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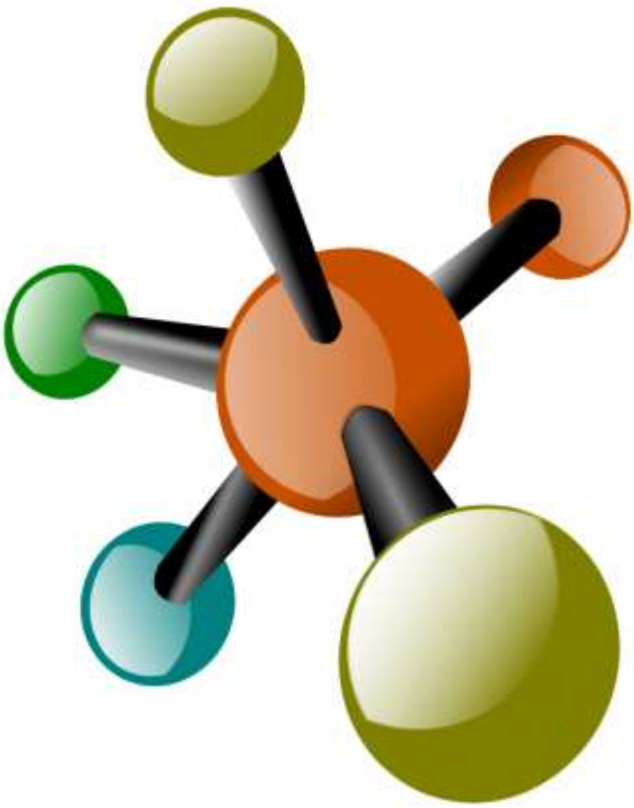
Friend, Philosopher, Guide

Molecular Biology



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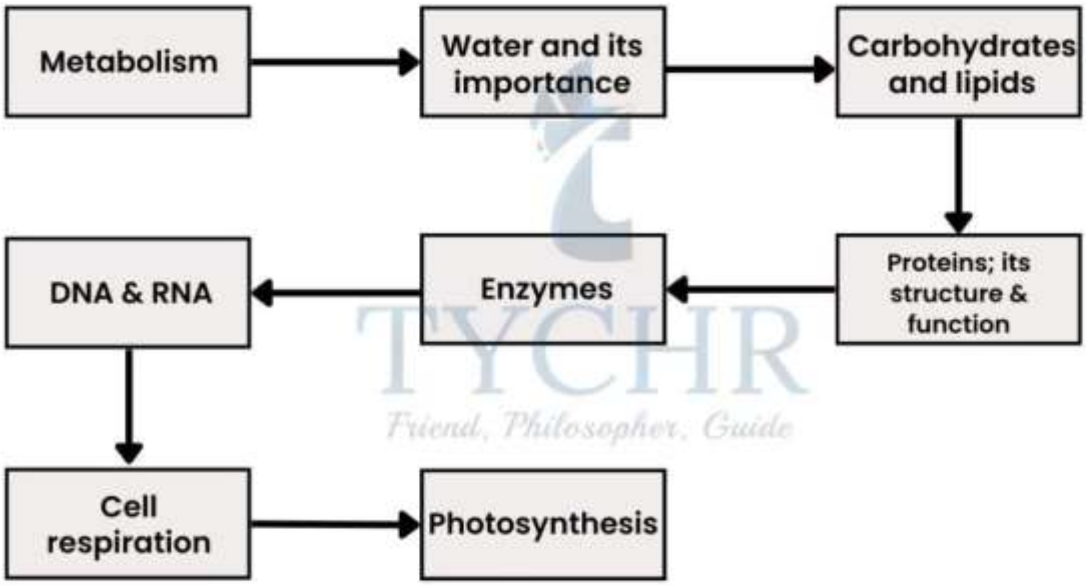
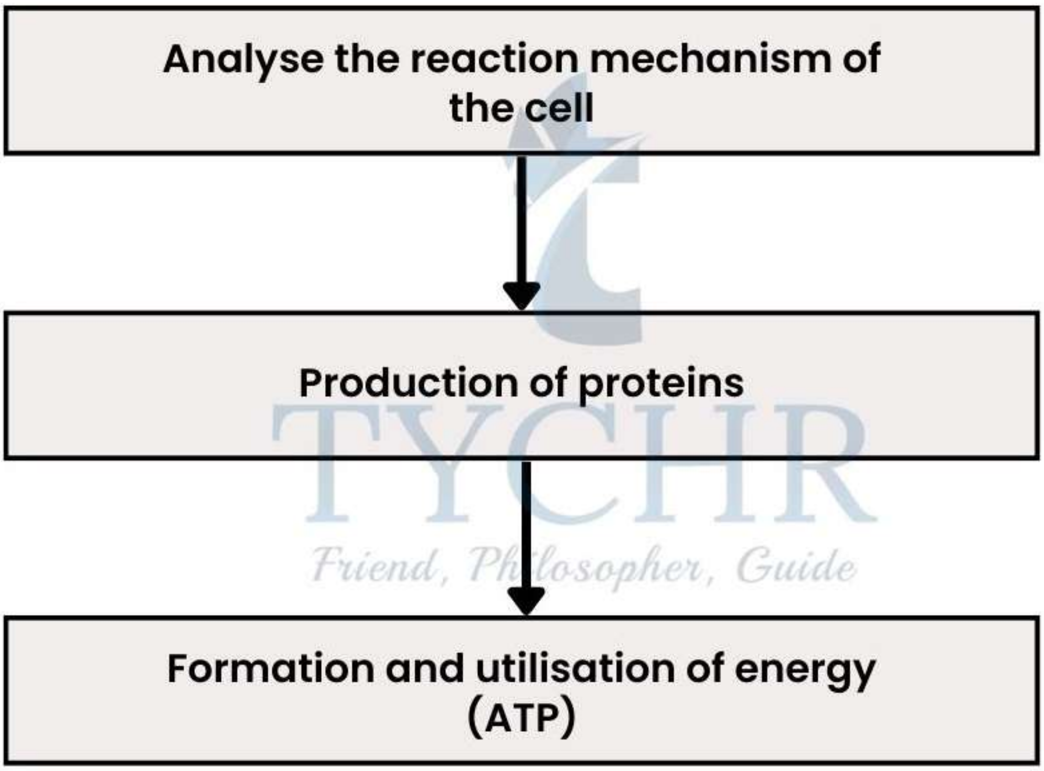
Molecular Biology

Approaching The Topic

- **Understanding the topic**



- **Application of these concepts**



Molecular Biology

- There are primarily four biochemical molecules; Carbohydrates, lipids, proteins and nucleic acids. These four molecules interact in many ways to carry out metabolism.
- Carbohydrates and lipids are involved in structural basis, and proteins and nucleic acids are required for the physiological functions inside the body.

Molecules	Sub-Components	Example
Carbohydrates	Monosaccharides	Glucose, galactose, fructose, ribose
	Disaccharides	Maltose, lactose, sucrose
	Polysaccharides	Starch, glycogen, cellulose, chitin
Lipids	Glycerol, fatty acids, phosphate groups	Fat stored in adipose tissue
Proteins	Amino acids	Enzymes, antibodies, peptide hormones
Nucleic acids	Nucleotides	DNA, RNA, ATP

- **Carbon is the keystone element** for life on Earth, because it forms the structural foundation of living organisms.

Metabolism: Inside a cell, in an aqueous medium many molecular collisions occur, these collisions provide energy for the reactants to undergo chemical reactions. These reactions result in the metabolism of the cell.

- Enzymes are used by the cells to increase the likelihood of successful collisions so as to lead a useful reaction.
- These enzyme-catalyzed reactions function in two ways; it converts large, complex molecules to smaller, simple molecular forms (**catabolism**) and it converts simple molecules into larger, more complex molecules (**anabolism**).
- Catabolism occurs through **hydrolysis reactions** like in;
  - Monosaccharides
    Ex- Lactose + water → glucose + galactose
  - Polysaccharides
    Ex- starch + water → glucose
  - Lipids
    Ex- triglyceride + 3 water→ glycerol + 3 fatty acids
  - Polypeptide
    Ex- Protein + water→ amino acids
- Anabolism occurs through condensation reactions like in; Amino acids protein + water

Water – "Solvent Of Life"

1.) Chemical Structure

It is a covalently bonded structure involving one Oxygen and two Hydrogen atoms. These are polar covalent bonds formed by unequal sharing of electrons, having positive and negative charges at the Oxygen and Hydrogen side respectively. These opposite charges make it to possess hydrogen bonding between water molecules.

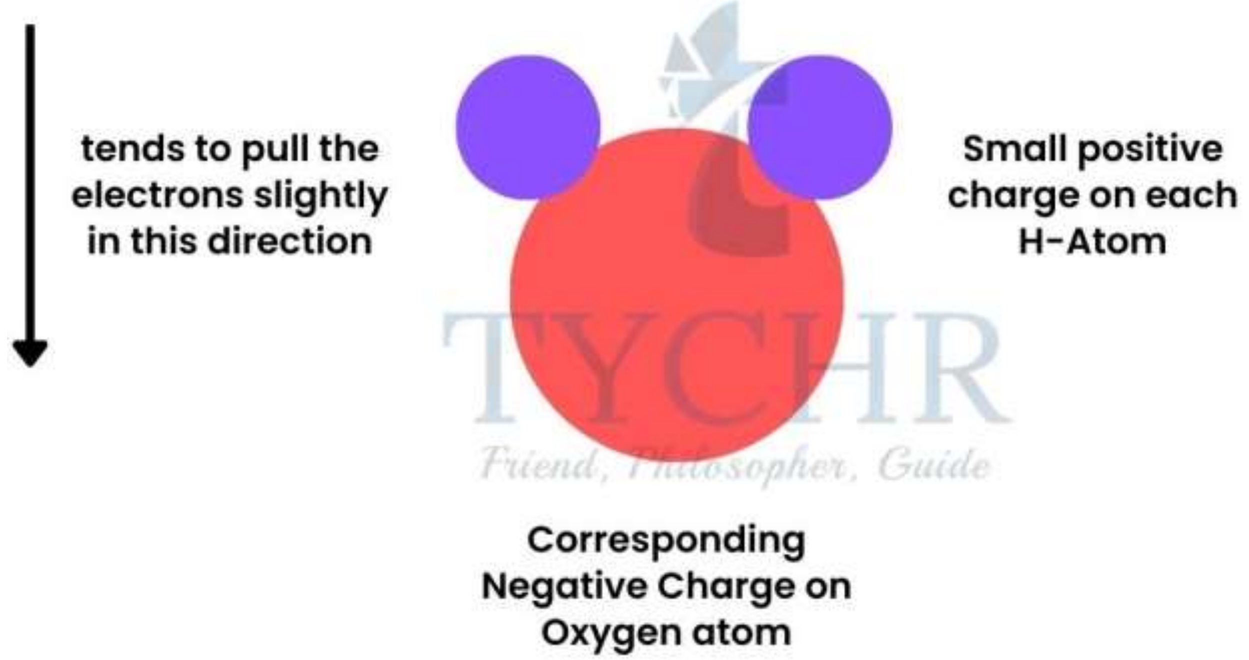
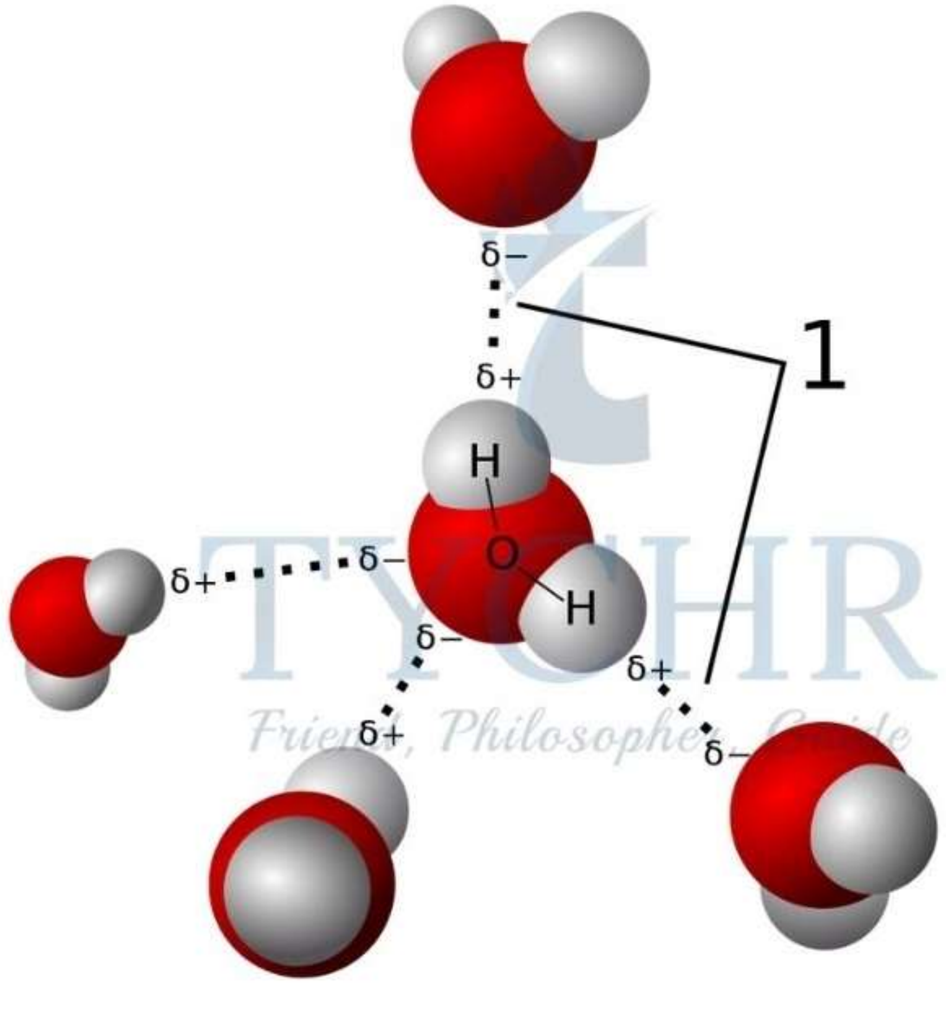
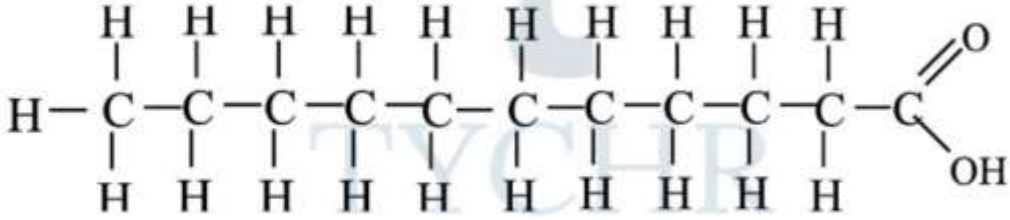


Fig. 2.1 Water molecule



2.) Water exhibits certain properties which are:

- Cohesive property
  When molecules of the same type attracted towards each other, is called cohesion. Water with its negative and positive charges forms ephemeral hydrogen bonds, possesses cohesion.
  This property of water is responsible for its surface tension.
- Adhesive property
  When unlike molecules attract each other, that is called adhesion. Water shows this property remarkably in leaves of the plants. Adherence of water with cellulose of cell walls helps to keep water intact and keep the cells moist.
- Thermal properties
  Water has high specific heat capacity i.e. it can absorb or give off great amount heat without changing its temperature much.
  And it also has high heat of vaporization which means it can absorb great amount of heat when it evaporates. This property makes the body cool when sweat evaporates off the skin.
- Solvent properties
  Water acts as an excellent solvent for biochemically important molecules like carbohydrates, proteins etc. Every living thing has water as an aqueous component, to put out the reactions.
  Example: Blood, is largely made up of water.
- It has a high boiling point.
- Water works on the principle "like dissolves like" and dissolves only polar solutes, being a polar molecule. These polar solutes are called **hydrophilic** (water-loving) and include alcohol, carbohydrates etc.
  Hydrophobic (water-fearing) solutes like methane (CH4) do not dissolve in the water because they are non-polar.



Structure of saturated fatty acidIn the molecular structure of saturated fatty acid, there is a carboxyl group at one end a long chain of carbon with hydrogens attached to it. Carboxyl group have some polarity due to presence of Oxygen atom but the rest of the molecule has chain of non-polar C-C bonds with hydrogen, which makes the overall polarity of the molecule very less. Therefore fatty acids are considered as non-polar.

Are protein molecules polar?

Polarity of proteins depends upon the arrangement of amino acids. Some molecules are polar and some are non-polar.

Ex- In a cell, membrane peripheral proteins are hydrophilic and integral proteins are hydrophobic.

3.) Blood transports various substances throughout the body and it all depends upon the polarity of the solutes or solubility in water. Certain molecules with their solubility and mode of transport are described in table:

Substance	Solubility In Water	Mode Of Transport
Sodium chloride	High solubility	Ionizes in blood plasma into Na^+ and Cl^-
Amino acids	Varying solubility, dependent upon the arrangement	Aqueous blood plasma
Glucose	High solubility	Aqueous blood plasma
Oxygen	Low solubility (travels as O_2 molecule)	Binds to haemoglobin which further carries it
Fats	Very low solubility	Blood proteins
Cholesterol	Very low solubility	Blood proteins

Carbohydrates And Lipids

Carbohydrates- Its Formation And Properties

Formation

- An anabolic process.
- Carbohydrate is a form of sugar. Monosaccharides (single sugar units) combined by condensation reactions to form disaccharides and polysaccharides.
- Disaccharides are molecules, containing two monosaccharides like in sucrose (glucose + fructose) and maltose (glucose + glucose) and polysaccharides are the molecules containing many monosaccharides like starch, glycogen and cellulose.

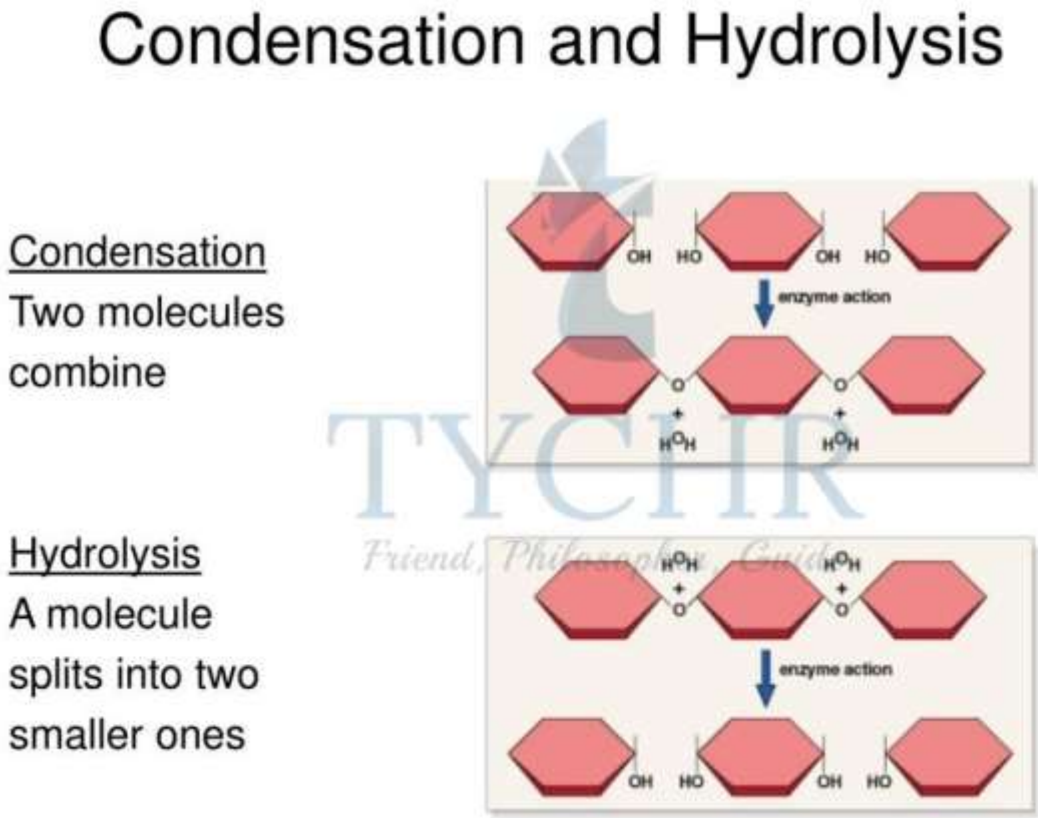


Fig. 2.2 Condensation and hydrolysis reactions between monosaccharides and disaccharides

- Properties
    - Three types of monosaccharides are found containing 3 carbons (trioses), 5 carbons (pentose) and 6 carbons (hexoses).
    - Formula is $C_nH_{2n}O_n$, where n is number of carbon atoms.

- Polysaccharides formed due to condensation have certain functions to perform.
  Some are mentioned in the table:

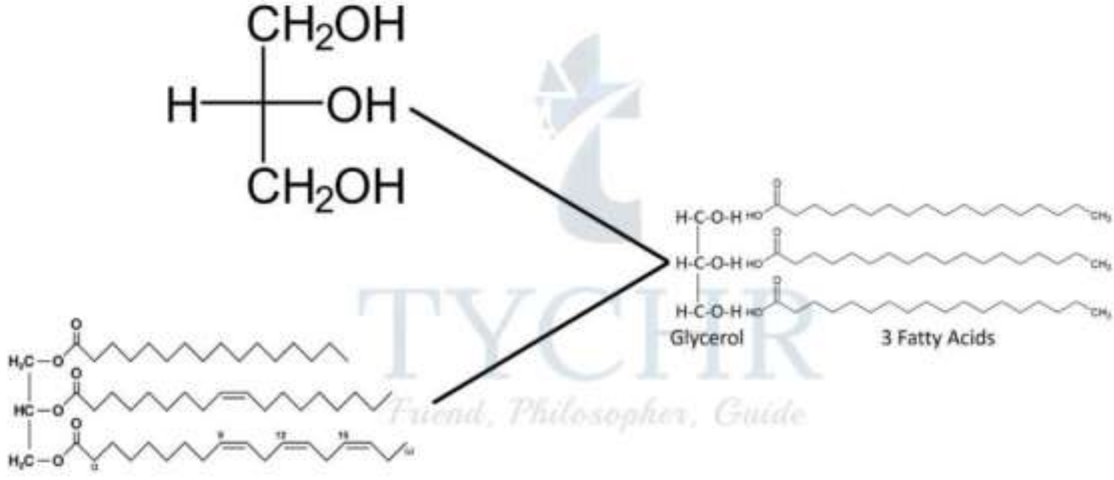
Polysaccharide	Functions
Cellulose	Major component of cell wall in plant cells, give rigidity to plant parts such as roots, stem and leaves.
Starch	Organic storage product in plants, specifically in chloroplast in the form of granules.
Glycogen	Storage product in liver and muscle of animals.

Lipids

Fatty acids

- When a hydrocarbon long chain has carboxyl group at one end and methyl group at the other, it is called saturated fatty acids.
- If one double bond exists in the chain of hydrocarbons, the fatty acid is then called monounsaturated fatty acids.
- When two or more double bonds are present, then it is called **polyunsaturated fatty acids**. Ex- olive oil
- Polyunsaturated fatty acids can be saturated by hydrogenation
- Hydrogenated fatty acids are called trans fatty acids and they are called cis fatty acids while naturally curved (original).

- 3 Fatty acids + glycerol lipids

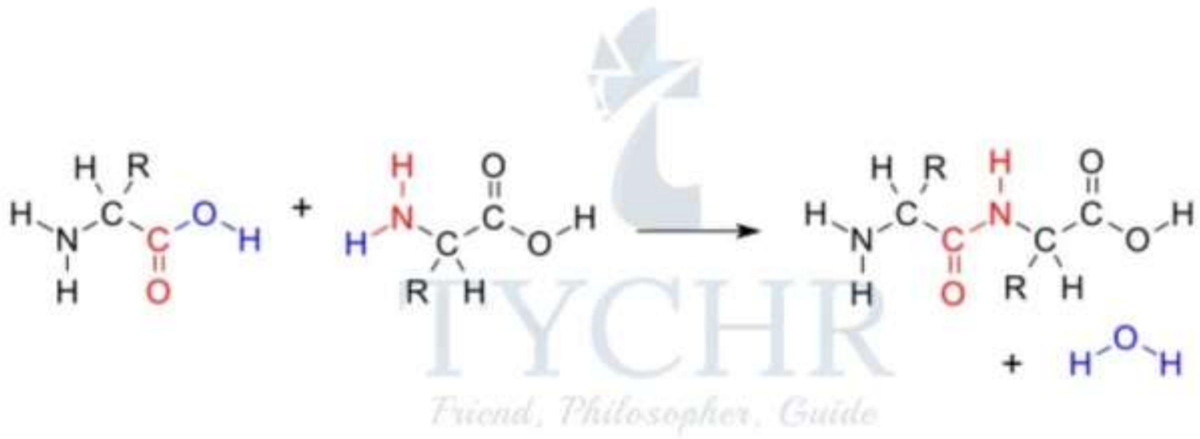


3 Fatty acids + glycerol → lipids

- Lipids get hydrolysed into two carbon segments which ultimately fulfil the energy requirements by the production of ATP through cellular respiration.
- They are insoluble in water, therefore can be stored in large amounts.
- If the energy is stored in terms of lipids, then it is twice as that of carbohydrate stored energy.
- Lipids are poor conductors of electricity and fats are liquid at body temperature. This makes the advantage for some organs inside the body, as this can be shock absorbent to them like the kidney.
- They are stored as fats in adipose tissue and used as long-term storage for use in the time of need. This is the last reservoir to be exploited in the body if we starve for a long time.

Proteins

Formation Of Polypeptides

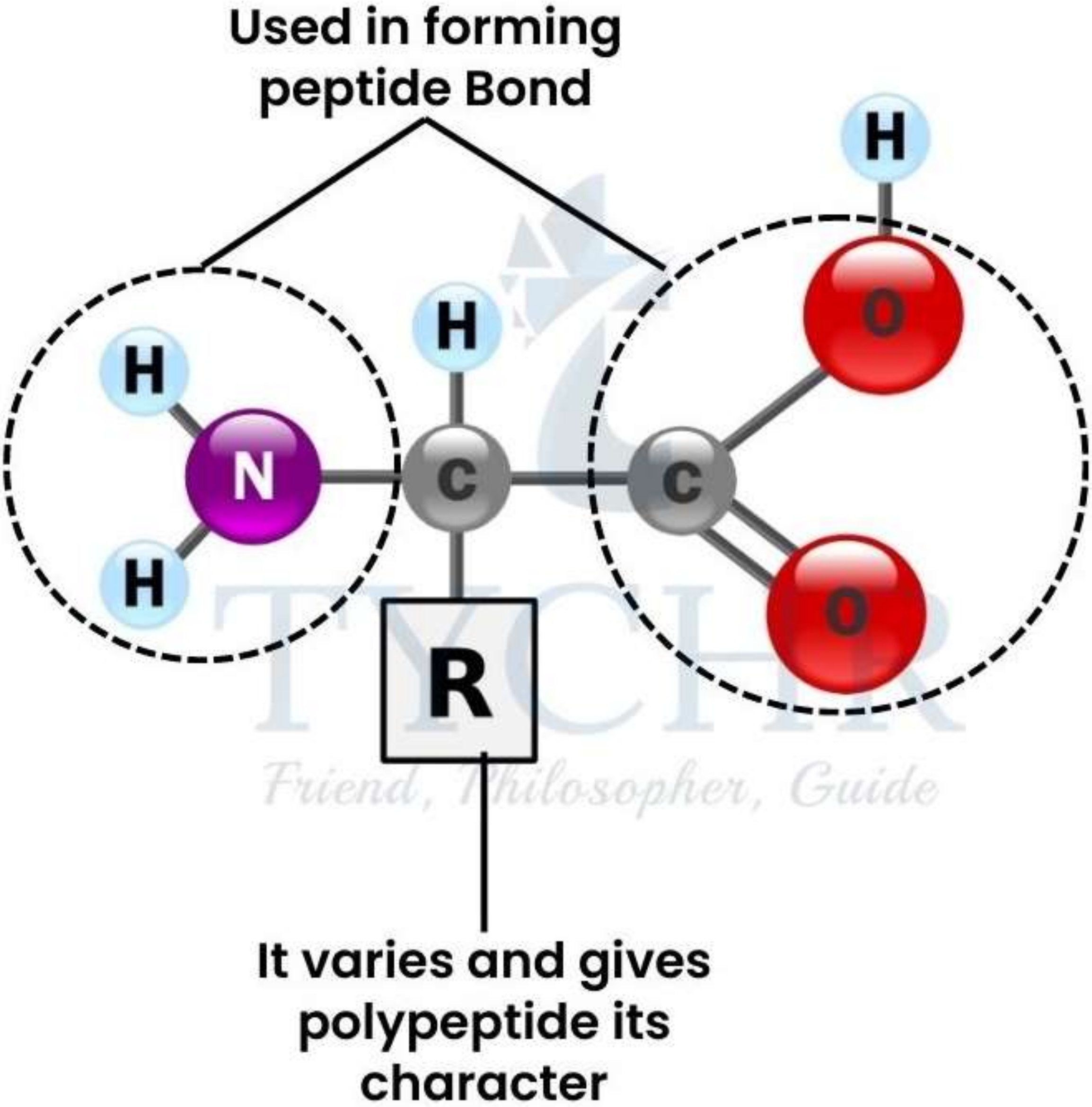


Condensation of two amino acids into a dipeptide with a peptide bond

- Amino acids are linked together by condensation to form polypeptides, by the process called translation. Condensation of two amino acids into a dipeptide with a peptide bond
- Each polypeptide has its own amino acid sequence and 3-D shape, which forms its function.

Amino acids

There are 20 different types of amino acids out of which 16 are polar and 4 are non-polar. The general structure of amino acid is:

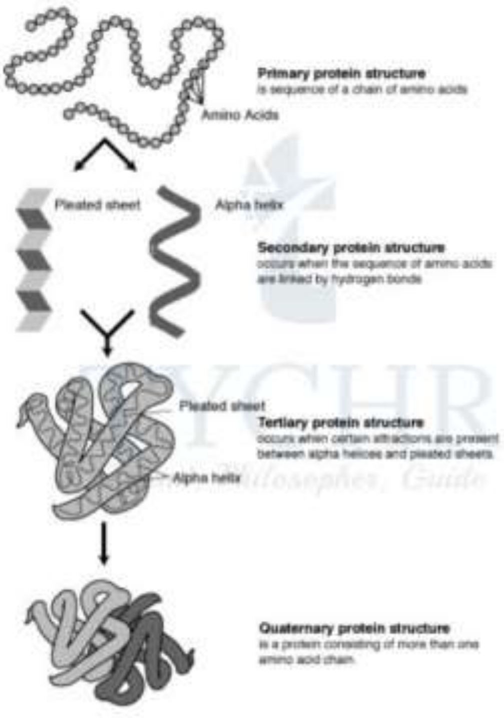


- Ribosomes link these amino acids together and form polypeptide which can be of huge numbers.
- Number of polypeptide sequences depends on the number of amino acids taken.
  These sequences can be calculated by the formula 20n, where 'n' is number of amino acids.
- Formations of polypeptides occur under the control of gene. There are 20,000 to 25,000 genes in the normal human cell.

- These polypeptides further combine and condensed in proteins.

Levels of polypeptide and types of protein structure

- Two or more polypeptides bond together to perform a particular function, together they are considered as protein.
- All the organisms are found to be genetically different due to specific DNA sequences called genomes and so their proteome.
- Structure of proteins goes from the simple primary to the globular quaternary. It possesses a three-dimensional shape (specific shape for the particular function).



- Examples of some common proteins:

Proteins	Functions
Insulin	Release by pancreas and is involved in for decrease and increase in blood sugar level.
Collagen (3 polypeptides)	Component of connective tissue like skin, ligaments, tendons etc.
Spider silk	Spun by spiders for making webs, drop lines nest building and other uses.

Immunoglobulin	It recognises an antigen as a part of immune response.
Rubisco	It catalyses the carbon-fixing reactions in photosynthesis
Rhodopsin	A pigment found in the retina of the eye, used in/for low light conditions.
Haemoglobin	Found in red blood cells, binds with oxygen and transports it to various tissue and organs of the body.
Lysozyme	This is an enzyme, present in tears and nasal mucus and helps in killing bacteria by digesting their cell walls
Integrin	Membrane protein used to make connections between structures inside and outside of the cell

Enzymes

What are enzymes?

- Enzymes are solely proteins that acts as catalysts in the metabolic reactions occur inside the cells.
- They have globular shape and may be secondary or tertiary in structure.
- They have an active site on which substrate binds. The working of this active site is regarded as like of "lock and key", because substrate fits in the active site of the enzyme like the key fits in the lock. Substrates and their active sites are specific for each other.
- They lower the activation energy of the reactions, due to which reactions are more likely to occur in the present of the enzymes.

Factors affecting enzymatic reactions

- **Temperature**

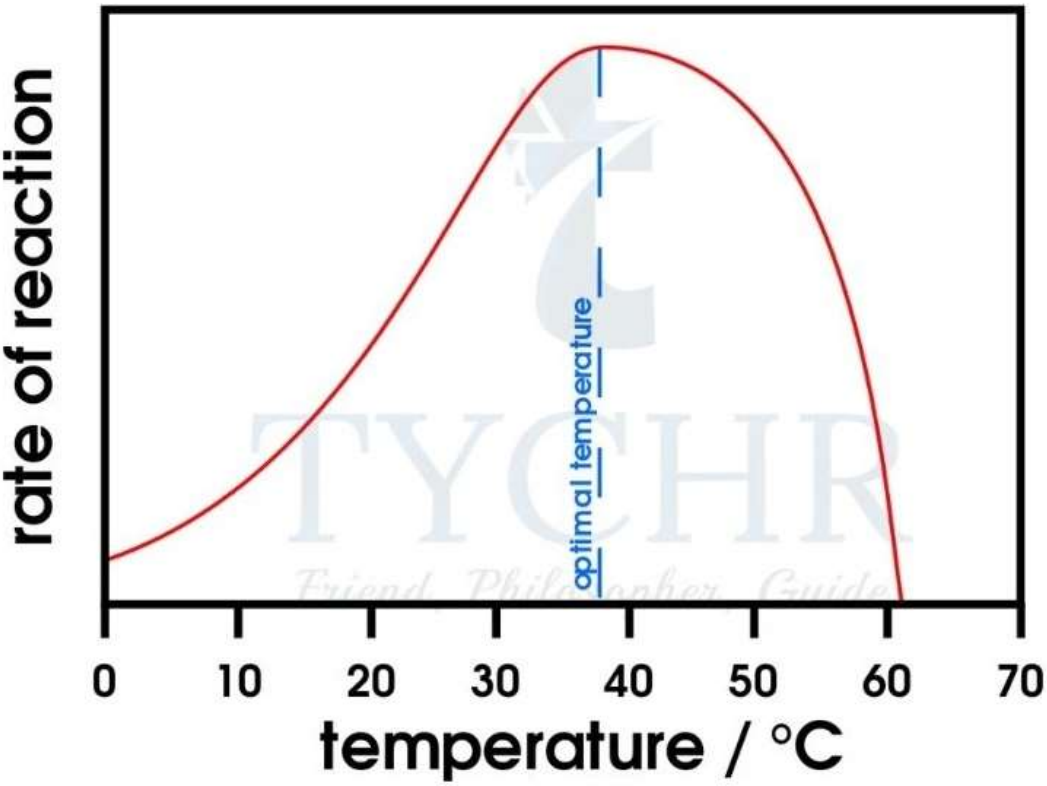


Figure 2.3 Graph showing effect of temperature on the enzymatic activity

- As the temperature rises, the molecular movement increases which results in more collisions with greater energy. So, the enzymatic reaction rate will also increase.
- There is an upper limit of the temperature, after which enzyme starts to denature i.e. it starts losing its shape and denatured enzyme can't perform its activity.

- **pH**

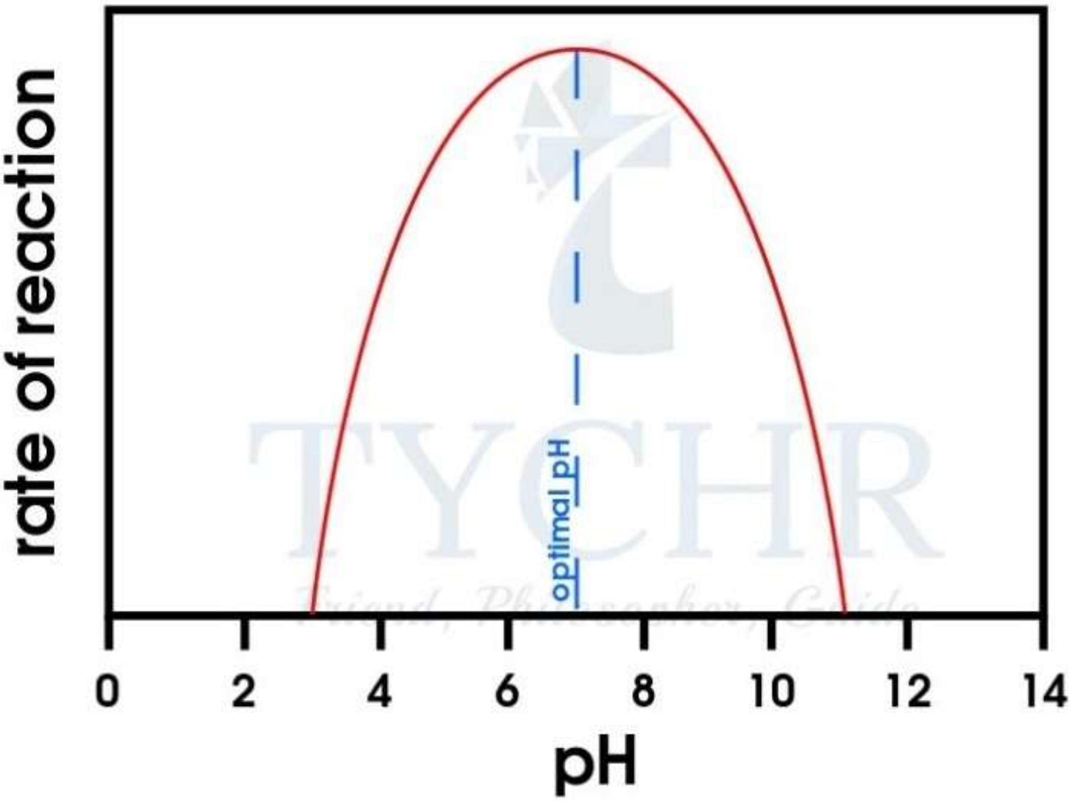
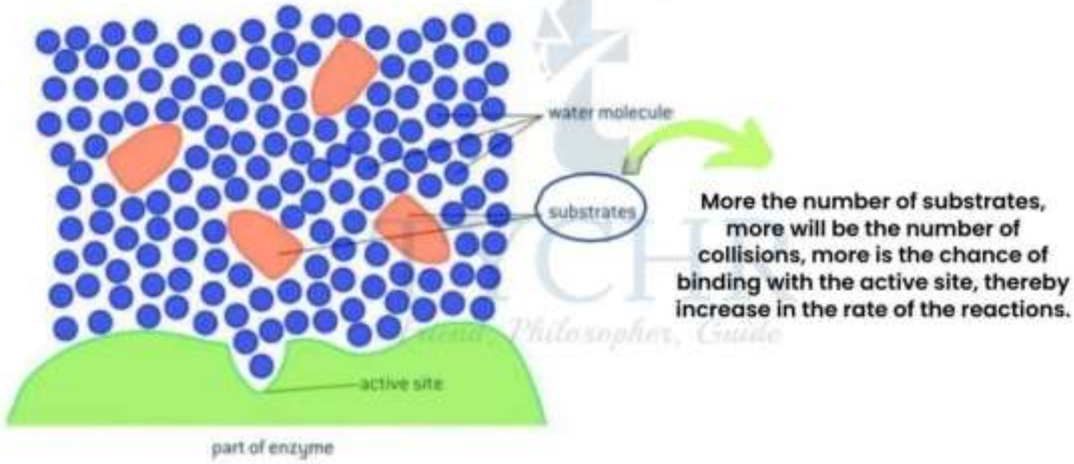


Fig. 2.4 Graph showing effect of pH on the enzymatic activity

- Amino acids present in the active sites of the enzyme have positive or negative charges at their ends, which may bond with the H+ ions of acidic solution or OH- ions of alkaline solution.
- Similar bonding can happen with the charged amino acid ends of the substrates.
- Therefore, the enzyme will lose its shape and may denature. So, much higher or much lower pH will thereby inhibit its activity.
- There is not one pH at which all the enzymes work, but it may vary with some like pepsin in the stomach. Pepsin is most active in the acidic pH. Also protease enzyme works efficiently in alkaline pH of 9 or 10.

- **Substrate concentration**



Substrate concentration

Enzymes in the industry

- **Immobilized enzyme**: These enzymes are trapped in tiny pores on beads of **calcium alginate**. So, as long as the beads can be recovered the enzymes can be reused as well.
- These immobilized enzymes are reused repeatedly in the industries because the extracting of pure enzymes is expensive.
- Advantages of using immobilized enzymes:
    - A pure form of enzyme is available to use rather than the mixture like in cells.
    - Immobilization increases the stability of the enzymes in the changing temperature and pH.
    - These enzymes can take up more substrate concentration and therefore the rate of the reaction increases.
- Immobilized enzymes are used for the production of lactose-free milk. Lactose is the natural sugar present in the milk which is broken down to its sub units (glucose + galactose) by the enzyme lactase.
- These enzymes are produced from Kluveromyces lactis (yeast present in the milk). Some individuals by the older age, lost their ability to produce lactase and therefore cannot digest lactose in the milk (lactose intolerant). Milk is pre-digested by the immobilized lactase (trapped in the alginate beads) and becomes lactose-free which can be fed to lactose intolerants.

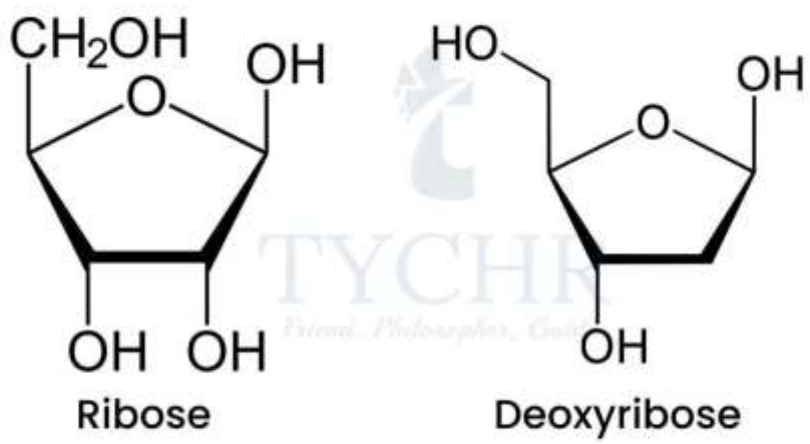
DNA And RNA

Structure

- Three types of nucleic acids are found in nature namely; adenosine triphosphate (ATP), deoxyribonucleic acid (DNA) and ribonucleic acid (RNA).
- Nucleotides are the fundamental units of the nucleic acids which contain a phosphate group, pentose sugar (5-C monosaccharide sugar) and a nitrogenous base.
- There are four nitrogenous bases in either of RNA and DNA

RNA Nitrogenous Bases	DNA Nitrogenous Bases
Adenine	Adenine
Guanine	Guanine
Cytosine	Cytosine
Uracil	Thymine

- Uracil occurs in RNA only while thymine occurs in DNA.
- DNA contains deoxyribose pentose sugar while RNA contains Ribose pentose sugar.



- Ribose (Left) And Deoxyribose(Right)
- These monomer nucleotides linked with each other to form a polymer strand of RNA. Two of these strand combined together to form a double helix DNA strand.

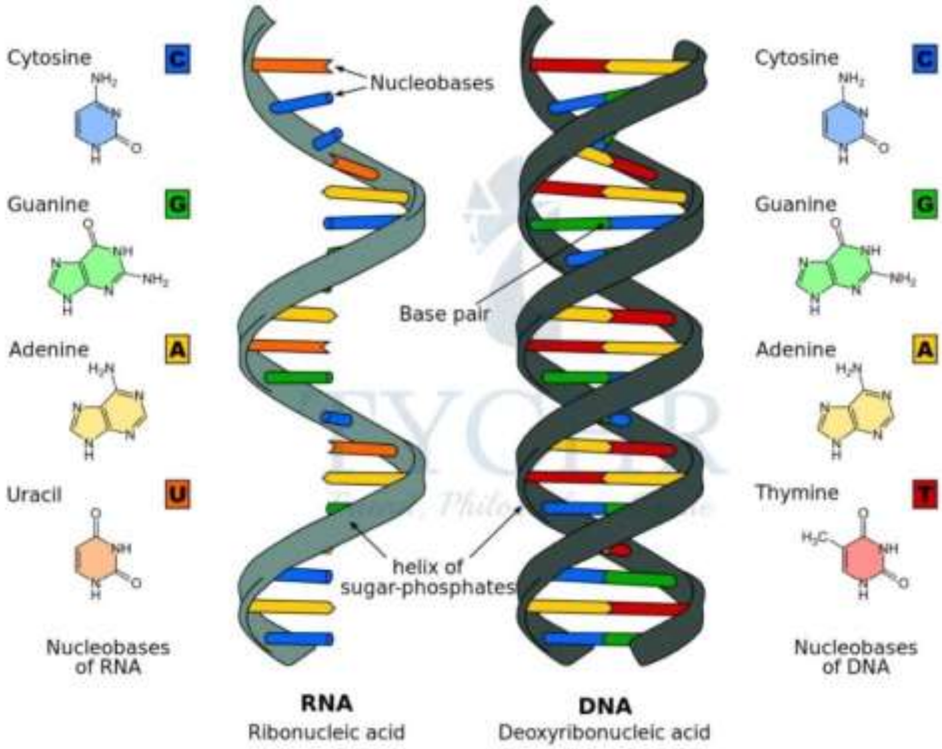


Figure 2.6 RNA structure and Double stranded DNA structure

- In a double helix, there is always complementary base pairing i.e. Adenine (A) is paired with thymine (T) and Guanine (G) is paired with Cytosine (C).
- DNA double helix structure was proposed by Watson and Crick in early 1950s.
- The two strands are anti-parallel to each other. One is going in the direction 5’ 3’ and the other is going in 3’ 5’ direction.
- There are roughly 10 billion bp in each turn and distance between consecutive bp is 0.34 nm.

DNA Replication, Transcription And Translation

DNA Replication

- This process occurs during the cell division in which the DNA content is doubled.
- This is also an enzyme catalysed process involving helicase and DNA polymerase.
- Two complementary strands produced take up the free floating nucleotide in the nucleoplasm and again form the double stranded DNA.
- DNA polymerase enzymes catalyse the new bond formation between the nucleotides and the complementary strand.
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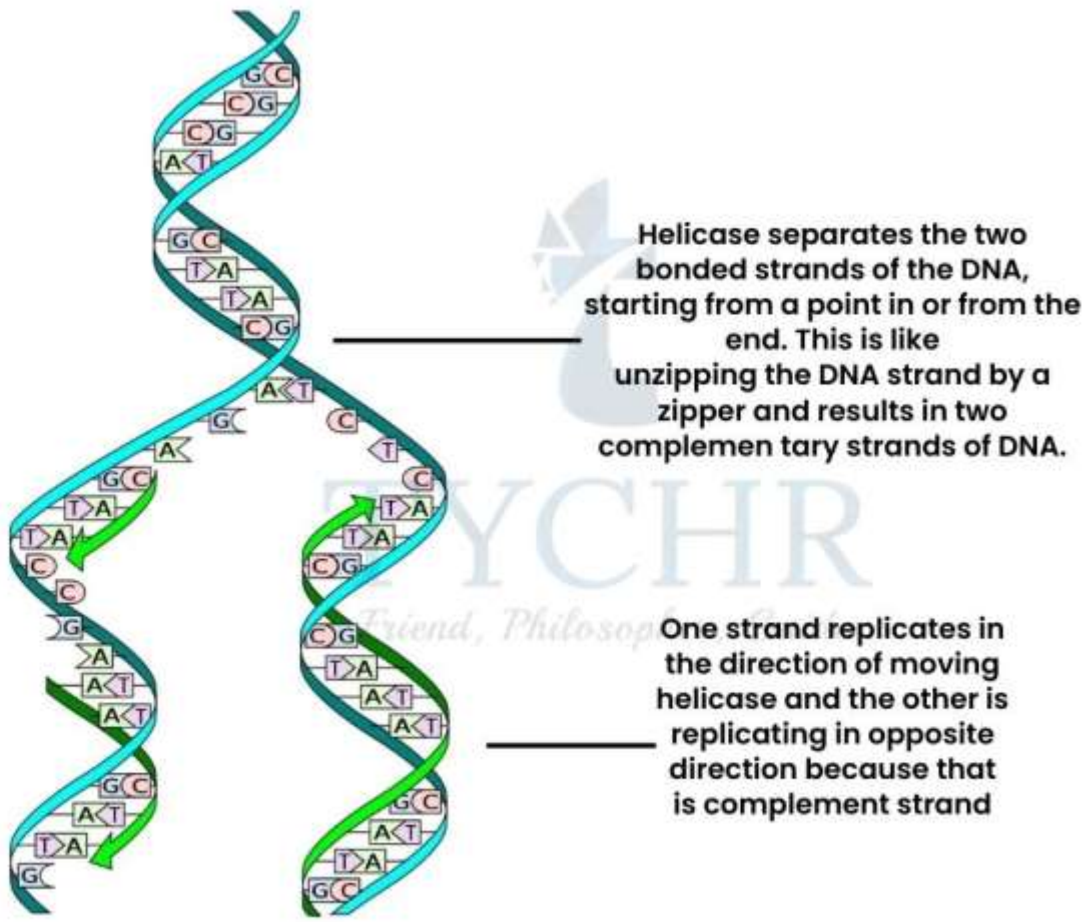
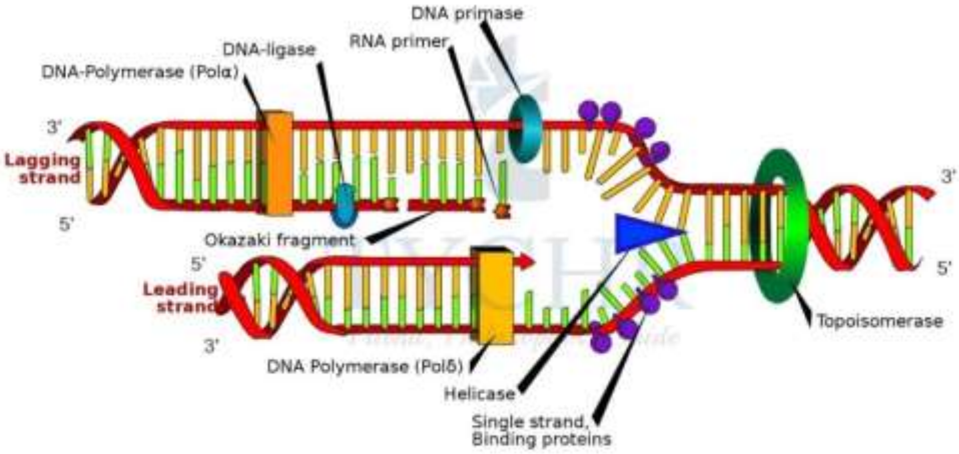


- It is a semi-conservative process because half of the newly synthesised DNA is still old. Meselson and Stahl's experiment proves the semiconservative nature of DNA.

Transcription

- One of the two major sets of reactions leading to protein synthesis, other is **translation**.
- Genes are present on the DNA inside the nucleus and the protein synthesis occurs outside the nucleus in the cytoplasm. Therefore, the **mRNA (messenger RNA)** acts as the intermediary molecule to transfer the information for protein synthesis from nucleoplasm to cytoplasm.
- Process follows:
    - Unzipping or separating of the double stranded DNA, at the location of the specific gene using RNA polymerase for the whole process.
    - RNA polymerase moves along one of the unzipped DNA templates, RNA nucleotides present in the nucleoplasm binds to the template strand of the DNA.
    - Uracil is now paired with adenine instead of thymine.
    - Single, shorter (than DNA) mRNA strand is formed.



Transcription

- The strand which has the same base sequence as that of mRNA (while having uracil in the place of thymine) is called sense strand. And the other template which is having complementary base sequence is called antisense DNA strand.
- The mRNA detaches from the template DNA and floats in the nucleoplasm which gradually passes through the nuclear pores into the cytoplasm.
- This mRNA has all the information of polypeptides synthesis in the form of codon triplets (set of three bases).

Translation

- Process of synthesis of polypeptide with the help of cell organelle, ribosome.
- Three types of RNA are used in this process namely; mRNa, rRNA, tRNA

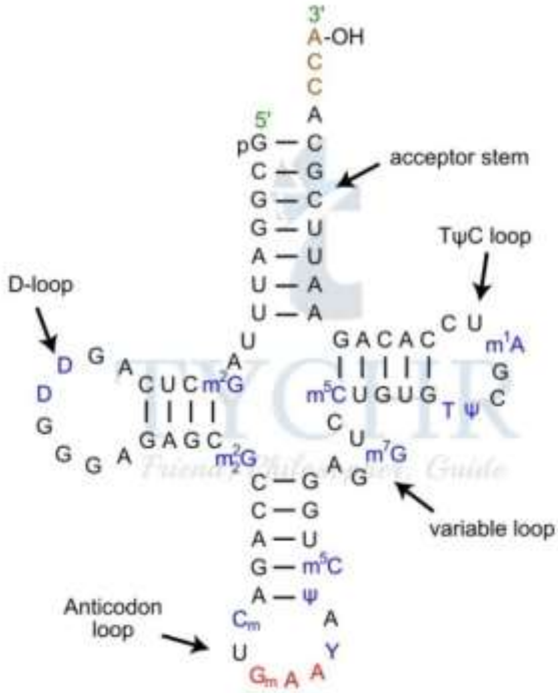


Figure 2.8 t-RNA molecule

- **Process follows:**
    - The tRNA molecule gets attached with the ribosomes to start the translation process. Specific tRNA molecules are attached, whose anticodon must be complementary to the first codon triplet of mRNA molecules.
    - Two tRNA molecules attach with the ribosomes at two separate positions in one line, one at the start and the second to continue with the second triplet and bring a second amino acid which is joined with the first through enzyme catalysed peptide bond.
    - The first tRNA molecule breaks its bond from the first amino acid it synthesised and the second tRNA shifts from its position to the position earlier occupied by the first tRNA. It creates the room for the third tRNA to get in.
    - This repetitive process continues until the last triplet codon of the mRNA arrives which is in fact the stop codon like UGA and UAG (does not code for any amino acid).

- The entire mRNA is now translated into the polypeptide which now floats in the cytoplasm.

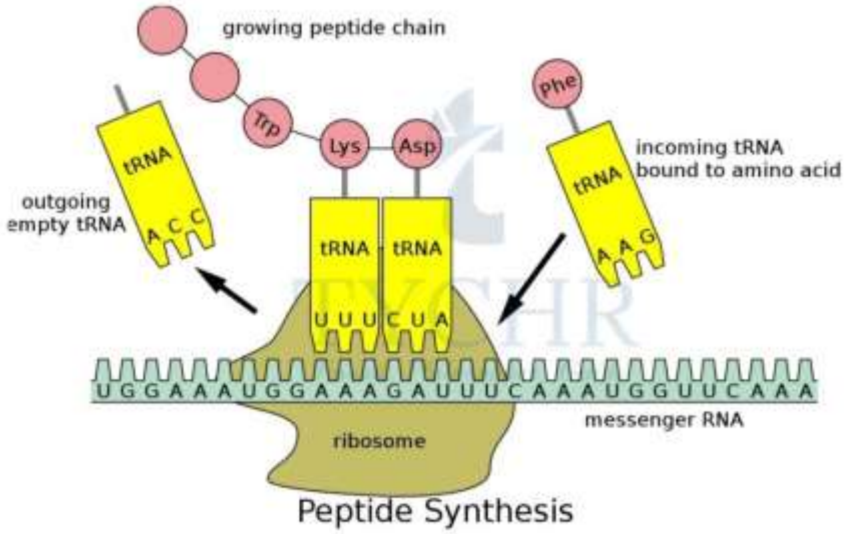


Figure 2.9 Translation by ribosomes

Cell Respiration

Introduction

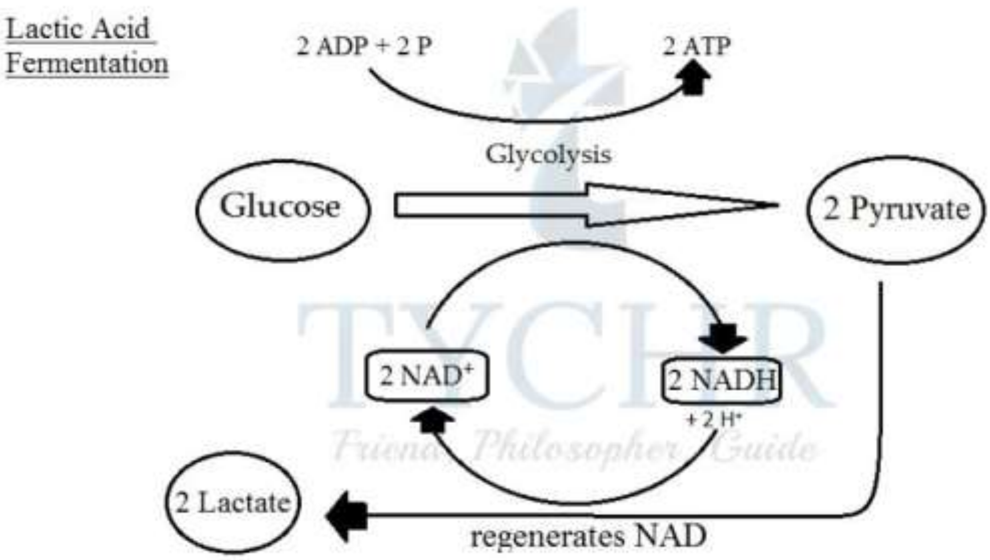
- A variety of biochemical pathways that can be used to metabolize glucose in a cell is called cell respiration.
  It follows the common pathway when initiated for all organisms, referred to as
  Glycolysis ('lysis' means to break)
- Fate of glycolysis;
- Glycolysis is the method of slow oxidation of the glucose using various enzymes. It is a sequential process and at every step a bond is broken with the release of energy, which is released in the form of ATP.
- In anaerobic conditions, this breakdown of glucose occurs through fermentation.
- Fermentation is of two types; alcoholic fermentation and lactic acid fermentation.

Alcoholic fermentation:

- Yeast (single-celled fungus) is used when oxygen is not present.
- In this process after glycolysis (primary process), yeast take up the glucose and generate ATP molecules and convert both of the pyruvate molecules into ethanol.
- There is a release of CO_2 from every molecule of pyruvate (3-C) converted into ethanol (2-C).

Lactic acid fermentation

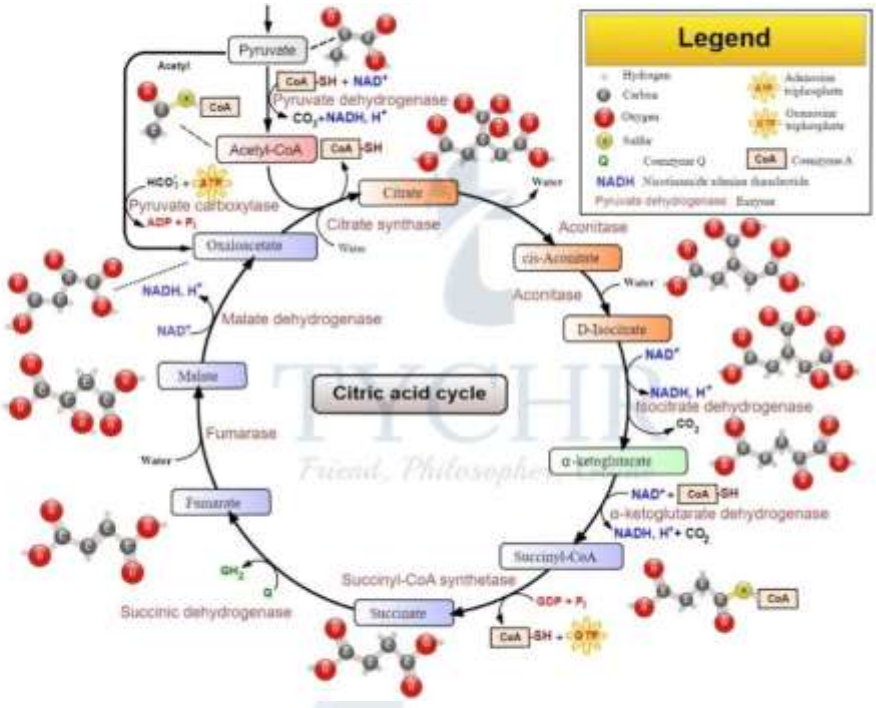
- This process occurs when oxygen cannot be supplied sufficiently due to much more usage at a time.
- In the situation, when a person exercises beyond his/her daily routine, the pulmonary and cardiovascular system supply as much oxygen as possible but sometimes the rate of exercise exceeds the capacity of supply of oxygen.
- Thereby some of the glucose molecules enter the anaerobic pathway for the urgent production of ATP and the two pyruvate (3-C) molecules are then converted into lactate (3-C), this is called lactic acid fermentation.



Aerobic pathway of cell respiration

- It involves complete oxidation of glucose into water + CO_2 + ATPs.
- It is much more efficient process than anaerobic pathway, because it produces more number of ATPs and causes complete disintegration of 6-C glucose molecule.

- Pyruvates formed by glycolysis enter the mitochondria of the cell for further metabolization.



Photosynthesis

Introduction

The conversion of in the light energy into the chemical energy is called photosynthesis. It forms the basis of food for every organism on the earth. Plants and certain bacteria are autotrophic which can use sunlight and inorganic matter to convert into useful organic matter (sugar).

How plants absorb light energy?

- In the leaves of the plants, there is a presence of green colour organelle called
  chloroplast which contains the light absorbing pigment chlorophyll in it.
- Plants use the human visible spectrum of electromagnetic waves as a light to make food.
- Chloroplasts itself are green in colour, therefore they reflects back green light and absorbs red and blue light. This is the reason why

plants show much more efficient photosynthesis in blue and red light.

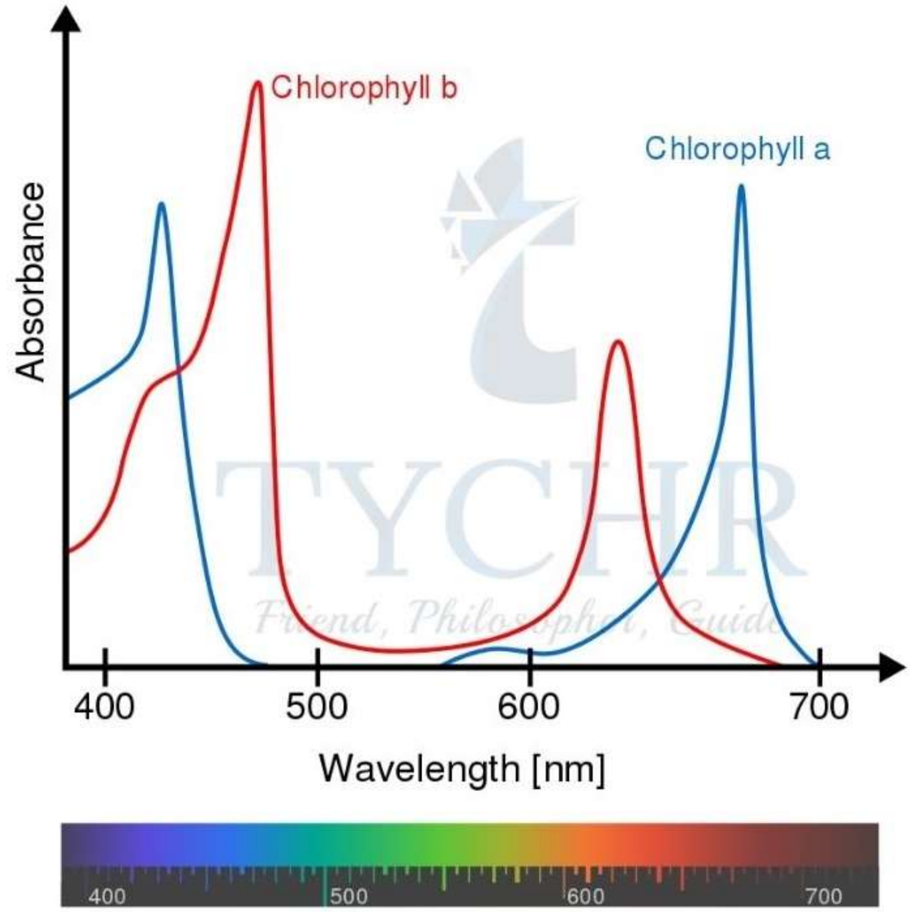
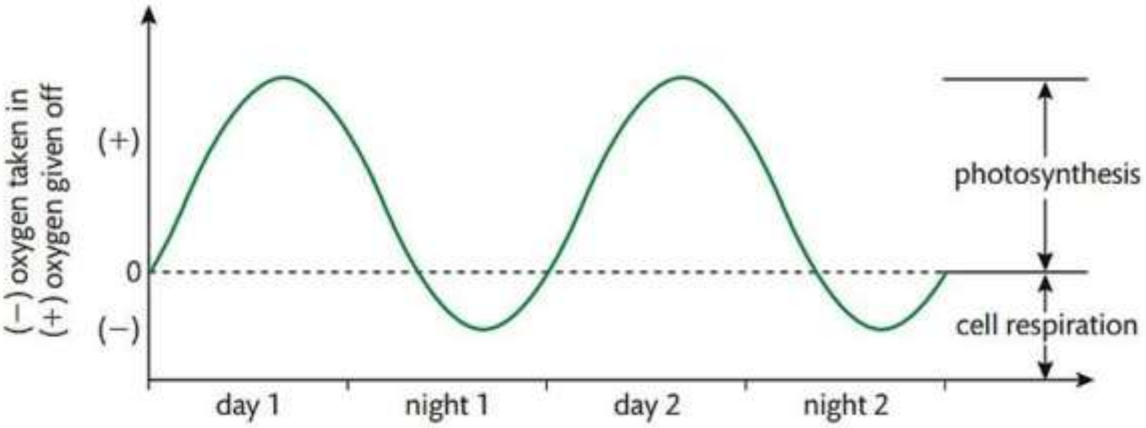


Fig. 2.11 Graph showing rate of photosynthesis w.r.t colour of light

- Photosynthesis completes in two stages:
  - Light dependent reactions
    - Pigments like chlorophyll, xanthophyll and carotenoids trap light energy and convert it into the chemical energy (ATP).
    - Water gets split into H^+ + e^- = H and Oxygen. Hydrogen and ATP are useful products and oxygen gets released as a waste product for plants.
  - Light-independent reactions
    - It happens at night.
    - ATP and hydrogen produced in the daylight is now used to convert CO_2 and H_2O into glucose.
      $6CO_2 + 6H_2O\ C_6H_{12}O_6 + 6O_2$
      Glucose

- Glucose is the only molecule that can be formed out of photosynthesis.

- Rate of photosynthesis
  - Photosynthesis gives off the oxygen and in the cellular respiration oxygen is taken in.



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A. Plants take in much less oxygen for their biochemical processes, than animals.
B. Photosynthetic rate is affected by many external factors like light, temperature and CO2 concentrations. These are also called the limiting factors of photosynthesis, because if any of these factors limit in any contrast, it can affect the overall rate of photosynthesis.

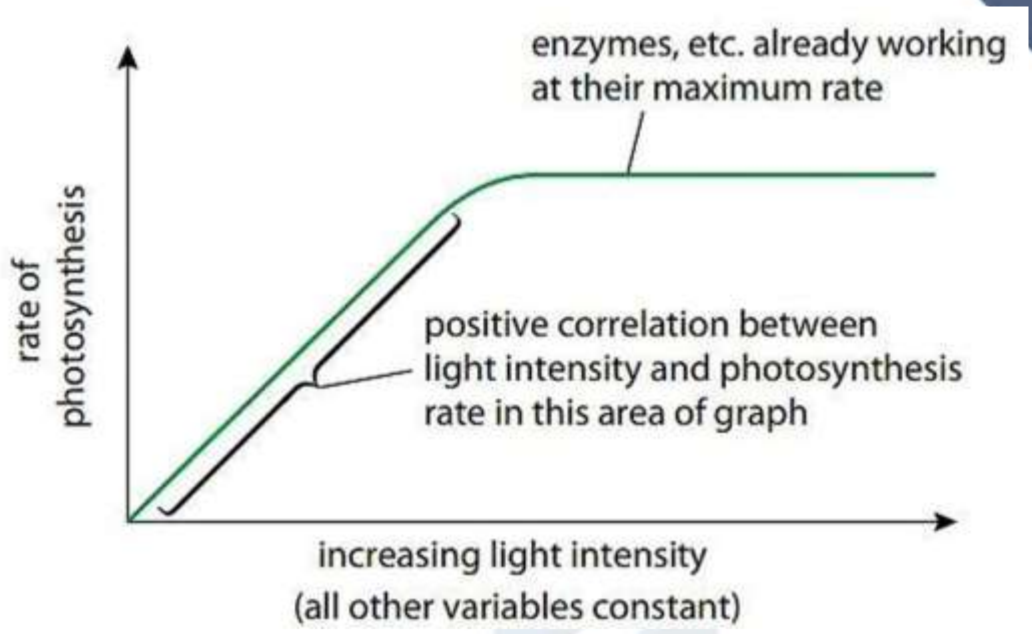

Fig. 2.12 Rate of photosynthesis vs. light intensity

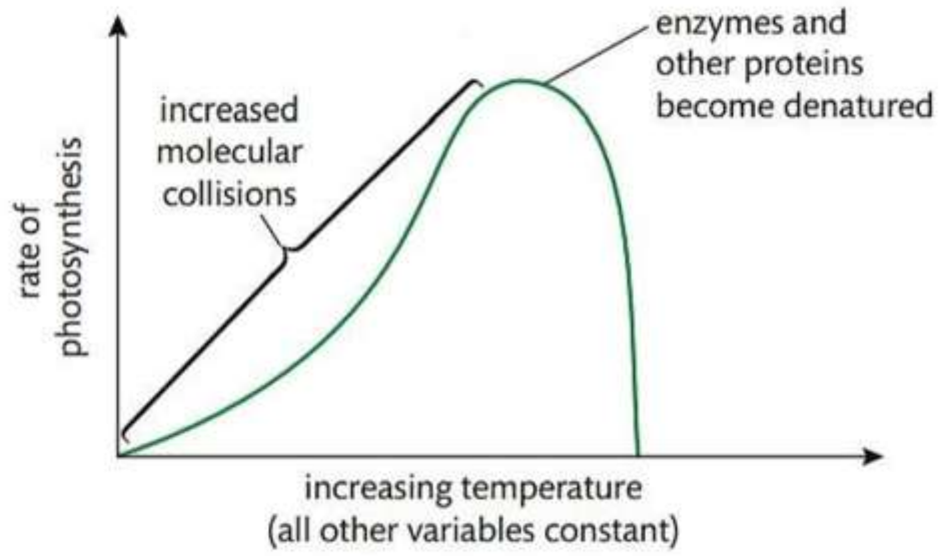

Fig. 2.13 Rate of photosynthesis vs. temperature

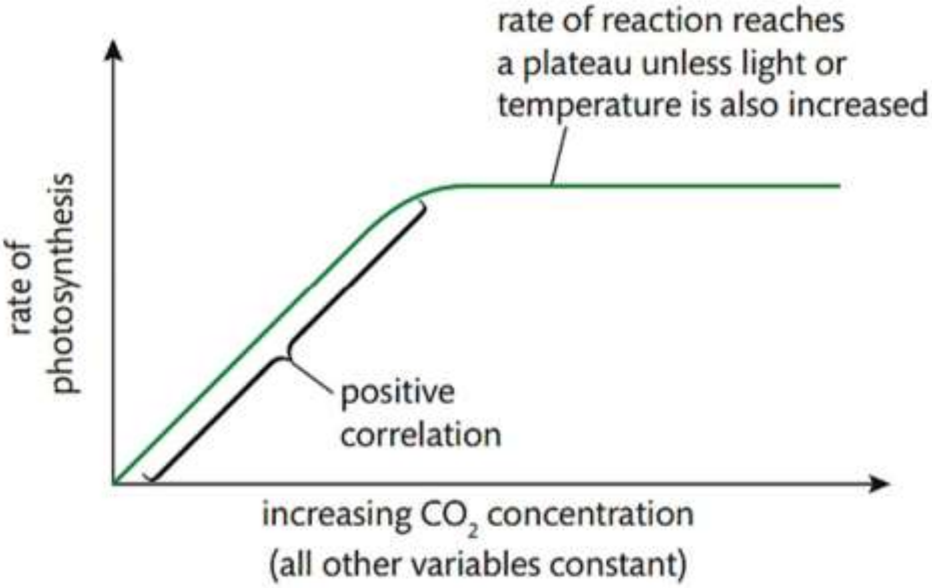

Fig. 2.14 Rate of photosynthesis vs. CO2 concentration

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