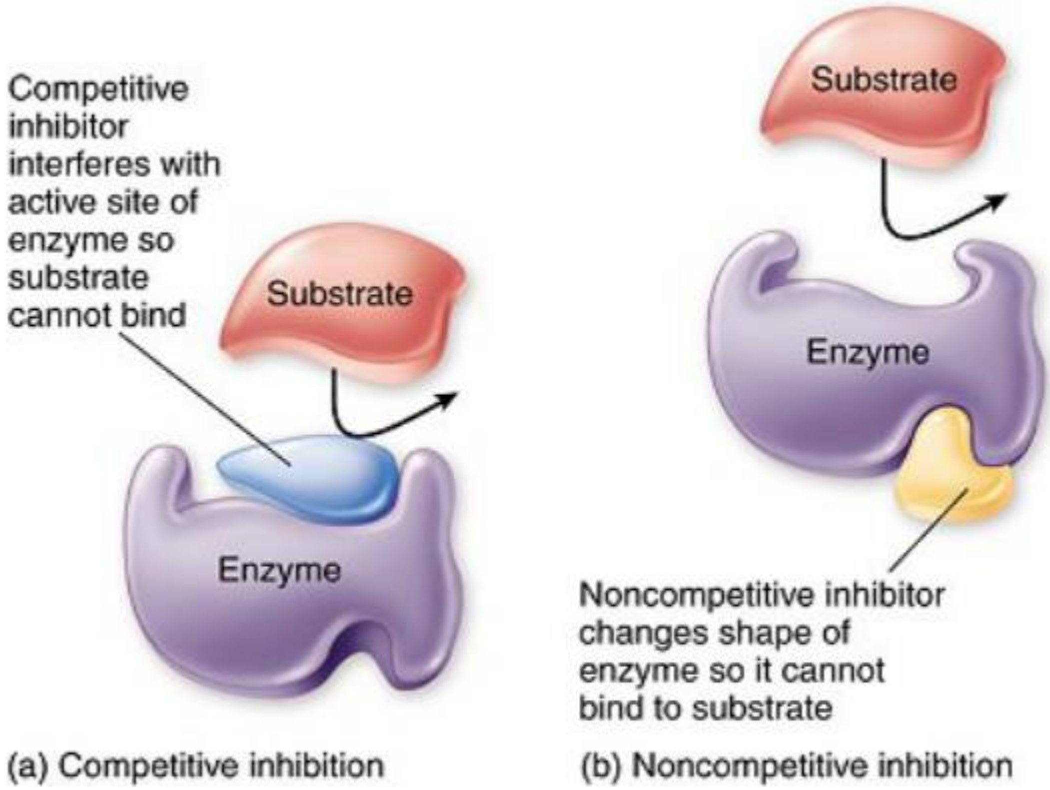
Competitive Inhibition

- 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

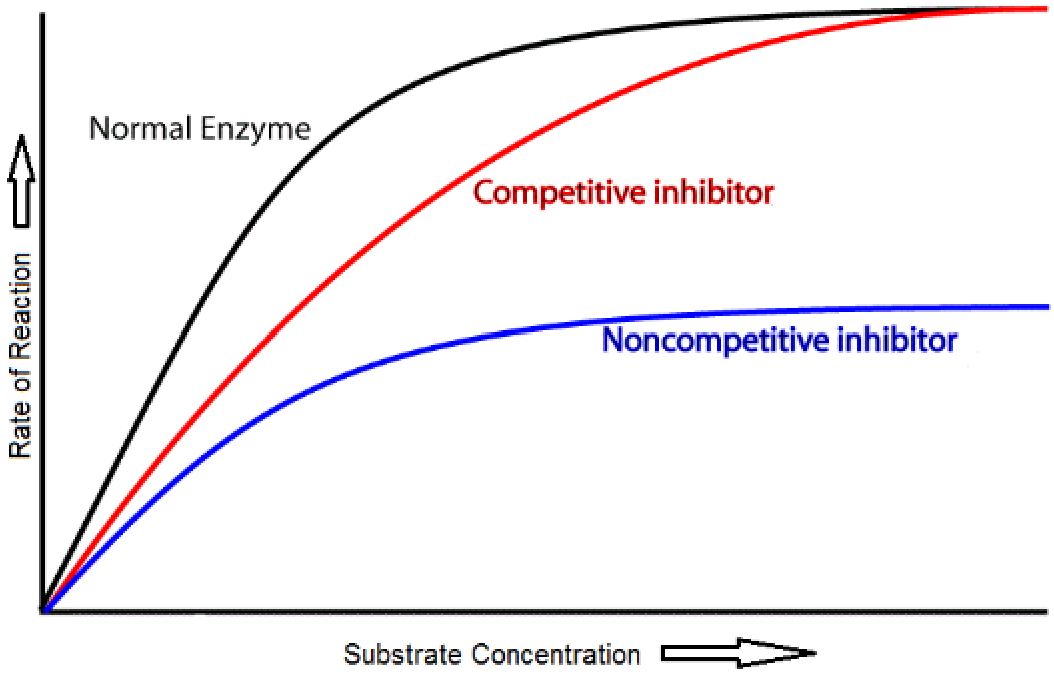
- Non-competitive inhibition occurs when an inhibitor does not compete for the active site with the substrate, but instead binds to a separate site on the enzyme.

- 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.

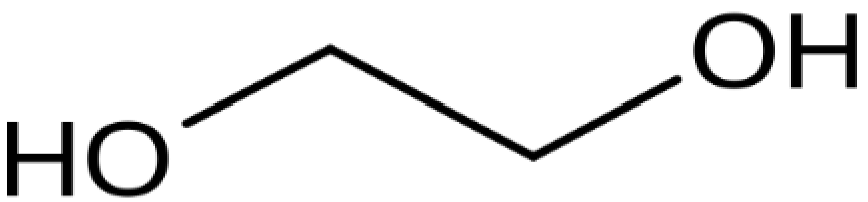


ß - Many enzyme inhibitors have been used in medicine.

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

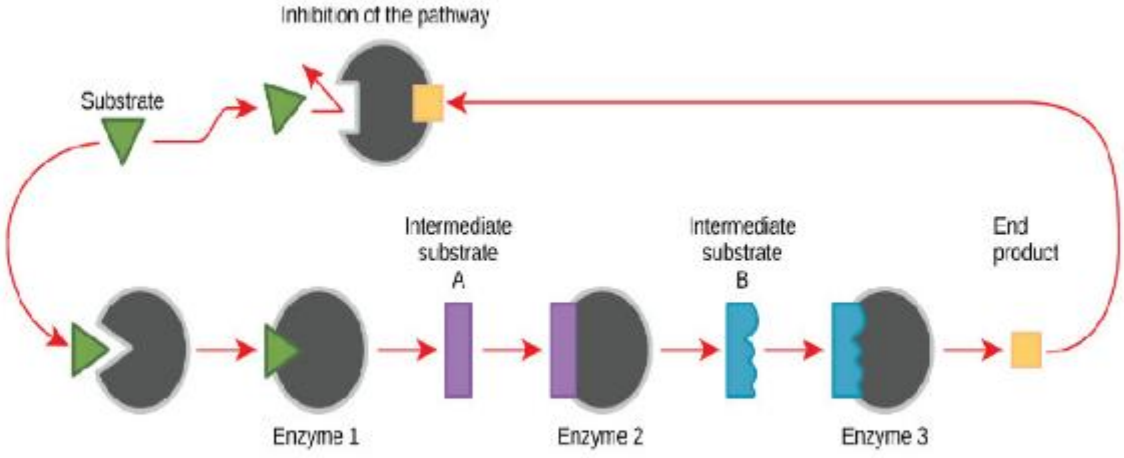
- Ethanol is used as treatment to block the enzyme responsible for metabolizing ethylene glycol into glycolic acid and oxalic acid (these two molecules are more toxic that the original molecule)
- Ethanol acts by competing with ethylene glycol for the active site of alcohol dehydrogenase, the first enzyme 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

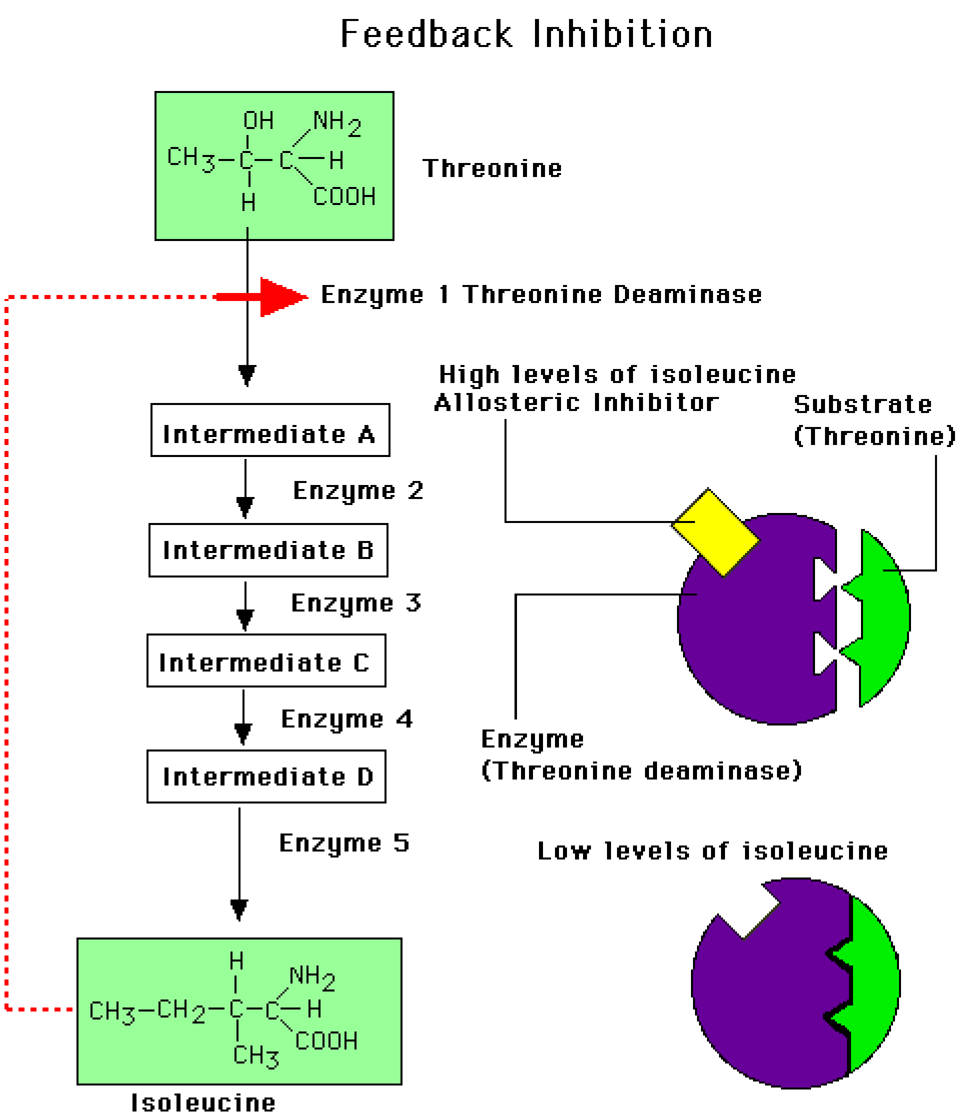
∑ - Metabolic pathways can be controlled by end-product inhibition.

- 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

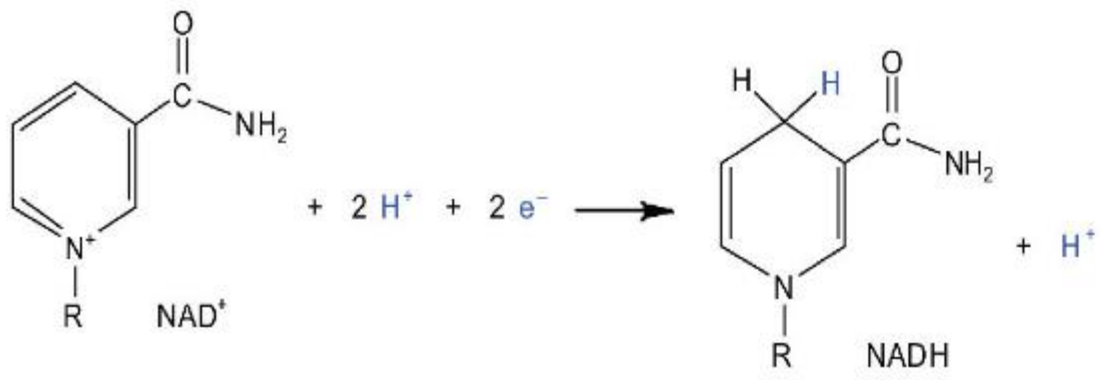
Nature of Science: Paradigm shift—the chemiosmotic theory led to a paradigm shift in the field of bioenergetics. (2.3)

∑ - 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)

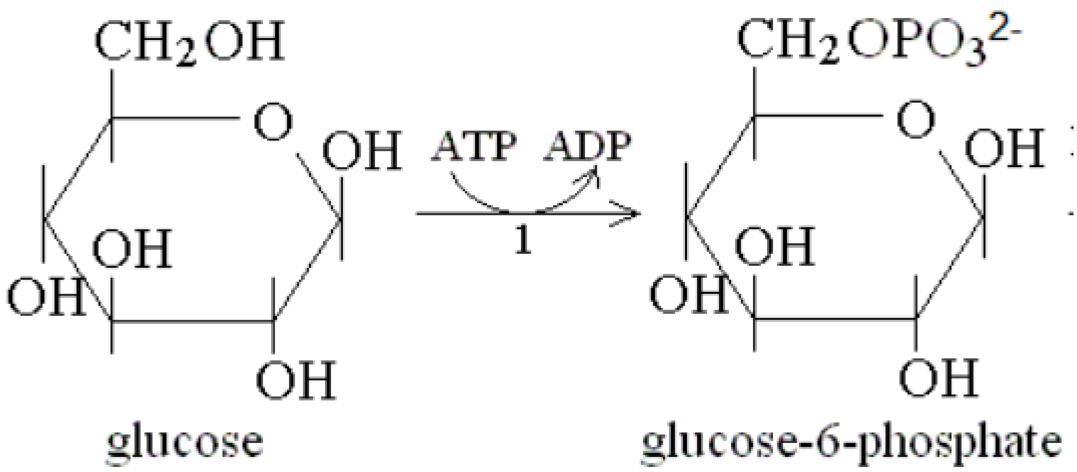
$$2\,H_2O \rightarrow O_2 + 4\,H^+ + 4\,e^- \qquad (\Delta E_0 = -1.23\ V)$$

- 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.

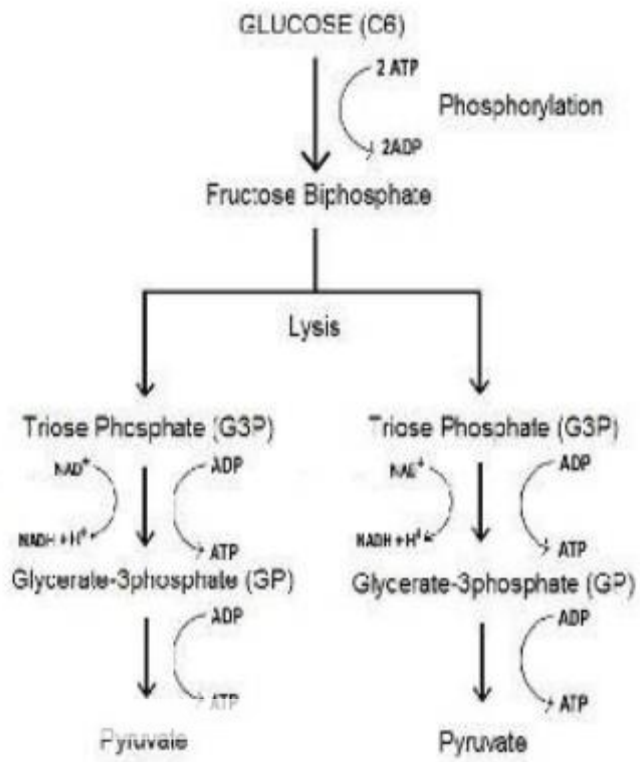
- Phosphorylation occurs when a phosphate (PO_4^{3-}) molecule is added to an organic molecule to make the molecule less stable and more likely to react
- Phosphorylation basically activates the molecule and is an endergonic reaction
- The removal of the phosphate through hydrolysis is an exergonic reaction
- 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

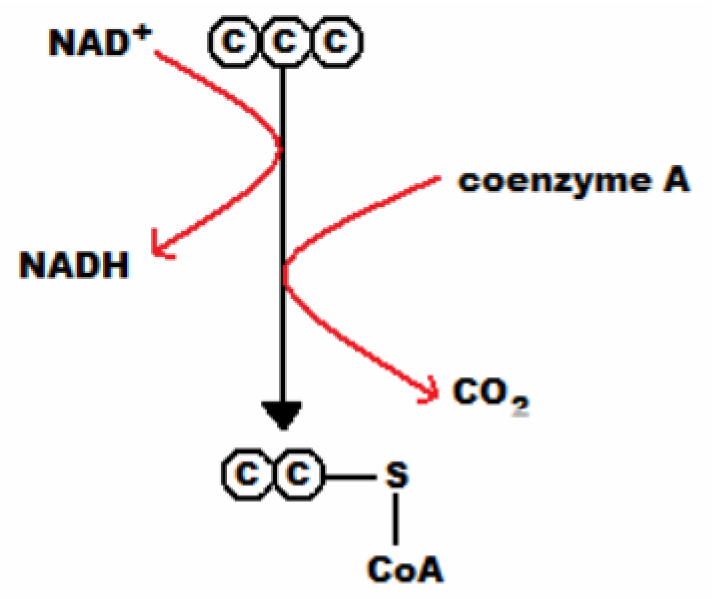
∑ - In aerobic cell respiration pyruvate is decarboxylated and oxidized, and converted into acetyl compound and attached to coenzyme A to form acetyl coenzyme A in the link reaction.

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.

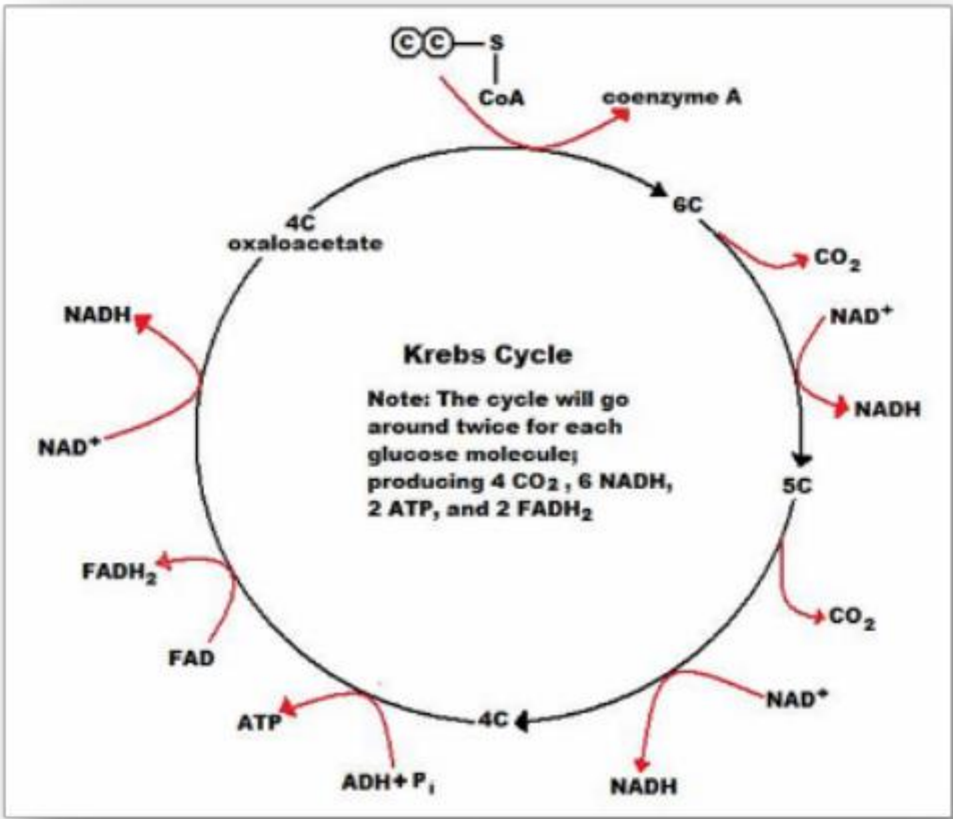
β - Skill: Analysis of diagrams of the pathways of aerobic respiration to deduce where decarboxylation and oxidation reactions occur

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

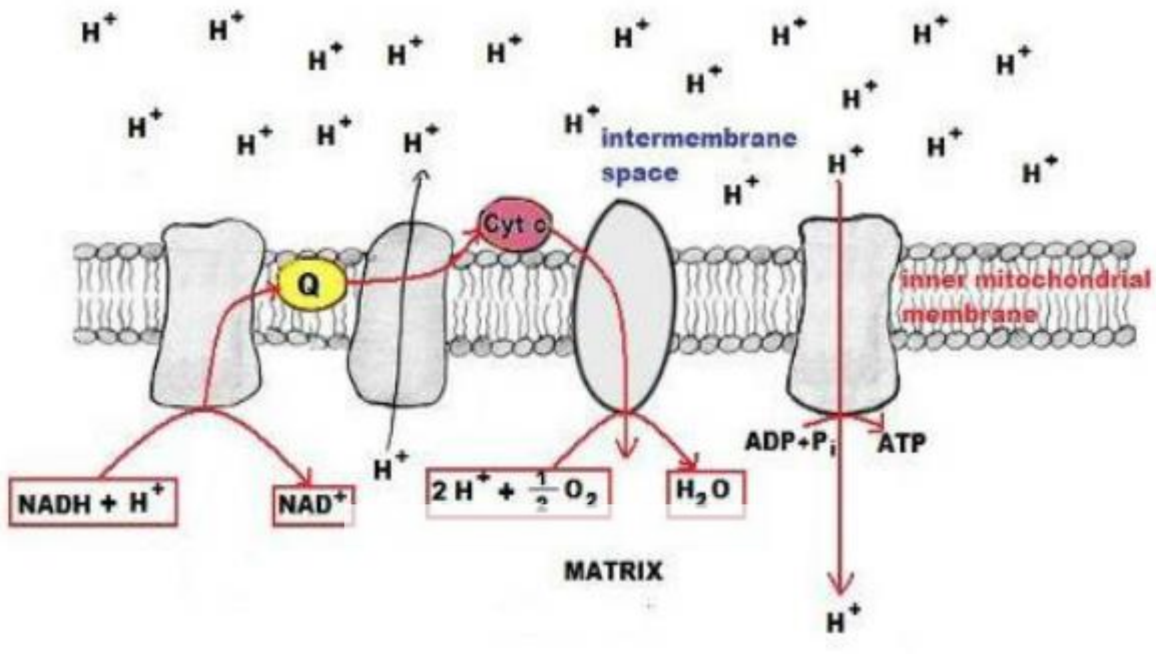
∑ - Transfer of electrons between carriers in the electron transport chain in the membrane of the cristae is coupled to proton pumping.

∑ - 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

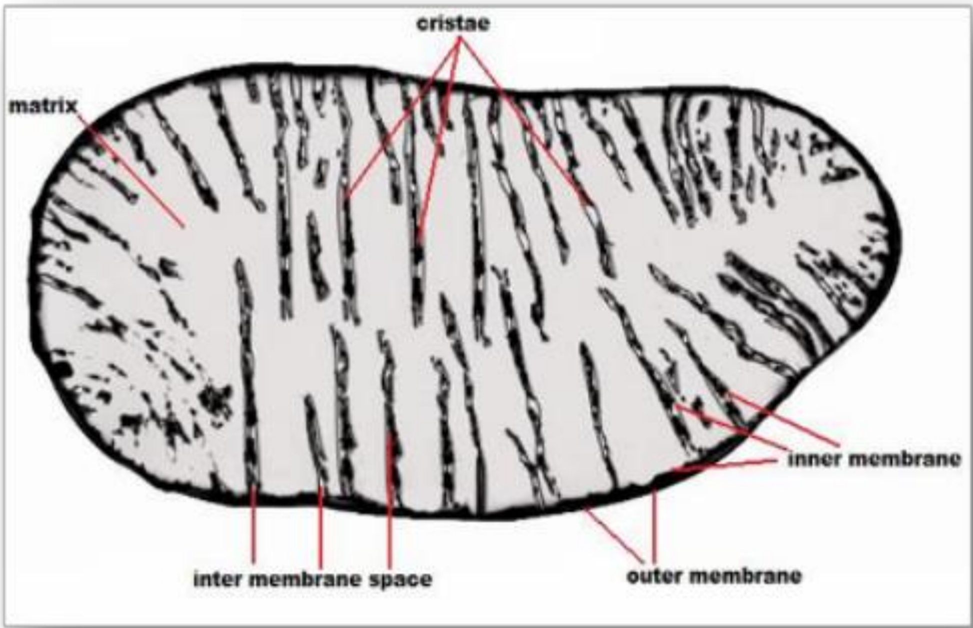
∑ - Oxygen is needed to bind with the free protons to maintain the hydrogen gradient, resulting in the formation of water.

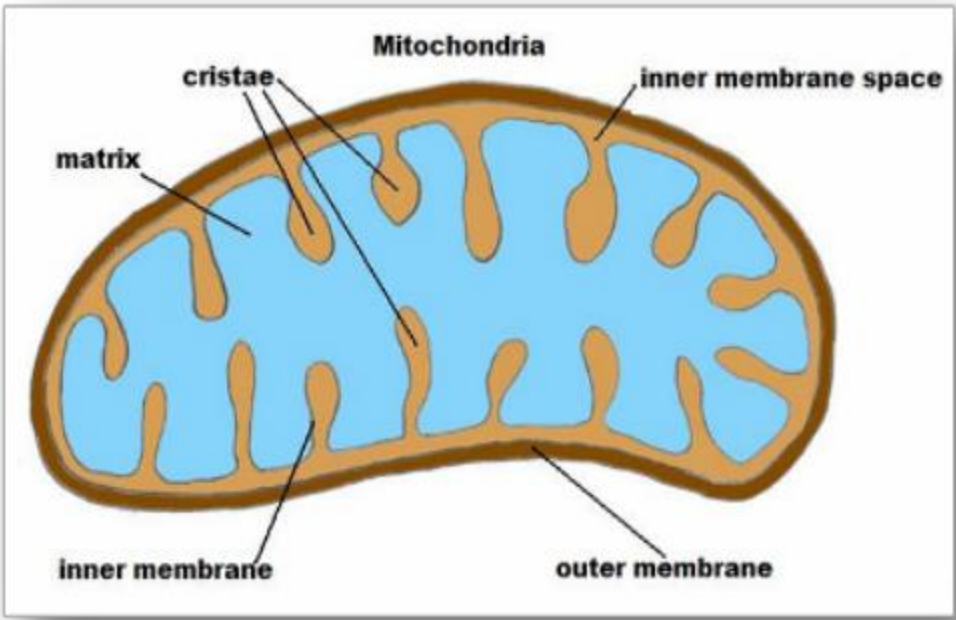
Role of Oxygen

- 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.

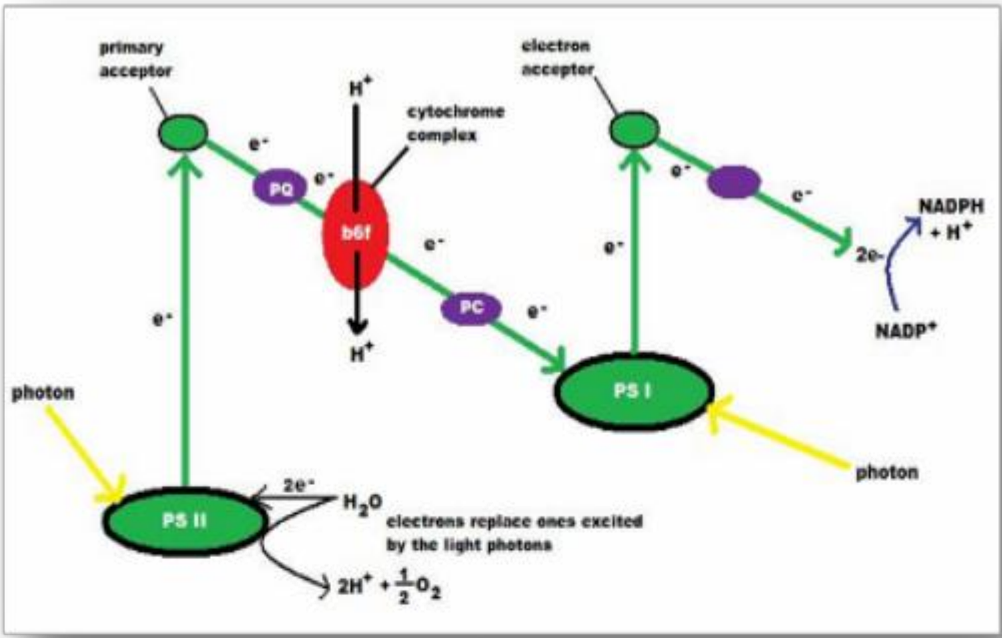
- The production of ATP from ADP and phosphate using energy derived from light is called **photophosphorylation.**
- Photophosphorylation occurs on the thylakoid membrane of the chloroplasts.
- As electrons pass along the electron transport chain between PS II and PS I, the electrons release energy that 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 ($NADP^+ + 2e^- + H^+ \rightarrow$ 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).

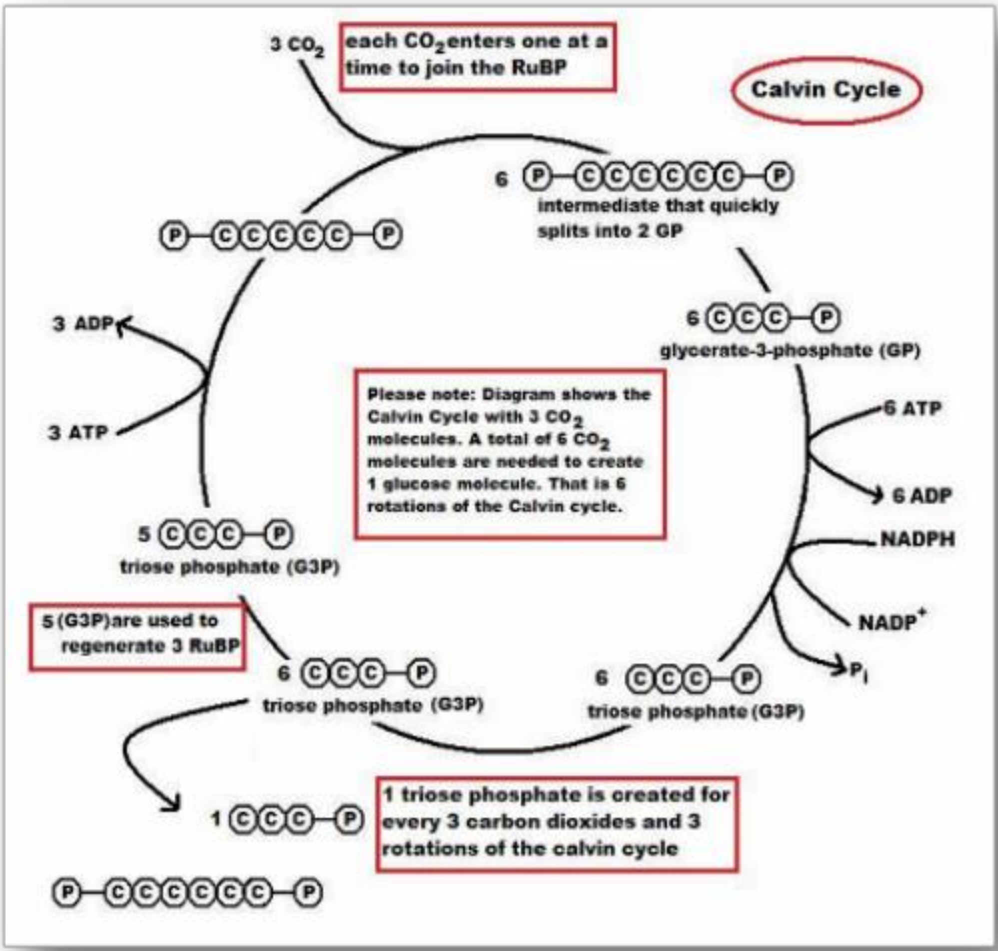
∑ - Triose phosphate is used to regenerate RuBP and produce carbohydrates.

∑ - 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*****

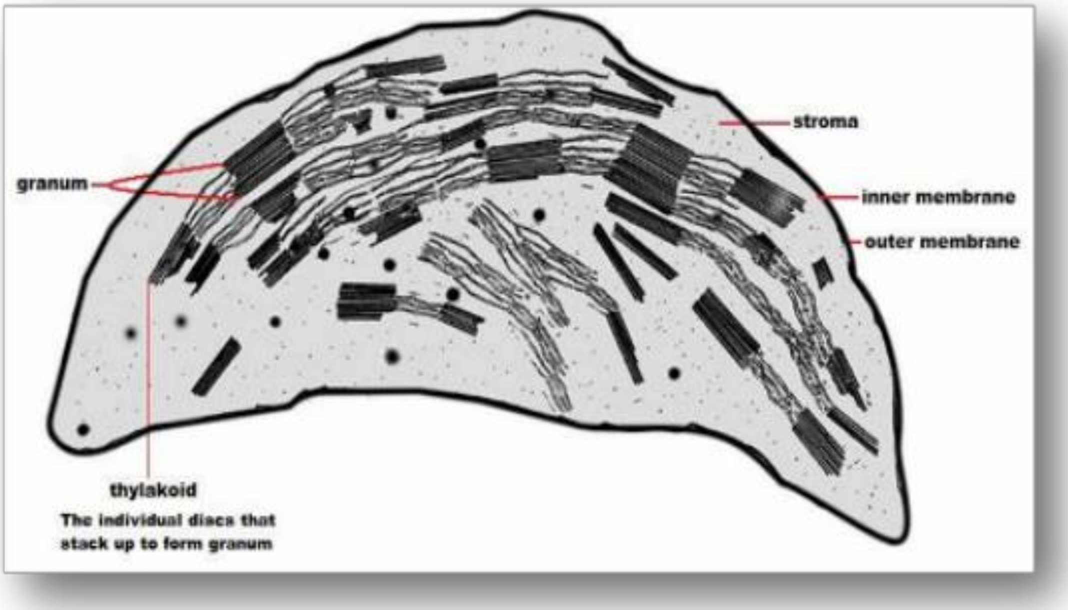
∑ - The structure of the chloroplast is adapted to its function in photosynthesis.

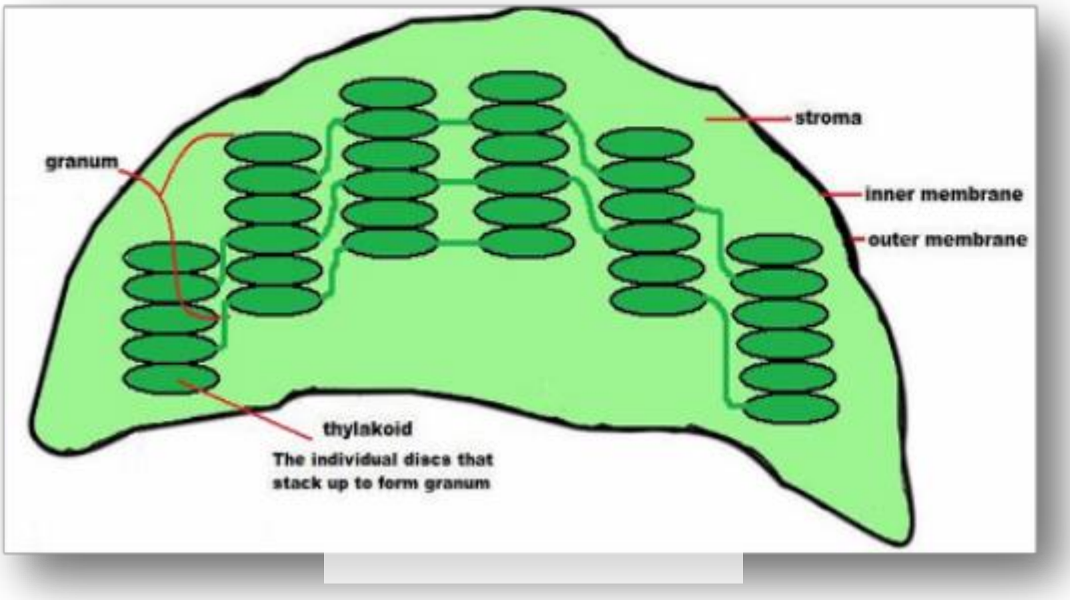
Structure	**Function**
Thylakoid membrane – large surface area from the extensive membrane	Increased SA allows for greater absorption of light by the photosystems in the membrane
Stroma – cytosol-like fluid filled region contains many enzymes	Allows for the concentration of enzymes necessary for the 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.

Topic 1 - Cells
Topic 2 - Molecular Biology
2.1 Molecules to metabolism
2.2 Water
2.3 Carbohydrates and lipids
2.4 Proteins
2.5 Enzymes
2.6 Structure of DNA and RNA
2.7 DNA replication, transcription and translation
2.8 Cell respiration
2.9 Photosynthesis
Topic 3 - Genetics
Topic 4 - Ecology
Topic 5 - Evolution & Biodiversity
Topic 6 - Human Health and Physiology
Topic 7 - Nucleic Acids
Topic 8 - Respiration and Photosynthesis (AHL)
Topic 9 - Plant Biology (AHL)
Topic 10 - Genetics and Evolution (AHL)
Topic 11 - Physiology (AHL)