KIPS
ENTRY TESTS
SERIES

PREP BOOK

BIOLOGY

MDCAT

- Topic-wise Complete Syllabus
- Comprehensive Course Revision
- Detailed Explanation of Topics
- Key Points, Tables, Flows Sheets & Diagrams
- Critical Concepts; Critical Thinking

A Kitab Dost Publication

Dedication

"The Teacher of the Universe"

(صلی اللہ علیہ وآلہ وسلم)

With whose existence and

by having the charity of His knowledge

the cosmos got illuminated with the light of

insight and wisdom and the journey of human

enlightenment was made possible.

TABLE OF CONTENT

TOPIC-1

BIO-DIVERSITY (ACELLULAR LIFE / VARIETY OF LIFE)

COURSE CONTENT

- Discovery of Viruses
- Characteristics of Viruses
- Classification of Viruses
- Structure of Viruses
- Bacteriophages
- Viral Diseases
- HIV and AIDS

Zubaid

DISCOVERY OF VIRUSES

- The word virus is derived from a Latin word '*venom*' meaning '*poison*'. In past, the term virus was associated with infectious diseases which have unknown cause.
- The first evidence about the existence of virus came when C. Chamberland, who worked with L. Pasteur, found that the causative agents of rabies could pass through the porcelain filter (pore size of ***100-1000 nm***).
- Now a days, viruses can be defined as '***non-cellular infectious entities***' which contain either RNA or DNA, normally encased in proteinaceous coat, and reproduce only in living cells.

CRITICAL CONCEPT!

How Viruses Originate

Regressive hypothesis: Viruses evolved from free-living cells, or from intracellular prokaryotic parasites.

Progressive hypothesis: Viruses originated from RNA and DNA molecules, or self-replicating entities similar to transposons or other mobile genetic elements, that escaped from a host cell with the ability to enter another cell.

Virus first hypothesis: Suggests that viruses may have been the first self-replicating entities before the first cells.

- The contribution of various scientists in the field of *virology* is listed in the following table.

Name of Scientist	Year	Contribution
E. Jenner	1796	Developed 1st vaccine against small pox.
C. Chamberland	1884	Filterable nature of rabies viruses.
D. Ivanowski	1892	Filterable nature of TMV.
W. M. Stanley	1935	Isolation, purification and crystallization of TMV.
Twort and D'Herelle	1915, 1917	Discovered bacteriophages.

CRITICAL THINKING

1. ________ of viruses was a major breakthrough in understanding viruses.
   A. Purification B. Characterization
   C. Crystallization D. Isolation

CHARACTERISTICS OF VIRUSES

- Viruses are extremely small infectious agents which can only be seen under an electron microscope.
- They cannot be grown on artificial culture media. They can reproduce only in living cells where they ***reproduce by replication***.
- All viruses are generally ***resistant to the broad range of available antibiotics*** such as penicillin, streptomycin and others.
- They range in size from ***250nm*** of ***poxviruses*** to the ***20nm*** of ***parvoviruses***.
- They are ***10*** to ***1000 times smaller than most of the bacteria***, so they can pass through the pores of filter from which bacteria cannot pass.

CRITICAL THINKING

2. Which of the following do not have fossils record?
   A. Plants B. Bacteria
   C. Animals D. Viruses

- Viruses show characteristics of both living and non-living things.
- The *living characteristics* of viruses are:

i. Viruses occur in ***different varieties*** or ***strains***.
ii. They have their own genetic material in the form of either DNA or RNA that can undergo mutation.
iii. They reproduce by using the metabolic machinery of the host cell.
iv. They enter the cells of living organism and cause disease i.e., ***Obligate intracellular parasites.***
v. They get ***destroyed by the UV-rays.***

- The ***non-living characteristics*** of viruses are:

i. They lack cellular structure, co-enzyme and enzyme synthesis system and ***do not have metabolic activities*** of their own.
ii. They can be ***crystallized and stored.***
iii. They ***do not respire***, and behave as ***inert infectious particle*** outside the host.

CRITICAL CONCEPT!

Viroids:
Viroid is an infectious particle smaller than any of the known viruses. Particle consists only of an extremely small circular ssRNA, lacking the protein coat. Viroids appear to be transmitted mechanically from one cell to another through cellular debris.

- ***Prions*** are infectious particles made only of proteins and cause mysterious brain infection in man and mad cow infection in cow.
- ***Viroids*** are minute particles of RNA and lack protein coat. They cause diseases in both plants and animals.

CRITICAL THINKING

3. **What are prions?**
A. Misfolded versions of normal brain protein
B. Tiny molecules of RNA that infect plants
C. Viral DNA that has had to attach itself to the host genome
D. Viruses that invade bacteria

CLASSIFICATION OF VIRUSES

- Viral classification is either based upon ***host organisms, morphology, genome type***, and ***mode of action in the host***. In some cases, the ***mode of replication*** is also important in classification.
- The internationally agreed system of virus classification is based on the structure and composition of the viral particle.

CRITICAL CONCEPT!

Ability of Viruses to Infect Life Forms:
Viruses infecting cells from the three domains of life, archaea, bacteria and eukarya, share homologous features, suggesting that viruses originated very early in the evolution of life.

Classification of Viruses Based Upon Host

Host	Virus	Description
Bacteria	Bacteriophages	It attacks bacteria. It contains ***DNA genome (some have RNA genome)*** with a polyhedral/hexagonal head and a tail.
Plants	Plant viruses	More than 2000 types of viral plant diseases are known. Most plant viruses have an ***RNA genome***. Many viruses have rod shaped capsid like TMV, potato yellow dwarf virus.
Animals	Animal viruses	Animal viruses occur as parasites in animals. In many viral infections viruses attack and destroy certain cells in the human body causing the symptoms and diseases. • Viruses cause foot and mouth disease in livestock. • ***Rous sarcoma*** virus causes cancer in animals. • ***Poxvirus*** causes small pox. • ***Picornavirus*** causes polio, hepatitis A etc. • ***Paramyxovirus*** causes measles and mumps.

Classification of Viruses Based Upon Structure

(i) On The Basis of Capsid

Helical capsid	Tobacco mosaic virus
Polyhedral capsid	Adenoviruses
Enveloped	Viruses having an outer envelope studded with glycoprotein spikes e.g., influenza viruses.
Complex capsid	Bacteriophages

(ii) On The Basis of Genomes	
ds-DNA	For example, poxvirus, adenovirus and herpes virus.
ss-DNA	For example, parvovirus causes mild rashes.
ds-RNA	For example, reovirus causes diarrhea.
ss-RNA	Serves as mRNA e.g., Rubella virus
ss-RNA	Template for mRNA synthesis e.g., Orthomyxovirus (influenza virus)
ss-RNA	ssRNA act as template for DNA synthesis e.g., Retrovirus (HIV)

STRUCTURE OF VIRUSES

- Viruses have very simple structure. A complete, mature and infectious particle is known as ***virion***. Primarily, it can be divided into two parts i.e., ***core*** and ***coat***.

Central Core

- The core is inner part of virion which consists of viral genome and various proteins (enzymes).
- Genome is the genetic material, which is ***either DNA or RNA*** and may be single stranded or double stranded.
- ***Core proteins*** include one or more enzymes that facilitate the virus in its mode of action with host body. For example, retroviruses and hepatitis 'B' virus contain ***reverse transcriptase*** which converts single stranded RNA genome into double stranded DNA genome.

CRITICAL CONCEPT!

RNA viruses contain only RNA as their genetic material. To replicate their genomes in the host cell, the RNA viruses must encode their own enzymes that can replicate RNA into RNA or, in the retroviruses, into DNA. These *RNA polymerase enzymes* are more likely to make copying errors than DNA polymerases, and therefore often make mistakes during transcription. For this reason, mutations in RNA viruses occur more frequently than in DNA viruses. This causes them to change and adapt more rapidly to their host.

Outer Coat

- The coat is the outer covering of viral particle which consists of ***capsid and envelope***.
- The capsid is the protective coat of proteins surrounding the central core. It is composed identical repeating subunits known as ***capsomeres.***
- The number of capsomeres is specific to a particular kind of virus. For example, 162 capsomeres are present in capsid of herpes virus and 252 in the capsid of adenovirus.
- There are two forms of symmetry in viral capsid. When the capsomeres are arranged in 20 triangles, it is called icosahedral (polyhedral or spherical). When the capsomeres are arranged in a hollow coil that appears rod shaped, it is called helical.
- A few viruses have an additional ***lipoprotein envelope*** around the capsid which is derived from the cell surface membrane of the host and also contain virally encoded proteins. Non-enveloped viruses are known as ***naked viruses.***

CRITICAL THINKING

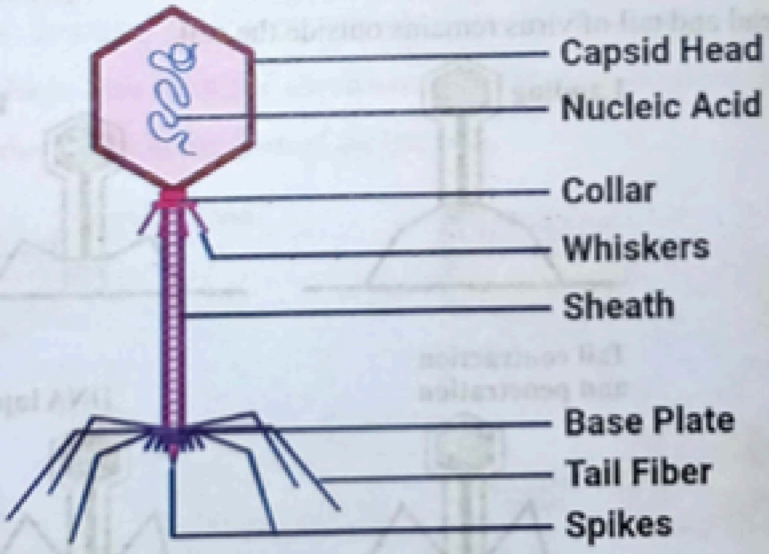
4. Which of the following statements about viral structure is true?
A. All viruses are encased in a viral membrane
B. The capsomere is made up of small protein subunit called capsids
C. DNA is the genetic material in all viruses
D. Glycoproteins help the viral attachment to host cell

BACTERIOPHAGES

The word '***bacteriophage***' literally means '***eater of bacteria***' so, a bacteriophage is a type of virus that infects bacteria.

Structure of Bacteriophages

- It is generally a ***tadpole shaped***, with a head, neck and a tail.
- The inner core of head consists of ***DNA genome (some have RNA genome).*** Below the head is ***narrow neck or collar*** which separates head and tail.
- ***Tail*** is a hollow tube made up of proteins through which nucleic acid passes during infection. The tail is surrounded by ***contractile sheath***, which contracts during infection of the bacterium.
- At the end of the tail, a ***base plate*** is present which possesses about ***six tail fibres*** and ***tail pins/spikes*** at its lower surface and are involved in the binding of the phages to the bacterial cell receptors.
- At the bottom of core tube of tail, ***lysozyme*** is present which is released when tail contracts. This enzyme ***hydrolyzes portion of host cell wall*** so that core tube can penetrate into the host cell during infection.



Life Cycle of Bacteriophage

- So far, the best studied phage virus is that which infect *E. coli*, and is called T phage (T for type), and among them T_2 and T_4 phages are mainly used in phage studies.
- Bacteriophages show two types of cycles i.e., ***lytic cycle*** and ***lysogenic cycle*** and comprises two main steps i.e., ***infection process*** and ***replication within the host cells.***
- The initial steps in the infection process are quite similar in both cycles, but mode of replication is much different in lytic cycle and lysogenic cycle.

Steps of Infection Process

Bacteriophage replicates only inside the bacterial host and the common steps of infection process are as under:

(i) Attachment/Adsorption

- The first step in the infection process is the adsorption/attachment of the phage to the bacterial cell.
- This step is mediated by the tail fibers and tail pins/spikes. Phages attach to specific ***receptors in the bacterial cell wall.***
- During this, ***week chemical union*** between virion and receptor site takes place.

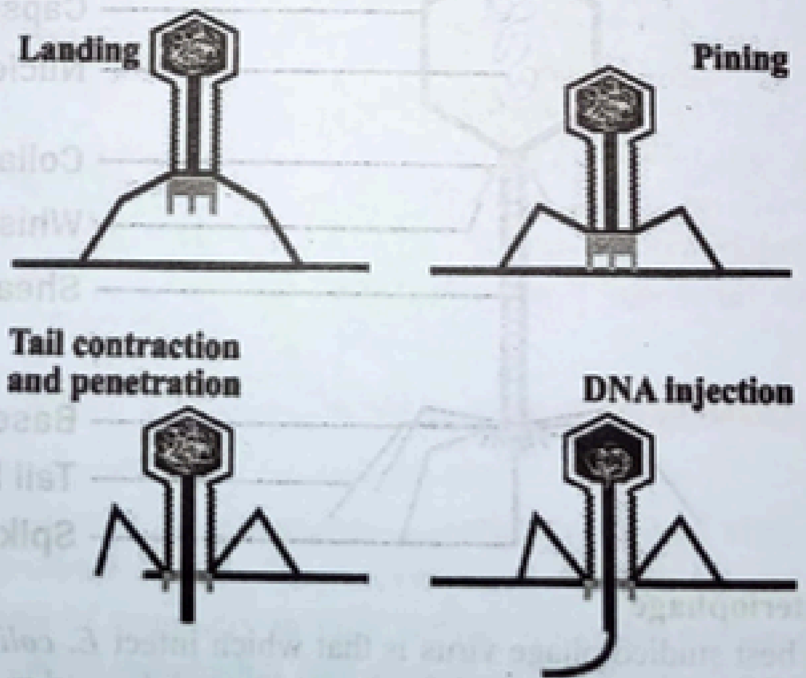
> **CRITICAL CONCEPT!**
>
> Many viruses use some sort of *glycoprotein* to attach to their host cells via molecules on the cell called ***viral receptors***. For these viruses, attachment is required for penetration; after this virus complete its replication inside the cell.

(ii) Penetration

- The binding of the phage to the bacterium results in the ***contraction of the sheath*** and ***release of lysozyme*** that digest the portion of bacterial cell wall.
- As a result, the hollow core tube is pushed through the bacterial cell wall and cell membrane.

(iii) Injection

Third step is injection of viral DNA in bacterial cell. The protein coat, which forms the phage head and tail of virus remains outside the cell.



Replication Process

Two types of cycles are usually seen i.e., lytic and lysogenic cycle.

Lytic Cycle

(i) Viral DNA takes control of the host's biosynthetic machinery.

(ii) It induces the host cell to synthesize necessary viral components (DNA & Proteins) and start multiplying.

(iii) About 25 minutes after initial infection, approximately 200 new bacteriophages are formed.

(iv) Bacterial cell bursts.

(v) Newly formed phages are released to infect the bacteria and another cycle begins.

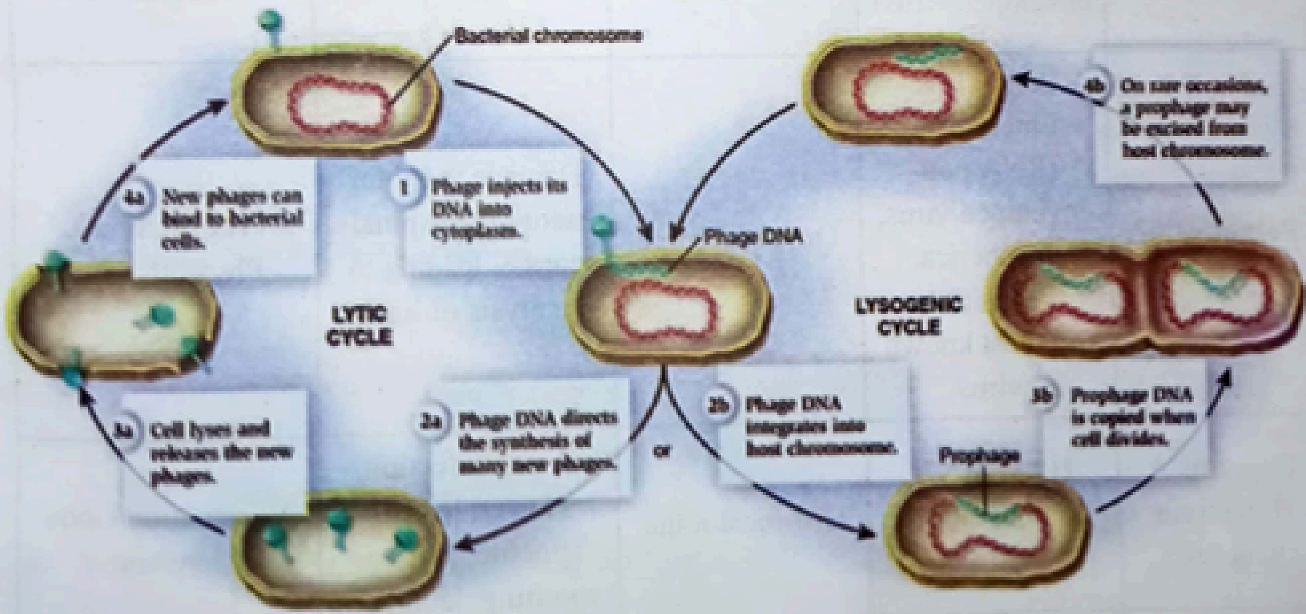
Lysogenic Cycle

(i) Viral DNA, instead of taking over the control of host's machinery, becomes incorporated into the bacterial chromosome. Phage in this dormant state is called prophage and this process is called lysogeny.

(ii) Bacterium continues to live and reproduce normally. Viral DNA being the part of bacterial chromosome passes to each daughter cell in all successive generations.

(iii) Sometimes viral DNA gets detached from the host's chromosome and lytic cycle starts. This process is called ***induction***.

(iv) Induction involves either a ***spontaneous or environmentally induced*** (***desiccation, exposure to UV or ionizing radiations, or exposure to mutagenic chemical*** etc.) excision of the prophage from bacterial chromosomes. This results in the initiation of a typical lytic cycle, which ends in the lysis of the bacteria.



Feature	Lytic Cycle	Lysogenic Cycle
Virus	Lytic or virulent phage	Lysogenic or temperate phage
Relationship	Master–Slave	Host – Guest relation
Effects	Infectious cycle	Non-infectious cycle
Viral DNA	Takes Control	Integrated
Bacterial DNA	Destroyed	Remains intact

VIRAL DISEASES

There are many diseases which are caused by viruses. Some common viral diseases, their causative agent, mode/source of transmission, symptoms, and treatment/immunization are summarized in the following table.

Disease	Virus	Source of Transmission	Symptoms	Prevention
Herpes Simplex (Oral herpes)	HSV-1 (DNA, enveloped virus)	Oral secretions or physical contact with sores or by objects (Toothbrush, utensils)	Blisters/ Vascular lesions in epithelial layers of ectodermal tissue. Most commonly in mouth, lips, and skin sites.	Antiviral drugs/ Avoid contact
Measles	Paramyxovirus (RNA enveloped virus)	Coughing & Sneezing	Fever, runny nose, cough, red eyes, red flat rashes on skin	Auto-immunity, Vaccination
Mumps	Paramyxovirus (RNA enveloped virus)	Coughing & sneezing	Fever, muscle pain, headache, painful swelling of parotid glands	Auto-immunity, Vaccination
Poliomyelitis	Polio virus/ Enterovirus (RNA non-enveloped virus, in spherical capsid). Smallest known virus	Oro-fecal route	Damage to motor neurons of spinal cord & leading to paralysis of limbs	Vaccination / Physiotherapy
Hepatitis A (Infectious hepatitis)	HAV (RNA non-enveloped virus)	Oro-fecal route	Acute infection (Fever, loss of appetite, nausea, vomiting, jaundice)	Vaccination/Good hygiene

Hepatitis B (Serum hepatitis)	HBV (DNA enveloped virus)	Contaminated blood , Sexual contact, Mother to newborn	Acute (vomiting, yellowish skin, tiredness, dark urine, abdominal pain) & chronic (liver cirrhosis & liver cancer)	Vaccination/ Alpha interferons/ Screening of blood
Hepatitis C (Infusion hepatitis)	HCV (RNA enveloped virus)	Infected blood or blood products	Chronic (ocassionally fever, dark urine, abdominal pain, yellow skin) with cirrhosis & liver cancer	No Vaccination/ Alpha interferon & Ribavirin/ Screening of blood
Hepatitis D	Viroid	Blood or serum	Same as hepatitis B but more severe	Same as hepatitis B
Hepatitis E	HEV (RNA non-enveloped virus)	Oro-fecal route	Acute infection (Nausea, vomiting, diarrhea, jaundice)	No anti-viral treatment and vaccine Good hygiene
AIDS	(HIV) RNA enveloped virus	Contaminated blood, Sexual contact	Opportunistic infections, Swollen lymph nodes	Vaccination not available. Use of ART to control the virus to increase the life expectancy of HIV positive individuals.

CRITICAL THINKING?

5. Naturally occurring endonucleases are very effective against:

A. Protozoans B. Viruses
C. Bacteria D. Bacteriophages

6. Which of the following is having more chances mutation then other?

A. Poxvirus B. Herpes simplex
C. Hepatitis B virus D. Hepatitis C virus

HIV AND AIDS

- ***Retroviruses are associated with tumor production*** in animals like fowl, rodents and cats.
- Human immunodeficiency virus which causes acquired immunodeficiency syndrome (AIDS) is an example of retrovirus.
- May be ***non- specific*** in their action but usually infect those cells containing ***specific receptors***.

CRITICAL CONCEPT!

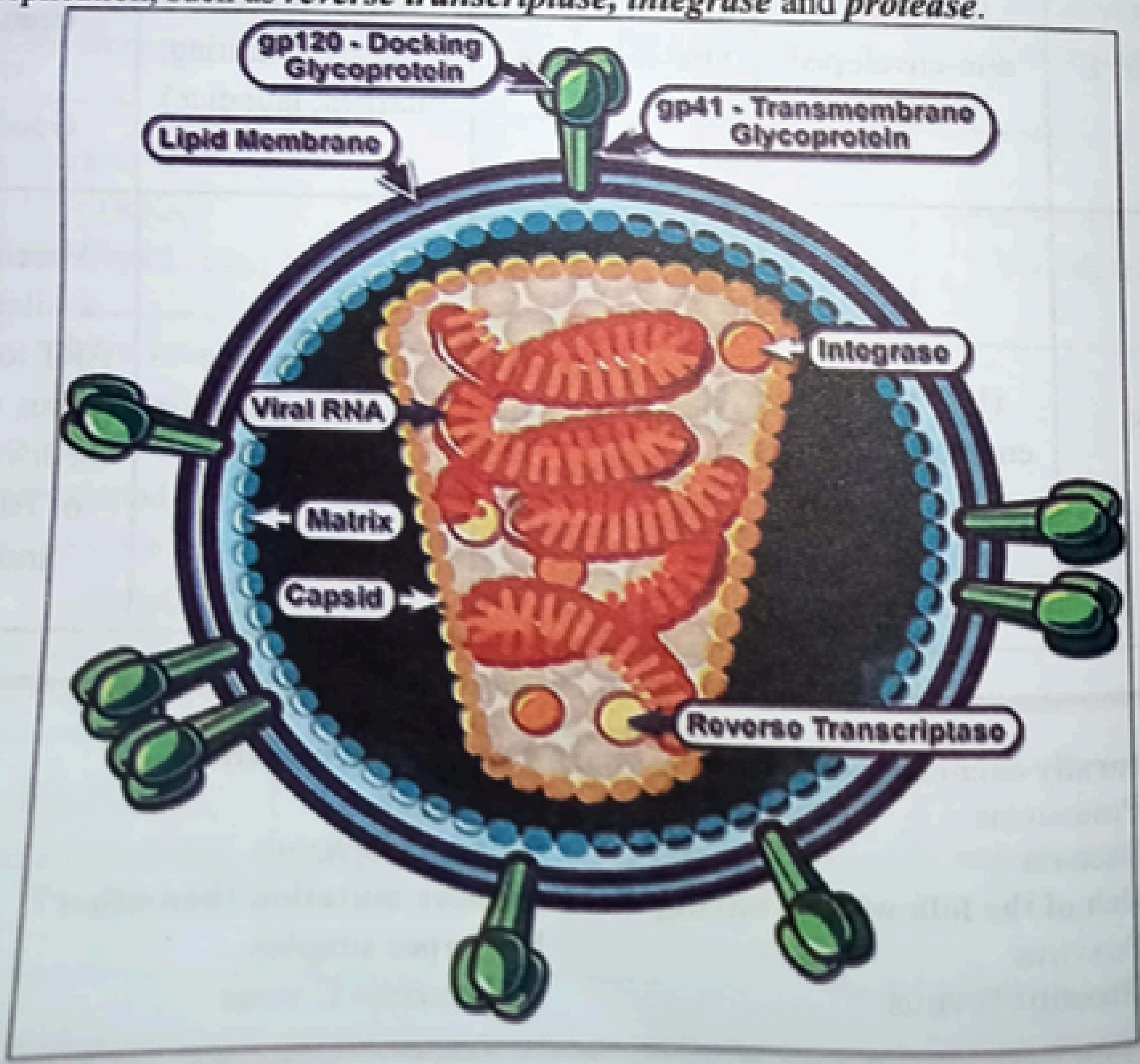
Retroviruses:
Retroviruses are having two RNA molecules, which may be positive sense RNA and/or negative sense RNA.

Structure of Human Immunodeficiency Virus

- They are ***spherical in shape*** and ***100nm*** in diameter.
- The outer covering is a ***lipoprotein envelope*** which consists of two layers of lipids; different proteins are embedded in the viral envelope, forming '***spikes***'. These spikes consist of the ***outer gp120*** and ***inner transmembrane gp41***. The gp120 is needed to attach to the host cell, and gp41 is critical for the cell fusion process.
- Beneath envelope, another protein shell is present which is made up of ***matrix proteins***.
- *The HIV capsid is somewhat* ***conical shaped***.
- *The HIV* core contains two single strands of RNA molecules and enzymes needed for *HIV* replication, such as ***reverse transcriptase, integrase*** and ***protease***.

CRITICAL CONCEPT!

Viruses also having linear as well as circular genome.



CRITICAL THINKING

7. Which of the following virus is having linear genome?
A. Bacteriophages
B. Retroviruses
C. Paramyxoviruses
D. *Vibrio cholerae*

- The reverse transcriptase is used to convert viral RNA genome into viral DNA genome, integrase is used to incorporate viral DNA into host DNA while protease is used to break large structural proteins into smaller units. These structural proteins are encoded by three out of the nine HIV genes.

Host Specificity

- Primary host of HIV are ***helper T-lymphocytes*** (CD4 cells).
- In addition, macrophages and certain brain cells may also be affected.

Mode of Transmission

- By intimate ***sexual contact*** (virus present in body secretions and blood, which gets entry in recipient blood from minor wear and tears, more common in homosexuals).
- Contact with blood and breast feeding.
- ***Prick*** of an infected needle or surgical instruments (problem for health care providers).

Acquired Immunodeficiency Syndrome (AIDS)

AIDS first reported in ***young homosexual males***, having one or more complex symptoms like severe pneumonia, vascular cancer, sudden weight loss, swollen lymph nodes and immune deficiency or decreased immune functions.

CRITICAL THINKING

8. Which of the following viruses is having maximum rate of replication?
A. Herpes Simples Virus
B. HIV
C. Polio Virus
D. Hepatitis A Virus

Life Cycle/Infectious Cycle of HIV

Following steps are involved in the life cycle of HIV.

- The initial step in the life cycle of HIV is adsorption/attachment which is characterized by the binding of gp120 envelope protein to the CD_4 receptor on the surface of T_4 cell.

- Next is the fusion of viral envelope with the cell membrane takes place and the virion enters the cell by endocytosis. Once inside the host cell, the HIV particle sheds its protective coat i.e., ***uncoating occurs***. This leaves the viral ss-RNA in the cytoplasm along with the viral envelope.
- Reverse transcriptase synthesizes ss-DNA complementary to the viral RNA.
- After ***reverse transcription***, the viral genomic RNA is disintegrated by RNAse. The ss-cDNA is replicated to form ds-DNA.
- The ds-cDNA then integrates into the host cell DNA. ***Integration*** is mediated by ***'integrase'***.
- The integrated DNA is now called ***provirus.*** Viral mRNA is transcribed from the proviral DNA by host specific ***RNA polymerase.*** During ***transcription***, not only viral mRNAs for different protein are formed but viral genomic RNA is also produced.

> **CRITICAL CONCEPT!**
>
> Influenza virus is packaged in a viral envelope that fuses with the plasma membrane. In this way, the virus can exit the host cell without killing it.

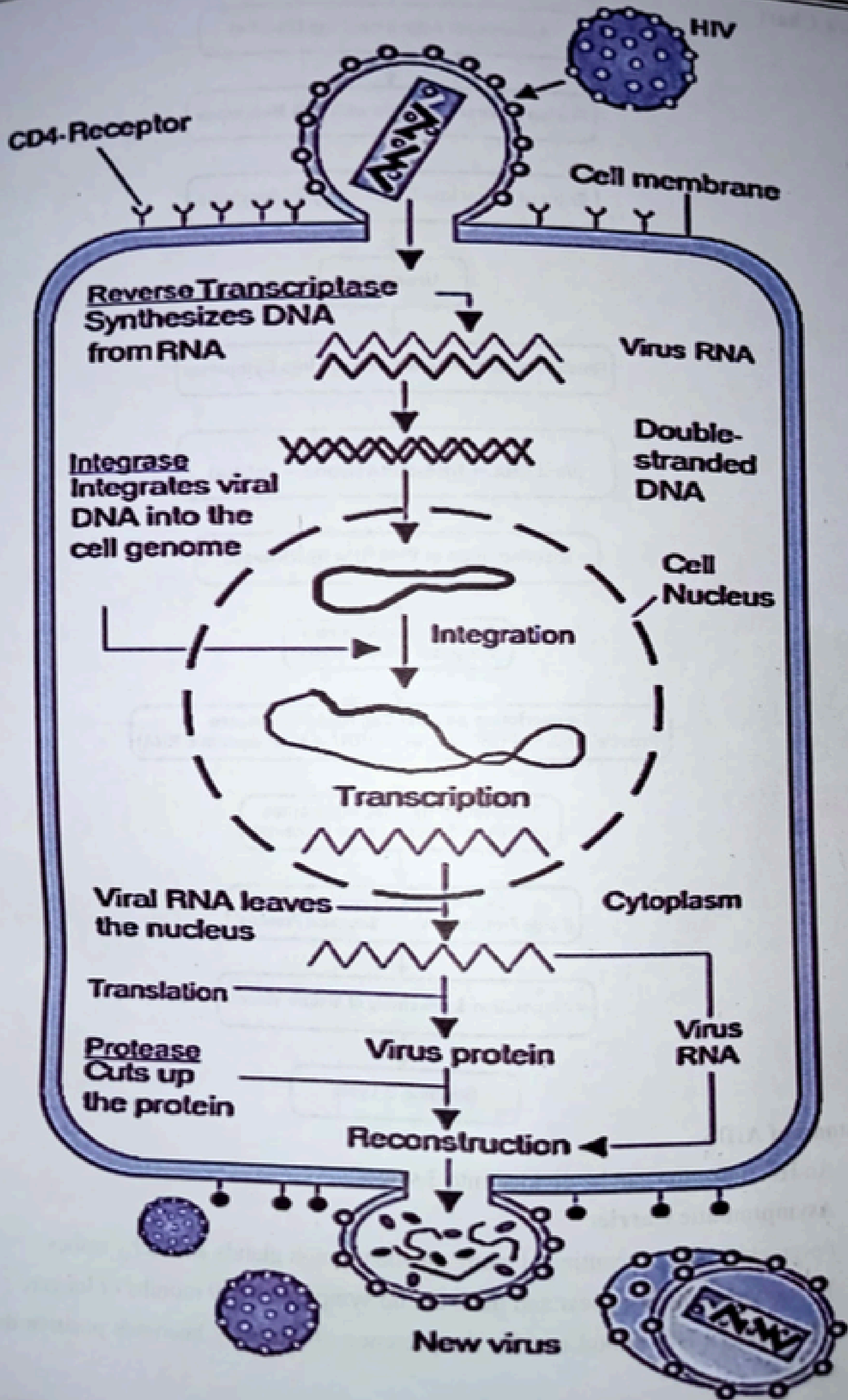
- The viral mRNAs are ***translated by the host ribosomes*** into several large proteins, which are then cleaved by ***proteases*** to form the viral proteins.
- The viral components are assembled and mature virions are produced.
- Finally, the ***mature virions are released by budding off*** from the host cell and enclosing a portion of the host cell membrane around them. In this way, host cell size is decreased enough that it becomes non-functional.

The complete mechanism of infectious cycle of HIV is shown in the following diagram and flow chart.

CRITICAL THINKING

9. All type of viruses exits the host cell without bursting them except:

A. Herpes simplex
B. Paramyxovirus
C. Polio virus
D. Hepatitis A virus


HIV
CD4-Receptor
Cell membrane
Reverse Transcriptase
Synthesizes DNA
from RNA
Virus RNA
Double-
stranded
DNA
Integrase
Integrates viral
DNA into the
cell genome
Cell
Nucleus
Integration
Transcription
Viral RNA leaves
the nucleus
Cytoplasm
Translation
Virus
RNA
Protease
Cuts up
the protein
Virus protein
Reconstruction
New virus

Flow Chart

Adsorption/ Attachment (gp120-CD4)

↓

Fusion of Viral Envelope with Cell Membrane

↓

Entry of Virion into Host Cell by Endocytosis

↓

Uncoating

↓

Release of Viral RNA & Enzymes into Cytoplasm

↓

Reverse Transcription
(Viral RNA → RNA-cDNA Hybrid → dsDNA)

↓

Disintegration of Viral RNA by RNAases

↓

Integration by Integrase
(Integrated DNA/Provirus)

↓

Transcription by Host Cell RNA Polymerase
(Proviral DNA → Proviral RNA – mRNA + Viral Genomic RNA)

↓

Translation by Host Ribosomes
(mRNA → Several Large Proteins)

↓

Cleavage by Viral Proteases
(Large Proteins → Virion Structural Proteins)

↓

Incorporation & Assembly of Mature Virions

↓

Budding & Lysis

Symptoms of AIDS

An HIV infection can be divided into 3 stages:

(i) **Asymptomatic Carrier**

- Fever, chills, aches (continued pain), swollen lymph glands and itchy rashes.
- These symptoms disappear and there are no symptoms for 9 months or longer.
- The standard HIV blood test for the presence of antibody becomes positive during this stage.

(ii) **AIDS Related Complex (ARC)**

- Swollen lymph glands in neck, armpit or groin that persist for months. Other symptoms include night sweats, persistent cough, flu, persistent diarrhea, loss of memory, inability to think clearly, loss of judgment and depression.

(iii) **Full Blown AIDS**

- It is the final stage. In this stage, there is severe weight loss and weakness due to persistent diarrhea and usually one of the several opportunistic infections i.e. Kaposi's sarcoma (cancer or lesion on skin), fungal infection, viral infection, gastrointestinal disease, respiratory disease, nervous system and eye diseases).

Treatment of AIDS

- ***Antiretroviral therapy*** (ART) is done for treatment. It is not a cure but it controls virus so that HIV positive person can live a longer, healthier life and reduce the risk of transmitting HIV to others.
- When ART is accessible and started early in the course of infection, the lifespan of HIV-positive people is typically very close to that of comparable HIV negative people.

Control Measures Against HIV Transmission

- AIDS can be controlled by preventing transfer of body fluid like blood, serum, semen, etc., from patient to unaffected person. The following behavior of precautionary measure will prevent AIDS;
  - ➢ Do not use used syringes and needles.
  - ➢ For blood transfusion, blood must be used after proper screening for HIV.
  - ➢ Do not share toothbrushes, blades and towels with anyone. Special cares to be taken at barber's shop or hair cutting saloons.
  - ➢ Surgical instruments must be properly sterilized.
  - ➢ Refrain from immoral sexual activities and follow Islamic teachings to pass healthy, neat and clean life.
  - ➢ HIV positive mother should not feed their babies.
- Shaking hands, hugging, coughing or sneezing and swimming in the same pool do not transmit HIV.
- One cannot get AIDS from inanimate objects such as toilets, door knobs, telephones, office machines and house hold furniture.
- AIDS is ***not transmitted by mosquitoes*** and ***other insects***.

TOPIC-2 BIOENERGETICS

COURSE CONTENT

- Introduction to Bioenergetics and photosynthesis
- Role of Light
- Role of photosynthetic Pigments
- Role of H_2O and CO_2
- Mechanism of Photosynthesis and Photosystems
- Light Dependent Reactions (Non-Cyclic and Cyclic Photophosphorylation)
- Light Independent Reactions/Dark Reaction
- Cellular Respiration (Types and Mechanism of Anaerobic Respiration)
- Mechanism of Aerobic Respiration
- Glycolysis
- Pyruvic Acid Oxidation
- Krebs Cycle
- Respiratory Chain/Electron Transport Chain
- Energy Budget Calculation and Regulation of Cellular Respiration
- Importance of G3P and Cellular Respiration of Fats and Proteins

INTRODUCTION TO BIOENERGETICS AND PHOTOSYNTHESIS

Bioenergetics

- Living things cannot grow, reproduce, or exhibit any of the characteristic of life without a ready supply of energy. All the metabolic reactions involve energy transformations. The quantitative study of ***energy relationships*** and ***energy conversions*** in biological systems is called ***bioenergetics***.
- All life on planet earth is powered, directly or indirectly by ***solar energy***.
- The chloroplasts of plants capture light energy coming from sun and convert it into chemical energy that gets stored in sugar and then in other organic molecules.
- With the emergence of photosynthesis on earth, O_2 began to accumulate slowly in the atmosphere. The presence of free O_2 made possible the evolution of cellular respiration.
- Respiration releases great deal of energy, and couples some of this energy to the formation of ***ATP molecules***, which is a kind of ***chemical link between catabolism and anabolism***.

Photosynthesis

- Photosynthesis can be defined as 'the process in which energy poor inorganic oxidized compounds of carbon (CO_2) and hydrogen (mainly H_2O) are reduced to energy rich carbohydrate i.e., glucose (sugar) using the light energy that is absorbed and converted into chemical energy by chlorophyll and some other photosynthetic pigments.
- The process of photosynthesis in green plants can be summarized as:

Reduction

$$\underset{\text{Carbon dioxide}}{6CO_2} + \underset{\text{Water}}{12H_2O} \xrightarrow[\text{Chlorophyll}]{\text{Light}} \underset{\text{Glucose}}{C_6H_{12}O_6} + \underset{\text{Oxygen}}{6O_2} + \underset{\text{Water}}{6H_2O}$$

Oxidation

- From the above overall reaction of photosynthesis, it becomes evident that carbon dioxide, water and light are the reactants while glucose and oxygen are the products.
- Water appears on both sides of the equation because water is used as reactant in some reactions and released as product in other. However, because there is no net yield of H_2O, we can simplify the summary equation of photosynthesis for purpose of discussion:

$$6CO_2 + 6H_2O \xrightarrow{\text{Chlorophyll}} C_6H_{12}O_6 + 6O_2$$

Relation between Photosynthesis and Respiration

- Chemical equation of photosynthesis is almost exactly opposite to the overall equation of aerobic respiration ($C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$ + Energy).
- Photosynthesis uses the products of respiration and respiration uses the products of photosynthesis.
- Photosynthesis occurs only during daytime, whereas respiration goes on day and night.

Light Variations and Compensation Point

- During darkness, leaves and other actively metabolizing cells respire and utilize oxygen and release carbon dioxide.
- At dawn and dusk, when light intensity is low, the rate of photosynthesis and respiration may for a short time, equal one another. Thus oxygen released from photosynthesis is just the amount required for cellular respiration. Also the carbon dioxide released by respiration just equals the quantity required by photosynthesizing cells.
- At this moment there, is no net gas exchange occurs between the leaves and the atmosphere. This is termed as ***compensation point.***

  As the light intensity increases, so does the rate of photosynthesis and hence the requirement for more carbon dioxide increases which respiration alone cannot supply. Similarly, the oxygen produced during photosynthesis is more than the need of the respiring cells, so the result is the net release of oxygen coupled with the uptake of carbon dioxide.

ROLE OF LIGHT

Role of Light and Types of Spectra

- Sunlight is an electromagnetic or radiant form of energy. The full range of electromagnetic radiation in the universe is called ***electromagnetic spectrum***.
- Photosynthetic pigments are the substances that absorb part of ***visible light*** (380-750nm wavelengths).
- Light behaves as waves as well as sort of particles called ***photons***.
- The effectiveness of a particular wavelength of light for the process of photosynthesis primarily depends upon its absorption by the plants. As different wavelengths/colours of visible light are differently absorbed by various photosynthetic pigments. Therefore, each wavelength has its own effectiveness for the process of photosynthesis.
- Not all the light falling on leaf is absorbed. Only about 1% of the light falling on the leaf surface is absorbed, the rest is reflected or transmitted.

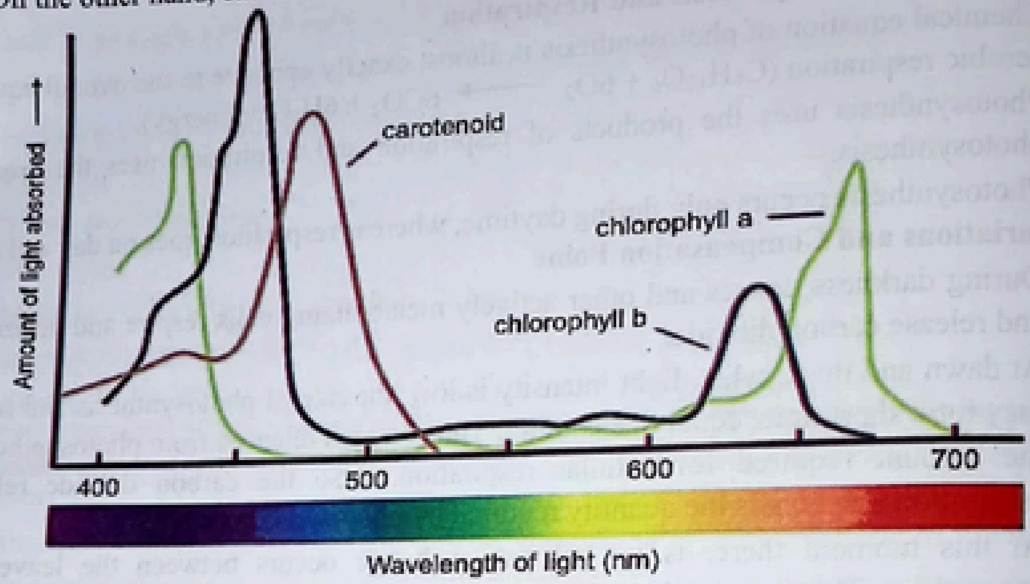
Spectrum of Light for Plants

There are two types of spectra:

1. Absorption spectrum
2. Action spectrum

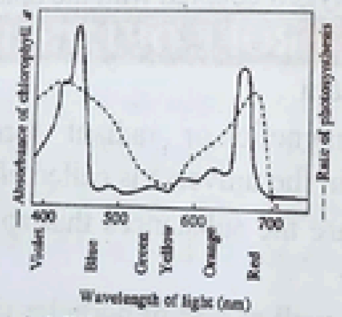
Absorption Spectrum

- Graph showing relative absorption of different wavelengths of light by different photosynthetic pigments is called absorption spectrum.
- The absorption spectrum of different pigments indicate that they absorb different wavelengths of visible light and these wavelengths are not absorbed at the same rate.
- The main photoreceptors are chlorophyll 'a' and 'b'. Both show more absorption in ***violet-blue*** (400nm to 470nm) and ***orange-red*** (630nm to 670nm) regions of the visible spectrum.
- On the other hand, ***carotenoids show more absorption at 430nm to 500nm.***



CRITICAL THINKING

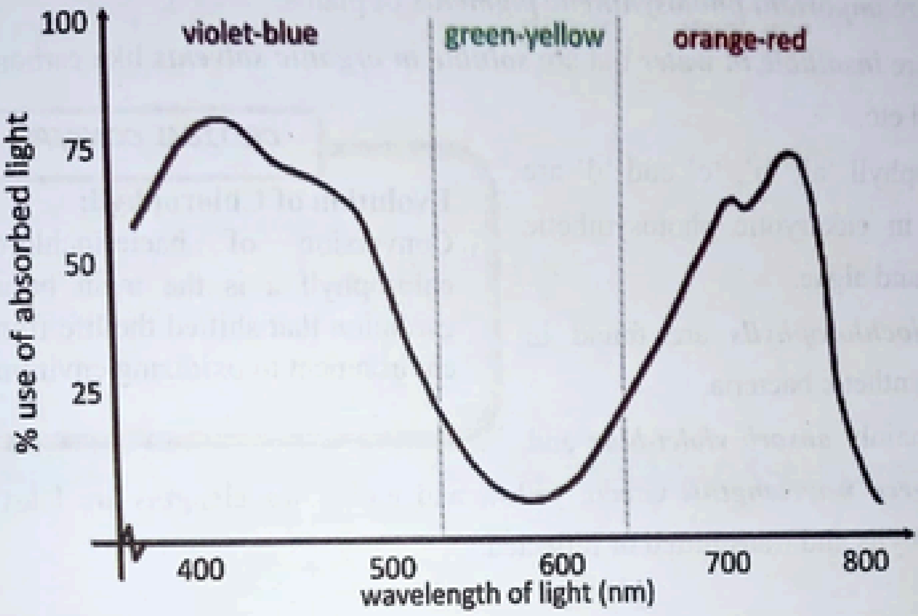
1. **Figure shows the absorption spectrum for chlorophyll and the action spectrum for photosynthesis. Why are they different?**



A. Green and yellow wavelengths inhibit the absorption of red and blue wavelengths
B. Bright sunlight destroys photosynthetic pigments
C. Oxygen given off during photosynthesis interferes with the absorption of light
D. Other pigments absorb light in addition to chlorophyll 'a'

Action Spectrum

- Graph showing relative effectiveness of different wavelengths of light in driving photosynthesis is called action spectrum of photosynthesis.
- The first action spectrum was obtained by German biologist T.W. Engelmann in 1883. He worked on *Spirogyra*.
- Action spectrum can be obtained by illuminating plant with light of different wavelengths and then estimating relative CO_2 consumption or oxygen release during photosynthesis.
- Analysis of action spectrum indicates that ***blue (430nm) and red (670nm)*** wavelengths of light are most effective for the process of photosynthesis.



Comparison of Absorption and Action Spectra

- Action spectrum of photosynthesis corresponds to absorption spectrum of chlorophyll. The same two peaks and the valley are obtained for absorption of light as well as for CO_2 consumption.
- However, the action spectrum of photosynthesis does not parallel to the absorption spectrum of chlorophyll exactly.
- Photosynthesis in the most absorbed range is more than the absorption itself.
- Likewise, photosynthesis in 500-600nm (including green light) is more than the absorption of green light by chlorophylls. This difference occurs because of the accessory pigments.
- When equal intensities of light are given, there is more photosynthesis in red than in blue part of spectrum.

Feature	Absorption Spectrum	Action Spectrum
Peaks	Narrower	Broader
Valley	Broader and deep	Narrower and not deep

ROLE OF PHOTOSYNTHETIC PIGMENTS

- Pigment is any substance that absorbs light energy. All the wavelengths that are absorbed by the pigments are ***disappeared***.
- A particular pigment shows only those wavelengths which are reflected back.
- All the pigments that take part in photosynthesis are ***embedded in thylakoid membranes/grana lamellae*** within chloroplasts.
- Higher plants have two major groups of pigments i.e., ***chlorophyll and carotenoids***.

Chlorophylls

- They are ***important photosynthetic pigments*** of plants.
- They are ***insoluble in water*** but are ***soluble in organic solvents*** like carbon tetrachloride, alcohol etc.
- Chlorophyll 'a', 'b', 'c' and 'd' are found in eukaryotic photosynthetic plants and algae.
- ***Bacteriochlorophylls*** are found in photosynthetic bacteria.
- They mainly ***absorb violet-blue*** and ***orange-red wavelengths.*** Green, yellow and indigo wavelengths are least absorbed by chlorophylls and transmitted or reflected.

> **CRITICAL CONCEPT!**
>
> **Evolution of Chlorophyll:**
> Conversion of bacteriochlorophyll to chlorophyll a is the main basic point in evolution that shifted the life from reducing environment to oxidizing environment.

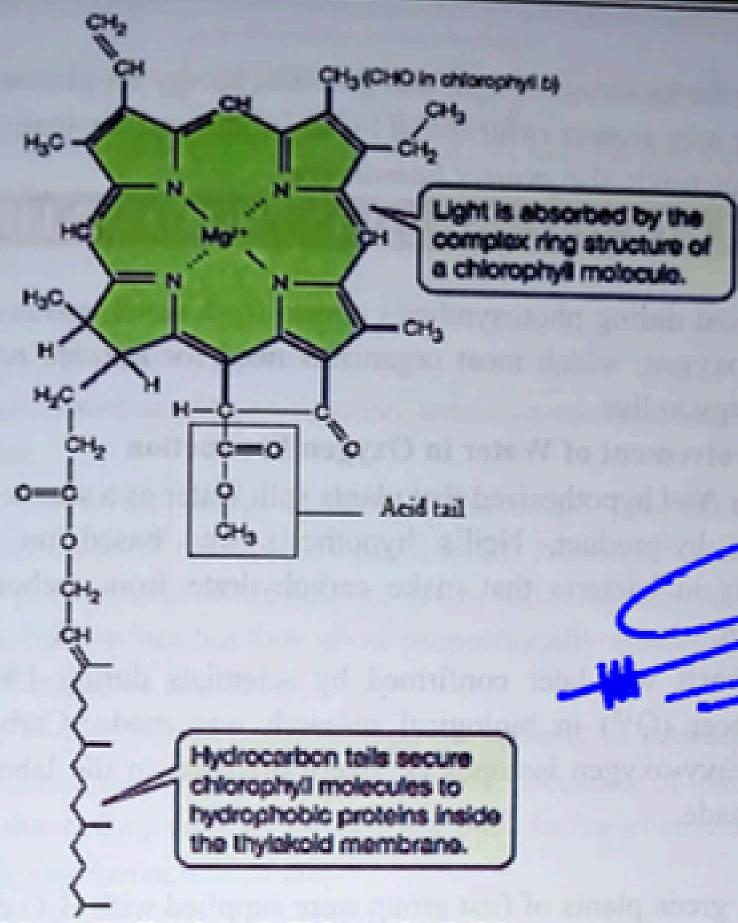
Structure

- A chlorophyll molecule has two parts i.e. ***hydrophilic head*** and a ***hydrophobic tail.***
- ***Hydrophilic head*** is flat, square, light absorbing complex porphyrin ring or tetrapyrrole ring structure containing magnesium as central metal ion, which is coordinated with nitrogen. The Mg^{2+} porphyrin complex has two side chain.
- The head region is exposed on the surface of thylakoid membrane.
- The haem portion of hemoglobin is also having a porphyrin ring but containing an iron atom instead of magnesium atom in the center.
- ***Acid chain*** is a methyl ester.
- ***Long hydrocarbon tail*** which is attached to one of the pyrrole rings is phytol ($C_{20}H_{39}$). The chlorophyll molecule is embedded in the hydrophobic core of thylakoid membrane by this tail.

Chlorophyll 'a' and 'b'

- Of all the chlorophylls, chlorophyll 'a' is the most abundant and the most important photosynthetic pigment.

  It takes part directly in the light dependent reactions.



Differences between Chlorophyll 'a' and Chlorophyll 'b'

Features	Chlorophyll 'a'	Chlorophyll 'b'
Molecular Formula	$C_{55}H_{72}O_5N_4Mg$	$C_{55}H_{70}O_6N_4Mg$
Functional Group	$-CH_3$	$-CHO$
Occurrence	All photosynthetic organisms except photosynthetic bacteria	Found alongwith chlorophyll 'a' in all green plants and green algae
Forms	Differ slightly in their red absorbing peaks e.g. 670,680,690,700 nm	No such different forms
Colour	Blue – green	Yellow- green

Carotenoids-Accessory Pigments

- Carotenoids are terpenoid lipids, which are yellow, orange, red and brown pigments. They absorb strongly the ***blue-violet wavelength of light***.
- ***Carotenoids and chlorophyll 'b'*** are called accessory pigments, since they absorb light and transfer the energy to chlorophyll 'a', which then initiate the light reaction. It is generally believed that the order of transfer of energy is:

  Carotenoids → Chlorophyll 'b' → Chlorophyll 'a'
- There are two types of carotenoids; ***carotenes and xanthophylls***. The carotenes are orange-red pigments composed of isoprenoid units and are found in all photosynthetic eukaryotes. The most widespread and important carotene is β-carotenes.
- ***Xanthophylls are yellow to orange*** in colour that are oxygen containing derivatives of carotenes. Lutein and zeaxanthin ($C_{40}H_{56}O_2$) are the two primary xanthophylls found in green leafy vegetables and other foods like eggs. Yellow colour of leaves in autumn is due to lutein. The xanthophylls of brown algae is called fucoxanthin ($C_{40}H_{56}O_6$).

Functions

- They broaden the spectrum of light that provides energy for photosynthesis.
- Some of these may ***protect chlorophyll*** by absorbing and dissipating intense light.
- Similarly, carotenoids also ***protect human eyes***.

ROLE OF H_2O AND CO_2 IN PHOTOSYNTHESIS

Role of Water

- Oxygen released during photosynthesis comes from water and is an important source of atmospheric oxygen, which most organisms need for ***aerobic respiration*** and thus for obtaining energy to live.

Discovery about Involvement of Water in Oxygen Production

- In 1930s, ***Van Niel*** hypothesized that plants split water as a source of hydrogen, releasing oxygen as a by-product. Neil's hypothesis was based on his investigations on photosynthesis in bacteria that make carbohydrate from carbon dioxide, but do not release oxygen.
- Neil's hypothesis was later confirmed by scientists during 1940s when first use of biological tracer (O^{18}) in biological research was made. Carbon dioxide and water containing heavy-oxygen isotopes O^{18} were prepared in the laboratory. Two groups of plants were made.

First Group

- Experimental green plants of first group were supplied with H_2O containing O^{18} and with CO_2 containing common oxygen O^{16}.
  These plants produced O^{18}.

$$\text{Group} - 1 \text{ plants: } CO_2 + 2H_2O^{18} \longrightarrow CH_2O + H_2O + O_2^{18}$$

Second Group

- Plants in the second group were supplied with H_2O containing common oxygen O^{16} but with CO_2 containing O^{18}.
  These plants did not produce O^{18}.

$$\text{Group 2 Plants: } CO^{18}{}_2 + 2H_2O \longrightarrow CH_2O^{18} + H_2O^{18} + O_2$$

These experiments showed that oxygen produced during photosynthesis comes from water.

ole of CO_2 in Photosynthesis

urce of CO_2

Carbon dioxide acts as carbon source for the synthesis of organic compounds in photosynthesis. Therefore, plants are known as autotrophs because they use inorganic compounds for the synthesis of their organic compounds.

Reduction of CO_2 is done during light-independent reactions of photosynthesis by using ATP and NADH (products of light-dependent reaction). Due to this, sugar is formed. This shows that photosynthesis is not possible in the absence of CO_2.

About **10 *percent*** of total photosynthesis is carried out by terrestrial plants, and the rest occurs in oceans, lakes and ponds.

Aquatic photosynthetic organisms use dissolved CO_2, bicarbonates and soluble carbonates that are present in water as carbon source.

Photosynthesis occurring on land utilizes atmospheric CO_2. Air contains ***0.03-0.04*** percent of CO_2.

CRITICAL THINKING

2. **The splitting of carbon dioxide to form oxygen gas and carbon compounds occurs during:**
   A. Photosynthesis
   B. Respiration
   C. Both photosynthesis and respiration
   D. Neither photosynthesis nor respiration

Passage of CO_2 in Plants

- Carbon dioxide enters the leaves through stomata and gets dissolved in the water absorbed by the cell wall of mesophyll cells. Stomata are found in large number in a leaf. Their number is proportional to the amount of gas diffusing into the leaf. ***Stomata*** cover only ***1-2%*** of the leaf surface but they allow proportionally much more CO_2 to diffuse.

Effect of Opening and Closing of Stomata

- The entry of CO_2 into the leaves depends upon the opening of ***stomata***.
- Stoma is an opening surrounded by ***guard cells***. Because of peculiar structure and changes in their shape, they regulate the opening and closing of stomata.
- Stomata are adjustable pores, which are;

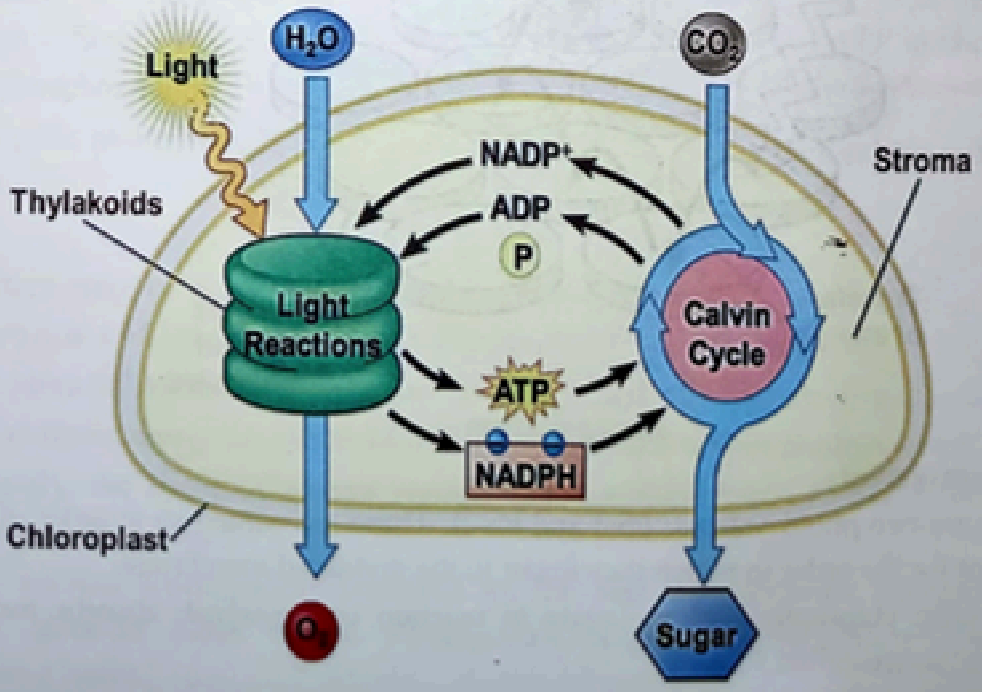
1. Open during daytime when CO_2 is required.
2. Closed at night when photosynthesis stops.

MECHANISM OF PHOTOSYNTHESIS AND PHOTOSYSTEMS

- Photosynthesis is a 'redox process'.
- Overall equation of photosynthesis is:

$$6CO_2 + 12H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light}} C_6H_{12}O_6 + 6O_2 + 6H_2O$$

- These reactions of photosynthesis consist of two parts i.e. light-dependent reactions and light-independent reactions.



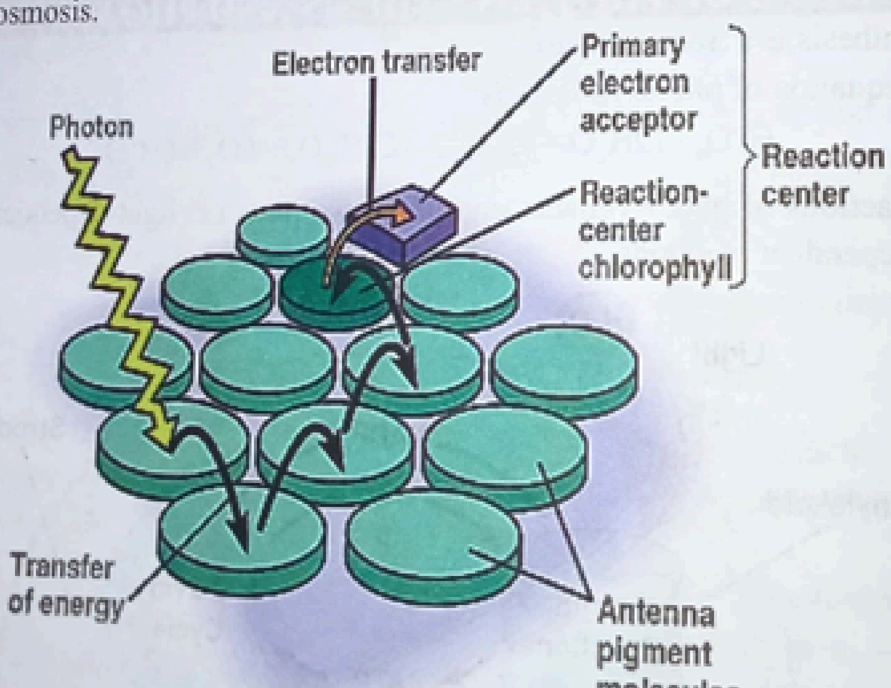
- Light dependent phase occurs on ***thylakoid membrane***. In this phase, light energy is used to make ***ATP*** and ***NADPH***; whereas water and oxygen are supposed to be input and output, respectively.
- Light independent phase occurs in ***stroma of chloroplast*** and requires the products of light reactions i.e., ATP and NADPH. Since these products are available in day-time, therefore, dark reactions also occur in day time. In this phase, CO_2 acts as input which is converted into G3P, the output of this phase.

Arrangement of Pigments (Photosystems)

- Photosynthetic pigments are organized into clusters called ***photosystems***.
- Photosystems are meant for efficient absorption and utilization of solar energy and are ***located on thylakoid membranes***.
- Each photosystem consists of two parts:

(i) The peripheral part of photosystem is called ***antenna complex*** which consists accessory pigments such as chlorophyll 'b' and carotenoids, which channelize energy to reaction centre.

(ii) The central part of the photosystem is called as ***reaction centre*** and is constituted by chlorophyll 'a' along with primary electron acceptor and associated electron carriers of electron transport system. Electron transport system plays role in generation of ATP by chemiosmosis.



Photosystem

Types of Photosystem

- There are two photosystems; PS-I and PS-II. These are named so in order of their discovery and not for the order in which they occur in the thylakoid membrane.
- ***PS-I*** have chlorophyll 'a' molecule in reaction centre which absorbs maximum light of 700nm, hence called P_{700}.

- *PS-II* has a form of chlorophyll 'a' molecule in reaction centre which absorbs maximum light of 680nm, hence called ***P_{680}***.
- As chlorophyll 'a' can absorb light of a narrow wavelength, it works with the pigments of antenna complex to gain energy from a larger part of the spectrum. The pigments absorb light of various wavelengths and pass along their gained energy to chlorophyll 'a' of the reaction centre.
- When the energy reaches the chlorophyll 'a', its electrons become so excited that they escape and move to a nearby electron transport chain. In this way, chlorophyll molecule is oxidized.

LIGHT DEPENDENT REACTIONS

Such types of reactions, which require light and constitute that phase of photosynthetic reaction during which light energy is absorbed by chlorophyll and other photosynthetic pigments and is converted into chemical energy are called ***light reactions***.

As a result of this energy conversion, reducing and assimilating powers in the form of $NADPH_2$ ($NADPH + H^+$) and ATP are formed. Both temporarily store energy and carry along with H^+ to the light independent reactions.

The production of ATP during light reaction is called ***photophosphorylation*** and the mechanism is called ***chemiosmosis.*** The most important event in light reaction is the production of ATP.

Non-Cyclic Photophosphorylation

- It is predominant pathway of light reaction in higher plants that occurs in routine. In this process, both photosystems are utilized and two electron transport chains are involved.
- Formation of ATP during non-cyclic electron flow is called non-cyclic photophosphorylation.

> **CRITICAL CONCEPT!**
>
> **Redox Reactions in Living Systems:**
> In ETC, all molecules oxidize and reduce in the same manner and sequence. This oxidation and reduction produce energy that can be utilized for the formation of ATP in chemiosmosis.

- Non-cyclic photophosphorylation is also called ***Z-scheme,*** due to flow of electrons in Z-shape.

Mechanism

- Important steps of non-cyclic photophosphorylation are:

(i) **Absorption of Light by PS-II and Excitation of its Electrons**

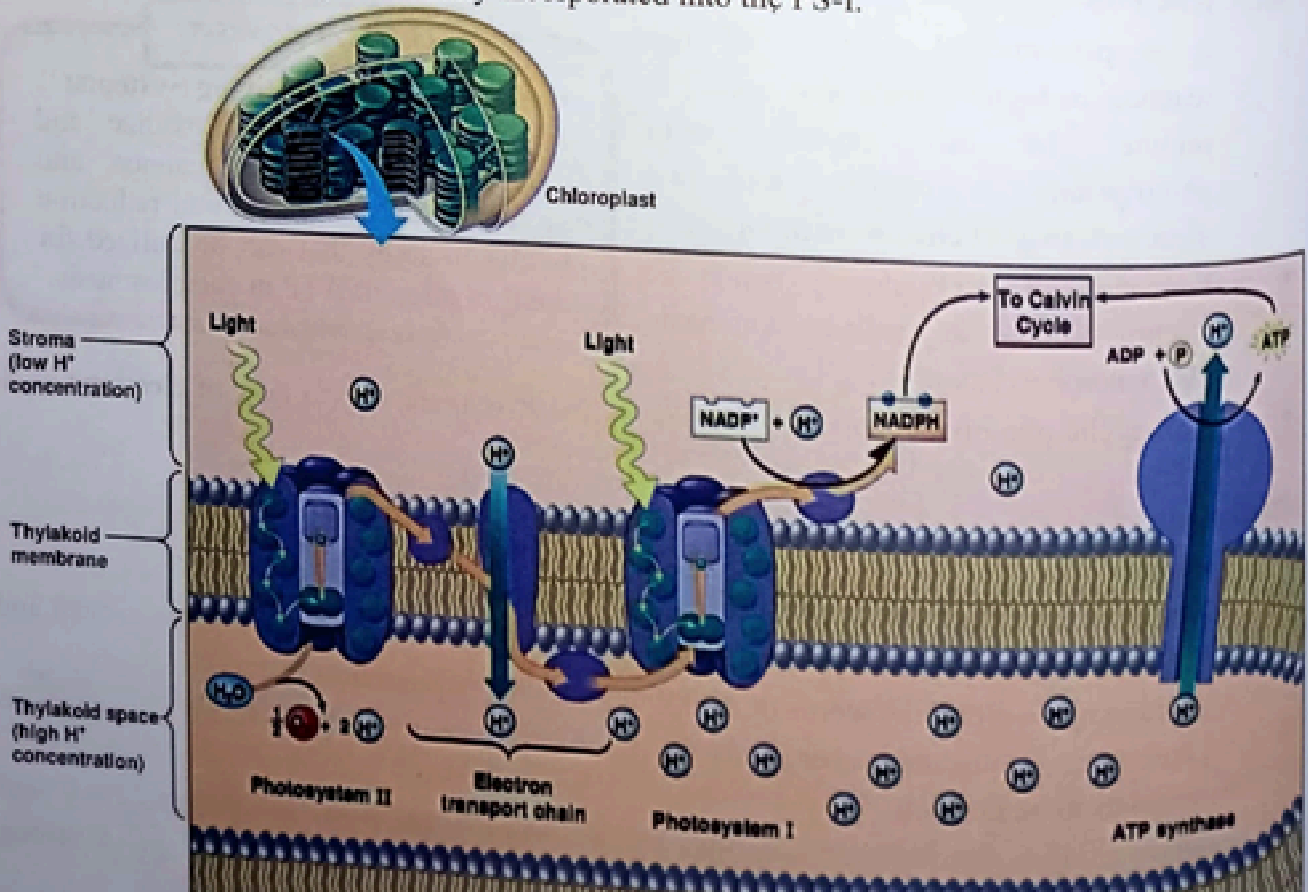
- When photons strike the antenna complex of PS-II, the two electrons become excited and begin to move along the atoms of different pigments within photosystems.
- Ultimately, the absorbed energy reaches the reaction centre of PS-II (P_{680}) and causes its electrons to be excited.
- These excited electrons are captured by the ***primary electrons acceptor*** of PS-II and leaves ***electron holes*** in the photosystem behind making chlorophyll 'a' a strong oxidizing agent.

(ii) Photolysis of Water

- The electron holes of photosystem must be filled so that in the presence of water splitting enzyme reactions can proceed.
- When water reacts with oxidized state of chlorophyll in photosystem, it ***breaks up into $2H^+$, $2e^-$, and $\frac{1}{2}O_2$***. The electrons released from water are used to fill the electron holes of PS-II

(iii) Electron Flow from PS-II to PS-I

- The energized electrons, captured by the primary electron acceptor, now begin to flow to PS-I through an electron transport chain.
- The electrons move from ***primary electron acceptor (pheophytin) to plastoquinone (Q_A & Q_B)***. From Pq, the electrons flow through ***cytochrome complex***, which consist of ***cyt-b_6 and cyt-f***.
- The cytochrome complex is not only an electron carrier but it also works as ***proton pump***. The electron flow through the cytochrome complex stimulates it to pump the protons from stroma to thylakoid interior space. In this way, the energy of flowing electrons is transformed into a ***gradient of protons.***
- The proton gradient activates an enzyme in thylakoid membrane called ATP synthase which not only moves the proton back into the stroma but also catalyzes a reaction in which ADP and Pi are combined to form ATP.
- This whole mechanism which involves the flow of electrons, pumping of protons and generation of ATP by thylakoid membranes is called ***chemiosmosis***.
- The energized electrons, after losing their energy, move from cytochrome complex to the ***plastocyanin (Pc)*** and finally incorporated into the PS-I.



(iv) Absorption of Light by PS-I and Excitation of its Electrons

- When P_{700} in the reaction centre of PS-I molecule absorbs photons of light, electrons are boosted to a higher energy level. P_{700} molecule passes these excited electrons to a primary electron acceptor of PS-I, thus creating ***'electron holes'***.
- The electron holes of P_{700} are filled by the electrons received from the ***P_{680} (PS-II)*** via electron transport chain.

(v) Electrons flow from PS-I to $NADP^+$

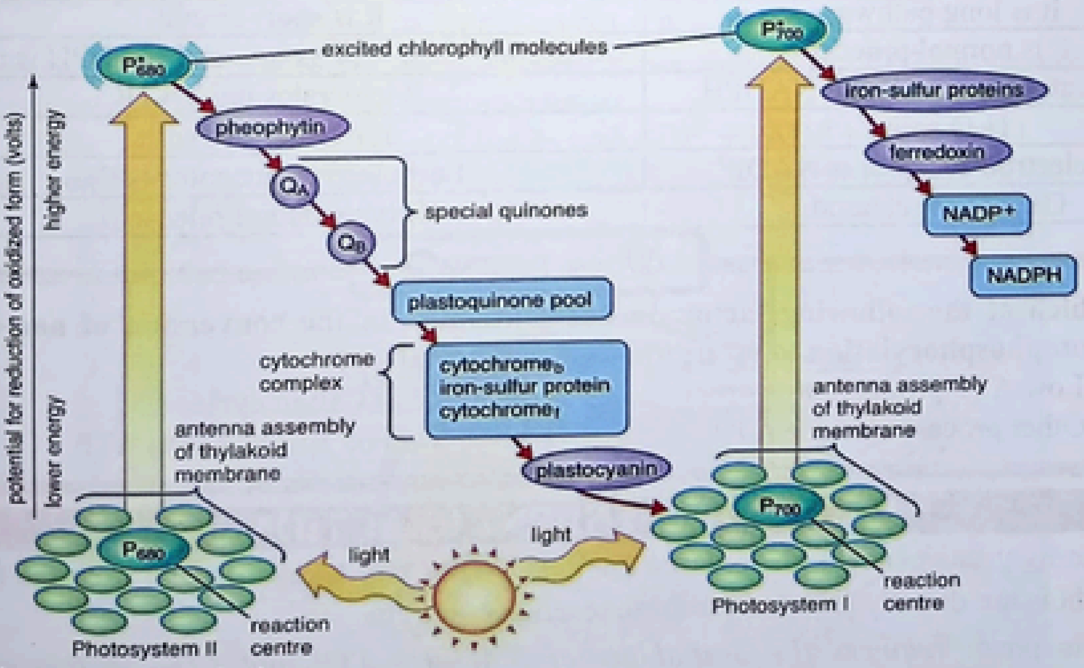
- The primary electron acceptor of PS-I passes the photo-excited electrons to a second electron transport chain. These electrons are accepted by ***iron containing Ferredoxin (Fd).***
- An enzyme called, ***NADP reductase (a Flavoprotein)*** transfers the electrons from Fd to $NADP^+$.
- $NADP^+$ combines with electrons and H^+ to form NADPH.
- ***One photon excites one electron.***

Passage of Electrons

PS II → PEA → Pq → Cytochrome Complex → Pc → PS I → PEA → Fd → $NADP^+$

End Products of Light Reaction

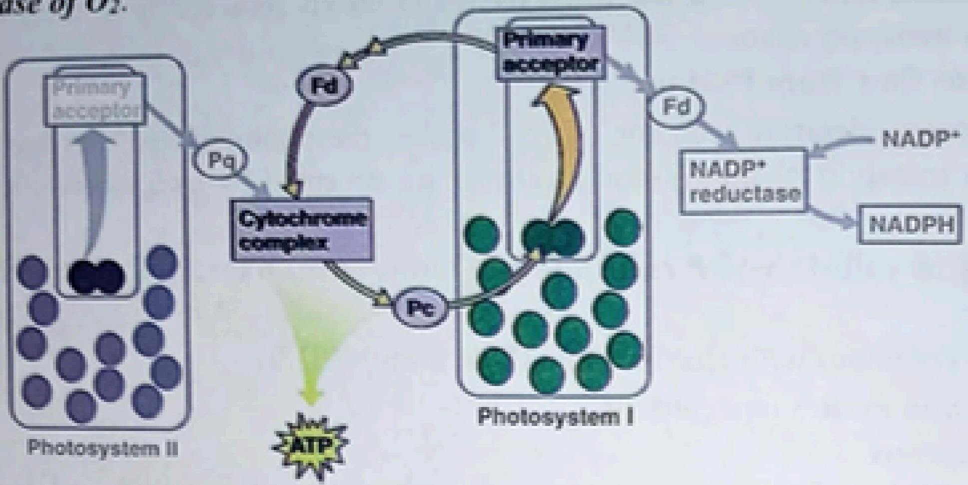
- NADPH/ $NADPH_2$
- ATP
- Molecular oxygen



Cyclic Photophosphorylation

- The rise in NADPH and deficit of ATP may stimulate a temporary shift from a non-cyclic to cyclic electron flow until ***ATP supply catches up the demand***.
- In this mechanism, ***only PS-I is utilized***.
- It absorbs energy from photon. When energy reaches the reaction centre of PS-I, the electrons are boosted up to higher energy level. Such excited electrons are first captured by the primary electron acceptor of PS-I, then they move through an electron transport chain containing ferredoxin, cytochrome b_6-f complex and plastocyanin.

- When electron passed from cytochrome b_6-f complex, ATP molecules are generated by chemiosmosis.
- Finally, the electrons after losing the energy return back to P_{700} in PS-I reaction centre. There is ***no production of NADPH, no occurrence of photolysis of water*** and therefore, ***no release of O_2***.



Comparison of Cyclic and Non-Cyclic Phosphorylation

Non-Cyclic Photophosphorylation	Cyclic Photophosphorylation
Electrons are not reused.	Electrons are reused.
First electron donor is water	First electron donor is PS-I
It involves both PS-I and PS-II.	It involves only PS-I.
It is long pathway.	It is short circuit.
It is normal process.	It occurs when ATP is less and NADPH is more.
It generates both ATP and NADPH.	It generates only ATP.
H_2O splits.	H_2O does not split
Last electron acceptor is $NADP^+$	Last electron acceptor is P_{700}
Oxygen is released.	Oxygen is not released.

CRITICAL THINKING

3. **Which of the following factor do not contribute in the conversion of non-cyclic photophosphorylation to cyclic photophosphorylation?**
   A. Low ATP production
   B. Fast rate of Calvin cycle
   C. Other process also use ATP
   D. High level of NADPH than ATP

LIGHT INDEPENDENT REACTIONS

- The light independent phase/dark reaction/Calvin cycle takes its name from the fact that light is not directly required for these reactions to occur.
- This phase ***requires the availability of NADPH, ATP and CO_2***. In this phase of photosynthesis, NADPH is used to reduce CO_2 and ATP is used to incorporate energy.
- Finally, CO_2 is converted into G3P, which is later used to make glucose.
- These reactions take place in ***stroma of chloroplast***.
- It is divided into three steps:

(i) Carbon fixation
(ii) Reduction
(iii) Regeneration of CO_2 acceptor

CO_2 Fixation

- Carbon fixation refers to the initial incorporation of CO_2 into organic material/***RuBP***. It is generally referred as CO_2 acceptor because it is capable of combining with CO_2 with the help of ***RuBisCO***, which is most abundant protein in chloroplasts and probably the most abundant protein on earth.
- Three intermediate molecules of six carbons are formed during this reaction. These molecules are ***highly unstable*** and exist for such a short time that they cannot be isolated.
- Each six carbon molecules breaks down to form two molecules of 3-PGA, a phosphorous containing compound with three carbon atoms.

$$\mathbf{CO_2 + RuBP\ (C_5) \rightarrow C_6\ Intermediate\ compound \rightarrow 2\ PGA\ (C_3)}$$

Reduction

- In this phase, six molecules of 3-PGA react with six ATP molecules, a phosphate from each ATP is transferred to each 3-PGA.
- In this way, 3-PGA molecule converted into 1,3-bisphosphoglycerate. These molecules are then reduced by NADPH and finally glycereldehyde 3-phosphtae (G3P) molecules are produced.
- Total six molecules of G3P are produced in this phase but only one molecule is released from the cycle while rest of the five molecules is used to regenerate the CO_2 acceptor molecules in the next phase.

$$\mathbf{PGA + ATP + NADPH_2 \rightarrow PGAL + ADP + P_i + NADP^+ + H_2O}$$

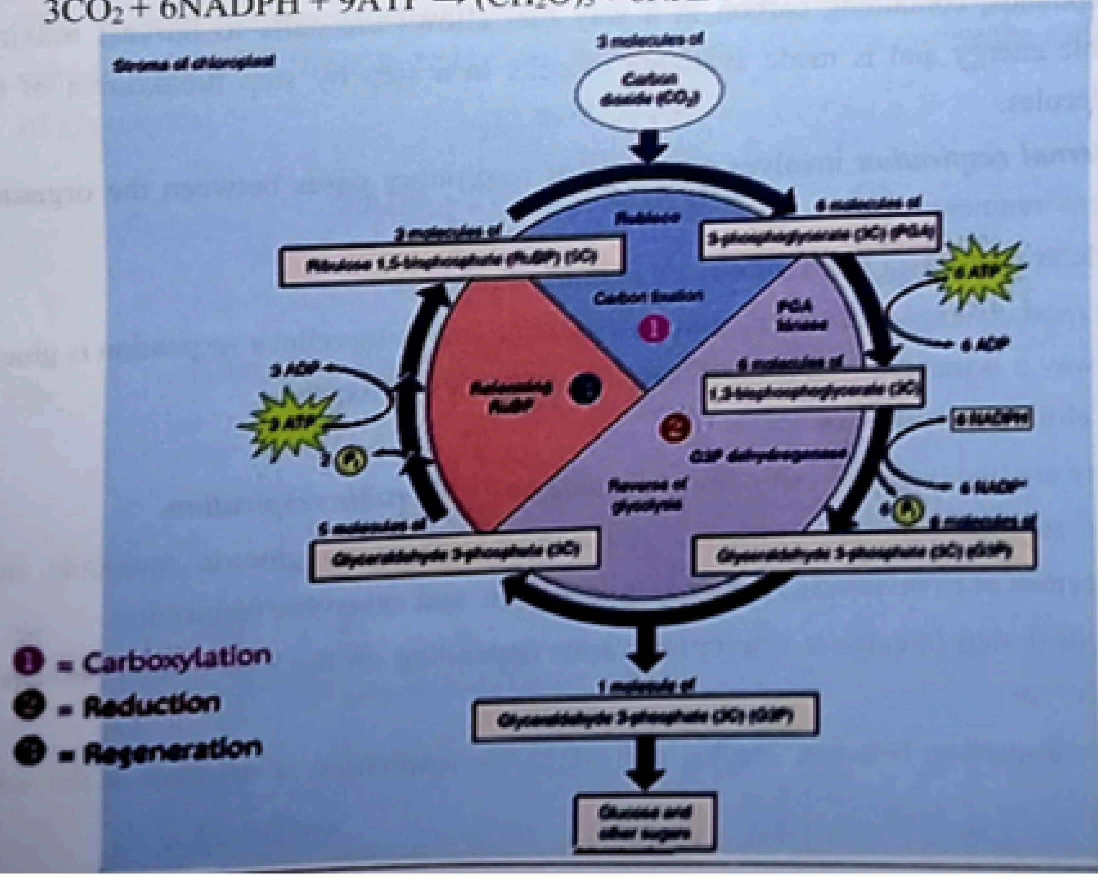
Regeneration of RuBP

- In this phase, five molecules of G3P are used to regenerate three molecules of RuBP.
- This conversion requires energy that is provided by ATP from light reactions. For regeneration of 3 molecules of RuBP, 3 ATP molecules are consumed.

$$\mathbf{5PGAL + ATP \rightarrow ADP + P_i + 3\ RuBP}$$

- However, in order to produce glucose molecule, two molecules of G3P are required. The overall process of Calvin cycle is represented as:

$$3CO_2 + 6NADPH + 9ATP \rightarrow (CH_2O)_3 + 6NADP^+ + 9ADP + 9Pi + 3H_2O$$



CRITICAL THINKING

4. **Calvin cycle is also known as dark reactions. In cyclic pathway using products of light reaction, carbohydrate is produced. How many molecules of ATP and NADPH are used in synthesis of a polymer having 20 glucose molecules?**
   A. 360 ATP and 180 NADPH
   B. 360 ATP and 240 NADPH
   C. 180 ATP and 360 NADPH
   D. 180 ATP and 120 NADPH
5. **Assume a thylakoid is somehow punctured so that the interior of the thylakoid is no longer separated from the stroma. This damage will have the most direct effect on which of the following processes?**
   A. The splitting of water
   B. Absorption of light energy by chlorophyll
   C. The synthesis of ATP
   D. The reduction of $NADP^+$

Comparison of Light and Dark Reactions

Features	Light Reactions	Dark Reactions
Site	Grana of chloroplast	Stroma of chloroplast
Requirement of Light	Yes	No
Products	O_2, ATP and $NADPH_2$ are the end products.	In Calvin cycle, ATP and $NADPH_2$ are used to prepare carbohydrates (G3P)

CELLULAR RESPIRATION

- ***Cellular respiration*** is the universal process by which organisms breakdown complex compounds, containing carbon in a way that allows the cells to harvest maximum of usable energy and is made available to cells in a step by step breakdown of C-chain molecules.
- ***External respiration*** involves exchange of respiratory gases between the organism and its environment.
- Cellular respiration is ***essentially an oxidation*** process.
- The most common fuel used by the cell to provide energy by cellular respiration is glucose and the way it is metabolized depends on the ***availability of oxygen***.

Types of Cellular Respiration

- There are two types of respirations: ***aerobic and anaerobic respiration***.
- First step of cellular respiration (Glycolysis that splits glucose molecule into two molecules of pyruvic acid) is common in aerobic and anaerobic respiration.
- The next step in cellular respiration varies depending on the type of cell and prevailing conditions.
- The comparison between aerobic and anaerobic respiration is mention in the following table.

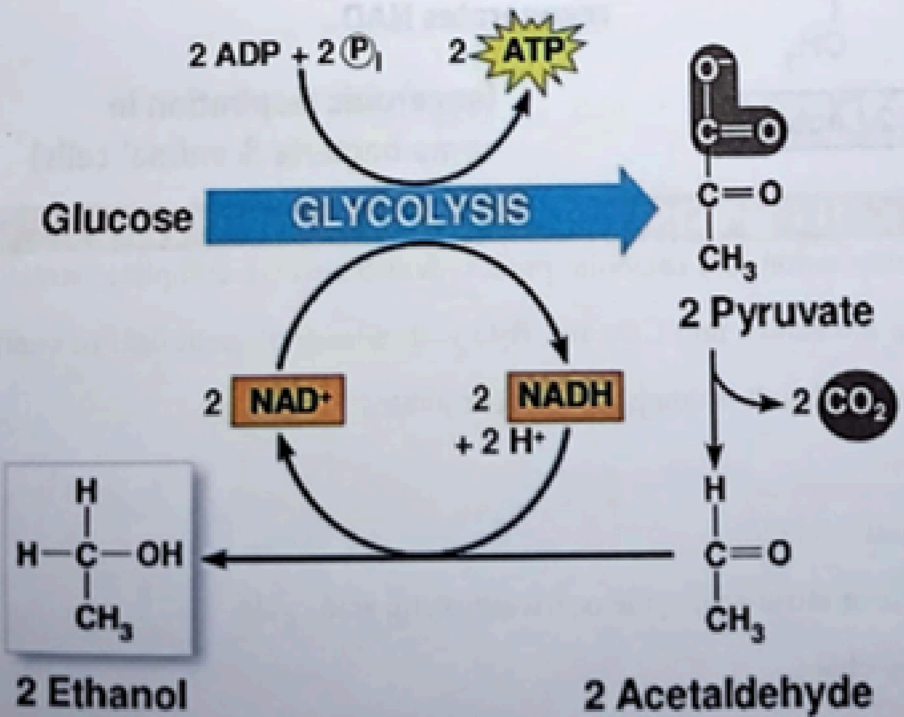
Feature	Aerobic Respiration	Anaerobic Respiration
Involvement of Oxygen	Occurs in presence of O_2	Occurs in absence of O_2
Reactants	Glucose & O_2	Glucose
Glucose Breakdown	Involves complete breakdown of glucose	Involves incomplete breakdown of glucose
End Products	CO_2, H_2O and energy	Lactic acid or Ethyl alcohol & CO_2
ATP Formed	Total: 40 ATP Net: 36 or 38 ATP	Total: 4 ATP Net: 2 ATP
Location in Eukaryotic Cell	Mitochondria	Cytoplasm

Mechanism of Anaerobic Respiration

- Anaerobic respiration is incomplete breakdown of glucose in the absence of oxygen. It is also known as ***fermentation***. There are two pathways of anaerobic respiration depending upon the nature of final products.

(i) **Alcoholic Fermentation**

- Alcoholic fermentation is ***found in yeast***. It consists of glycolysis followed by the decarboxylation of pyruvate to acetaldehyde and then reduction of acetaldehyde by NADH to ethyl alcohol.
- This pathway operates anaerobically because after NADH transfers its electron to acetaldehyde, it is 'free' to return and pick up more electrons during the earlier reactions of glycolysis.



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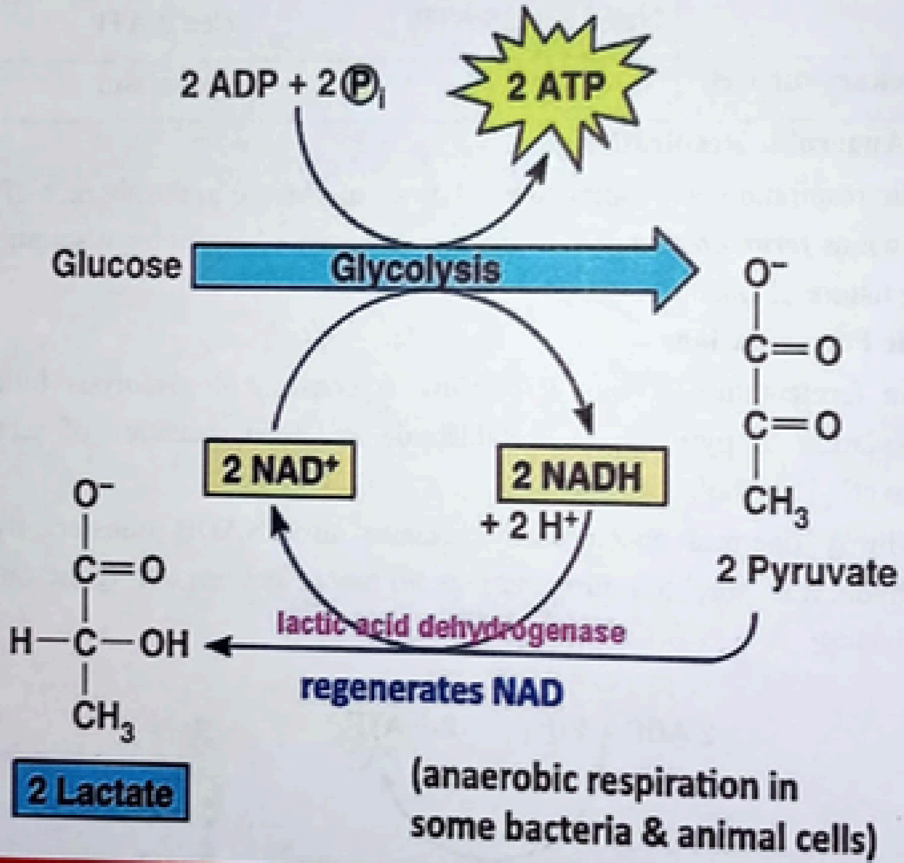
Lactic Acid Fermentation

> **CRITICAL CONCEPT!**
>
> **Cori Cycle:**
> Lactic acid produced in skeletal muscle is converted to glucose in the liver, and transported back to skeletal muscle.

- It consists of glycolysis followed by the reduction of pyruvate by NADH to lactic acid.
- It ***occurs in anaerobic bacteria and muscle cells*** of humans and other animals during strenuous physical activities when oxygen supply is exhausted. The ***accumulation of lactic acid causes muscle fatigue*** and muscles become unable to contract.



MECHANISM OF AEROBIC RESPIRATION

- Aerobic respiration is a catabolic process which involve complete oxidative breakdown of organic molecules into CO_2 and H_2O with release of great deal of energy in the form of ATP molecules. It is completed in four phases:

(i) Glycolysis

(ii) Pyruvic acid oxidation

(iii) Krebs cycle or citric acid cycle or tricarboxylic acid cycle

(iv) Respiratory chain

Lactic Acid Fermentation

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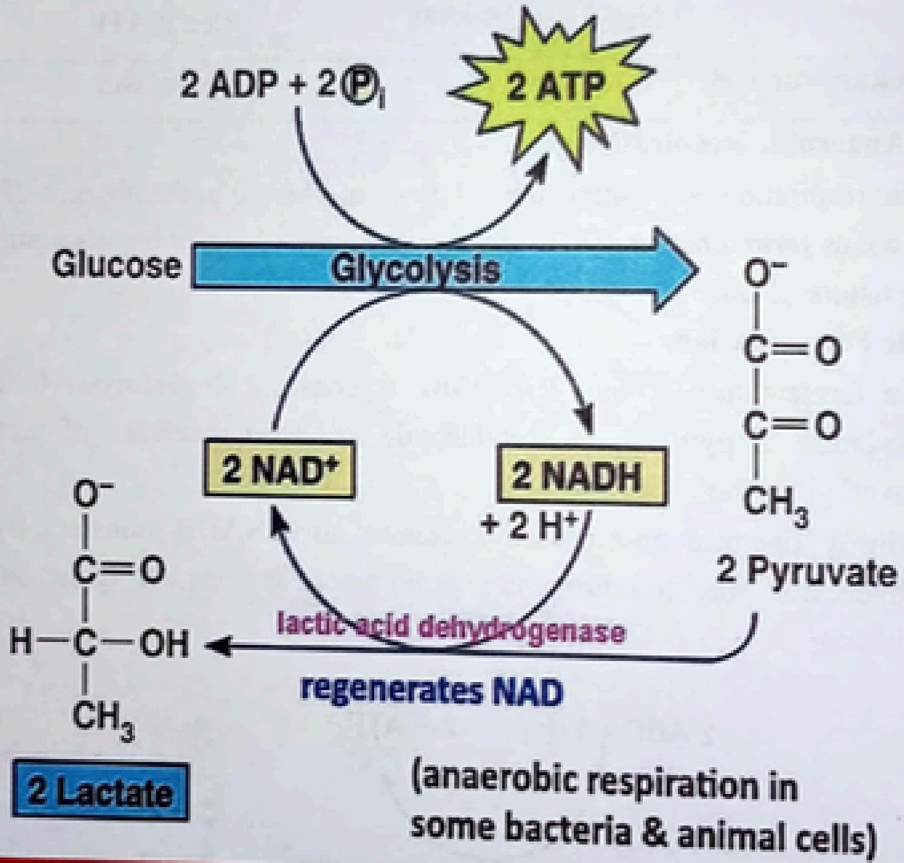

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(iv) Respiratory chain

GLYCOLYSIS

- Glycolysis is the breakdown of glucose or similar hexose into two molecules of pyruvic acid through a series of enzymatic reactions releasing some molecules of ATP and NADH.
- It occurs in ***cytoplasm***.
- It takes place in the absence (***Anaerobic***) or in the presence of O_2 (***Aerobic***).
- Enzymes, ATP, and Coenzyme NAD^+ are essential for glycolysis.

Phases of Glycolysis

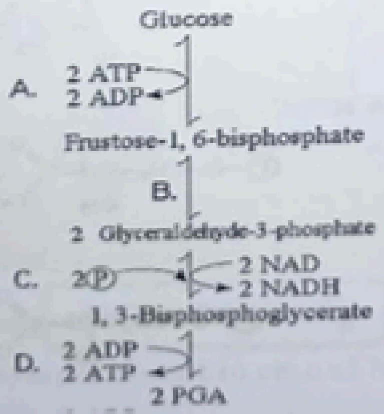
- There are two phases of glycolysis i.e. ***preparatory phase*** and ***oxidative phase***.
- ***Preparatory phase*** is an investment phase in which two ATP molecules are consumed. Its end products are two molecules of G3P, and one molecule of DHAP which will also isomerizes to form G3P.
- ***Oxidative or pay off phase*** is characterized by the ATP production through ***substrate level phosphorylation***. It also produces NADH which upon further oxidation in respiratory electron transport chain yields more ATP molecules.

CRITICAL THINKING

6. Which of the following conversions shows the activity of Kinase?

A. Phosphoenol pyruvate to Pyruvate
B. 1, 3-Bisphosphoglycerate to 3-Phosphoglycerate
C. Fructose 6-phosphate to Fructose 1, 6 bisphosphate
D. α-Ketoglutarate to Succinate

7. A summary of glycolytic reactions is given. Mention a point where redox reaction is taking place.

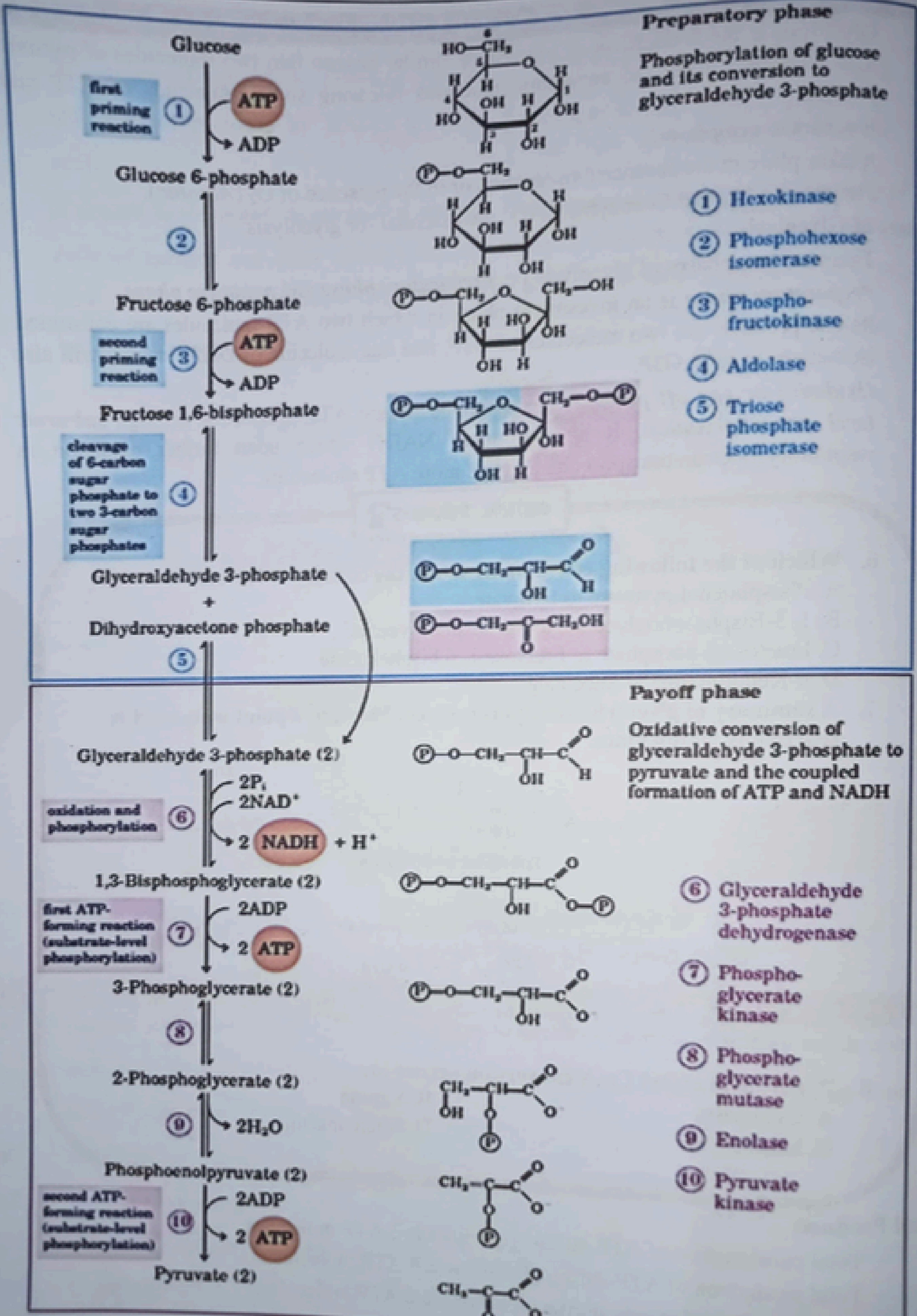


8. Pyruvate to acetyl Co-A conversion occurs in:

A. Cytoplasm
B. Stroma
C. Matrix
D. Nucleoplasm

End Products

- Total consumption of ATP during glycolysis is 2 ATP molecules.
- Total production of ATP during glycolysis is 4 ATP molecules.
- Net production of energy during glycolysis is 2 ATP molecules.


Preparatory phase
Phosphorylation of glucose and its conversion to glyceraldehyde 3-phosphate
Glucose
first priming reaction
1
ATP
ADP
Glucose 6-phosphate
2
Fructose 6-phosphate
second priming reaction
3
ATP
ADP
Fructose 1,6-bisphosphate
cleavage of 6-carbon sugar phosphate to two 3-carbon sugar phosphates
4
Glyceraldehyde 3-phosphate
+
Dihydroxyacetone phosphate
5
1 Hexokinase
2 Phosphohexose isomerase
3 Phospho-fructokinase
4 Aldolase
5 Triose phosphate isomerase
Payoff phase
Oxidative conversion of glyceraldehyde 3-phosphate to pyruvate and the coupled formation of ATP and NADH
Glyceraldehyde 3-phosphate (2)
2Pᵢ
2NAD⁺
oxidation and phosphorylation
6
2 NADH + H⁺
1,3-Bisphosphoglycerate (2)
first ATP-forming reaction (substrate-level phosphorylation)
7
2ADP
2 ATP
3-Phosphoglycerate (2)
8
2-Phosphoglycerate (2)
9
2H₂O
Phosphoenolpyruvate (2)
second ATP-forming reaction (substrate-level phosphorylation)
10
2ADP
2 ATP
Pyruvate (2)
6 Glyceraldehyde 3-phosphate dehydrogenase
7 Phospho-glycerate kinase
8 Phospho-glycerate mutase
9 Enolase
10 Pyruvate kinase

PYRUVIC ACID OXIDATION

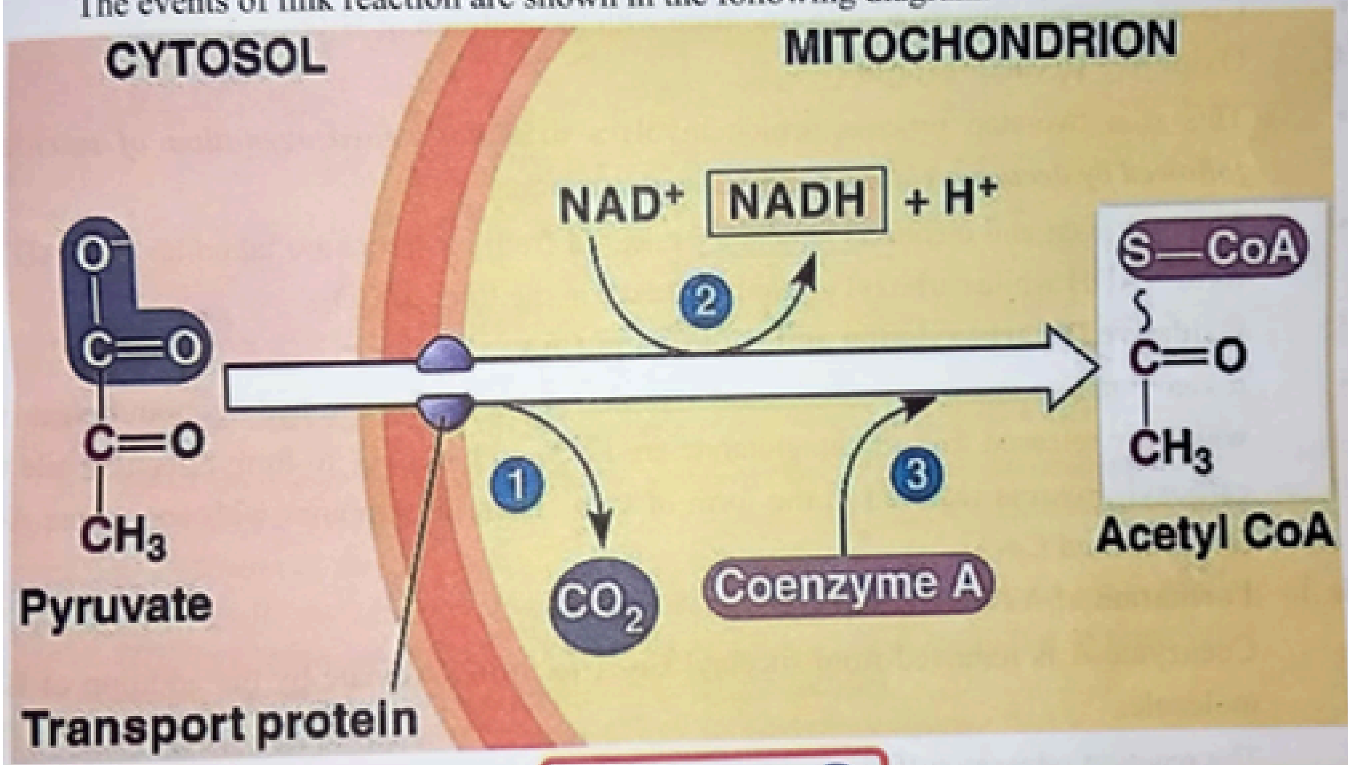
Because pyruvate is a charged molecule, it must enter the mitochondrion via active transport with the help of transport protein called *pyruvate translocase*.

On entering the mitochondria, pyruvate molecules do not directly participate in Krebs cycle but they undergo an intermediate phase, called ***oxidation of pyruvate*** or ***link reaction***.

CRITICAL CONCEPT!

Relationship b/w Pyruvic Acid and Lactic Acid:
Pyruvic acid is less dangerous than the Lactic acid but it is converted into lactic acid during anaerobic conditions. This lactic acid fermentation gives NAD^+ that works in the glycolysis to maintain minimum supply of energy in anaerobic condition i.e., 2 ATPs.

The events of link reaction are shown in the following diagram.



CRITICAL THINKING

9. **Which of the following enzyme is absent in case of MODY and cause high glucose level in blood?**
   A. Glucokinase
   B. Phosphofructokinase
   C. Pyruvate kinase
   D. Enterokinase

KREBS CYCLE

- This cyclic metabolic pathway was discovered by British Scientist Sir Hans Krebs. Therefore, it is also called ***citric acid cycle*** or ***tricarboxylic acid (TCA) cycle*** because the first compound which is formed in the cycle is citrate/citric acid that contains three carboxylic groups. The Krebs cycle comprises following steps.

1. **Synthesis**
- Acetyl CoA and H_2O molecule combine with oxaloacetate to form citrate/citric acid. It is the first product of Krebs cycle. ***CoA is liberated***.

2. **Dehydration**
- Citrate undergoes re-organization by the removal of H_2O molecule. The resulting compound is ***cis-aconitate***.

3. **Hydration**
- Cis-aconitate is converted into isocitrate with the addition of H_2O.

4. **Oxidative Decarboxylation**
- This is a two-step process, which involves ***oxidation/dehydrogenation of isocitrate, followed by decarboxylation*** to form α-ketoglutarate.
- The hydrogen and electrons which are released from isocitrate are taken up by NAD^+ to form NADH while carboxyl group is released in the form of CO_2.

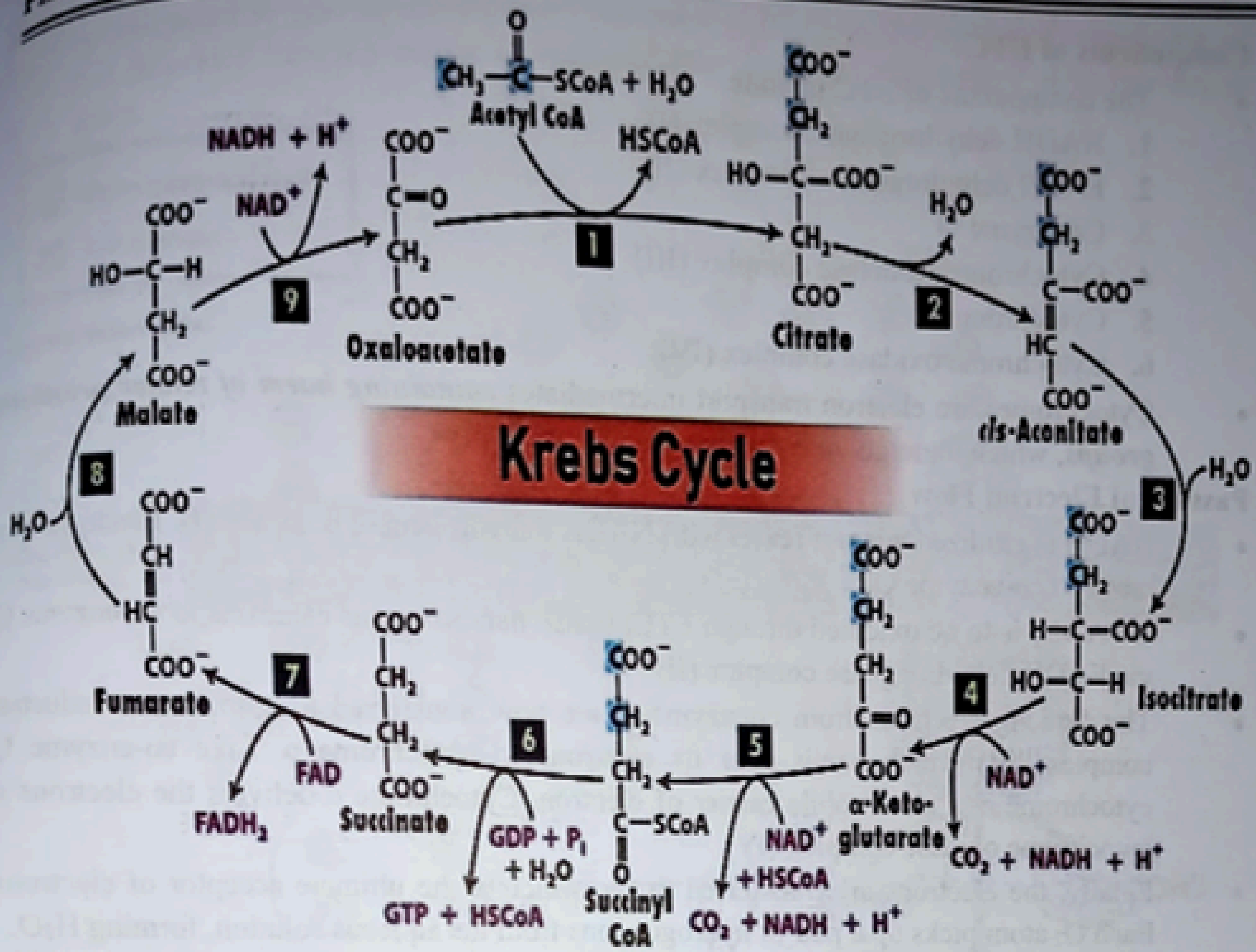
5. **Oxidative Decarboxylation and Addition of CoA**
- α-ketoglutarate again undergoes oxidative decarboxylation. The hydrogen and electrons which are released from α-ketoglutarate are taken up by NAD^+ to form NADH while the carboxyl group is released in the form of CO_2. Then, it combines with coenzyme-A to form succinyl Co-A.

6. **Formation of ATP**
- Coenzyme-A is removed from succinyl Co-A to form succinate by the addition of H_2O molecule.
- The reaction releases sufficient energy which is used to generate ATP molecules.

7. **Dehydrogenation/Oxidation**
- Succinate undergoes dehydrogenation/oxidation to form fumarate. The hydrogen and electrons which are released from succinate are taken up by FAD to form $FADH_2$.

8. **Hydration**
- A H_2O molecule gets added to fumarate to form malate.

9. **Dehydrogenation/Oxidation**
- Malate undergoes dehydrogenation/oxidation to produce oxaloacetate.
- The hydrogen and electrons which are released from malate are taken up by NAD^+ to form NADH.
- Oxaloacetate picks up another molecule of acetyl CoA to repeat the cycle.



CRITICAL THINKING

10. All of the following reactions involve reduction of coenzymes except:

A. Succinate to fumarate B. Isocitrate to α-ketoglutarate
C. Pyruvate to acetyl Co-A D. Fumarate to malate

11. TCA cycle involves inter-conversion of carbohydrate molecules. Which of the following process takes place only once during the completion of one cycle?

A. Isomerization B. Reduction
C. Oxidation D. Decarboxylation

- One Krebs cycle yields one molecule of ATP, three molecules of NADH and one molecule of $FADH_2$.

RESPIRATORY CHAIN/ELECTRON TRANSPORT CHAIN

- After Krebs cycle, most of the energy of glucose is in the form of NADH and $FADH_2$ molecules which will get enter into the ETS.
- The reduced NADH and $FADH_2$ are oxidized and their electrons are passed along a series of oxidation-reduction to the final acceptor i.e., O_2.

CRITICAL CONCEPT!

Energy Production in Living System:
In living systems, energy is being released in bits as per requirement of the body. This is being done to avoid the release of extra heat energy and denaturation of proteins including enzymes.

Components of ETC

- The components of ETC include:
  1. NADH dehydrogenase complex (I)
  2. FADH dehydrogenase complex (II)
  3. Coenzyme Q
  4. Cytochrome reductase complex (III)
  5. Cytochrome-c
  6. Cytochrome oxidase complex (IV)
- Cytochromes are electron transport intermediates ***containing haem of related prosthetic groups***, which undergo valency changes of iron atom.

Passage of Electron Flow

- NADH is oxidized when it reacts with NADH dehydrogenase complex (I). Electrons now move to co-enzyme Q.
- If $FADH_2$ is to be oxidized through ETC, it also hands over its electrons to co-enzyme Q, via FADH dehydrogenase complex (II).
- The flowing electrons from coenzyme Q are now transferred to cytochrome reductase complex (III) which hands over its electrons to cytochrome c. Like co-enzyme Q, cytochrome c is also mobile carrier of electron. Cytochrome c delivers the electrons to cytochrome oxidase complex (IV).
- Finally, the electrons are transferred to O_2, which is the ultimate acceptor of electrons. Each O_2 atom picks up a pair of hydrogen ions from the aqueous solution, forming H_2O.
- Energy released during passage of electrons from one carrier to the next is used to pump H^+ from mitochondrial matrix to the inter-membranous space. There are three such sites, corresponding to three enzymes present in the ETC.

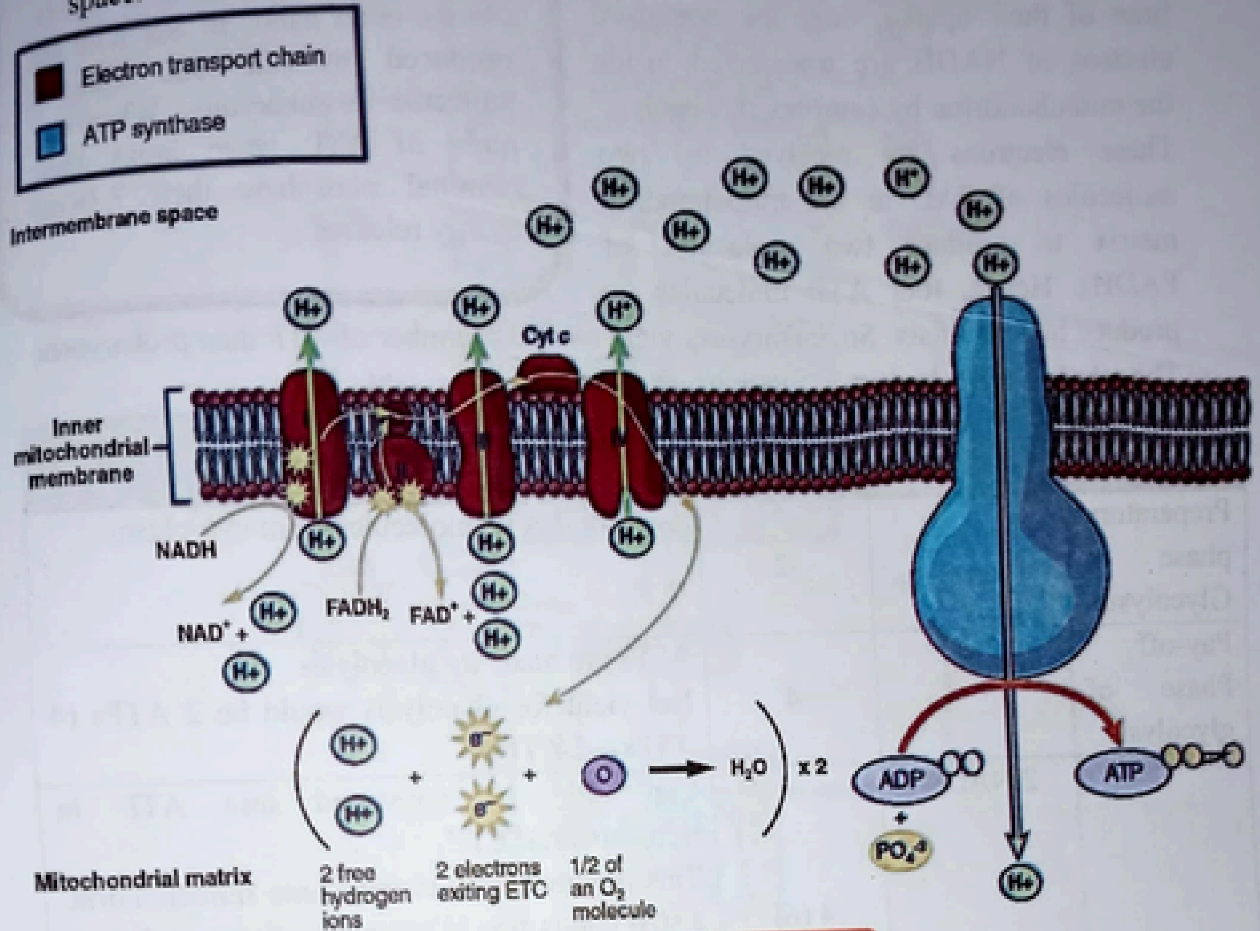
Chemiosmosis and Oxidative Phosphorylation

- Oxidative phosphorylation is the synthesis of ATP molecules with the help of energy liberated during oxidation of reduced co-enzymes, produced in respiration.
- The enzyme required for this purpose is called ***ATP synthase***, which is located in the inner mitochondrial membrane.

> **CRITICAL CONCEPT!**
>
> Cardiolipin is a phospholipid present in the cristae of mitochondria that is impermeable to Na^+, K^+, Cl^-, NAD^+, AMP, GTP and CoA.

- It consists of two parts i.e., ***F_0 and F_1***.
- F_0 is embedded in the membrane and involves in the movement of H^+ from inter-membrane space to mitochondrial matrix.
- F_1/elementary particles are a head-like part which is projected from the surface of the membrane towards matrix.
- ATP synthase becomes active only when a H^+ gradient is established.
- The energy of proton gradient is used in attaching a phosphate to ADP molecules.
- Oxidation of one molecule of $NADH_2$ produces 3 ATP molecules while oxidation of $FADH_2$ forms 2 ATP molecules. The theory of ATP production by this mechanism is called ***chemiosmosis***.

- As compared to photosynthesis, here pumping of H^+ is across the inner membrane of mitochondrion between matrix of mitochondrion and mitochondrion's inter-membrane space.



CRITICAL CONCEPT!

Chemiosmosis Site	Proton Pumping	H^+ Diffusion
Chloroplast	Stroma to Lumen	Lumen to Stroma
Mitochondria	Matrix to inter-membrane space	Inter-membrane space to Matrix
Bacteria	Cytoplasm to periplasmic space	Periplasmic space to cytoplasm

ENERGY BUDGET CALCULATION AND REGULATION OF CELLULAR RESPIRATION

- In prokaryotes, there are no mitochondria, the whole process of respiration occurs within the cytoplasm, so no ATP is consumed in transporting across the organelle. Therefore, 38 ATPs are made from one glucose molecule in bacteria while 36 are made in a eukaryotic cell.
- Actually, two molecules of NADH of glycolysis are produced in the cytoplasm.

CRITICAL CONCEPT!

Series of reaction always use feedback/Allosteric inhibition method to control the metabolic pathways.

- These cannot be taken by the mitochondria because the mitochondrial membrane is impermeable for NADH. Therefore, at the time of their uptake, only the energized electros of NADH are transferred inside the mitochondrion by complex mechanism. These electrons are received by two molecules of FAD in the mitochondrial matrix to produce two molecules of $FADH_2$. Hence, four ATP molecules are produce instead of six. So, eukaryotes yield two less number of ATP than prokaryotes.

CRITICAL CONCEPT!

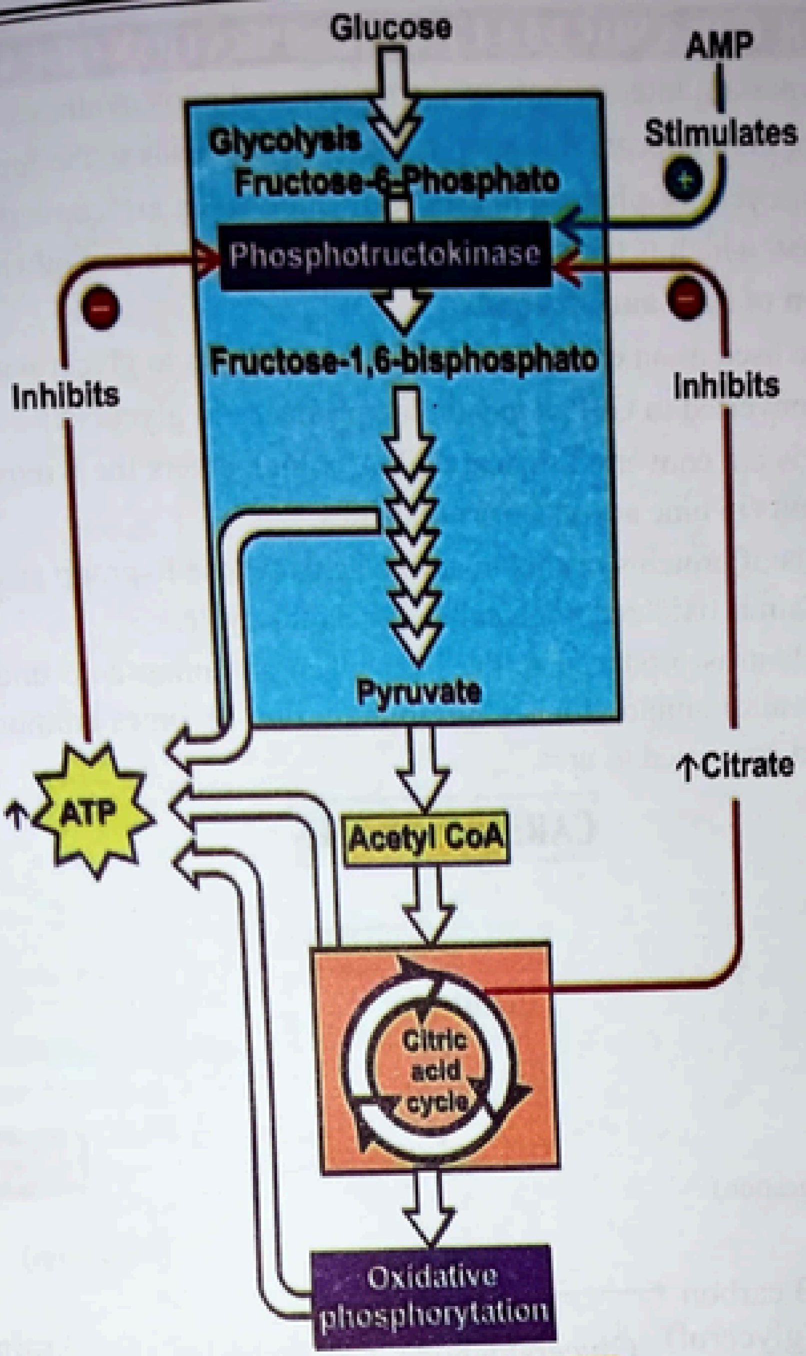
One mole of Glucose is having 686Kcal energy in its C-H bonds. On the other hand, 36 Net ATP are produced by the one Glucose molecule in eukaryotes. When one mole of ATP when break their terminal phosphate then 7.3Kcal energy releases.

- The whole energy budget is summarized in the following table:

Pathway	Coenzyme Yield	ATP Yield	Source of ATP
Preparatory phase of Glycolysis	———	-2	Input of 2 ATP molecules from cytoplasm.
Pay-off Phase of glycolysis		4	ATPs are made by glycolysis. Net yield for glycolysis would be 2 ATPs (4 ATPs – 2 ATPs)
	2 NADH	4 (6)	Can only be converted into ATP in mitochondrial ETC. This requires them to enter into mitochondria, a step that is free in some organisms, and costs 2 ATPs in others. This is what causes the differences in net yield of aerobic respiration.
Pyruvate Oxidation	2 NADH	6	ETC
Krebs Cycle		2	Substrate level phosphorylation
	6 NADH	18	ETC
	2 $FADH_2$	4	ETC
Total Yield		36 (38) ATPs	Complete breakdown of one glucose molecule to CO_2 and H_2O.

CRITICAL THINKING

12. When one mole of glucose is broken down to 38 Net ATPs per glucose releases in the prokaryote then it means it is giving ________ percentage yield.
A. 2%
B. 38%
C. 40%
D. 90%



CRITICAL THINKING

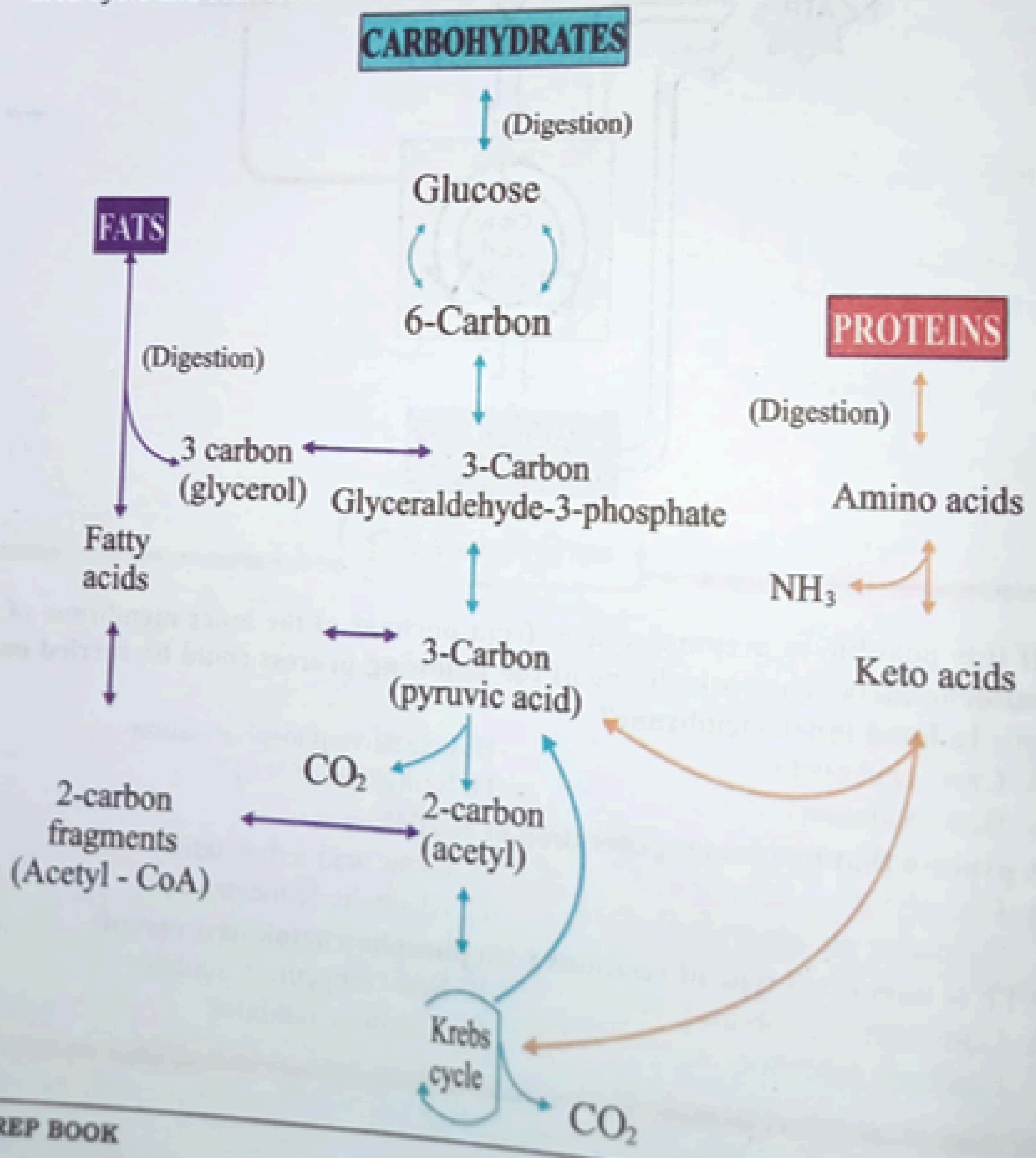
13. **If it is possible to prepare vesicles from portions of the inner membrane of the mitochondria. Then which one of the following process could be carried on by this isolated inner membrane?**
    A. Citric acid cycle
    B. Oxidative phosphorylation
    C. Beta oxidation
    D. Reduction of NAD^+
14. **A process that involves regeneration of NADH is:**
    A. Glycolysis
    B. Lactic acid fermentation
    C. Oxidative phosphorylation
    D. Alcoholic fermentation
15. **ATP is having all type of relations with phosphofructokinase except:**
    A. Competitive inhibitor
    B. Non-competitive inhibitor
    C. Feedback inhibitor
    D. Allosteric inhibitor

IMPORTANCE OF G3P AND CELLULAR RESPIRATION OF FATS AND PROTEINS

- G3P is an important intermediate of respiration and photosynthesis.
- In respiration, G3P appears during glycolysis which leads to the formation of pyruvate.
- In the Calvin cycle of photosynthesis, G3P molecules are converted into hexose within the chloroplast, which is then converted to sucrose, starch and other organic molecules.

Cellular Respiration of Fats and Proteins

- When fats are used as an energy source, it breaks down to glycerol and fatty acids.
- Glycerol is converted to G3P, a metabolite produces in glycolysis.
- The fatty acids are converted to acetyl CoA, which enters the Krebs cycle. An 18-carbon fatty acid results in nine acetyl CoA molecules.
- The hydrolysis of proteins results in amino acids whose R-group size determines whether the carbon chain is oxidized in glycolysis or Krebs cycle.
- The carbon chain is produced in the liver when an amino acid undergoes ***deamination*** i.e., the removal of amino group. This amino group becomes ammonia, which enters the urea cycle and converted to urea.



TOPIC-3 » BIOLOGICAL MOLECULES

COURSE CONTENT

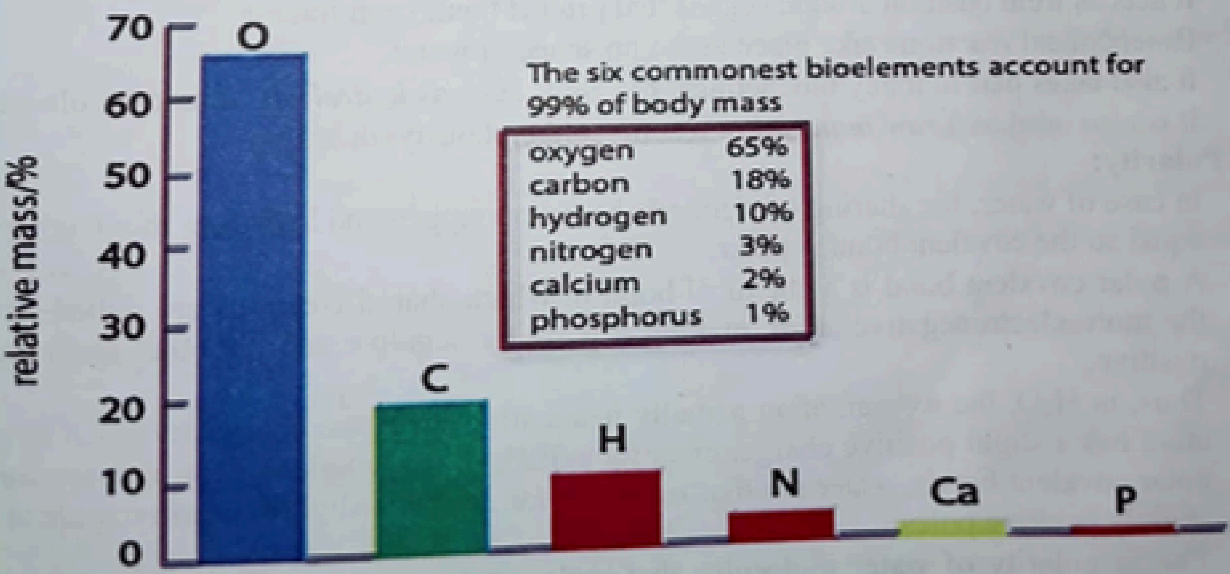
- Introduction to Biological Molecules
- Importance of Water
- Carbohydrates
- Proteins
- Lipids
- Nucleic Acids
- Conjugated Molecules

INTRODUCTION TO BIOLOGICAL MOLECULES

- ***Biochemistry*** is a branch of biology which deals with the study of chemical components and the chemical processes in living organisms.
- A basic knowledge of Biochemistry is essential for understanding anatomy, physiology, because all of the structures of an organism have biochemical organization. For example, photosynthesis, respiration, muscle contraction can all be described in biochemical terms.

Chemical Composition of protoplasm

- Approximately 25 elements out of 92 naturally occurring elements of earth are found in living beings. These are called ***bioelements***. However, human body is composed of only 16 of these bioelements.
- These elements can be classified on the basis of their proportion in organisms. The six common bioelements that constitute *99%* of protoplasm are called ***major bioelements***.
- ***Minor bioelements*** are those that are found as less than *1%* whereas those that are found as less than *0.01%* of the protoplasm are called ***trace elements***. The relative percentages of bioelements are mentioned in the following bar chart.
- The bioelements are combined with each other and form thousands of different biomolecules which may be *organic* and *inorganic*.



Other bioelements include (about 1%) - potassium (0.35%), sulphur (0.25%), chlorine (0.15%), sodium (0.15%), magnesium (0.05%), iron (0.004%), copper (trace), manganese (trace), zinc (trace), iodine (trace).

- The table below shows proportion of different bioelements in a typical bacterial and mammalian cell.

Sr. No.	Chemical Components	% Total Cell Weight	
		Bacterial Cell	Mammalian Cell
1.	Water	70	70
2.	Proteins	15	18
3.	Carbohydrates	3	4
4.	Lipids	2	3
5.	DNA	1	0.25
6.	RNA	6	1.1
7.	Organic molecules (enzymes, hormones, metabolites)	2	2
8.	Inorganic ions Na^+, K^+, Ca^{2+}, Mg^{2+}etc.)	1	1

- The four fundamental kinds of biological molecules are ***carbohydrates, proteins, lipids and nucleic acids***.
- During ***condensation/dehydration synthesis***, when two or more monomers join, a OH^- is removed from one monomer, and a H^+ is removed from the other to make H_2O and a covalent bond is formed between the monomers.
- The ***hydrolysis*** is essentially the reverse of condensation i.e., the breakdown of an oligomer/polymer into its monomers by the addition of H_2O molecules.

IMPORTANCE OF WATER

Importance

- Water is the ***medium of life*** and is ***most abundant compound*** in all organisms.
- It varies from 65 to 89% in different organisms.
- Human tissues contain about 20% water in bone cells and 85% in brain. Jellyfish has exceptionally large amount of water i.e., 99% (hence the body shows transparency).
- It acts as a ***lubricant against friction***, e.g., tears protect the surface of eye from the rubbing of eyelids.
- It acts as fluid cushion around organs that protect them from trauma.
- Biochemical reactions take place in the presence of water.
- It also takes part in many biochemical reactions such as ***hydrolysis*** of macromolecules.
- It is also used as a ***raw material*** in reactions like photosynthesis.

High Polarity:

- In case of water, the sharing of electrons between oxygen and hydrogen in not completely equal so the covalent bond is polar.
- A polar covalent bond is a chemical bond in which shared electrons are pulled closer to the more electronegative atom, making it partially negative and the other atom partially positive.
- Thus, in H_2O, the oxygen atom actually has a slight negative charge and each hydrogen atom has a slight positive charge, even though H_2O as a whole is neutral. Because of its polar covalent bonds, water is polar molecule i.e., it has a slightly negative pole and two slightly positive poles.
- This is polarity of water molecules that makes it an excellent or universal solvent for polar substances.
- Ionic compounds or electrolytes can be easily dissolved in water, non-polar substances having charged groups in their molecules can also be dissolved in water.
- Such compounds when dissolved in water, dissociates into positive and negative ions and

are in more favorable state to react with other molecules and ions. This is the reason why all chemical reactions in living beings occur in aqueous medium.

CRITICAL THINKING

3. Hydrogen bonds are especially important for living organisms because:
A. Once formed, they never break
B. They occur only inside of organisms
C. They are strong and maintain physical stability of molecules
D. They allow biological molecules to dissolved in water

High Specific Heat Capacity:

- Heat capacity can be defined as 'the amount of heat required for minimum increase (1°C) in temperature of a substance. The specific heat capacity of water can be represented as number of calories required to raise the temperature of 1g of water upto1°C.
- Water has relatively a very high heat capacity than any other substance due to its hydrogen bonding, because much of the heat absorbed by water is utilized in the breakdown of hydrogen bonding.
- Due to this high heat capacity, water works as ***temperature stabilizer or regulator*** for organisms in the hot environment and hence protects the living material against sudden thermal changes.

Heat of Vaporization:

- Amount of heat required to change 1g of water is from liquid to gaseous state is called ***heat of vaporization***.
- Specific heat of vaporization of ***water is 574 Kcal/ kg***.
- Evaporation of only 2ml out of 1 liter of water lowers the temperature of remaining 998ml by 1°C.
- The advantage of high heat of vaporization of water is that it provides cooling effect to plants and animals.

Cohesion and Adhesion Property of Water:

- ***Cohesion*** is the attraction among water molecules which enables them to stick together.
- Water flows freely due to cohesion.
- Water molecules also have attraction to polar surfaces. This attraction is called ***adhesion.***
- Both cohesion and adhesion are due to hydrogen bonds among water molecules. These properties enable it to circulate in living bodies and to act as ***transport medium***.

Hydrophobic Exclusion

- Hydrophobic exclusion can be defined as 'reduction of the contact area between water and hydrophobic substances which are placed in water'.
- For example, if few drops of oil are placed on the surface of water solution, the oil drops will tend to join into a single group.
- Biologically, hydrophobic exclusion plays key role in ***maintaining the integrity of lipid bilayer membrane***.

CARBOHYDRATES O.N Saccharides

- Literal meaning is '*hydrated carbons*', a carbon associated with water.
- They are composed of carbon, hydrogen, and oxygen. Mostly hydrogen and oxygen are found in same ratio as in water (2:1).
- Chemically, they are defined as 'polyhydroxy aldehydes or ketones or complex substances which on hydrolysis yield polyhydroxy aldehyde or ketone subunits'.
- Their *general formula* is $C_x(H_2O)_y$ where 'x' is the whole number from three to many thousands whereas 'y' may be same or different whole number. ($C_nH_{2n}O_n$)

Simple carbohydrates are the main ***source of energy*** in cell.

Some carbohydrates are the main ***constituents of cell wall*** in plants, fungi and microorganisms.

Examples are cellulose in wood, cotton and paper, starches present in cereals, root tubers, cane sugar and milk sugar.

Their main source is green plants, which produce them by photosynthesis. Even all the other compounds of plants are synthesized from carbohydrates.

Carbohydrates combine with proteins and lipids to form ***glycoprotein & glycolipids***, respectively. These compounds are collectively called glyco-conjugates.

CRITICAL THINKING

3. Glucose and hexanoic acid each contain six carbon atoms, but they have completely different properties. Glucose is used as a primary fuel by the cell while hexanoic acid is poisonous. Their differences must be due to:

A. Monomers B. Macromolecules
C. Functional groups D. Quaternary structures

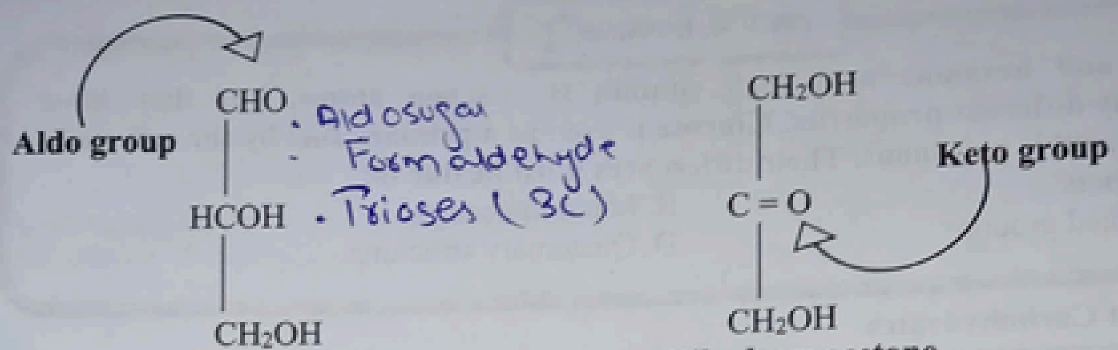
Major Groups of Carbohydrates

Feature	Monosaccharides	Oligosaccharides	Polysaccharides
Common Name	Simple sugars	Complex sugars	Most complex sugars (Branched or unbranched) → Amylose, amylopectin
No. of sugar units	One	Two – Ten	More than 10
Taste	Sweet	Less sweet	Tasteless
Solubility in water	Easily soluble in water	Less soluble in water	Sparingly soluble in water/More or less insoluble in water
Hydrolysis	Cannot be hydrolyzed	Can be hydrolyzed	Can be hydrolyzed
General Formula	$(CH_2O)_n$/ $C_nH_{2n}O_n$/ $C_n(H_2O)_n$	$C_n(H_2O)_{n-1}$ (for disaccharides)	$C_x(H_2O)_y$
Classification	• On the bases of number of carbon atoms e.g. trioses (3C), tetroses (4C), pentoses (5C) etc. • On base of functional group e.g. aldo and keto sugars.	On the basis of monosaccharides released during hydrolysis e.g. disaccharides, trisaccharides etc.	On the basis of structural complexity & relation e.g. starch, glycogen, cellulose, dextrin, agar, pectin and chitin.

Monosaccharides

- Monosaccharides are true carbohydrates which are either polyhydroxy aldehydes or polyhydroxy ketones.
- In nature, monosaccharides with ***3 – 7 carbon atoms*** are found.
- All carbon atoms except one have hydroxyl group. This exception is carbon of aldehyde or ketone group.

PMC Topic-3



Glyceraldehyde   Dihydroxyacetone

Classification of Monosaccharides

Atoms	Type	Formula	Aldo Form	Keto Form	Role
3 C	Trioses	($C_nH_{2n}O_n$) $C_3H_6O_3$	Glyceraldehyde	Dihydroxyacetone	Intermediates in photosynthesis & respiration
4 C	Tetroses	$C_4H_8O_4$	rare in nature Erythrose Present in bacteria	Erythrulose	Intermediates in photosynthesis in bacteria
5 C	Pentoses	$C_5H_{10}O_5$	Ribose	Ribulose	Ribose is found in RNA while Ribulose is found in Calvin cycle
6 C	Hexoses	$C_6H_{12}O_6$	galactose → milk Glucose mannose → plant cell wall	Food, Seminal vesicles Fructose	Energy source, Polysaccharide formation
7 C	Heptoses	$C_7H_{14}O_7$	Glucoheptose	Sedoheptulose	Intermediates in photosynthesis in bacteria

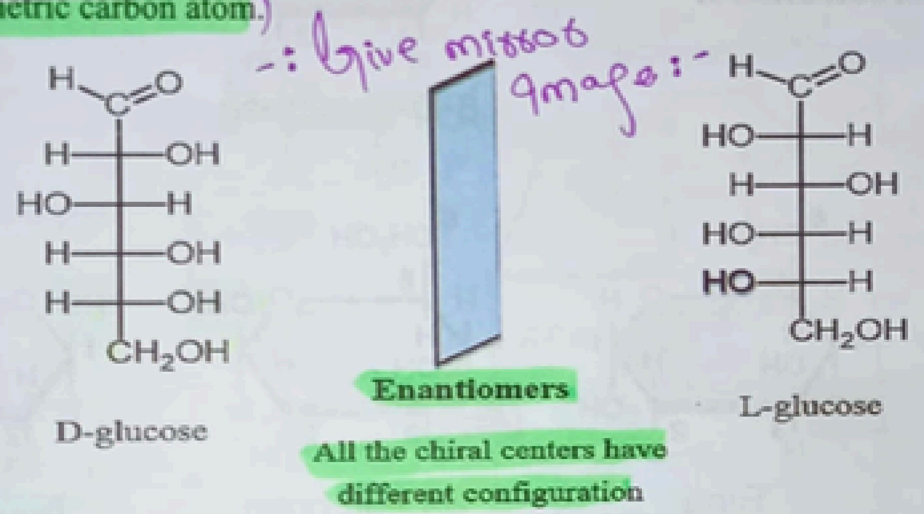
Chemical/Ring Structure of Monosaccharides

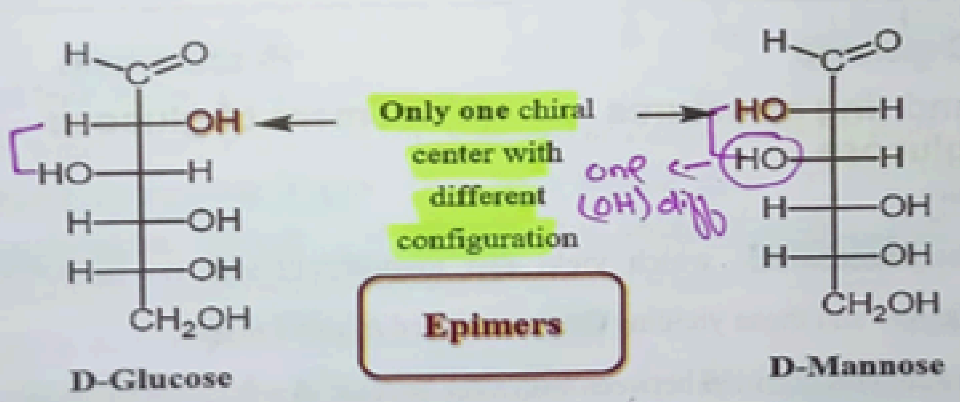
- Monosaccharides are usually found in open chain structure in crystalline form but when dissolved in water, most of them (e.g. pentoses and hexoses) are converted into ring structure.
- Two types of ring structures are formed e.g. *Furanose* (5 corners) is a five membered ring in which one oxygen atom and four carbon atoms are found, oxygen atom is linked with C_1 and C_4. All pentoses and ketohexoses are converted into furanose ring. *Pyranose* (6-corners) is a six membered ring in which one oxygen atom and five carbon atoms are found, and oxygen atom is linked with C_1 and C_5. Only aldo-hexoses are converted into pyranose ring.

Sterioisomerism in Monosaccharides

- Those isomers in which hydrogen and hydroxyl groups are arranged in different pattern to the asymmetric carbon atoms are called ***stereoisomers***.

- An (*asymmetric carbon*) atom is that which makes bonds with four different atoms/groups around it.
- In monosaccharides, the number of stereoisomers actually depends upon the number of asymmetric carbon atoms in its structure and can be calculated by the formula 2^n, where 'n' is the number of asymmetric carbon atoms.
- *Enantiomers* are non-superimposable mirror images of one another. An example of an enantiomer is the 'D' and 'L' isomers of glucose.
- *Epimers* have different arrangement of hydrogen and hydroxyl groups at (only one asymmetric carbon atom).



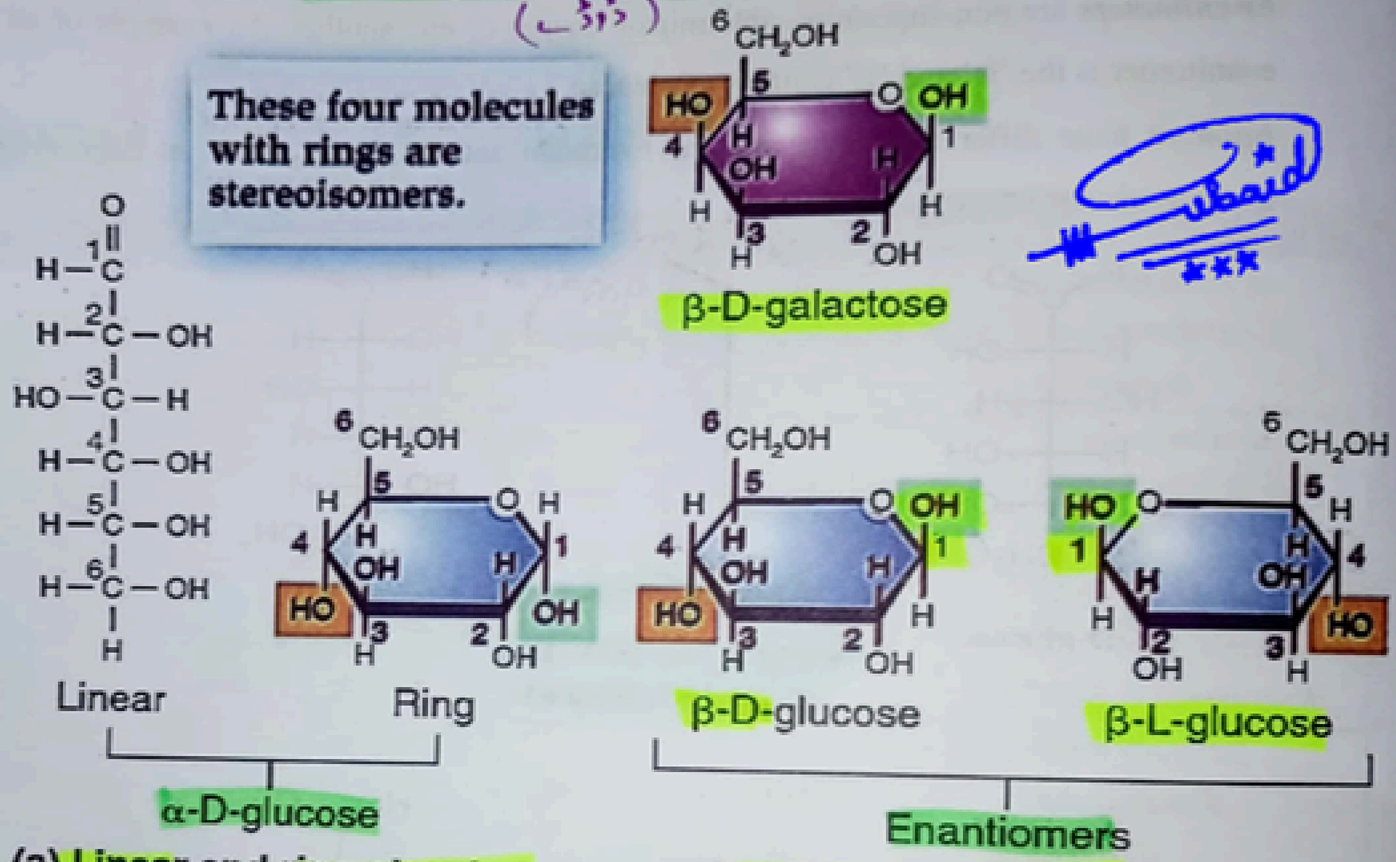


- Each pentose and hexose exists in either 'α' or 'β' form depending upon position of hydrogen and hydroxyl groups at C_1. If OH^- group is found downward at C_1, it is called 'α' sugar and if OH^- group is present upward at C_1 then it is known as 'β' sugar.

Glucose

- It is naturally produced in (green plants) which takes CO_2 from air and H_2O from soil to synthesize glucose.

- Synthesis of *10g of glucose* requires *717.6 Kcal* of solar energy, which in turn is stored in glucose molecule and becomes available in all organisms when it is oxidized in the body.
- Our ***blood contains 0.08%***glucose.
- Starch, cellulose, and glycogen yield glucose on complete hydrolysis.
- In free form, glucose is present in figs, grapes, and dates.



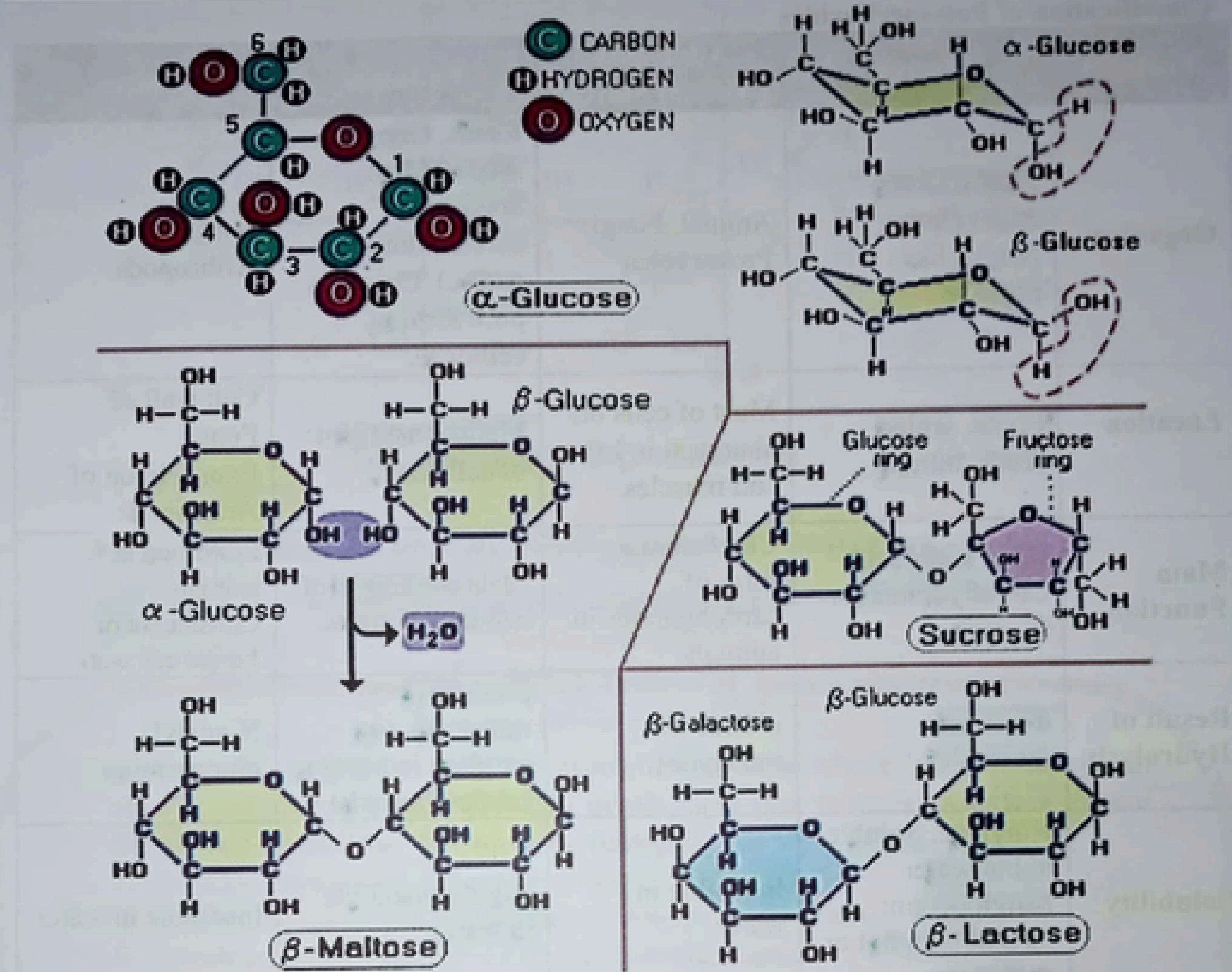
(a) Linear and ring structures of α-D-glucose

(b) Isomers of glucose

Oligosaccharides

- Those oligosaccharides which yield two monosaccharides on hydrolysis are called ***disaccharides*** and those yielding three are called ***trisaccharides.***
- The covalent bond formed between two monosaccharides is called **glycosidic bond**.
- ***Maltose***, ***sucrose***, and ***lactose*** all are disaccharides. Their general formula is $C_{12}H_{22}O_{11}$.

Disaccharide	Source and Common Name	Monomers	Glycosidic Bond
Maltose	Candies, Barley, Sweet potatoes, Fruits (Malt Sugar)	Glucose + Glucose	1,4-glycosidic bond
Sucrose	Sugar Cane (Cane Sugar)	Glucose + Fructose	1,2-gycosidic bond
Lactose	Milk (Milk Sugar)	Galactose + Glucose	1,4-glycosidic bond



Reducing and Non-Reducing Sugars

- Sugars which give positive result on ***Benedict or Fehling tests*** are called reducing sugars. These act as reducing agents. They have free aldehyde or free ketone group. All monosaccharides, lactose and maltose are reducing sugars. Ketoses must first ***tautomerize*** to aldoses before they act as reducing sugars.
- ***Sucrose*** is an example of non-reducing sugar.
- ***Polysaccharides*** are also non-reducing sugars.

Glucose & fructose Both are reducing agent. So they are most similiar disaccharide

Polysaccharides

- They are formed by several monosaccharide units linked together by glycosidic bonds.
- They act as structural components, food and energy stores.
- The polysaccharides which are formed by the condensation of only one kind of monosaccharides are called ***homo-polysaccharides*** e.g. starch, glycogen, cellulose, chitin (N-containing polysaccharide); whereas the polysaccharides which are formed by condensation of different kind of monosaccharides are called ***hetero-polysaccharides*** e.g. agar, pectin, peptidoglycan.

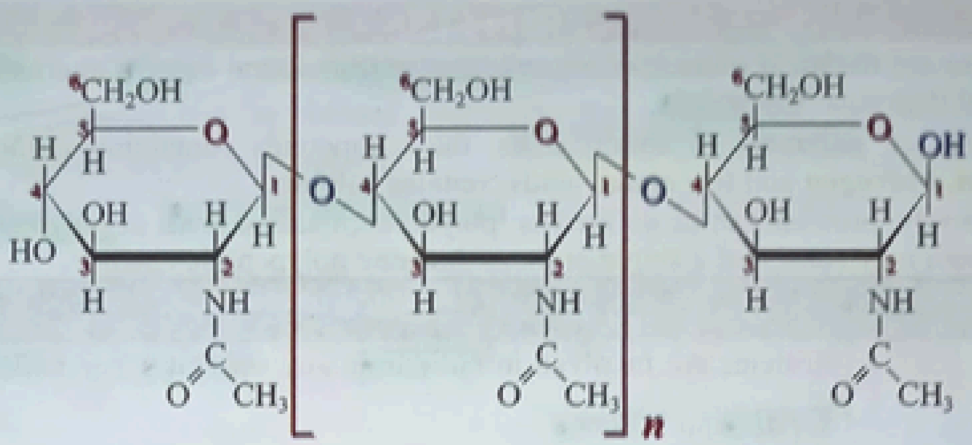
Hetero saccharide

Classification of Polysaccharides

Features	Starch	Glycogen (Animal Starch)	Cellulose	Chitin
Organism	Plants, Green Algae, Some fungus like protists	Animal, Fungi, Prokaryotes	Plants, Green Algae (Most abundant carbohydrate in nature). Cotton is pure form of cellulose.	Fungi, Arthropods
Location	Fruits, grains, seeds, tubers.	Most of cells but abundant in liver and muscles.	Main constituent of cell walls.	Cell wall of Fungi, Exoskeleton of Arthropods
Main Function	Main source of carbohydrates for animals.	Chief storage form of cardohydrates in animals.	Main constituent of cell wall of plants.	Protection in animals, Constituent of fungal cell wall
Result of Hydrolysis	α-Glucose molecules	α-Glucose molecules	β-Glucose molecules (α-amylase in our gut cannot digest it)	N-acetyl glucosamine
Solubility	Amylose: Soluble in hot water Amylopectin: Insoluble in hot or cold water	Insoluble in water	Highly insoluble in water	Insoluble in water
Branching	Amylose: Unbranched Amylopectin: Branched	Branched (More than Amylopectin)	Unbranched	Unbranched
Glycosidic Linkage	Amylose: α-1, 4 Amylopectin: α-1, 4 & α-1, 6	α–1,4 & α–1,6	β–1,4	β–1,4
Iodine Test	Blue colour with iodine test	Red colour with iodine test	No colour change on iodine test	No colour change on iodine test

Structure of Chitin

- Chitin is the ***second most abundant organic molecule on earth***. It is also an example of ***homopolysaccharides***.
- Due to the occurrence of chitin in fungal cell wall, it is also known as ***fungal cellulose***.
- It is the derivative of ***N-acetyl glucosamine*** monomers, which is a ***modified form of glucose***.
- The structure of N-acetyl glucosamine and glycosidic linkage is shown in the following diagram.



β-(1,4)-N-acetyl-D-glucosamine

Tests for Carbohydrates

- Benedict or Fehling test to detect reducing and non-reducing sugars.
- Iodine test is used to detect different types of polysaccharides.

CRITICAL THINKING

4. **The enzyme called pancreatic amylase is a protein whose job is to attack on starch molecules in food and help break them into maltose. Amylase cannot break down cellulose. The possible reason is:**
   A. Cellulose molecules are too much large
   B. Starch is made of glucose, while cellulose is made of other sugars
   C. Cellulose is like a fat, not a carbohydrate like starch
   D. Monomers in cellulose bond together differently than in starch
5. **Carbohydrates are commonly found as starch in plant storage structures. Which of the following five properties (1-5) of starch make it useful as a storage material?**
   1. **Easily translocated**
   2. **Chemically non-reactive**
   3. **Easily digested by animals**
   4. **Osmotically inactive**
   5. **Synthesized during photosynthesis**

   A. 1 and 5 only　　B. 2 and 4 only
   C. 2 and 3 only　　D. 1, 3 and 5 only
6. **It gives red color with iodine:**
   A. Storage homo-polymer with no branching (Glycogen)
   B. Storage homo-polymer with branching
   C. Structural hetero-polymer with no branching
   D. Structural homo-polymer with no branching

PROTEINS

- Proteins are the ***most abundant organic compounds*** found in cells and comprising over 50% of their total dry weight.
- Proteins are polymers of amino acids, the compounds containing ***carbon, nitrogen, oxygen, hydrogen*** and few amino acids contains sulphur.
- Chemically, proteins can be defined as 'polymers of amino acids or polypeptides chains'. A protein may consist of a single or more than one polypeptide chain.

Example	Major Functions
Building Structures	Proteins are involved in building many structures e.g. collagen, elastin, keratin and histones.
Enzymes	Catalyze chemical reactions and control whole metabolism of cell.
Hormones	Regulate metabolic processes.
Transport Proteins	Carrier protein that transports O_2 (Hemoglobin), lipids, metal ions etc.
Antibodies	Defend the body against pathogenic attack.
Clotting Proteins	Prevent loss of blood after injury.
Mitotic Apparatus	Helps in movement of chromosomes during anaphase of cell division.

Amino Acids

- Amino acids are the building blocks of proteins. About ***170 types of amino acids*** have been found in cells and tissues.
- Out of 170 types only ***25 are constituents of proteins.***
- Most of the proteins are, however, ***made of 20 types of amino acids.***

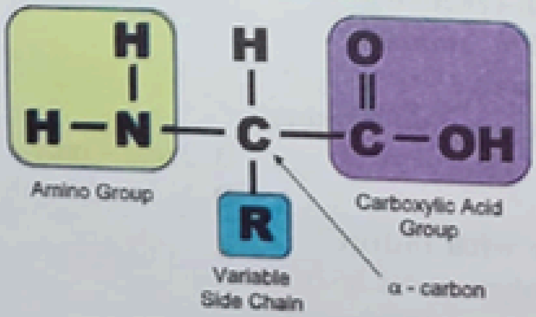
10 essential
10 non-Essential

Basic Structure of Amino Acid

Symmetrical OR Chiral carbon

- An amino acid is an organic compound contains a central carbon atom, called ***alpha carbon***. To this, a hydrogen atom, an amino group (-NH_2), a carboxylic group (-COOH) and a variable group known as R-group are attached.
- The R-group has a different structure in each of 20 biologically important amino acids and determines their individual chemical properties.

Classification is due to type of R group.

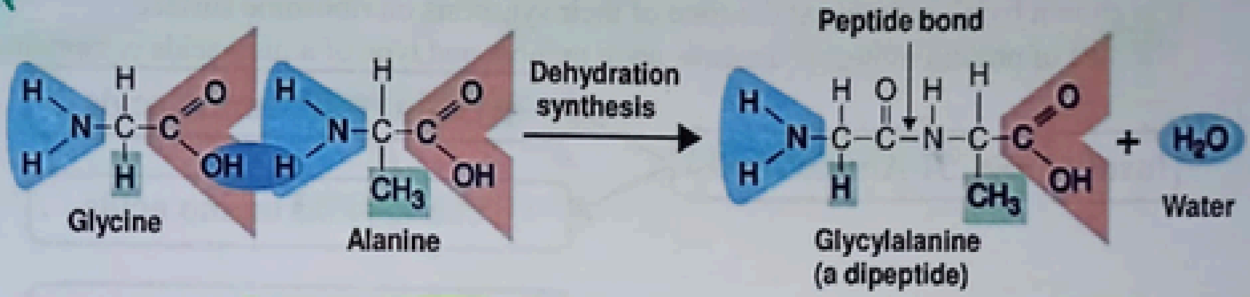


Peptide Bond Formation

- Dipeptides, oligopeptides and polypeptides are formed by the ***dehydration condensation*** of amino acids on the ribosomes under the instructions of mRNA which takes these instructions from DNA.
- Amino acids link together to form a polypeptide molecule.

- Two amino acids combine together via a peptide bond to form a dipeptide e.g., glycine and alanine chemically interact with each other to form glycylalanine. Similarly, tri, tetra and pentapeptides can be formed. Naturally, this dehydration condensation reaction occurs during translation of mRNA.

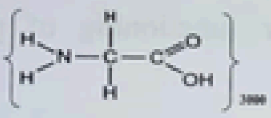
contains (H) instead of R grp. R

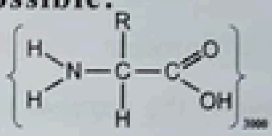


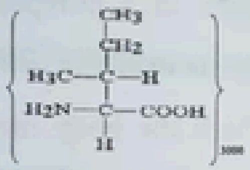
- In this figure, -OH of carboxyl group of glycine combines with H of amino group of alanine releasing water molecule and forming C-N link called ***peptide bond***.

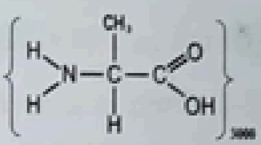
CRITICAL THINKING

7. Only one of the followings is technically possible:

A. 

B. 

C. 

D. 

Structure of Proteins

There are four levels of organization of protein molecules.

Feature	Primary	Secondary	Tertiary	Quaternary
Information	Number and sequence of amino acids in protein molecule.	Structural conformation (form or shape) e.g. coil or helix	Bending and folding of polypeptide chain and forming regular 3-D globular shape.	(Two or more) chains aggregate and held together by hydrophobic interactions.
Bonds	Peptide bond	Hydrogen Clockwise ↑ Anticlockwise wise	Ionic, Hydrogen, Disulphide bridges, Peptide	Hydrogen, Ionic bonds, Disulphide, Hydrophobic interactions, Peptide
Example	Insulin, Hemoglobin, myoglobin	Alpha helix (α-helix), helix β β-pleated sheet	Human myoglobin	Hemoglobin

zic zac way

Primary Structure

- *F. Sanger* was the first scientist who determined the sequence of amino acids in a protein molecule.
- The sequence of amino acids in a protein molecule is determined by the order of nucleotides in the DNA.
- It is shown by all proteins at the time of their synthesis on ribosome surface.
- The size of protein molecule depends upon number and type of amino acids comprising it.

Insulin → 51 Amino Acids → α chain → 21 amino acids; β chain → 30 amino acids

Hb → 574 Amino Acids → α chain → 141 x 2 amino acids; β chain → 146 x 2 amino acids

Sequence of amino acid in a polypeptide chain is a characteristic feature of primary structure of protein which is responsible for proper functioning of protein. It is determined by the ***sequence of nucleotides in DNA***.

Even due to ***point mutation***, the sequence of amino acids in a polypeptide may be disturbed which causes severe defects in the body as it happens in ***sickle cell anemia***.

Sickle cell anemia is a ***serious hereditary disorder*** in which the body makes ***sickle or crescent shaped RBCs*** and contains abnormal hemoglobin called ***sickle hemoglobin*** ***(Hb^S)***. The presence of Hb^S causes the cells to develop a sickle or crescent shape.

- It is caused by a point mutation in β-globin gene in which only one nucleotide is replaced by another which causes a change in sequence of β-chain of hemoglobin. Hb^S shows only one difference from Hb^A i.e., ***glutamic acid replaced by valine*** at ***position number six***.

Secondary Structure

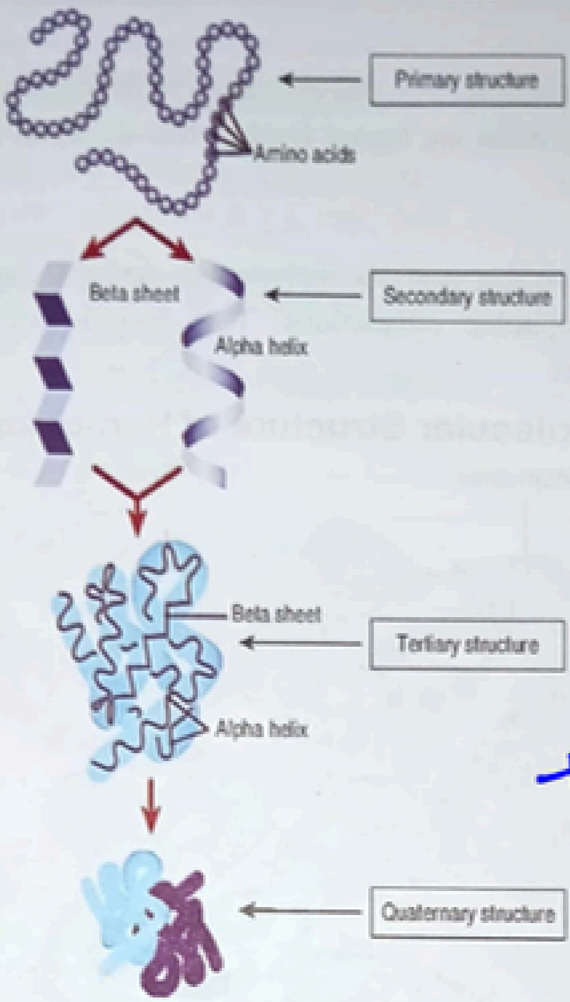
- α- helix and β- pleated sheets are its examples.
- ***α- helix*** is a very uniform geometric structure with ***3.6 amino acids*** in e...
- ***B-pleated sheet*** is formed by the folding ba...

CRITICAL CONCEPT!

Hemo...
The n...
hemog...
compo...
polype...
group.
duplic...
the *HB*...

α-helix clock wise
β-helix anticlock wise
Spiral structure

Bond.
• Peptide Bond
• Disulphide Bond
• H. Bond.
Intra chain
Inter chain
[S-S]
II



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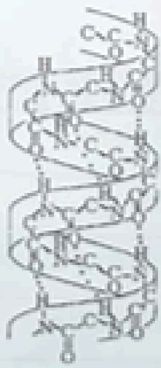
CRITICAL THINKING

8. Figure best illustrates the:



A. Secondary structure of a polypeptide B. Tertiary structure of a polypeptide
C. Quaternary structure of a protein D. Double helix structure of DNA

9. A peptide chain assumes secondary structure through the formation of:

A. Peptide bonds B. Inter-chain ionic bonds
C. Intra-chain hydrogen bonds D. Intra-chain disulphide bonds

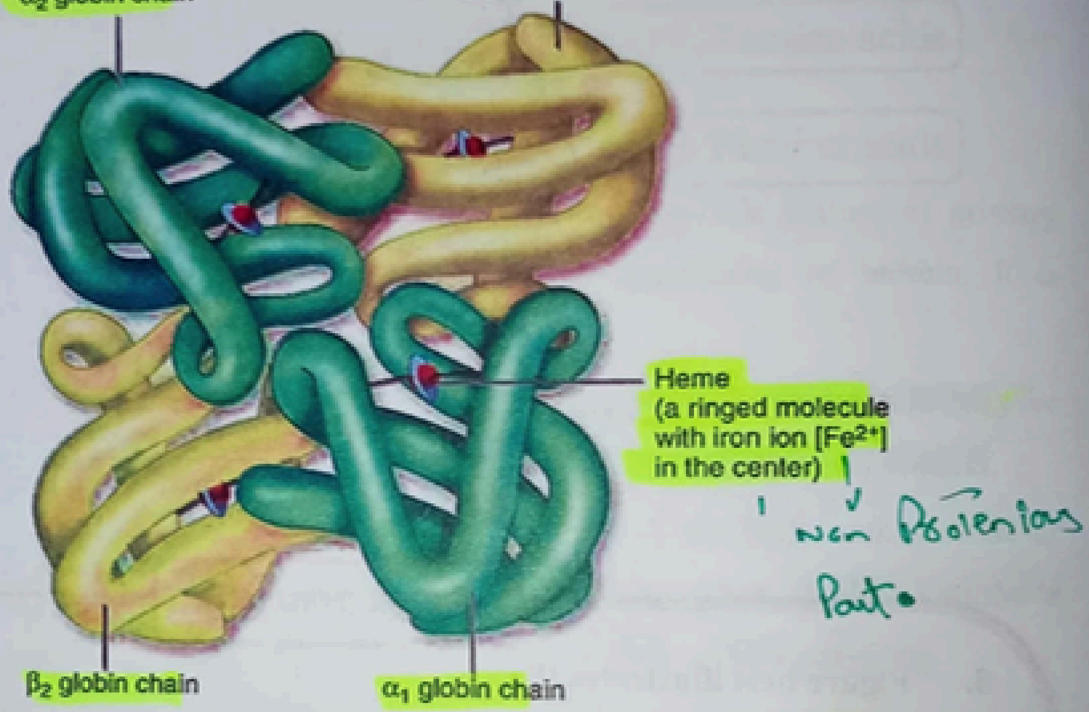
Tertiary Structure

In aqueous environment, the most stable tertiary conformation is that in which hydrophobic amino acids are buried inside while the hydrophilic amino acids are on the surface of molecule.

Quaternary Structure

In many highly complex proteins, polypeptide tertiary chains are aggregated and held together by hydrophobic interactions. This specific arrangement is the quaternary structure of proteins.

Molecular Structure of Hemoglobin



Classification of Proteins

Feature	Fibrous Protein	Globular Protein
Shape	Fibrils form	Spherical or ellipsoidal
Structural organization	Secondary	Tertiary or quaternary
Solubility in aqueous media	Insoluble in aqueous media	Soluble in aqueous media
Crystal Nature	Non-crystalline	Can be crystallized
Elasticity	Elastic in nature	Inelastic in nature
Role	Play structural role	Play functional role
Stability	More stable	Less stable
Examples	Silk fibers, myosin tail, fibrin, and keratin	Enzymes, antibodies, protein hormones, and hemoglobin.

Important Structural Proteins	
Collagen	Matrix of bone and cartilage
Elastin	Elasticity to tendon and ligaments
Keratin	Protective coverings e.g. hair, nails, quills, feathers, horns and beaks
Histone	Chromosome → chromatin formation
Important Functional Proteins	
Enzymes	Control metabolism
Hormones	Regulation of physiological activities
Antibodies	Immunity
Hemoglobin	Transport of gases
Fibrinogen	Blood clotting
Ovalbumin	Storage of amino acids in eggs
Casein	Storage of amino acids in milk

CRITICAL THINKING

10. Which of the following organic molecule is having intra-molecular hydrogen bonding?

A. Fibrin B. Polysaccharides

C. Lecithin D. ATP

LIPIDS → lipose → fats like

- Lipid is collective term for variety of organic compounds such as fats, oils, waxes and fat-like molecules (steroids) found in the body. Therefore, it is defined as a heterogeneous group of organic compounds mostly related to fatty acids.
- They are ***insoluble in water*** but ***soluble in organic solvents*** like ether, alcohol, chloroform and benzenes.
- Their hydrophobic nature makes them best suited to be a ***structural component of cell membranes***.
- Lipids store ***double the amount of energy*** as compared to same amount of carbohydrates because of high proportion of C-H bonds and very low proportion of oxygen.
- May act as ***insulating layer*** e.g., waxes in exoskeleton of insects, and cutin which is an additional protective layer on the cuticle of epidermis of some plant organs. E.g. leaves, fruits, seeds.

CRITICAL CONCEPT

Solubility of Lipids:
The only property of terpenoids that resembles to the other type of lipids is "water insolubility".

Classification of Lipids

- Lipids are broadly classified into simple, complex and derived, which are further sub-divided into different groups.
- ***Simple lipids*** are esters of fatty acids with various alcohols e.g., acylglycerols and waxes.
- ***Complex lipids*** contain other groups in addition to an alcohol and fatty acids e.g., phospholipids, glycolipids and lipoproteins.
- ***Derived lipids*** are derivatives of simple and complex lipids e.g., terpenes, steroids, prostaglandins and cholesterol.

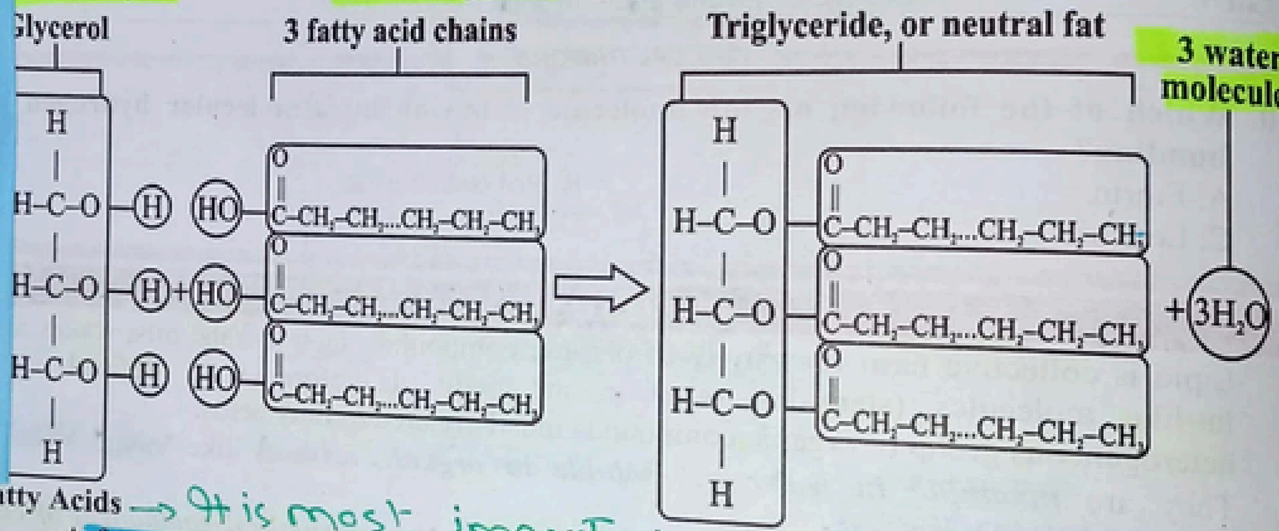
Acylglycerols

- The most abundant lipids in living things are acylglycerol. Chemically, these can be defined as ***'esters of glycerol and fatty acids'***.

$$\text{Fatty Acid} + \text{Glycerol} \xrightarrow{\text{Esterification}} \text{Acylglycerol} + H_2O$$

- Glycerol is a tri-hydroxy alcohol which contains three carbons, each bearing a OH group.
3(OH)grp.
- When glycerol molecule combines with one fatty acid, a ***monoacylglycerol*** is formed. When two fatty acids combine with one glycerol, a ***diacylglycerol*** is formed and when three fatty acids combine with one glycerol molecule, a ***triacylglycerol*** is formed.
- Triacylglycerol is also called ***'neutral lipids'*** as all of three OH-groups are occupied by fatty acids and no charge bearing OH-group is left.

Three fatty acid chains are bound to glycerol by dehydration synthesis.



Fatty Acids → It is most important component of triglyceride

- A fatty acid is an organic compound containing one carboxylic acid group attached to a hydrocarbon chain.
- Fatty acids contain even number of carbon atoms (2-30). Each fatty acid is represented as R-COOH, where R is hydrocarbon tail.
- Solubility of fatty acids in organic solvents, hydrophobic nature and melting points depend upon number of carbon atoms and number of double bonds.
- Fats and oils are lighter than water and have a ***Specific gravity of about 0.8.***
- Fatty acids are either saturated or unsaturated.

Saturated Fatty Acid	Unsaturated Fatty Acid
No double bonds between carbon atoms	Upto six double bonds
Straight chain	Ringed /Branched
Solid at room temperature	Liquid at room temperature
Fats	Oils
Animals	Plants
	More useful for livi[illegible]

Fatty acid	Type	No. of Carbon	Source	Melting Point
Acetic acid	Saturated	2	Vinegar	16.6°C
Butyric acid	Saturated	4	Butter	-8°C
Palmitic acid	Saturated	16	Palm tree	63.1°C
Stearic acid	Saturated	18	Most fats and oils	70°C
Oleic acid	Mono-unsaturated	18	Olives	4°C
Linoleic acid	Poly-unsaturated	18	Vegetable oils	-5°C

Waxes → wide spread as protective coating of fruits & leaves.

- Waxes are ***highly hydrophobic compounds***.
- There are two types of waxes; ***natural waxes*** are simple lipids. They are typically esters of long chain fatty acids and long chain alcohols, such as ***bee's wax*** (Honeycomb) and ***cutin*** (Leaf surface).
- Natural waxes are ***chemically inert*** and ***resistant to atmospheric decay***.
- Waxes have ***protective functions*** in plants and animals.
- ***Synthetic waxes*** are generally derived from ***petroleum or polyethylene e.g. Paraffin wax***.

Phospholipids

- They are the derivatives of ***phosphatidic acid*** by addition of one of the nitrogenous base.
- One end of phospholipid molecule (head), containing the phosphate group and nitrogenous compound is polar and hydrophilic. Other end (tail) containing the fatty acid side chains is non-polar and hydrophobic. ↳ water level (soluble) ↳ (insoluble)

Glycerol + 2 Fatty Acids + Phosphate Group

↓

Phosphatidic Acid

\+

Nitrogenous Base

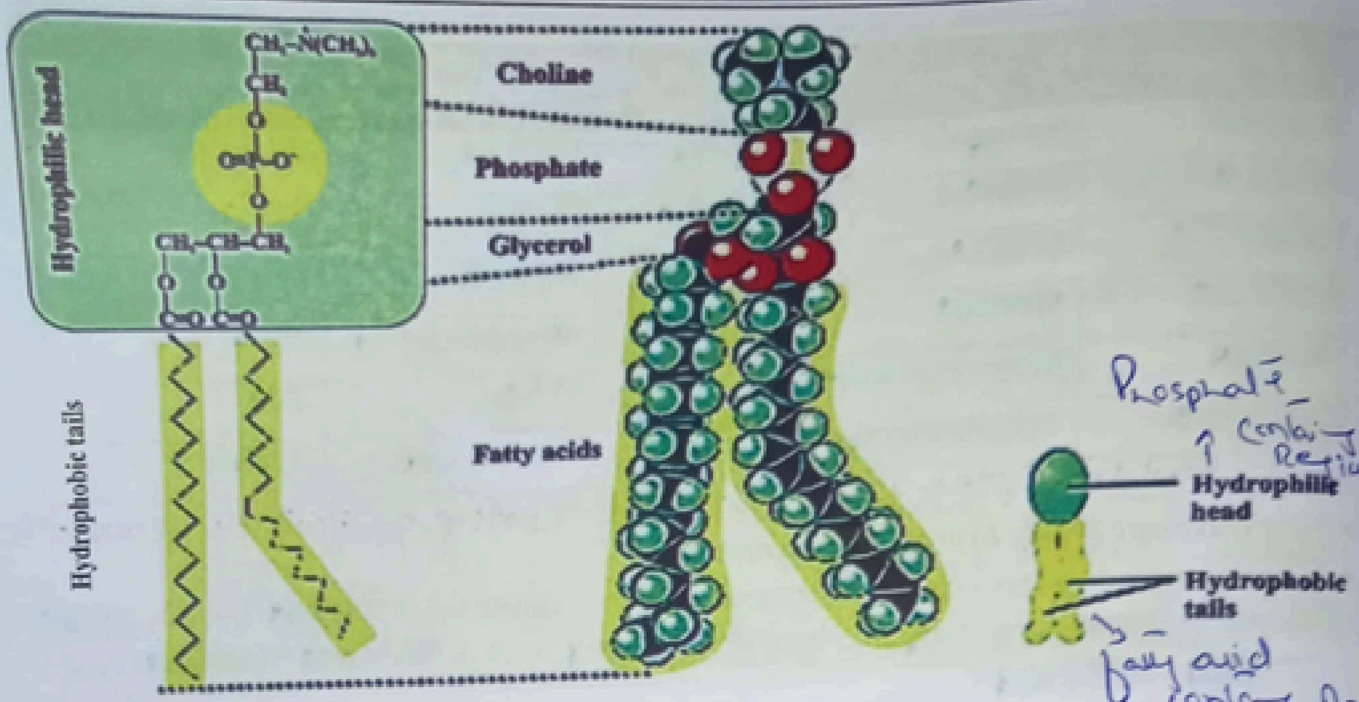
↓

Phospholipids

Example

- ***Phosphatidylcholine*** is one of its commonest examples, also called ***lecithin***.

(Head) (O.N)



Phosphate containing Region

fatty acid containing Region

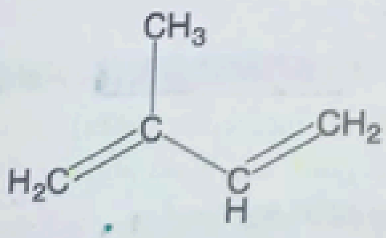
Function

- They are frequently associated with ***biological membranes*** and form lipid bilayer.

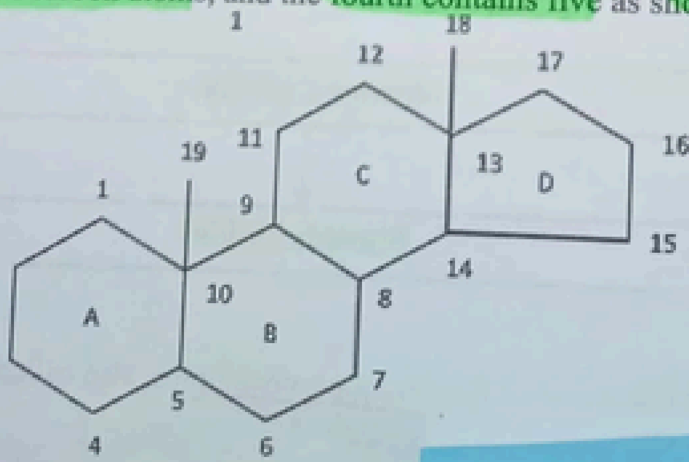
Terpenes

(isoprenoid)

- Terpenes are synthesized from a five-carbon building block known as ***isoprene unit*** (C_5H_8) which is shown below:



- This unit condenses in different ways to form many compounds. Two isoprene units' form monoterpene e.g., ***menthol***, four form diterpene e.g., ***vitamin A*** and six form a triterpene e.g., ***ambrein***. → In whale gut. eg Phytol Tail in Chlorophyll ring.
- Steroids are lipids of high molecular weight which ***can be crystallized***.
- A ***steroid nucleus*** consists of 17 carbon atoms arranged in four attached rings, three of the rings contain six carbon atoms, and the fourth contains five as shown below:



- The length and the structure of the side chains that extend from these rings disting one steroid from the other.
- Cholesterol is the precursor of a large number of equally important steroids w include the ***bile salts, testosterone, progesterone, estrogen etc.***
- ***Prostaglandins*** are derived from ***arachidonic acid*** and exist in virtually e mammalian cell and act as ***local hormone***.
- Their functions include;

1. Regulate B.P
2. Induce fever and inflammation
3. Intensify the sensation of pain
4. Help to regulate aggregation of platelets

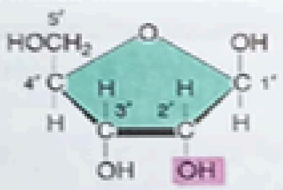
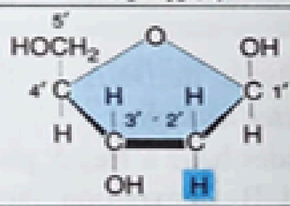
- The ability of ***aspirin*** to reduce fever and decrease pain depends on the inhibitio prostaglandin synthesis by inhibiting ***prostaglandin synthetase salicylate.***

NUCLEIC ACIDS

- Nucleic acids are of two types i.e., DNA and RNA, and both are ***linear unbranched polymers of nucleotides.***

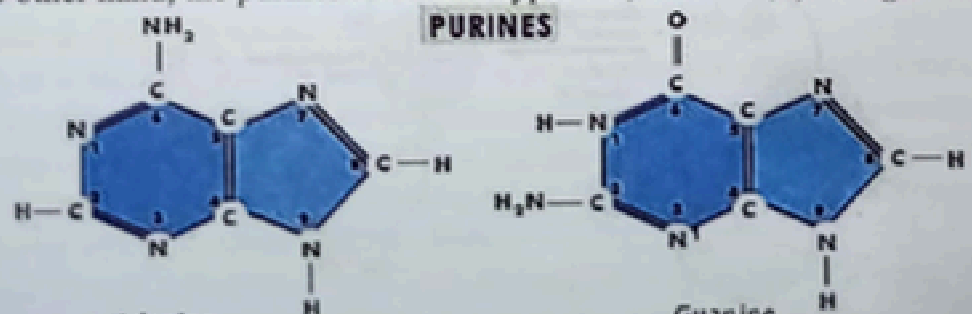
Chemical Composition of Nucleotides

- Each nucleotide consists of a ***pentose sugar, a phosphate group and a nitrogen containing base.***
- In DNA, the pentose sugar is deoxyribose ($C_5H_{10}O_4$), while in RNA; it is ribose ($C_5H_{10}O_5$).

Ribose	Deoxyribose
$C_5H_{10}O_5$	$C_5H_{10}O_4$
	

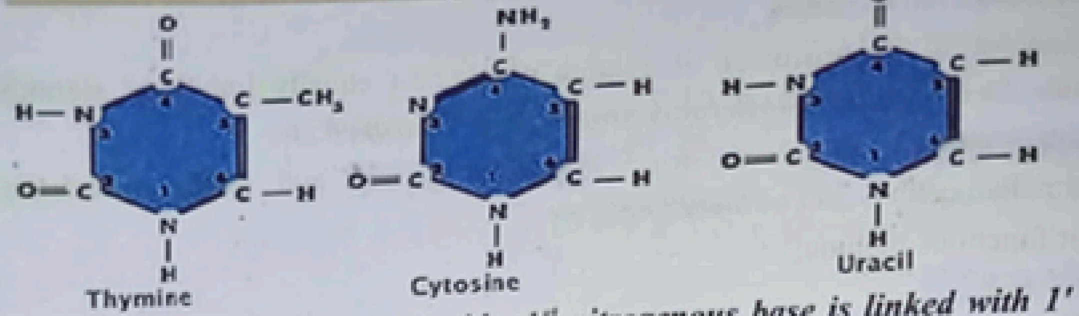
- ***Phosphoric acid/phosphate group*** is a common component of both types of nucleotides which provides ***acidic properties*** to DNA and RNA.
- The nitrogen containing ring structures are called ***bases*** which are of two types i.e., ***single ringed pyrimidine*** and ***double ringed purines.***
- Pyrimidines are of three types i.e., ***cytosine (C), thymine (T) and uracil (U)***. Thymine is only fund in DNA while uracil is only found in RNA.
- On the other hand, the purines are of two types i.e., ***adenine (A) and guanine (G)***.

PURINES

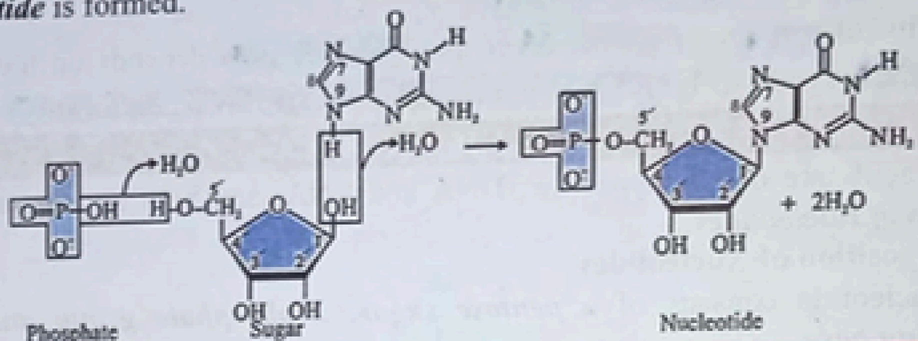


Adenine Guanine

PYRIMIDINES



- During the formation of a nucleotide, 1st ***nitrogenous base is linked with 1′ carbon of pentose sugar***. Such a combination is called ***nucleoside***.
- When a ***phosphoric acid is linked with 5′ carbon of pentose sugar of a nucleoside***, the ***nucleotide*** is formed.

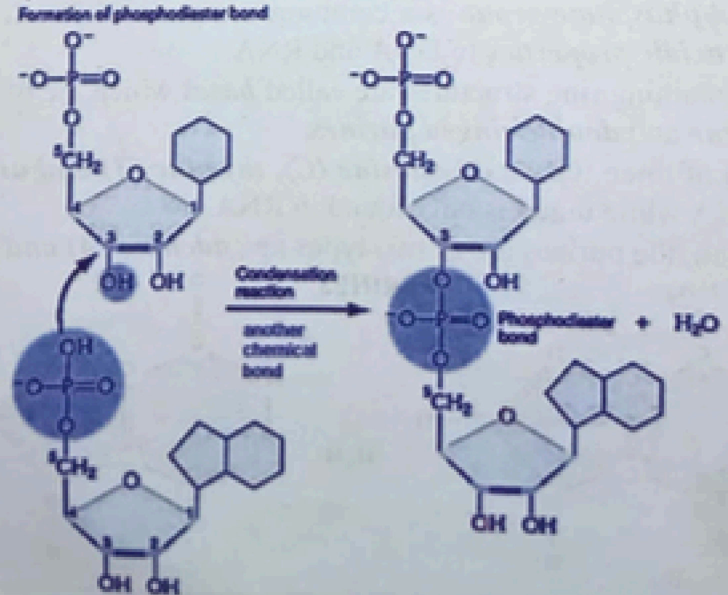


- The nucleotides which take part in the formation of DNA or RNA must contain three phosphates, but during their incorporation into DNA or RNA polymer, each nucleotide losses it's two phosphates.

> **CRITICAL CONCEPT!**
>
> The bond in between nitrogenous base and pentose sugar of nucleotide is called as N-glycosidic linkage.

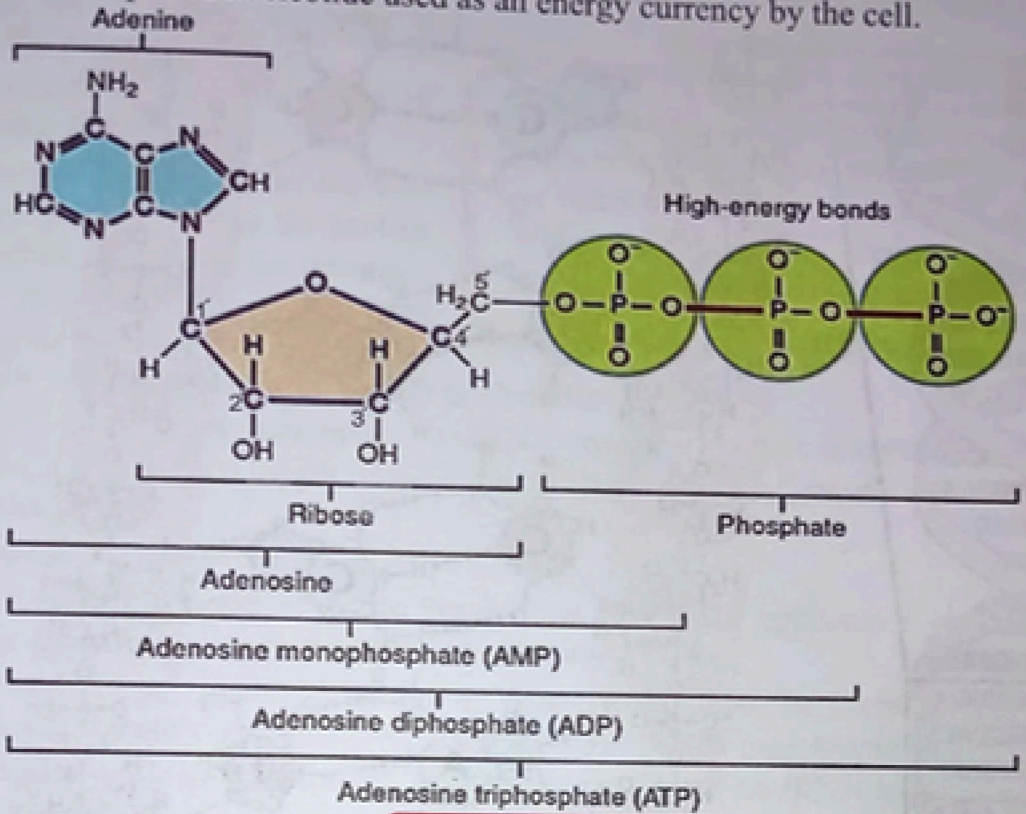
- Two nucleotides in DNA or RNA are connected through condensation reaction by ***phosphodiester linkage.***
- Polynucleotides have a free 5' phosphate group at one end and a free 3' hydroxyl group at the other end. By convention, these sequences are named from 5' to 3'.

Formation of phosphodiester bond



Important Examples of Nucleotides

- ATP is an imported nucleotide used as an energy currency by the cell.



CRITICAL THINKING

11. How many glycosidic linkages are present in a NAD^+?

A. 2 B. 1
C. 3 D. 0

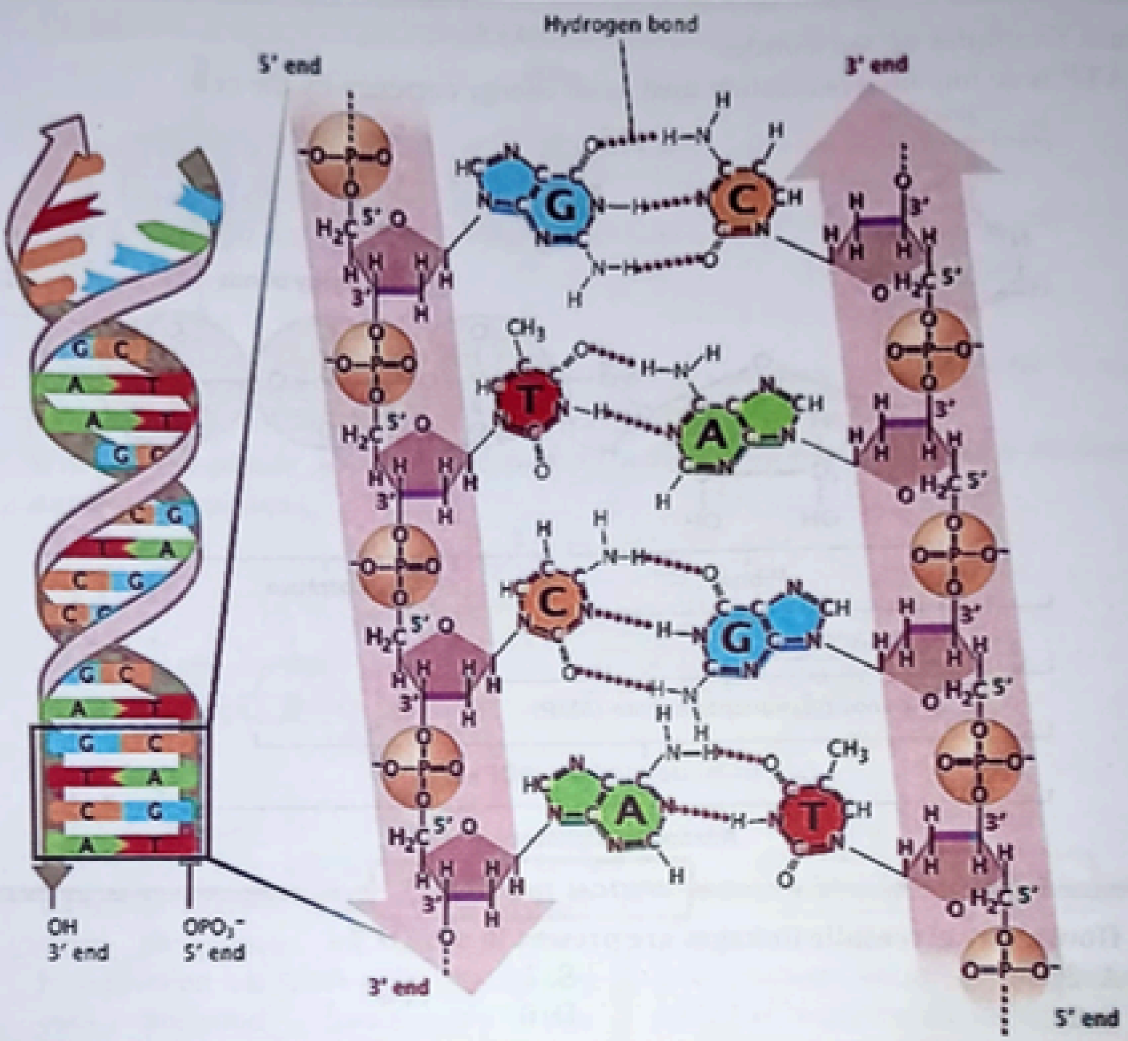
- NAD (Nicotinamide adenine dinucleotide), NADP (Nicotinamide adenine dinucleotide phosphate) and FAD (Flavin adenine dinucleotide) are important dinucleotides and used in several oxidation-reduction reactions in the cell.

Deoxyribonucleic Acid (DNA)

- DNA is ***hereditary material***. It controls the properties and potential activities of a cell.
- In 1951, ***Erwin Chargaff*** provided data about the ratios of different bases present in a DNA molecule.
- This data suggested that adenine and thymine are equal in ratio and so are guanine and cytosine. Similarly, total purines and total pyrimidines are in 1:1 in any DNA molecule.

Scale Model of DNA

- ***Maurice Wilkins and Rosalind Franklin*** described ***X-ray diffraction*** analysis of DNA. Watson & Crick presented scale model of DNA. Its salient features are given below:
- DNA is a dual polymer and made of two polynucleotide chains or strands.
- The two strands are coiled around each other in anti-parallel way to form a double helix (duplex).
- The two chains are held together by weak hydrogen bonds. Adenine and thymine are connected by two hydrogen bonds while guanine and cytosine are connected by three hydrogen bonds.
- Diameter of DNA double helix is ***2nm***.
- In each turn of DNA, there are about ***10 base pairs of about 34°A*** units.
- Base pairs are flat and the distance between two adjacent is ***0.34nm.***



Ribonucleic Acid (RNA)

- RNA is polymer of ribonucleotides.
- The RNA molecule occurs as single strand, which may be folded back on itself to give double helical characteristics. In this case, cytosine pairs with guanine and adenine with uracil.
- RNA is synthesized by DNA in a process known as ***transcription***.

Different types of Nucleoside and Nucleotides of RNA and DNA

Nitrogenous Base	RNA		DNA	
	Ribonucleosides	Ribonucleotides	Deoxyribonucleosides	Deoxyribonucleotides
Adenine	Adenosine	AMP, ADP, ATP	d- Adenosine	d- AMP, d-ADP, d-ATP
Guanine	Guanosine	GMP, GDP, GTP	d- Guanosine	d-GMP, d- GDP, d- GTP
Cytosine	Cytidine	CMP, CDP, CTP	d- Cytidine	d-CMP, d-CDP, d-CTP
Uracil/Thymine	Uredine	UMP, UDP, UTP	d-Thymidine	d-TMP, d-TDP, d-TTP

Types of RNA

Messenger RNA (mRNA)

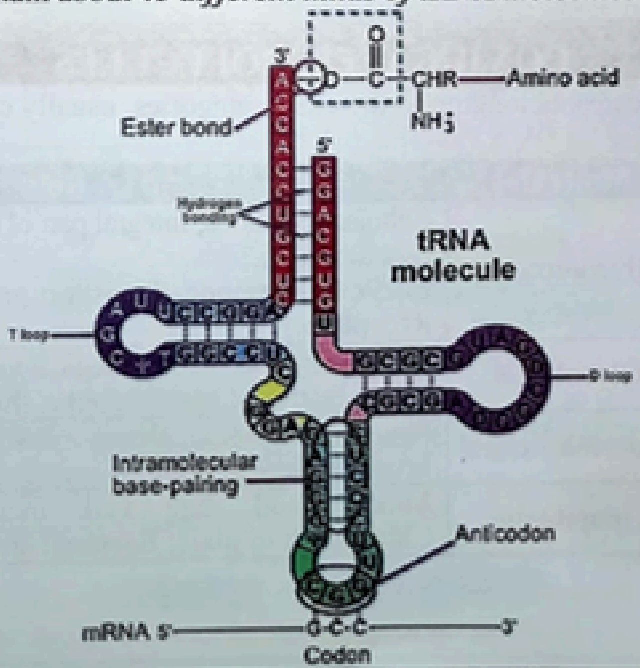
- It takes the genetic message from the nucleus to ribosome in the cytoplasm, where amino acids are arranged to form a specific protein molecule.
- It consists of a single strand of ***variable length***.
- Its length depends upon the size of the gene as well as the protein for which it is taking the message. For example, for a proteins molecule of 100 amino acids, mRNA will have the length of 300 nucleotides.

> **CRITICAL CONCEPT!**
>
> **Molecular Directions during Translation:** Ribosomes translocate always from 5' to 3' on mRNA during the process of translation. While polypeptide chains are always synthesized from N to C terminal.

- Actually every three nucleotides in mRNA encode a specific amino acid; such triplets of nucleotides along the length of mRNA are called ***codons of genetic codes***.

Transfer RNA (tRNA)

- It is ***smallest in size***.
- It is a single stranded molecule but it shows a duplex appearance at its some regions where complementary bases are bonded to one another.
- It shows a ***flat cloverleaf shape*** in two dimensional views. Its 5'-end always terminates in guanine base while 3'-end is always terminated with the base sequence of CCA.
- tRNA molecule has three loops. The ***middle loop*** in all the tRNA is composed of 7 bases, the middle three of which form ***anti-codon***, which is complementary to specific codon of mRNA.
- The ***D-loop*** recognizes the activation enzyme. ***Theta loop*** recognizes the specific place on the ribosome for binding during protein synthesis.
- There is one specific tRNA for each amino acid. So, there are at least 20 kinds of tRNA molecules. tRNA picks amino acids and transfers them to ribosomes.
- Human cells contain about ***45 different kinds of tRNA molecules***.



Ribosomal RNA (rRNA)

- It is the ***major portion of RNA*** in the cell, and may be upto 80% of the total RNA.
- It is transcribed by the genes present on the DNA of several chromosomes.
- These have the largest size among the RNA.
- It acts as machinery for the synthesis of proteins.
- It is strongly associated with the ribosomal proteins where 40 – 50 % of it is present.

Feature	mRNA	tRNA	rRNA
Function	Takes message from DNA to ribosomes	Transfers amino acids to ribosomes	Formation of ribosomes
Length	Single strand of variable length	Length of 75-90 nucleotides	Double helix with constant length
Percentage	3-4%	10-20%	80%

Difference Between DNA and RNA

Feature	DNA	RNA
Nucleotides	Deoxyribonucleotides	Ribonucleotides
Pentose Sugar	Deoxyribose	Ribose
Nitrogenous Bases	A, G, C, T	A, G, C, U
Physical Structure	Double stranded	Single stranded
Location	Chromosome, nuclei, mitochondria and chloroplasts	Nucleolus, ribosomes, cytosol, mitochondria, and chloroplast
Amount	Constant in each cell of same species	Variable from cell to cell
Role	Heredity	Protein synthesis

CRITICAL THINKING

12. Relation between amino acid and protein is similar to the one found between:

A. Thymine and uracil
B. Glucose and fructose
C. Nucleosides and nucleic acid
D. Nucleotides and nucleic acid

CONJUGATED MOLECULES

- Two different molecules, belonging to different categories, usually combine together to form conjugated molecules.

Components	Molecule	Role
Carbohydrates + Proteins	Glycoproteins	Cellular secretions, Integral part of biological membranes, Egg albumen. Enzyme, Hormone, Transport protein, Structural protein, Receptors.
Carbohydrates + Lipids	Glycolipids	Integral component of biological membranes and brain. White matter of brain, Myelin sheath of nerve fiber.
Nucleic acid + Histones	Nucleohistones	Found in ribosome, chromosome Involved in regulation of gene expression.
Lipids + Proteins	Lipoproteins	Milk, Blood, Egg yolk membrane, Cell nucleus, Chloroplast of plant, Bacterial antigen and viruses.

TOPIC-4 CELL STRUCTURE AND FUNCTION

COURSE CONTENT

- Introduction to Cell
- Compare the Structure of Typical Animal and Plant Cell
- Cell Wall
- Plasma Membrane
- Cytoplasm
- Cell Organelles: Ribosomes, Endoplasmic Reticulum, Golgi Complex, Lysosomes, Peroxisomes and Glyoxisomes, Vacuoles, Mitochondria, Plastids/Chloroplasts, Nucleus
- Compare the Structure of Typical Prokaryotic and Eukaryotic Cells

INTRODUCTION TO CELL

- The cell can be defined as 'the structural and functional unit of life/living organisms' and is the smallest unit that can carry out all activities of life.
- After the discovery of the cell in 17th century, a lot of information has been collected by different researchers. This information has been summarized in the form of ***cell theory***.
- The contribution of different scientists in the development of cell biology and emergence of cell theory is listed in the following table;

Robbert

Scientist	Year	Contribution
R. Hooke	1665	Discovered the 'cell'.
L. Oken	1805	Believed that 'all living things originate from or consists of vesicles or cells'.
J. B. de-Lamarck	1809	Expressed the idea that "nobody can have life if its constituent parts are not cellular tissues or are not formed by cellular tissues".
R. Brown	1831	Reported the presence of nucleus.
T. Schwann	1839	Formulated 'cell theory'.
M. J. Schleiden	1839	Formulated 'cell theory'.
R. Virchow	1855	Hypothesized that new cells were formed by the division of previously existing living cells (to put it in Virchow's words: ***'Omnis cellula e cellula'***.
L. Pasture	1862	Experimental proof for Virchow's hypothesis by demonstrating that bacteria could be formed only from existing bacteria.
A. Weismann	1880	All presently living cells have a common origin because they have basic similarities in structure and molecule etc.

- The generally accepted postulates of modern cell theory are as follows:

1. The cell is the fundamental unit of structure and function in living things.
2. All organisms are made up of one or more cells.
3. Cells arise from other cells through cellular division.

MICROSCOPY

- A ***microscope*** (Greek: micron=small + skopein=to look at) is an instrument for viewing objects that are too small to be seen by the naked or unaided eye.

- The science of investigating small objects using such an instrument is called ***microscopy***.
- The examination of a cell and its component depends upon the ***magnification powers*** of two convex lenses to produce a magnified image of a very small object and the ***resolving power***, which are described in the following table.

Magnification	Resolution
• Magnification is the number of times larger an image is as compared to the real size of the object. • Magnifying power of light (compound) microscope is about 500X-4000X that of naked eye (on average). • Magnifying power of electron microscope is upto 2,000,000X.	• Resolution is defined as the ability to distinguish between two separate points. • Resolution power of human naked eye is 1.0 mm. • Resolution power of a typical compound microscope is 250nm. • Resolution power of electron microscope is 2nm.

Comparison of Light & Electron Microscope

- There are two type of microscopes which are described in the following table.

Features	Light Microscope	Electron Microscope
Source of illumination	Visible light	Beam of electron
Magnifying Power	500X of naked eye	250,000X of naked eye
Resolution power	2µm	2-4 A
Main components	Glass lenses	Electromagnetic lenses
Objects seen	Larger than 200 nm	Smaller than 200 nm
Sample seen	Living/ Dead	Dead
Medium	Open (atmosphere)	Vacuum

Types of Electron Microscope

- There are two main types of electron microscope i.e., ***transmission EM (TEM)*** and ***scanning EM (SEM)***.

Features	Transmission EM	Scanning EM
Beam of electrons	It is passed through the specimen.	It is reflected through the specimen.
Beam observed	Transmitted	Reflected
Specimen Seen	Thin sections of specimen	Scan the surfaces
Field of vision	Somewhat lesser	Greater
Function	Used to see internal structures of cell	Used to see surface details of cell

Cell Fractionation

- ***Cell fractionation*** is the combination of various methods used to separate the cell organelles and other components ***based upon the size, density*** and ***density of the medium***.
- The principle of cell fractionation consists of two steps i.e., ***homogenization and centrifugation***.

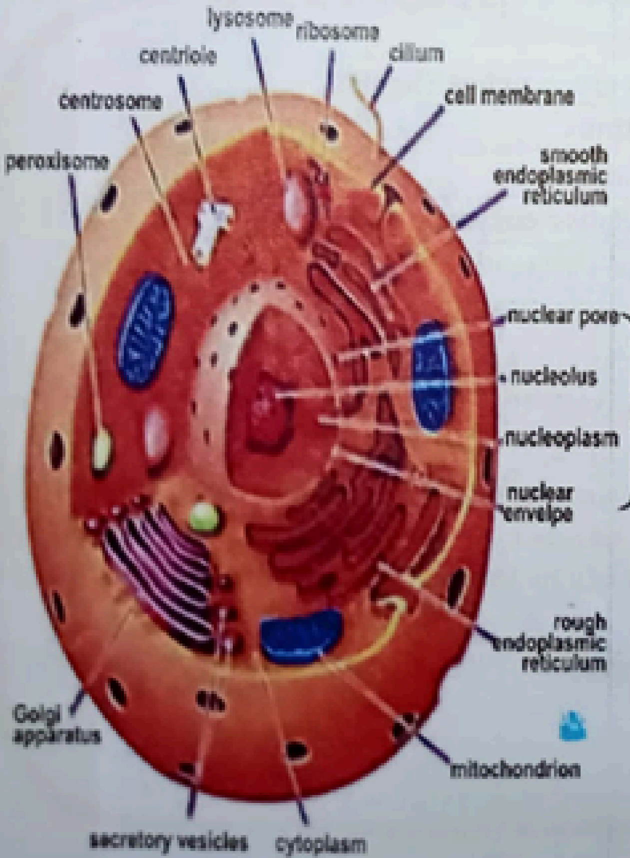
- ***Homogenization*** involves the grinding of the cells in a suitable medium with correct pH, ionic composition and temperature by ***using a blender***. In plants, ***pectinase*** *is* ***added to digest middle lamella***.
- The procedure gives rise to a ***uniform mixture*** of cells which is then centrifuged.
- ***Centrifugation*** is the process to separate substances on the basis of their size and densities under the influence of centrifugal force by using centrifuge.
- In ***density gradient centrifugation***, the cell components of different sizes and densities are ***separated in different layers***. The upper layers are less dense than lower layers.
- In ***differential centrifugation***, the size and shape of a particle determines how fast it settles.
- At each step, the content which settles in the bottom of the tube is called ***pellet*** and those that remain suspended above in the form of liquid are called ***supernatant***.
- After each speed, the supernatant can be thrown off and centrifuged again. A series of pellet containing cell organelles of smaller and smaller size can therefore be obtained.
- A cell consists of the following basic components:

(i) Plasma membrane, also cell wall in plant cells
(ii) Cytoplasm, containing cells organelles
(iii) Nucleus, with nuclear or chromatin material

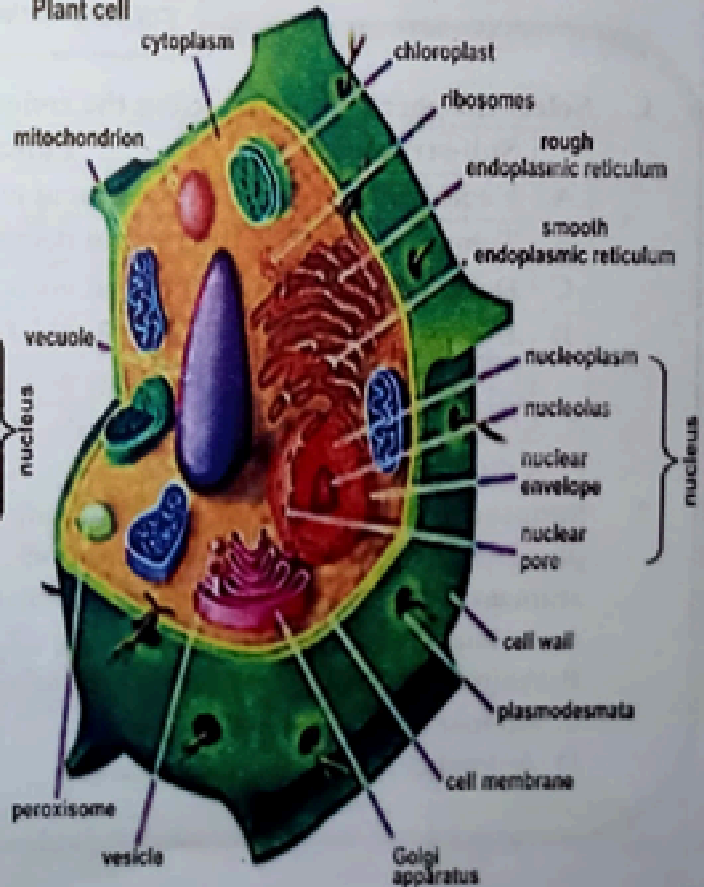
COMPARE THE STRUCTURE OF TYPICAL ANIMAL AND PLANT CELL

In the traditional system of classification, all organisms are divided into plants and animals. The main comparative features between animal and plant cells are shown in the figure below:

Animal Cell



Plant cell



These comparative features are also listed in the following table.

Features	Animal Cell	Plant Cell
Cell wall	×	✓
Plastids	×	✓
Glyoxysomes	×	✓
Centrosome (Centrioles)	✓	×
Mitotic Apparatus	Spindles + Asters	Spindles Only
Direction of Cytokinesis	Outwards → Inwards	Inwards → Outwards
Lysosomes	✓	×
Flagella	✓	×
Phagocytosis	✓	×
Position of Nucleus	Central	Peripheral
Mode of Nutrition	Heterotrophs	Autotrophs
Vacuoles	Small and many	Large and single
Storage Products	Glycogen	Starch
Cellular Shape	Do not have fixed shape	Have fixed shape

CRITICAL THINKING

1. **Select the correct answer using the codes given below the list:**

	Sub-structures		Functions
A	Nucleosome	1	Cell adhering junctions
B	Tubulin	2	Battery of degradative enzymes
C	Desmosomes	3	Structural units of chromatin
D	Lysosome	4	Protein units of microtubules
		5	Oxidative phosphorylation

A. A=2, B=5, C=4, D=3 B. A=3, B=4, C=1, D=2
C. A=3, B=5, C=4, D=2 D. A=2, B=4, C=1, D=3

2. **Suppose plant and animal cell having same rate of metabolism and similar physiology, in spite of these conditions, number of mitochondria are more in animal cells as compare to plant cell, what can be the best reason to explain this?**
A. Animal cell is very dynamic
B. Animals is having only one source of energy
C. Animal cell is without cell wall
D. Animal cell is having small vacuole

CELL WALL

Introduction to Cell Wall

- It is the outermost non-living covering present in plants, algae, fungi and prokaryotic cells while absent in animal cells. This is probably due to their locomotory mode of life.
- The cell wall of plant cell is different from that of prokaryotes, both in structure and chemical composition. Prokaryotic cell walls lack cellulose; its strengthening material is peptidoglycan or murein while fungal cell wall contains chitin.
- It is ***secreted by protoplasm*** of the cell and has variable thickness in different cells of the plant.
- The cell wall is porous *(called pits)* and allows free passage of water and dissolved material.

Structure

The plant cell wall consists of three main layers which are, primary wall, middle lamella and secondary wall.

(i) Primary Wall

The primary wall is a true wall and develops in newly growing cells. Some plant cells possess only primary cell wall such as leaves, storage cells and young growing cells. The primary wall is composed of the following material:

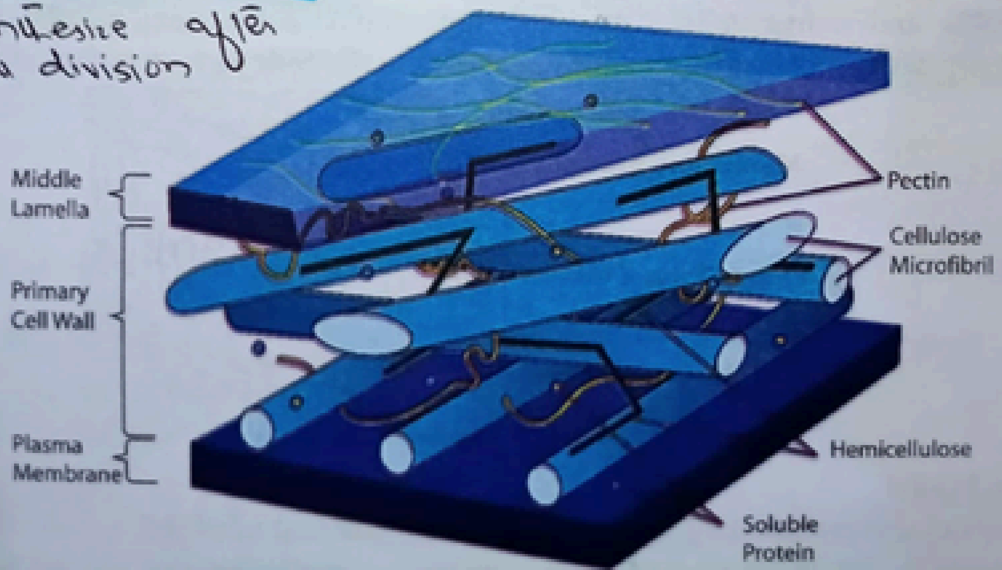
- ***Cellulose*** micro-fibrils are arranged in a crisscross arrangement. The microfibrils are held together by hydrogen bond to provide ***high tensile strength***.
- Some amount of ***pectin and hemicellulose*** is also deposited in it.
- The outer part of primary cell walls of plant epidermis in usually impregnated with ***cutin*** and ***wax***, forming a permeability barrier known as plant ***cuticle***.

(ii) Middle Lamella False wall

The middle lamella is first to be formed in between the primary walls of the neighboring cells.

- It is formed of sticky gel-like magnesium and calcium salts and pectin which help to stick the neighboring cells together.

• 1st Synthesize after cell division



(iii) Secondary Wall

The secondary wall is formed between the primary cell wall and plasma membrane and is formed when the cell is fully grown. It is comparatively thick and rigid as compared to primary wall.

cellulose &
hemicellulose

- Chemically, it is composed of *inorganic salts*, *silica*, *waxes*, *lignin*, and *cutin* etc.
- Lignin cements and anchors cellulose micro-fibrils together and it is mainly responsible for rigidness.

Functions of Cell Wall

Cell wall is very important. It performs following important functions:

(i) It provides a ***definite shape*** to the cell.

(ii) It prevents the cells from osmotic lysis, when cells are placed in hypotonic external environment.

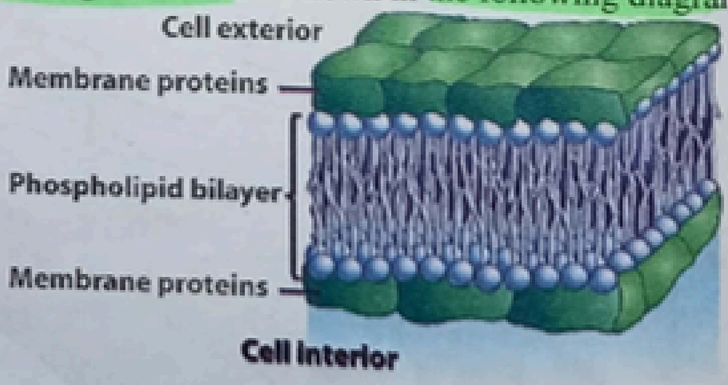
(iii) It provides ***protection*** to inner parts of cells and ***does not act as a barrier*** to the materials passing through it.

PLASMA MEMBRANE

- Plasma membrane is the boundary of protoplasm. It is found in all living prokaryotic and eukaryotic cells
- Plasma membrane is about 7 nm thick.
- Chemically, it is composed of:
  - Proteins (60-80%)
  - Lipids (20-40%)
  - Small amount of carbohydrates is also present in the form of glycolipids and glycoproteins.
- Many biologists contributed to establish the structural organization of the cell membrane by developing various membrane models, the most familiar of which are ***unit membrane model*** and ***fluid mosaic model***.

Unit Membrane Model

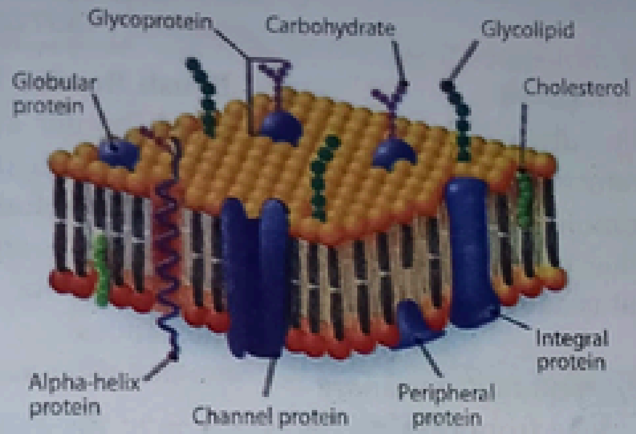
- This model was presented by J. David Robertson in 1959.
- According to unit membrane model, the cell membrane is composed of lipid bilayer that is sandwiched between inner and outer layer of proteins.
- This structure has hydrophobic component i.e. central non-polar part of phospholipid molecules and a hydrophilic part i.e., outer polar component of phospholipids and globular proteins covering both sides as shown in the following diagram.



Fluid Mosaic Model

- This model was proposed by S.J. Singer and G.L. Nicolson in 1972.
- According to fluid mosaic model, protein layers are not continuous and are not confined to the surface of the membrane but are embedded in lipid layers in a mosaic manner. These protein molecules may function as a gateway (charged pore) for the transport of materials.
- This model at present is the ***most accepted one***.

Scanned with CamScanner



Role of Different Molecules

- ***Phospholipids*** form lipid bilayer.
- ***Cholesterol*** helps to stabilize this lipid bilayer.
- ***Channel proteins*** allow a particular molecule or ion to cross the plasma membrane freely.
- ***Carrier proteins*** selectively interact with a specific molecule or ion so that it can cross the plasma membrane.

CRITICAL THINKING

3. The function of channel proteins in membrane is to:

A. Transport phospholipids across the membrane
B. Act as receptor molecules which can bind to ligands
C. Permit the diffusion of specific substances through the membrane
D. Bind to a substance on one side and release it on the other side of the membrane

- Some membrane proteins have enzymatic functions. They perform metabolic reactions directly e.g. ***adenylate cyclase*** catalyzes the transformation of ***ATP to cAMP***, a ***second messenger***, used for intracellular signal transduction, such as transferring into cells the effects of hormones like glucagon and adrenaline because they cannot pass through the plasma membrane.
- Some proteins in the plasma membrane act as ***receptors*** and receive signals from the other cells/endocrine glands.
- ***Glycoproteins*** and ***glycolipids*** are found on cell surface and help in recognition. Mostly these molecules act as cell surface markers.

Transport Mechanisms across Plasma Membrane

- Cell membrane is a ***differentially permeable*** or ***selectively permeable membrane***, allowing only the selective substances to pass through it.
- ***Lipid soluble*** substances pass through cell membrane more easily than others.
- Many small gas molecules and water etc. being neutral can easily cross.
- Ions being charged particles have some difficulty in crossing.

Passive and Active Transport

Passive Transport	Active Transport
High conc. → Low conc.	Low conc. → High conc.
Along the concentration gradient	Against the concentration gradient
Downhill movement	Uphill movement
Without use of cell energy (ATP)	With use of cell energy(ATP)

Diffusion and Osmosis

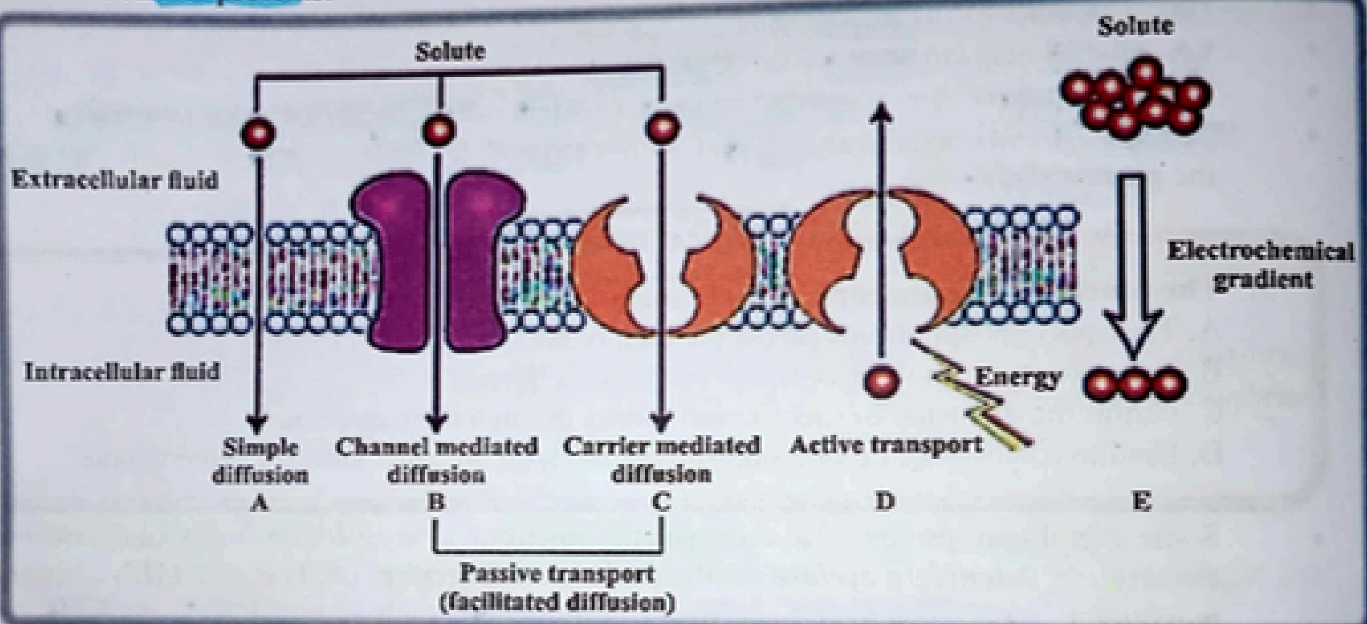
- Movement of solute molecules from higher concentration to lower concentration is called ***diffusion*** e.g. movement of respiratory gases.
- Movement of water molecules across the membrane from higher water potential to lower water potential is called ***osmosis***.

CRITICAL CONCEPT!

Brush Border Epithelium:
Brush border epithelium is a stria of microvilli on the plasma membrane of an epithelial cell (as in a kidney tubule or in small intestine) that is specialized for absorption of various substances.

Facilitated Diffusion

- It is a type of ***carrier mediated transport*** in which molecules move from higher concentration to lower concentration with the help of carrier proteins.



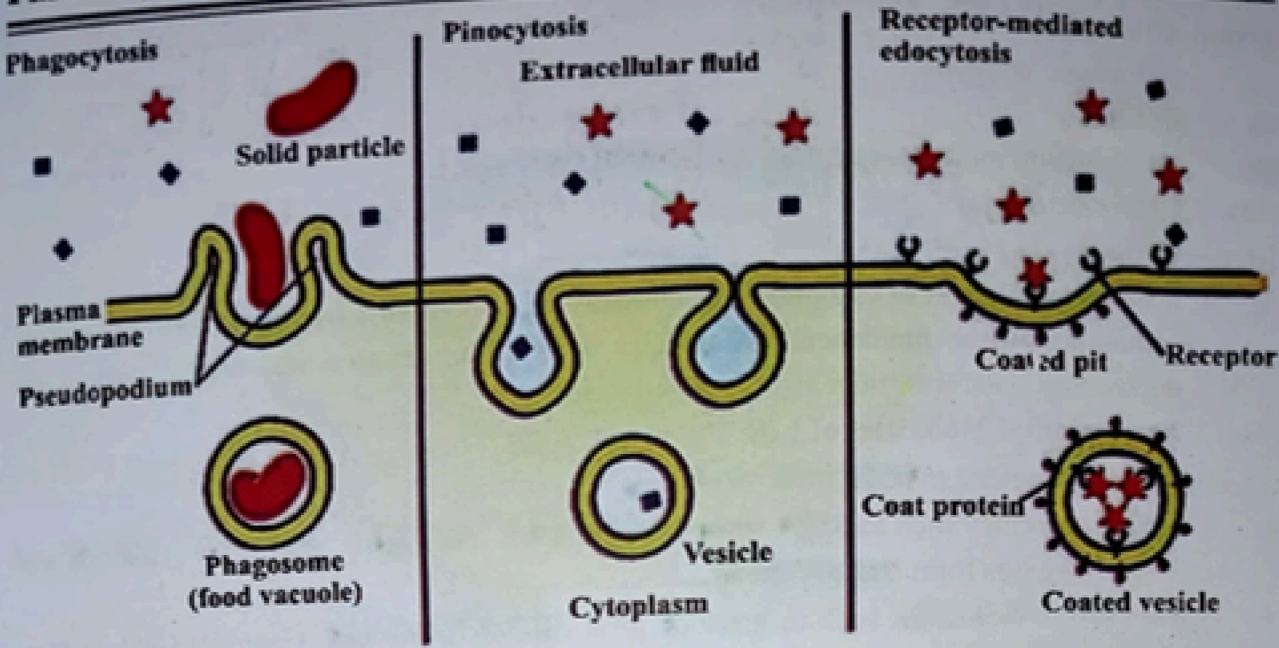
CRITICAL THINKING

4. Carrier molecules for performing their function always required configurationally change, of course this change requires energy which is provided by the system or cell, for Passive transport, configurational change also requires, who will provide this energy?

A. System or cell
B. Molecule itself
C. Carrier will use ATP
D. Non-metabolic energy by the system

Endocytosis and Exocytosis

- Intake of materials along the infoldings of cell membrane in the form of vacuole is called ***endocytosis***.
- Intake of material in solid form is called ***phagocytosis*** while intake in fluid form is called ***pinocytosis***.
- ***Exocytosis*** is the process by which cells remove materials from within the cell into the extracellular fluid. Exocytosis occurs when a vesicle fuses with the plasma membrane, allowing its contents to be ***released outside the cell***.



Some Other Functions of Plasma Membrane

Plasma membrane regulates cell's interaction with its environment by controlling transport of materials across the cell. Transport across plasma membrane occurs to;

1. Obtain nutrients
2. Excrete waste substances
3. Secrete useful substances
4. Generate ionic gradients essential for nervous and muscular activities
5. Maintain a suitable pH within the cells for enzyme activity

CRITICAL THINKING

5. Which of the following components of plasma membrane is involved in the enhancement of cell surface area?

A. Cilia
B. Microvilli
C. Desmosomes
D. Gap junctions

CYTOPLASM

- The word cytoplasm literally means 'living gel of the cell, and is described as the region between nuclear membrane and plasma membrane. This is the common component of both prokaryotic and eukaryotic cells.
- The major difference between the cytoplasm of these two fundamental kinds of cells is the presence or absence of cytoskeleton and membrane bound organelles.
- The living contents of the eukaryotic cell are divided into nucleus and the cytoplasm, the two collectively form ***protoplasm***.
- Cytoplasm consists of an aqueous ground substance containing a variety of cell organelle and other inclusions such as insoluble waste and storage products.

Composition • Peripheral part is like gel.

Cytoplasm contains:

Cytosol
• non viscous
• Near nucleus
• Glycolysis occurs in cytosol.

Cytogel
• highly viscous
• near Plasma membrane

(i) Cytosol
(ii) Fundamental molecules of life
(iii) Cell organelles

(i) Cytosol

It is the soluble part of cytoplasm. Chemically, it is about ***90% water*** and forms a solution containing all the fundamental molecules of life, i.e., amino acids, sugars, fatty acids, nucleotides, vitamins, salts and dissolved gases.

(ii) Fundamental Molecules of Life

- Some of them are in ionic form.
- Small molecules such as salts, sugars, amino acids, fatty acids, nucleotide, vitamins and dissolved gases form ***true solutions***.
- Some large molecules such as proteins form ***colloidal solutions***. Colloidal solution may be *sol* (non-viscous) or *gel* (viscous).

(iii) Cell Organelles

In living cells, the cytoplasm contains several cell organelles such as endoplasmic reticulum, mitochondria, Golgi complex, nucleus, plastids, ribosomes, lysosomes and centrioles.

Function of Cytoplasm

The most important functions of cytoplasm are:

(i) It acts as a *store house* of vital chemicals.

(ii) It is a *site of certain metabolic pathways* e.g. *translation*, *glycolysis*, *glycogenolysis* and *gluconeogenesis*.

(iii) A circular streaming movement can also be observed in cytoplasm due to the contractile activity of microfilaments. This movement is called Cyclosis which is responsible for distribution of cell contents in cytoplasm.

CELL ORGANELLES

An organelle is a sub-cellular structure that has one or more specific jobs to perform in the cell, much like an organ does in the body. Prokaryotic cells are equipped with little type of organelles while eukaryotic cells are equipped with much different type of organelles, forming true division of labor in these cells.

Non-Membranous	Single Membranous	Double Membranous
Ribosomes	Endoplasmic Reticulum	Mitochondria
Centrioles	Golgi apparatus	Plastids
Cytoskeleton	Lysosomes	Nucleus
	Glyoxysomes	
	Peroxisomes	
	Vacuoles	

Discovery of Organelles

Organelles	Discovered By
Ribosomes	George Emil Palade
Centrioles	Edouard Van Beneden
Cytoskeleton	Nikolai K. Koltsov
Endoplasmic Reticulum	Keith R. Porter, Albert Claude, Brody Meskers and Ernest F. Fullam
Golgi apparatus	Camillo Golgi
Lysosomes	C. R. De Duve
Peroxisomes	C. R. De Duve
Glyoxysomes	Harry Beevers
Mitochondria	Albert von Kolliker
Nucleus	Robert Brown

RIBOSOMES (Palade (1955))

Ribosomes were first observed using electron microscope as tiny and dense granules. These are roughly spherical, non-membranous bodies found in both eukaryotic as well as prokaryotic cells.

CRITICAL CONCEPT!

Ribosomes Found in Organelles:
Being organelles of prokaryotic origin, mitochondria and chloroplast have 70S ribosomes and small circular DNA in their matrix.

Chemical Composition

- Ribosomes are ***ribonucleo-proteins*** particles.
- Ribosomes consist of ***RNA*** and ***proteins*** in almost equal proportion.

Assembly of Ribosomes

- Ribosomes are assembled in the ***nucleolus***.
- From nucleolus they are transported to the cytoplasm through nuclear pores.

(in free state) nucleus, nucleolus (Bind state)

Form and Physical Structure

- They exist in two forms, either dispersed in the cytoplasm or attached with rough endoplasmic reticulum (RER) as tiny granules. Plasma membrane, Bacterial cell.
- Ribosomes consist of ***two subunits***: larger subunit and smaller subunit.
- The attachment is controlled by the presence of Mg^{2+} concentration or forming salt bonds between phosphate group of RNA and amino group of amino acid or both by Mg^{2+} and salt bonds. O-P-O [NH3]
- Ribosomes are attached to 5' end of mRNA through smaller subunits. & leave 3' end.

O=P-O, O-NH3

Type	Size	Larger Subunit	Smaller Subunit
Prokaryotic Ribosomes	Smaller, 70S	50S → Svedberg	30S
Eukaryotic Ribosomes	Larger, 80S, 70S	60S	40S

sedimentation due to density based.

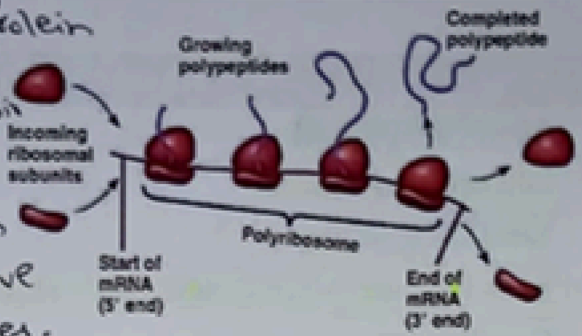
Functions

↳ 80S in cell & also 70S in mitochondria & cytoplasm

- Ribosomes are the factory for ***protein synthesis (translation)***.
- A group of ribosomes attached to mRNA is known as ***polysome*** or ***polyribosome***. In this way, several copies of same polypeptide can be produced in very less time.

• factory of Ribosome is nucleolus.

Eukaryotic make Protein remain inside the cell e.g. heamoglobin
Prokaryotic make Protein export from cell e.g. Digestive enzymes, hormones.



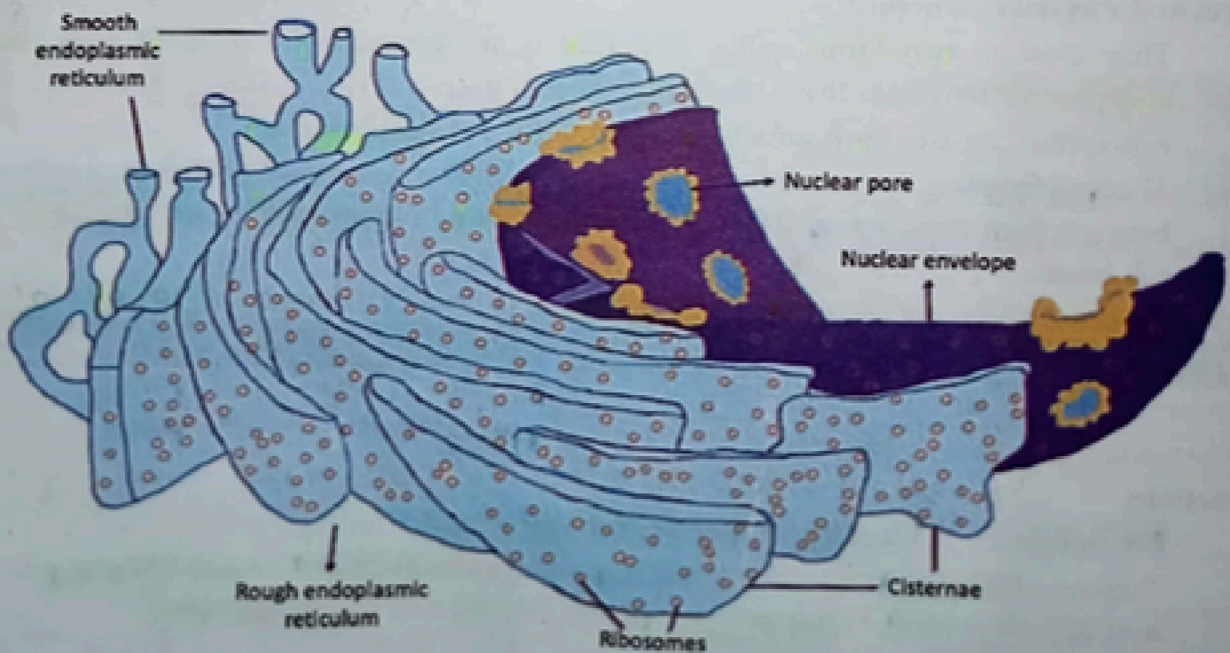
CRITICAL THINKING

6. **RNA binds with ________ ribosomal unit during translation in mitochondrial matrix.**

A. 30S B. 60S
C. 50S D. 40S

ENDOPLASMIC RETICULUM

- An interconnected network of *cisternae/elongated closed sacs* which is generally extended from nuclear membrane to the plasma membrane throughout cytoplasm of all eukaryotic cells is called endoplasmic reticulum.
- They vary in appearance from cell to cell.
- ***Cisternae*** are spherical or tubular membranes which separate the material present in these channels from that of cytoplasmic material.
- In skeletal and cardiac muscle cells, the modified form of SER is known as ***sarcoplasmic reticulum*** which is specialized for storage of Ca^{+2} in their lumen. If many ribosomes are attached on the small parallel cisternae of RER, then it is called ***ergastoplasm***. In nerve cells, the ergastoplasm is known as Nissl's granules/bodies.



Types and Functions

There are two *morphological forms* of endoplasmic reticulum; RER and SER.

Features	Rough Endoplasmic Reticulum	Smooth Endoplasmic Reticulum
Ribosomes	Ribosomes are attached with their outer surface	Ribosomes are not attached with their outer surface
Connection with the nuclear membrane	RER is directly connected with outer nuclear membrane	SER is not directly connected with outer nuclear membrane
Stability	More stable structure	Less stable structure
Composition	Mainly composed of cisternal form	Mainly composed of tubular and vesicular form
Relative abundance in body	Abundantly occur in the cells/tissues/organs which are actively engaged in protein synthesis and secretion	Abundantly occur in the cells concerned with glycogen and lipid metabolism
Example of Tissues/organs	Liver, pancreas and goblet cells etc.	Adipose tissues, muscles etc.
Functions	• Protein synthesis/Translation. After synthesis, they are either stored in the cytoplasm or transported out of the cell through these channels	• Metabolism of various types of molecules particularly lipids. • Involved in detoxification harmful drugs. • Transmission of impulses • Intracellular transport

CRITICAL THINKING

7. **Which of the following will not be channelized through RER?**
   A. Immunoglobulins B. Thyroid stimulating hormone
   C. Interferons D. Arginase
8. **Which of the following statement about the endoplasmic reticulum is correct?**
   A. It is involved in Glycogenolysis
   B. It consists of a collection of unconnected vesicles
   C. It is continuous with outer mitochondrial membrane
   D. It contain enzymes for the breakdown of cellular organelles
9. **Which type of membrane is most abundant within a cell?**
   A. ER membrane B. Golgi membrane
   C. Plasma membrane D. Nuclear membrane

General Functions of E.R

- They provide ***mechanical support*** to the cell, so that its shape is maintained
- They are also involved in ***transport of materials*** from one part of the cell to the other.
- Fragmented elements of disintegrated nuclear membrane and endoplasmic reticulum arranged around the chromosomes to ***form nuclear membrane during cell division.***
- All membranous organelles except mitochondria and chloroplast are formed by endoplasmic reticulum.

CRITICAL CONCEPT!

Three organelles are involved in Fatty acid metabolism, mitochondria, peroxysome and SER.

CRITICAL CONCEPT!

Proteins Synthesized by Different Classes of Cellular Ribosomes

Location of Ribosomes	Classes of Protein Synthesized
Membrane Free Ribosomes	Soluble cytosolic proteins, (soluble → in cytosol) Extrinsic membrane proteins, Localized to the cytoplasmic surface (e.g., actin, spectrin), Mitochondrial and chloroplast proteins encoded by nuclear DNA, Peroxisomal proteins
ER Membrane Bound Ribosomes	Secreted proteins, Integral plasma proteins, Lysosomal proteins, ER proteins, Golgi complex proteins, Extrinsic membrane proteins localized to the extra-cytosolic surface (e.g., Fibronectin)

GOLGI COMPLEX

Introduction => Found in Eukaryotic cell. Discovered by (Camilo Golgi in (1898)).

- Single cisternal sac is called ***Golgi body***.
- Stack of cisternae sacs is called ***Golgi apparatus***.
- Stack of cisternae sacs with associated vesicles is called ***Golgi complex***.
- Golgi apparatus in plants is called ***Dictyosomes*** which are used in construction of cell wall.

Structure

B'cz they have large no of cisternae (30). In Animal they are 3-4

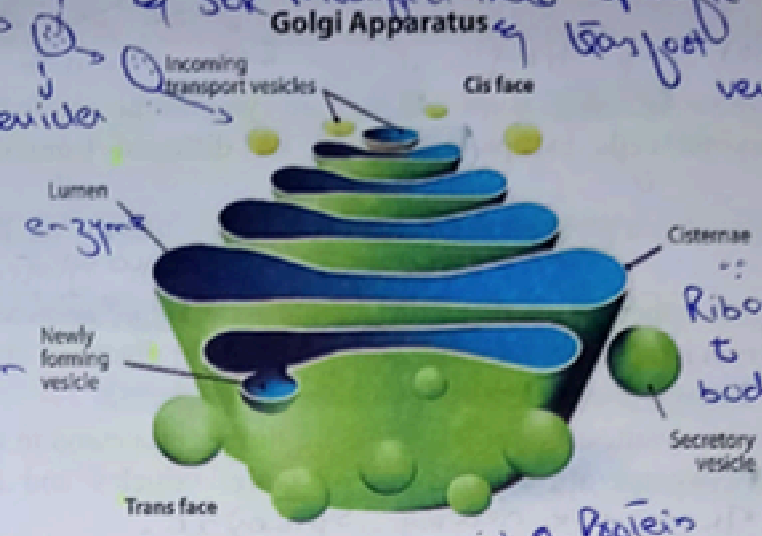
- Golgi apparatus is a stack of flattened, membrane bound sacs called ***cisternae***.
- Golgi complex is a complex system of interconnected tubules around the central stacks.
- At one end of the stack, new cisternae are constantly being formed by the fusion of (Lipo Protein) vesicles from the SER. [forming face).
- Golgi apparatus has two faces i.e. forming face and maturing face.
- ***Forming face*** (convex) is outer face also called as 'cis face'. Vesicles that bud off from smooth endoplasmic reticulum are fused together to form cisternae of Golgi apparatus at forming face.
- ***Maturing face*** (concave) is inner face also called as 'trans face'. Secretory granules/ Golgi vesicles are pinched off from maturing surface.

On maturing face cisternae break into vesicle again

Scanned with CamScanner

Protein form RER

RER → vesicles → SER modified into specific function. Golgi body in form of vesicle



E.g of Secretions :- Pancreas secrete granules contain enzyme help in digestion.
=> G.complex has involved in formation of granules.

∵ Secretions formed in Ribosome then move to (E.R) to Golgi bodies. => it is converted into finishing Product & Packed in membrane

Functions

it consist of Protein → Salivary Amylase → Salivary Pancreatic Amylase

- The main function of Golgi bodies is the *cell secretion*.
- They are involved in *modification of molecules*. Most important modifications are addition of carbohydrates into proteins and lipids and subsequent synthesis of *glycoconjugates*.
- During cytokinesis in plant cells, these are involved in formation of *phragmoplast*.
- An important function of Golgi apparatus is the *formation of primary lysosomes*.
- *Formation of acrosome* during spermatogenesis.

CRITICAL CONCEPT!

Endomembrane system:
The endomembrane system is a group of membranes and organelles in eukaryotic cells that works together to modify, package, and transport lipids and proteins. It includes the nuclear envelope, endoplasmic reticulum and Golgi apparatus, lysosomes and vesicles.

∵ lysosome, glyoxysome, Peroxisome originate from golgi body/apparatus.

Pathway and Fate of Processed Vesicles

Ribosomes → Endoplasmic reticulum → Transport vesicles → Golgi apparatus

Golgi apparatus → Packed inside a membrane → Golgi Vesicles → Lysosomes / Excretory granules

Golgi apparatus → Modification of proteins and lipids by adding carbohydrates and converting them into glycoproteins and glycolipids.

∵ In Plant cell division. golgi complex gives rise vesicles which contain cell wall synthesizing material

CRITICAL THINKING

10. Golgi apparatus is involved in processing of:
A. Salivary amylase B. Glucokinase
C. Phenylalanine hydroxylase D. EcoR1

They released enzyme. or are ... for extra cellular digestion.

LYSOSOMES

Organ Suicidal Bags

Introduction

They eat any foreign particles that enter into cell. Process is called phagocytosis

- Lysosomes (Lyso = Splitting: Soma = Body) are cytoplasmic organelles which are found in most eukaryotic cells except (RBCs) and are different from others due to their morphology.
- These were isolated as a separate component for the first time by De Duve in 1949.

Structure

Glycosylated membrane.

- These are roughly spherical in shape and bound by a ***single membrane*** and are simple sacs (vesicles) rich in ***acid phosphatase*** and several other digestive or ***hydrolytic enzymes*** (about 40) like carbohydrases, lipases, proteases and nucleases.
- These enzymes are synthesized on RER and are further processed in the Golgi apparatus. The processed enzymes are budded off as Golgi vesicles and are called ***primary lysosomes.*** → They are newly synthesize.

Two types — (Digest food particles)

① Autophagosome

- *Secondary lysosomes* are formed by the fusion of primary lysosome with food vacuole known as phagosome (phagocytic food vacuole).

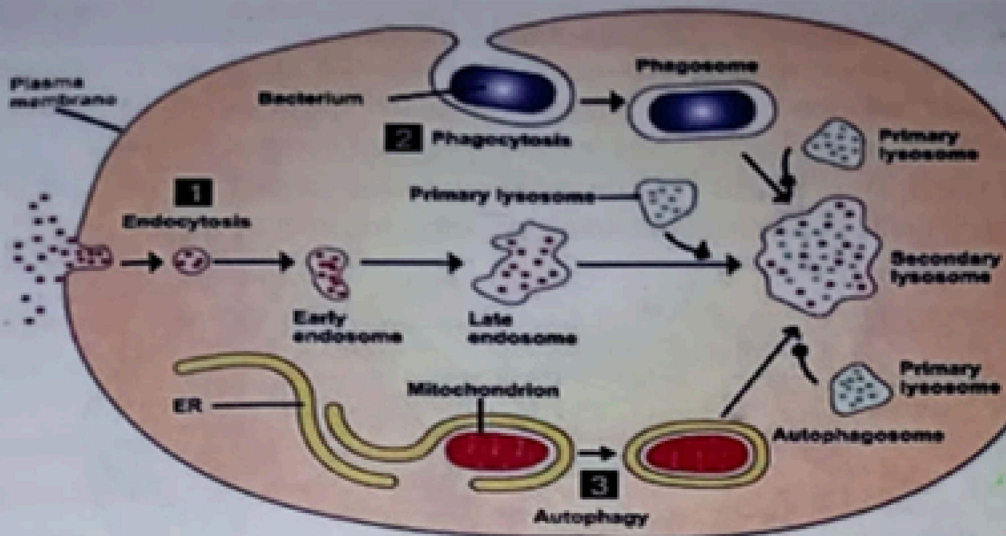
One — cytolysosome — they eat dead cell organelles

- *Tertiary lysosomes or residual bodies* contain undigested material after the absorption of digested food into the cytoplasm. In unicellular organisms, these are removed outside of cell by exocytosis while in multicellular organisms; these are retained in the cells as lipofuscin granules. ② Heterophagosome (Different) They digest solid & liquid particles.

Functions

Lipofuscin = they are dead chromosome that contain max lipid.

- In order to perform its function, the lysosomes ***fuse with endosomes***, ***phagosomes or autophagosomes*** forming ***secondary lysosomes.***
- The bio-molecules are further broken down into smaller monomers which are then recycled in the cell.
- Major functions of lysosomes include ***intracellular digestion***, ***autophagy***, ***autolysis***, and sometimes ***release of extracellular enzymes***.
- During intracellular digestion, food particles are stored in ***food vacuoles*** which will fuse with lysosomes, the resulting structure are called ***secondary lysosomes*** in which food begins to digest.
- The digested products are absorbed by the cytoplasm while the remaining wastes containing vesicles (***contractile vacuole***) fuse with the cell membrane (***exocytosis***) to eliminate undigested wastes.
- The process by which unwanted structures within the cells are engulfed and digested within the lysosomes is called ***autophagy***.
- This process either ***takes place in starvation*** period in order to obtain energy or it occurs in routine in order to control number of specific organelles. For example, if someone starts to perform heavy muscular exercise, the number of mitochondria begins to increase in his muscle cells, but if he leaves exercise, the number of mitochondria is again decreased by the process of autophagy.
- During ***developmental phase***, when a particular cell is required to be disintegrated, a type of cell death is committed, called ***autolysis***. This is a ***programmed cell death*** in which lysosomes burst and their enzyme contents are quickly dispersed throughout the cytoplasm, thus disintegrating the cell into fragments which are phagocytosed by the other cells.



Lysosomal Storage Diseases Both diseases are autosomal recessive.

- Several congenital diseases have been found to be due to accumulation within the cell of substances such as glycogen or glycolipids. These are called storage diseases. 20 such diseases have been discovered so far.
- These diseases are produced by a mutation that affects one of the lysosomal enzymes involved in the catabolism.
- In ***glycogenosis type II disease***, the liver and muscle appear to be filled with glycogen within membrane bound organelles. In this disease, an enzyme that degrades glycogen to glucose is absent. (α- Glycosidase) enzyme absent → β- Hexosiminase.
- ***Tay-Sach's disease*** is because of absence of an enzyme that is involved in the catabolism of lipids. Accumulation of lipids in brain cells leads to mental retardation and even death.

Both are due to fault in chromosome # (17).

PEROXISOMES AND GLYOXYSOMES

- Peroxisomes and glyoxysomes are collectively called as ***microbodies***.
- They are similar to lysosomes in the sense that they are ***single membranous, vesicular structure***. They contain enzyme (although different than lysosomes) and are ***smaller than lysosomes***, having ***diameter of 0.5 μm*** approximately.

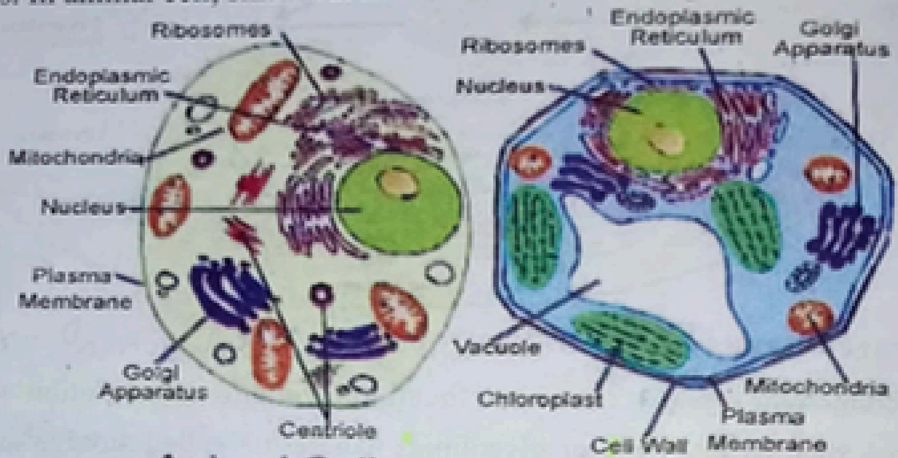
FEATURES	PEROXISOMES	GLYOXYSOMES
Occurrence	Present in all type of eukaryotic cells Plant & Animal	Present in plants/Germinating seedlings
Enzymes	Peroxidase, catalase, glycolic acid oxidase etc.	Catalase, glycolic acid oxidase, other enzymes etc.
Role	• Detoxification of alcohol • Formation and decomposition of H_2O_2 • Involved in photorespiration	• Lipid metabolism • Conversion of stored fatty acids to carbohydrates (Succinate) through ***glyoxylate cycle***

Due to this function it is called Peroxisomes.

• Seed rich lipids are castor bean, Soyabean. • Absent in Pea B/c of low lipid nature

VACUOLES

- Vacuoles are large vesicles that ***originate from the endoplasmic reticulum, Golgi complex and cell membrane***. They are present both in plant and animal cell.
- The membrane separating the vacuole from cytoplasm is called ***tonoplast***.
- In plant cell, a large central vacuole is present that is formed by coalescence of smaller vacuoles. In animal cell, small but numerous vacuoles are present.



Animal Cell   Plant Cell

Functions

- In animal cells, ***food vacuoles*** are formed by phagocytosis. Many freshwater protists have ***contractile vacuoles*** that pump excess water out of the cell, thereby maintaining a suitable concentration of ions and molecules inside the cell.
- In ***young plants***, many small vacuoles are present which can hold reserves of important organic compounds. These vacuoles may help in ***protection of plants against herbivores*** by storing compounds that are ***poisonous or unpleasant to animals***.
- ***Mature plant cells*** contain a central vacuole which contains ***cell sap***. It is plant's main reservoir of ***inorganic ions*** and ***metabolic intermediates***. They serve to ***expand*** the plant cells without diluting their cytoplasm
- They maintain the cells' ***turgor***, responsible for mechanical support, and rigidity of the leaves and young parts of the plants.

MITOCHONDRIA

roduction : mitoplas (when outer layer removed), (endosome -> All mitochondria in cell) , Sarcomeres -> increase of muscle

- They are also called as ***power house/battery/furnace*** of the cell and busiest and active organelle in cell.
- Their ***size and number*** vary from one to many thousand per cell depending upon the physiological activity of the cell. (maternal & haploid DNA)
- They are ***self-replicating***, contain ***circular DNA*** (1% of the total DNA of cell) and ***ribosomes***; thus, some proteins may also be synthesized in them.
- The diameter of mitochondria is 0.2-1.0 μm while length is 1-4 μm

cture

- When seen under compound microscope they ***appear as vesicles, rods, filaments***.
- When seen under electron microscope, then it shows that they are bounded by two membranes, a smooth outer membrane which somewhat like a sieve due to presence of ***porins*** (hence freely permeable) and an inner one forming infoldings ***(cristae)*** in mitochondrial matrix. (Rough)

water-filled proteins

Lipoprotein in nature.

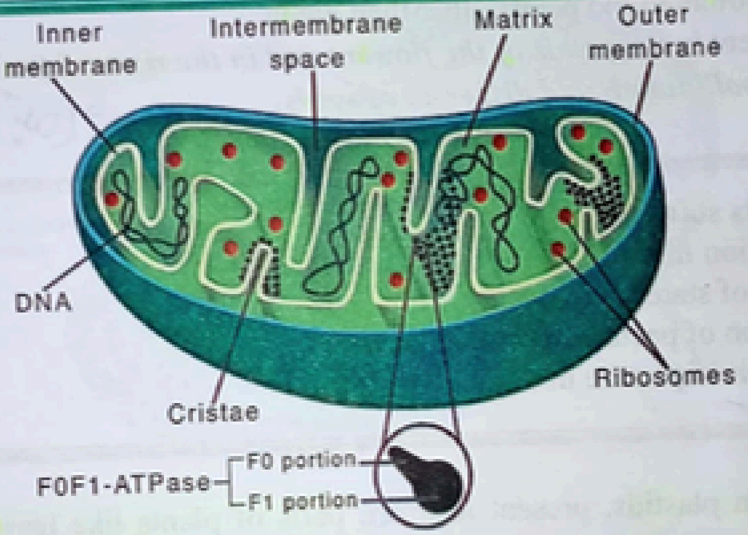
- The inner surface of cristae has granular structures called F_0-F_1 *particles* which are actually ***ATP synthase***.

embeded in lipids → hydrophilic; hydrophobic ↳ Both are Protein in nature.

- In addition, several other complexes are also found in the cristae, which serve as ***electron carriers*** in ETC.
- The inner membrane divides the mitochondrion into two internal compartments. The first is the ***inter-membrane space***, the narrow region between the inner and outer membranes.
- The second compartment, ***mitochondrial matrix***, is enclosed by the inner membrane.
- ***Mitochondrial matrix*** contains small circular DNA, all kinds of RNA, 70S ribosomes, enzymes, co- enzymes and organic and inorganic salts.

CRITICAL THINKING

11. Which organelle cannot metabolize the fatty acids?
A. Mitochondria B. Peroxysome
C. Chloroplast D. SER



Functions

- They are the sites of ***aerobic cellular respiration***. (without O_2)

CRITICAL CONCEPT!

ATP, TTP, GTP, and CTP all having energy in their phosphate bonds.

- Enzymes in mitochondrial matrix help in metabolic processes like ***pyruvic acid oxidation***, ***Krebs cycle***, ***aerobic respiration***, and ***fatty acid metabolism***. These processes extract energy from the organic food and convert them into ATP, an energy rich compound, which provides energy to the cell on demand.

O. food → ATP

- ADP is regenerated by mitochondria into ATP.

CRITICAL THINKING

12. It is related with mitochondria:
A. Replication of ATP synthase gene B. Glycosylation of albumin
C. Conversion of a hexose to triose D. Porphyrin synthesis

PLASTIDS/CHLOROPLASTS

- Plastids are found in ***plant and algal cells***, and they are necessary for essential life processes like ***photosynthesis and food storage***.
- On the basis of presence or absence, type of pigments, and stage of development, plastids have been classified into ***proplastids, leucoplasts, chromoplasts, and chloroplasts***.

Proplastids

Binary fission

- They are ***young, immature, self-replicating and developing plastids***.
- They divide and re-divide in Meristematic cells and are distributed to different cell types.
- Depending upon the structures in which they found, the intracellular factors and on the exposure of light, they may develop into leucoplasts, chloroplasts.

Leucoplasts

- They are ***colorless*** and found in parenchyma cells of root, stem and seeds.
- They are ***triangular, tubular*** or of some other shape.
- They ***store food***, e.g. ***amyloplast*** which stores starch, ***elaioplast*** which stores lipids and ***proteinoplast*** which stores proteins.

Chromoplasts

- They impart colors to the plants other than green.
- They are present in the ***petals of the flowers and in the ripened fruit***.
- They help in ***pollination and dispersal of seeds***. (پکنا)

CRITICAL THINKING

13. Ripening fruits soften due to:

A. Jelly formation in acidic pH
B. Conversion of starch into sugar
C. Solubilization of pectate of middle lamella
D. Incorporation of pectate in middle lamella

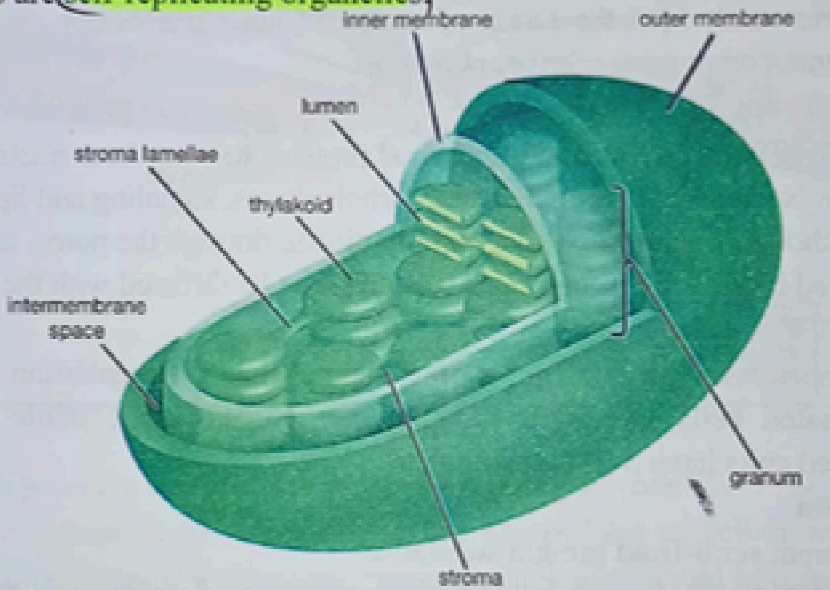
Chloroplast

- These are green plastids, present in green parts of plants like leaves, woody stem and unripened fruit coverings.
- Chloroplasts vary in their shape (***mainly discoid structure***) and size with a ***diameter of 4-6 μm***.
- Under light microscope they are heterogeneous structures with small granules called ***grana embedded in the matrix***.
- Each chloroplast is bounded by a smooth double membrane, called ***envelope***. The outer membrane is like mitochondria that contains ***porins*** and therefore ***freely permeable to small molecules***. The inner membrane is semi-permeable and ***rich in proteins***. Between the outer and inner membrane, there is ***inter-membrane space***.
- ***Stroma*** covers most of the volume of the chloroplast, contains proteins/enzymes required for the synthesis of carbohydrates during Calvin cycle. The most abundant and important enzyme is ***RuBisCO***.
- It also contains ***circular DNA*** and ***70S ribosomes***, so proteins are also synthesized here. Presence of these substances indicates that it is semi-autonomous organelle.

- The stroma contains a system of chlorophyll bearing double membrane, flattened sac-like structures, called ***thylakoids***, which are of two types i.e., ***smaller thylakoids*** and ***larger thylakoids***.
- Smaller thylakoids are ***disc-like*** sacs which are piled over one another like stacks of coins. Each stack of smaller thylakoids is called ***granum***. Each granum consists of 20-50 thylakoids and there are about 40-60 grana found in each chloroplast. Photosynthetic pigments are also found in the membranes of smaller thylakoids.
- ***Larger thylakoids*** connect the grana with each other and are also called ***Inter-grana.*** These membranes are colorless and do not have pigments, thus ***non-photosynthetic***.
- Membranes of grana are sites where sunlight energy is trapped and ATP is formed.
- Chloroplasts are self-replicating organelles.

CRITICAL CONCEPT!

Chloroplast energy can also be used by the cell.



Function of Chloroplasts

- It is the ***site of photosynthesis*** in plant cell, hence making them the most important energy transforming organelle of the eukaryotic cells.

NUCLEUS

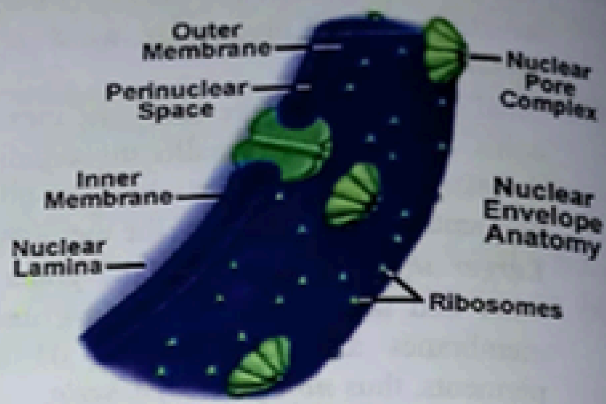
Introduction

- It is the most prominent and most important part of the cell, also called as brain of cell.
- They are visible only in non- dividing cells.
- In animal cell, they are ***central*** in position with exception of skeletal muscle fiber and adipose cells. In plant cells, they are pushed to ***periphery*** due to the presence of large vacuole.
- They may be ***irregular or spherical in shape***.
- A cell containing single nucleus is called ***mononucleate***, two as ***binucleate*** and with more than two as ***multinucleate***. It is absent in some eukaryotic cells, such as mature phloem sieve tube elements in plants and mature RBCs of most mammals; hence these cells are called ***anucleated.***

Structure

- A typical eukaryotic nucleus consists of nuclear envelope, nucleoli, nucleoplasm and chromatin network/chromosomes.

A) Nuclear Membrane



- Each nucleus is covered by two parallel membranes with a space of 10-15nm between them. This space is called perinuclear space. This arrangement of membrane is called as ***nuclear envelope*** which separates the nuclear material from the cytoplasm.
- The outer layer is continuous with the endoplasmic reticulum and the inner one encloses the nuclear contents.
- These membranes have same structure as per fluid mosaic model.

B) Nuclear Pores

- Nuclear pores result from the fusion of outer and inner membranes. They are composed of specialized transport proteins called ***nucleoporins***.
- They act as a ***gateway*** for the exchange of materials with the cytoplasm.
- This exchange includes RNA and ribosomal proteins moving from nucleus to the cytoplasm and proteins (such as DNA polymerase), carbohydrates, signaling and lipids moving into the nucleus. Although smaller molecules simply diffuse through the pores, larger molecules may be recognized by specific signal sequences and then be diffused with the help of nucleoporin into or out of the nucleus.
- Their number is variable depending upon the differentiation of the cell i.e. undifferentiated cells like eggs have 30,000 pores/nucleus while erythrocytes, well differentiated cells have 3- 4 pores/nucleus.

C) Nucleoplasm

- It is transparent semi-fluid ground substance.
- It contains DNA, RNA, proteins, Mg^{+2} ions, free nucleotides and enzymes (DNA and RNA polymerase).

CRITICAL THINKING

14. Part of eukaryotic cell where formation and action of primase takes place respectively:

A. Nucleoplasm and cytoplasm
B. Cytoplasm and nucleoplasm
C. Cytoplasm only
D. Nucleoplasm only

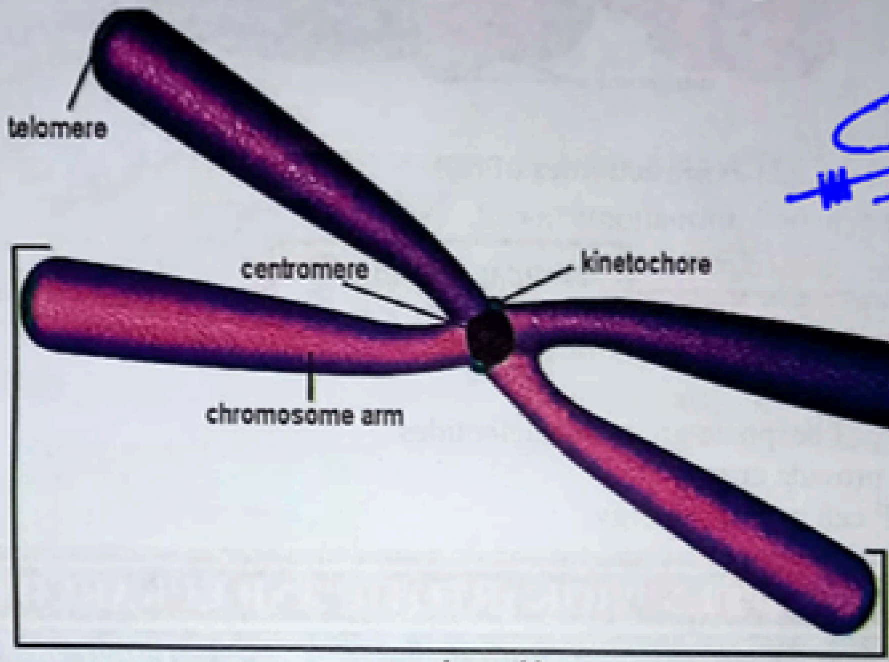
D) Nucleolus

- Nucleolus is non-membranous, darkly stained body within the nucleus, and may be one or more in the nucleus.
- It is usually attached to the chromatin at specific site called ***nuclear organizer region.***
- They appear during interphase & disappear during cell division.
- RNA (rRNA) is synthesized and stored in it.
- Nucleolus is composed of two regions: ***peripheral granular area*** containing precursors for ribosomal subunits and ***central fibril area*** containing rRNA and rDNA.

- It is the ***factory for ribosome synthesis***.

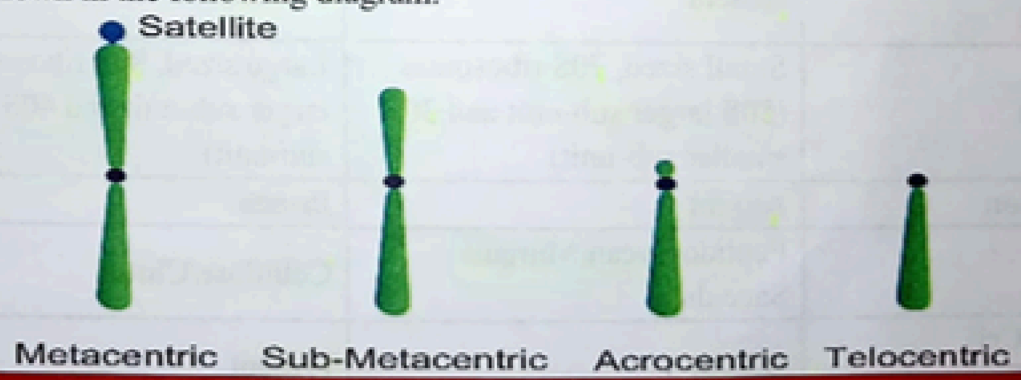
E) Chromatin & Chromosome

- Each chromosome is a thread like structure resulting from organization of chromatin material during cell division.
- Chemically chromosomes are composed of ***DNA and protein/histones***.
- Under compound microscope they appear to be made of arms (chromatids) and a centromere, the place where spindle fibers are attached during cell division.



Ubaid

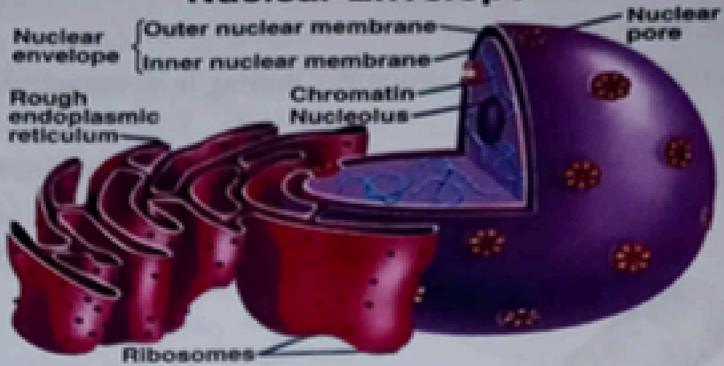
- ***Centromere/primary constriction*** is the place on the chromosome and ***Kinetochore*** is a place on centromere where spindle fibers are attached during cell division.
- Based on the position of centromere, chromosomes are divided into four categories which are shown in the following diagram.



Chromosome Number In Different Species

Species	Diploid (2n)	Haploid (n)	Species	Diploid (2n)	Haploid (n)
Man	46	23	Frog	26	13
Chimpanzee	48	24	*Drosophila*	8	4
Onion	16	8	Potato	48	24
Garden Pea	14	7	Pigeon	80	40

Nuclear Envelope



Functions

- It controls all the metabolic activities of cell.
- It has all the genetic information in a cell.

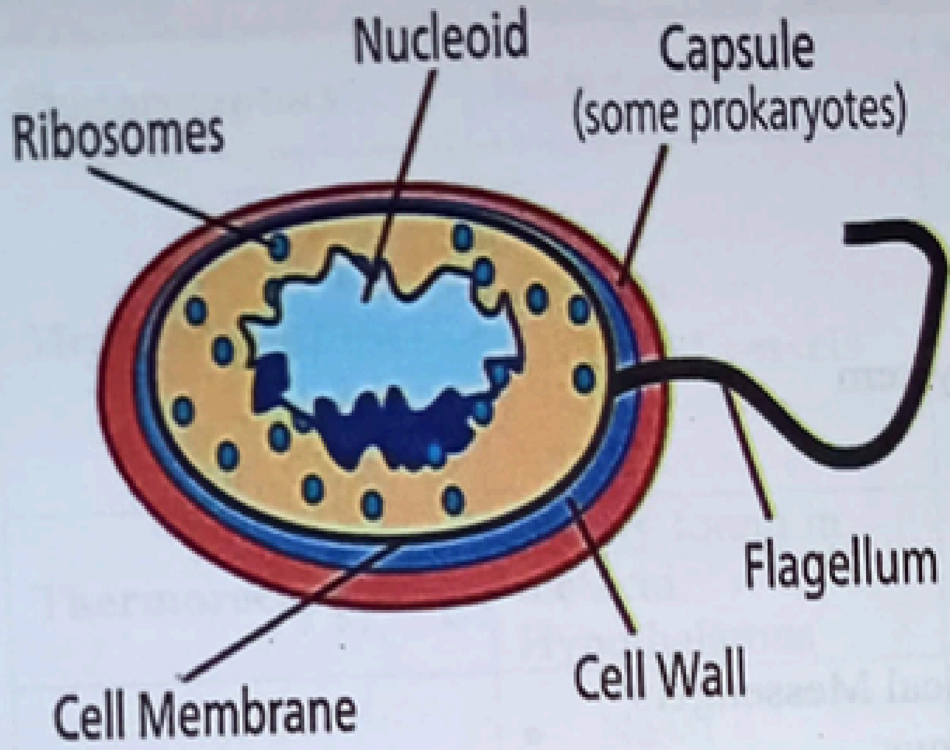
CRITICAL THINKING

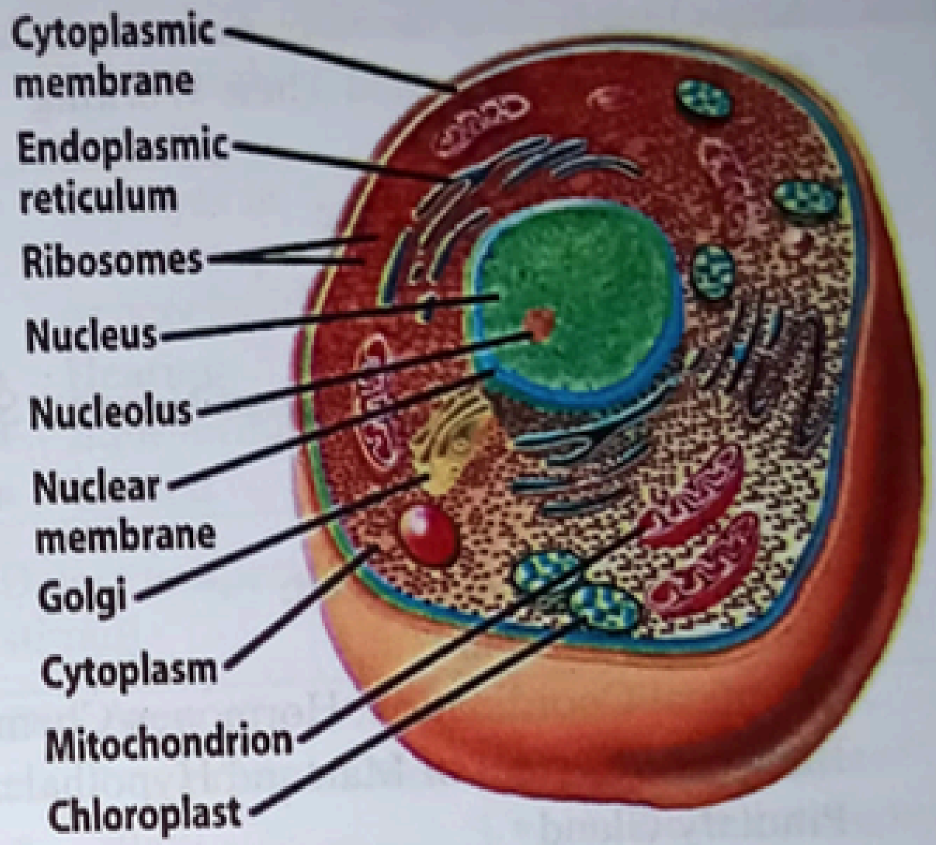
15. For DNA replication energy comes from:
A. System or Cell
B. Breaking of Phosphate group of nucleotides
C. Enzymes provide energy
D. Only ATP can provide energy

COMPARISON BETWEEN PROKARYOTIC AND EUKARYOTIC CELLS

Differences	Prokaryotic Cell	Eukaryotic Cell
Well Defined Nucleus	Absent	Present
DNA	Submerged in cytoplasm	Present in nucleus
Type of DNA	Circular DNA as nucleoid	Linear DNA in nucleus
Membrane Bounded Organelles	Absent	Present
Ribosomes	Small sized, 70S ribosomes (50S larger sub-unit and 30S smaller sub-unit)	Large sized, 80S ribosomes (60S larger sub-unit and 40S smaller sub-unit)
Cytoskeleton	Absent	Present
Cell Wall	Peptidoglycan/Murein/Sacculus	Cellulose/Chitin
Sterols in Cell Membrane	Absent	Present
Mesosomes	Present	Absent
Cell Division	Binary fission	Mitosis/Meiosis
Histones	Absent	Present
Protein in Flagella	Flagellin	Tubulin
Example	Bacterial cell, Cells of blue green algae	Plant and Animal cells, fungi and protists

Prokaryotes vs Eukaryotes





TOPIC-5 COORDINATION & CONTROL

COURSE CONTENT

- Steps Involved in Nervous Coordination
- Sensory Receptors and Their Working
- Neurons
- Reflexes and Reflex Arc
- Nerve Impulse
- Synapse
- Basic Organization of Human Nervous System
- Brain
- Spinal cord
- Peripheral Nervous System
- Nervous Disorders
- Chemical Coordination, Hormones/Chemical Messengers
- Endocrine System of Man and Hypothalamus
- Pituitary Gland
- Thyroid and Parathyroid Glands
- Pancreas
- Adrenal Glands
- Gonads
- Hormonal Feedback Mechanism

STEPS INVOLVED IN NERVOUS COORDINATION

The body of an animal is frequently exposed to variety of stimuli in its daily life. For an appropriate response to a particular stimulus, usually more than one body parts are involved, their activities are coordinated either by nervous system or endocrine system or both.

Nervous Coordination

- This type of co-ordination involves specialized cells or ***neurons*** linked together directly or indirectly via the central nervous system, to form network that connects the cell or organs which receive stimuli and those which carry out actions or responses.
- The neurons have the capacity to generate and conduct impulses which travel across the synapse.
- Three basic components of nervous system are:

(i) Receptors
(ii) Neurons
(iii) Effectors

CRITICAL THINKING

1. **Pick the example of an effector:**
   A. Osmoreceptors
   B. G-cells
   C. Limbic system
   D. Ear

SENSORY RECEPTORS AND THEIR WORKING

A ***cell*** or ***a neuron*** or a ***receptor organ*** which can detect changes in the external and internal environment of the animal is called a receptor. It acts as ***transducer*** because it converts one form of energy into another form. Receptors are classified based on stimuli as shown below.

Types	Location	Functions	Subtypes
Photoreceptors	Retina of eyes	• Detect light stimuli	• Rod cell • Cone cells
Mechanoreceptors	• Skin • Blood vessels	• Changes in pressure, position, or acceleration • Hearing • Equilibrium • Stretch	• Meissner's corpuscles • Pacinian's corpuscle • Baroreceptors
Thermoreceptors	Mostly found in the skin Hypothalamus	Detect temperatures stimuli	• Cold • Warm
Chemoreceptors	• Nasal epithelium • Tongue • Hypothalamus	Detection of • Ions or molecules • Smell • Taste • Blood pressure	• Osmoreceptors • Olfaction receptors • Gustation receptors
Nociceptors	• Skin • Joints • Internal organs	Detect pain	

Working of Sensory Skin Receptors

- At least five different sensations are perceived by the skin, i.e., touch, pressure, heat, cold, and pain.
- There are at least three different types of sensory endings concerned with these sensations:

Receptor	Location	Structure	Sensation
Free Nerve Endings	At the base of hair.	Free nerve endings.	Touch
Meissner's Corpuscles	In papillae which extend into ridges of the fingertips.	Specialized cellular encapsulated corpuscles, Spiral and twisted endings, each ending terminates in a knob.	Touch
Pacinian Corpuscles	Deep in the body.	Encapsulated neuron endings. Mostly located in the limbs.	Deep Pressure stimuli, vibration sensations.

Distribution of Receptors in the Skin

- Receptors are not evenly distributed throughout the skin rather are located at the sites of specific function.
- Their relative abundance also varies e.g.
  Pain receptors 27 X > Cold receptors.
  Cold receptors 10 X > heat receptors.

NEURONS

- It is the basic structural and functional unit of nervous system.
- Neurons can generate and conduct nerve impulses which travel across synapses and pass from receptors to effectors, bringing about nervous coordination.
- ***Neuroglial cells*** mostly present in higher animals, play important role in nutrition of neurons and their protection by myelin sheath. They constitute nearly half of the nervous system.
- Neurons once matured do not divide any further. However, they exhibit limited regenerative capabilities, only if neural cell body is intact.

CRITICAL CONCEPT!

Inability of Neurons to Divide: Neurons are unable to divide because they enter in G_0 phase permanently. Moreover, they lack centrioles thus unable to form mitotic apparatus.

Structure of Neuron

A typical neuron consists of:

(i) Cell body
(ii) Dendrites
(iii) Axons

Cell Body

- It is also called soma, is the ***chief nutritional part*** of the cell, and synthesizes materials necessary for growth and maintenance of neuron.
- It contains a single large centrally placed nucleus with a prominent nucleolus, and other cellular organelles, like E.R, ribosomes, Golgi apparatus, mitochondria embedded in cytoplasm.
- The cytoplasm is characterized by the presence of ***Nissl's granules*** which are group of ribosomes associated with RER and Golgi apparatus.
- If it is intact, the neuron can regenerate its axonal and dendrital components.

Dendrites

- These are processes that ***carry impulses towards the cell body***.
- These are usually short, thin, often highly branched cytoplasmic extensions and devoid of Schwann cells and thus non-myelinated.
- Axons of other neurons form synapses with the dendrites. They give a ***spiny look*** to the neurons.

Axons

- The processes ***carrying impulses/action potentials away from cell body*** are called axons.
- An axon is comparatively a ***long and thick nerve fibre*** which has a constant diameter and can vary in size from a ***few millimeters to a meter length***.
- It may be ***branched or unbranched***. It terminates by branching to form small extensions with enlarged ends, called ***pre-synaptic terminals***.
- Cellular organelles like mitochondria, microtubules and neurofibrils, R.E.R. and G.A are present throughout the axoplasm of the neuron.
- Most of the axons are surrounded by protective sheaths called ***myelin sheath***, which is important for neuronal nutrition, protection and proper propagation of impulses.

Myelin Sheath

- ***Schwann cells*** are neuroglial cells in peripheral nervous system. Usually axons are covered by these cells which are strop-like cells that wrap around axon fibres.

- These cells are also covered by a fatty substance called ***myelin sheath*** that ***acts as insulator***. This is why axons are called ***myelinated fibres***. A non-myelinated part of axon between two Schwann cells is called ***node of Ranvier***.

Types of Neurons

All neurons ***vary somewhat in size, shape, and characteristics*** depending on the function and the role of the neuron. Based upon function, there are three types of neurons:

(i) Sensory Neurons

- Sensory neurons carry sensory information from receptors to associative neurons present in CNS.
- The dendrite endings of some sensory neurons also act as receptors.
- They usually have single long dendrite called ***dendron***. It is structurally and functionally similar to axon.

(ii) Motor Neurons

- Motor neurons conduct impulses away from the central nervous system. The dendrites make contact with other neurons in the spinal cord. The terminal branches at the far end of the neuron are connected to an effector.

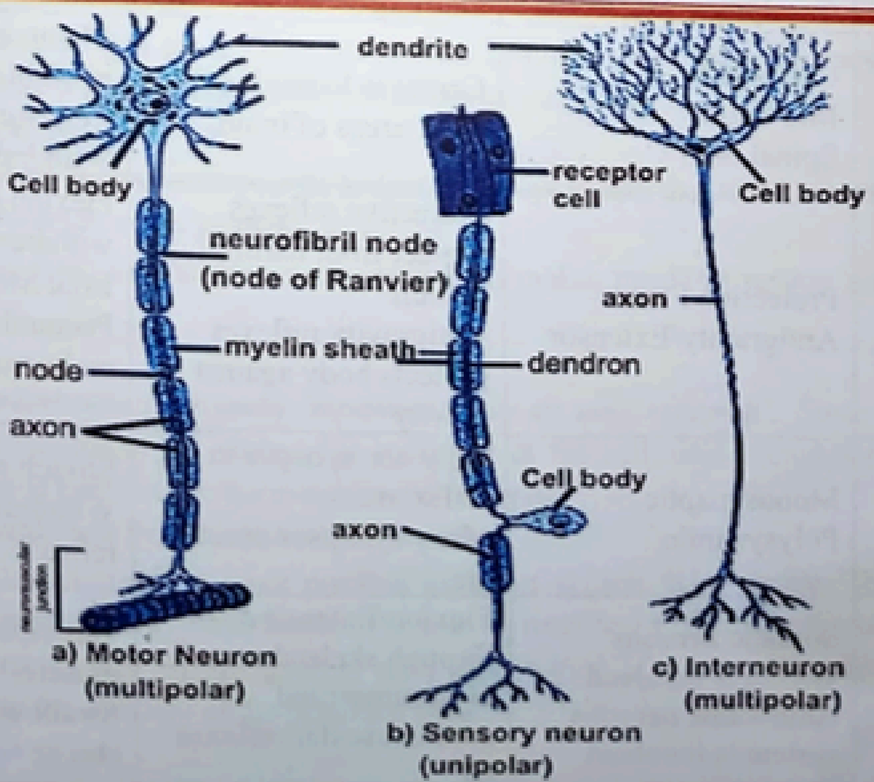
(iii) Associative Neurons

- Associative (intermediate/relay/inter/connector) neurons occur entirely within the CNS and connect sensory and motor neurons.
- The axon is ***comparatively thin and non-myelinated***.
- They are involved in processing and interpretation of information coming from receptors.

CRITICAL THINKING

2. Most of the brain tumors are caused by the uncontrolled mitotic divisions of:

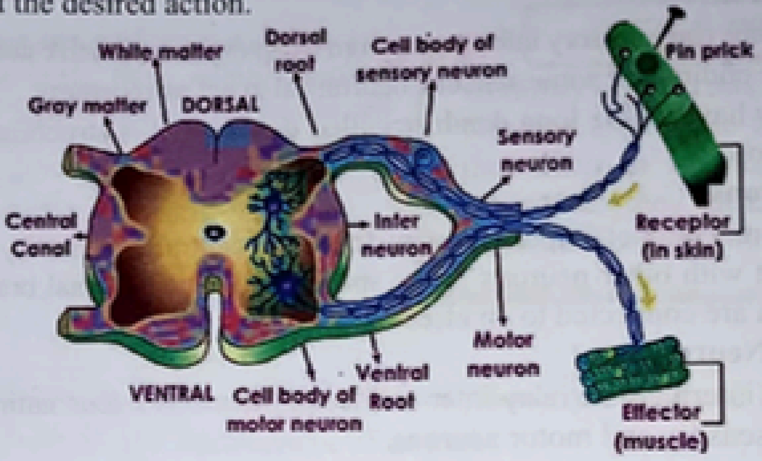
A. Neurons B. Neuroglial cells
C. Schwann cells D. Leydig cells



REFLEXES AND REFLEX ARC

Reflex Action and Reflex Arc

- Reflex action is an ***immediate, automatic*** and ***involuntary response*** to external and internal environmental changes/injurious stimuli.
- ***Reflex arc*** is the pathway of the passage of impulse during a reflex action, as shown below. Receptors → Sensory neuron → Intermediate neurons → Motor neurons → Effectors → Brings about the desired action.



Classification of Reflexes

- There are several ways to classify the reflexes of the body. Following are the classification of reflexes.

Classification based on	Types	Sub types/Working	Examples
Inborn or Acquired	Unconditioned Reflexes Conditioned Reflexes	Do not require Learning Requires previous learning	Suckling reflex after birth Secretion of saliva after smelling specific food
Structural involvement	Cerebellar Mid brain Spinal cord	Centre is located in these areas of brain	Maintain balance and equilibrium Reflex eye movement Withdrawal reflex
Physiological/ Functional	Protective/Flexor Antigravity/Extensor	Protective reflexes protect from harmful stimuli Antigravity reflexes protects body against gravity	Flexion of elbow to withdraw hands away from harmful stimuli Postural correction and maintenance
Number of synapses	Monosynaptic Polysynaptic	Only one synapse in reflex arc Many synapses in reflex arc	Stretch reflex Withdrawal/Protective reflex
Somatic Or Autonomic	Somatic nervous system is involved Autonomic nervous system is involved	Flexion/Extension through skeletal muscles Gastrointestinal, cardiovascular reflexes etc	Participation of skeletal muscles Swallowing, coughing etc

Importance of Reflex Action

It helps an animal to ***save himself from danger*** e.g. when a person steps on a sharp object this message is immediately conveyed by the pain receptors to the spinal cord which results in contraction of the muscles of the leg and immediate withdrawal of the leg.

NERVE IMPULSE

Definition

'Nerve impulse is a wave of electrochemical changes, which travels along the length of neurons involving movement of ions across the membrane and chemical reactions'.

Generation and Transmission of Nerve Impulse

- Here, word '***electrochemical***' refers to the electrical potential (***capacity to do electrical work***) that exists on neuron membrane. In case of neuron, the electrical potential is termed as ***membrane potential*** which is exhibited in two different forms i.e., ***resting membrane potential (RMP)*** and ***active membrane potential (AMP).***

(i) Resting Membrane Potential

- Potential difference across the membrane when neuron is in ***not being stimulated/non-conducting state*** is called resting membrane potential, and is characterized by more positive outside surface of neuron membrane than inner surface.
- Neuron in this state is in ***polarized form***.
- This means that there is an unequal distribution of ions on the two sides of the nerve cell membrane. Its value for a typical neuron is ***-70 mV***. RMP is established by the following factors:

Distribution and Active Movement of Na^+ and K^+

- The concentration of ***K^+ is 30X greater in the fluid inside the cell than outside*** and the ***concentration of Na^+ is nearly 10X greater in the fluid outside the cell than inside.***
- These ions are continuously moved against their concentration gradient though ***Na-K pumps*** by the expenditure of energy.
- For every ***two K^+*** that are actively transported inward, ***three Na^+*** are pumped out. So, inside becomes more negative than outside of the neuron membrane.

Negative Organic Ions

- There are many organic compounds in the neuron cytoplasm that also have negative charge i.e., some ***amino acids, many proteins***, and ***RNA***.
- Presence of these ions in the neuron cytoplasm makes inside of neuron more negative than outside.

Leakage of K^+

- The ***cell membrane is virtually impermeable to all ions except K^+***. Since the membrane is slightly permeable to K^+, some of it leaks out of the cell, thus accounts for more negative charges inside than outside the membrane of neurons.

(ii) Active Membrane Potential/ Action Potential

- AMP is characterized by more positive inside of neuron than outside. This happens when positive charges tend to move inside of neuron on receiving a particular stimulus.
- This electrochemical change appears on a short region of neuron for a brief period of time followed by the recovery of the polarized state.
- Its value is ***+50 mV***.

CRITICAL THINKING

3. **At which place of this neuron, changes in permeability of cell membrane can be calculated/detected?**

4. **Leakage of positive ions across the cell membrane occurs by:**
A. Active transport
B. Osmosis
C. Passive transport
D. Diffusion

Initiation of Nerve Impulse

- A stimulus capable to produce action potential in neurons is call ***threshold stimulus*** and if it is not capable to excite neurons, then it is called ***sub-threshold stimulus***.
- It results in a remarkable localized change in the resting membrane potential. It disappears for a brief instant and is replaced by action potential. This change is so brief (for a millisecond) that only a portion of neuron is in active state.

Influx of Na^+ (RMP → AMP)

- The passage of nerve impulse is associated with increase in permeability of Na^+ moving inwards upsetting the potential momentarily, making the inside more positive than outside.
- This increased permeability is due to ***opening of sodium gates***. When these gates open, Na^+ rushes into the neuron by ***diffusion***. Some K^+ moves out.
- Since, there are more Na^+ entering than leaving, the electrical potential of the membrane ***changes from -70 mV towards zero and then reaches to the +50 mV***. This reversal of the polarity across the two sides of membrane is called ***depolarization***.
- This electropositive inside and electronegative outside ***lasts for about 1 millisecond*** till the Na^+ gates are not closed.

Repolarization of Neuron (AMP → RMP)

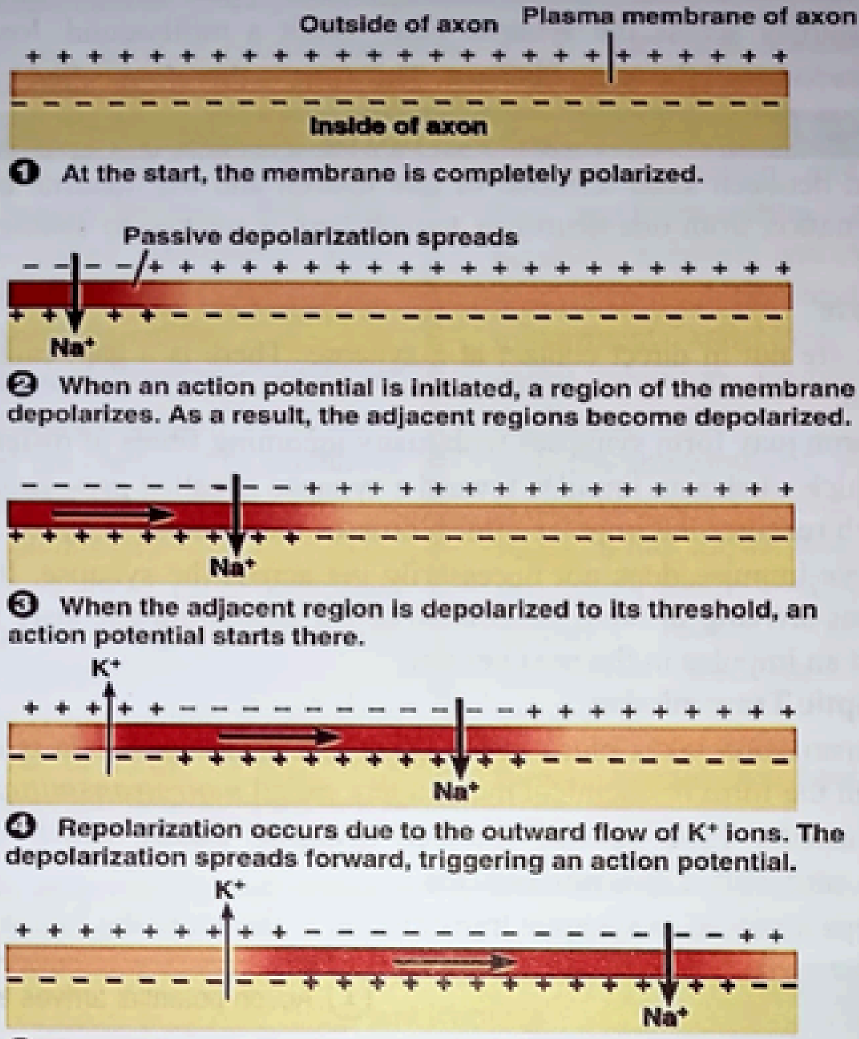
- It is the restoration of resting membrane potential, after the wave of depolarization has passed.
- It results from ***closure of Na^+ gates*** and ***opening of K^+ gates***, therefore K^+ diffuses out of the cell. Since K^+ is positively charged, this makes the inside of the cell more negative and starts the process of ***repolarization***.

Hyperpolarization

- A slight overshoot into a more negative potential inside than original RMP is called ***hyperpolarization***.
- It is due to ***slight delay in closing all the K^+ gates*** compared with Na^+ gates. As K^+ continue to enter the axon, their positive charge restores the normal potential.
- The Na-K pump continues to work during this time, so it gradually begins to restore the original RMP.

Refractory Period

- After an action potential, nerve fibre undergoes a period of recovery in which it regains its original ionic distribution and polarity and prepares itself for the next stimulation. This period of recovery is called ***refractory period***.
- Na^+/ K^+ pump restores the original ionic gradient and thus the resting potential.
- The whole process of depolarization and repolarization takes about 2- 3millisecond. The process of nerve impulse conduction is shown in the following diagram.



❶ At the start, the membrane is completely polarized.

❷ When an action potential is initiated, a region of the membrane depolarizes. As a result, the adjacent regions become depolarized.

❸ When the adjacent region is depolarized to its threshold, an action potential starts there.

❹ Repolarization occurs due to the outward flow of K^+ ions. The depolarization spreads forward, triggering an action potential.

❺ Depolarization spreads forward, repeating the process.

Velocities of Nerve Impulse

- Velocities of nerve impulse in axolemma and synaptic cleft are variable. In humans, ***non-myelinated nerve fibers***, nerve impulses travel at ***1-3 m/sec*** while ***myelinated fibres*** conduct at speeds of up to ***120 m/s***. So, the velocity of the nerve impulse is faster in myelinated neurons due to ***saltatory conduction*** which is rapid transmission of nerve impulse along an axon, resulting from the ***AMP jumping*** from one node of Ranvier to another, skipping the myelinated regions of the membrane.

CRITICAL CONCEPT!

Neuromodulators are long-lasting chemicals that act on synapses to alter nerve function. Many addictive drugs such as cocaine and nicotine act as neuromodulators.

- It is up to 50X faster than conduction through the fastest un-myelinated axon because they don't have to travel throughout every single space before moving to the next.
- Another reason that myelinated fibres conduct faster impulse is that ***myelin sheath acts as an insulating sheath*** and prevents loss of energy, so myelinated neuron fibres require less energy.
- Thick neuron fibres conduct faster impulses than thin fibres because resistant to the electrical flow is inversely proportional to the cross sectional area. So, with the increase in thickness of neuron fibres, there is decrease in resistance of fibre to nerve impulse.

- The short journey across the synapse takes about a millisecond, longer than a nerve impulse takes to travel the same distance. This time is therefore called ***synaptic delay***.

SYNAPSE

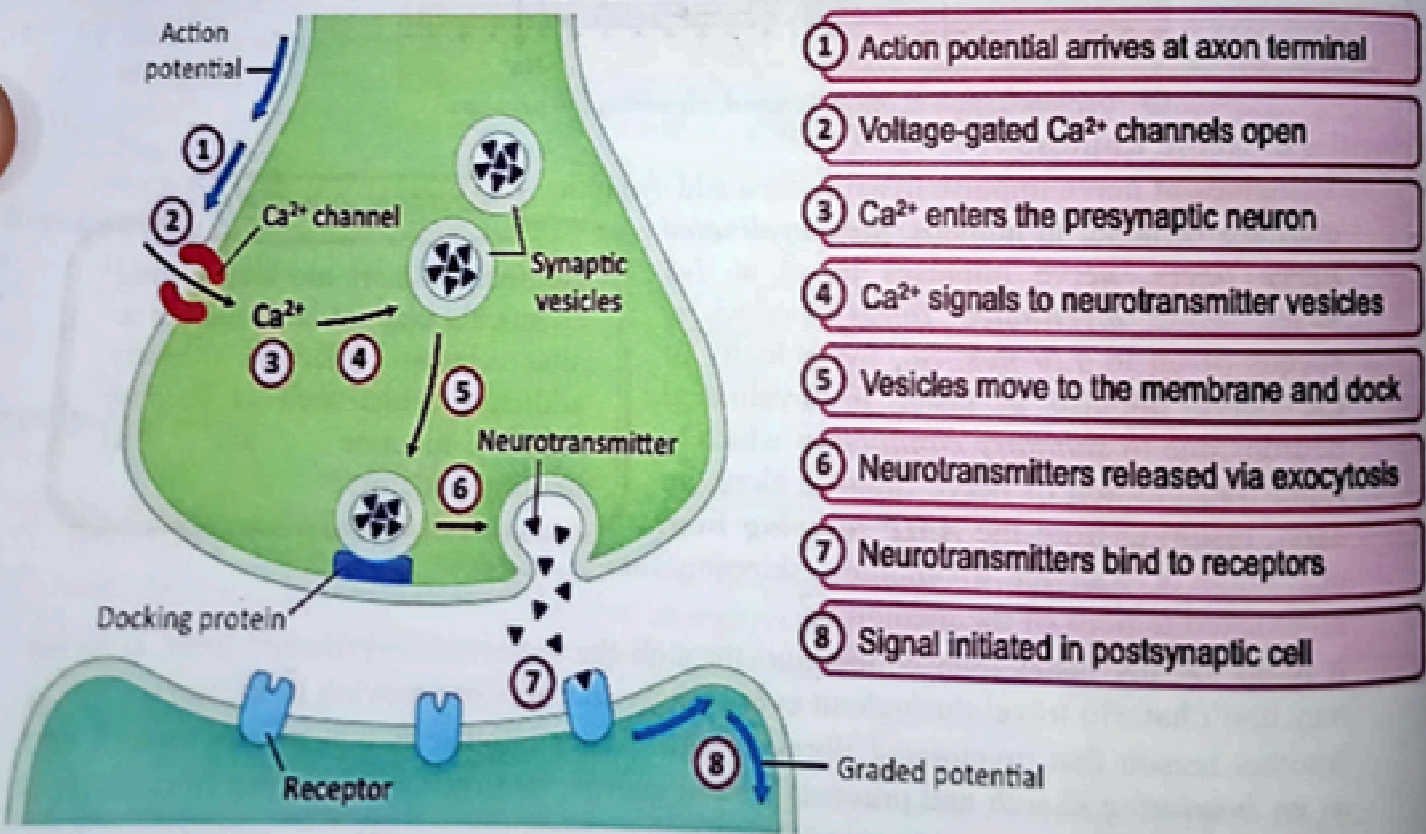
- The junction between axon terminal of one neuron and the dendrite of another neuron, where information from one neuron is transmitted or relayed to another neuron is called ***synapse***.

Structure of Synapse

- The neurons are not in direct contact at a synapse. There is a gap, called a ***synaptic cleft*** between them.
- A single neuron may form synapses with many incoming fibres of different neurons.
- A neuron which carries an impulse toward a synapse is called ***pre-synaptic neuron*** while the one which receives the impulse after it crosses the synapse is a ***post synaptic neuron***.
- A single nerve impulse does not necessarily get across the synapse. It may take two or three impulses arriving in rapid succession or perhaps simultaneously from two or more fibers to start an impulse in the next neuron.

Mechanism of Synaptic Transmission

- Synaptic transmission takes place in the form of a message which is transmitted across the synapse in the form of chemical messengers called ***neurotransmitters***.
- The axons usually have several rounded ***synaptic knobs*** which contain numerous membranous sacs, called ***synaptic vesicles***.
- The main steps involved in synaptic transmission is shown in the following diagram:



- Binding of neurotransmitters to the post-synaptic neuron receptors open some channels that allows Na^+ to diffuse across the post-synaptic membrane. As a result, post-synaptic membrane depolarizes and an action potential is generated. Since the depolarization brings the membrane potential towards threshold level, it is called ***excitatory post-synaptic potential (EPSP)***.

- At other synapses, different neurotransmitters bind to channels that are selectively permeable for only K^+ or Cl^-. When these channels open, the post-synaptic membrane hyperpolarizes, and this condition is called ***inhibitory post-synaptic potential (IPSP)***.

Classification of Neurotransmitters

- Neurotransmitters are chemicals, which are released at the axon ending of the neurons at synapse and are classified as ***excitatory*** and ***inhibitory neurotransmitters***.

Excitatory Neurotransmitters

- These neurotransmitters cause ***increased membrane permeability of Na^+*** and trigger nerve impulse.
- Acetylcholine is an example of excitatory neurotransmitter of PNS, while biogenic amines are important neurotransmitters in the CNS.

CRITICAL CONCEPT!

Brain function depends on a balance between excitation and inhibition. Too much excitation can result in psychotic behavior and even seizures. Too much inhibition results in mental impairment and even coma. The major inhibitory neurotransmitter in the human brain
is gema-aminobutyric acid (GABA), which controls Cl^- channels. Recent research has shown that low doses of drugs that block GABA activity can greatly reduce the learning disabilities associated with Down syndrome.

- These include ***epinephrine, nor-epinephrine, serotonin*** and ***dopamine***, all of which also function as hormones.
- Epinephrine and nor-epinephrine increase the heartbeat during stress while serotonin and dopamine affect sleep, mood, attention and learning.

CRITICAL THINKING

5. Which of the following function is related to excitatory neurotransmitter?

A. Increase heart beat B. Decrease Sweating
C. Constrict Pupil D. Decrease blood pressure

Inhibitory Neurotransmitters

- These neurotransmitters cause ***decreased membrane permeability to Na^+***, thus causing the threshold of stimulus to be raised.
- Gamma amino butyric acid (***GABA***) and ***glycine*** are the examples of inhibitory neurotransmitters.
- ***Endorphins*** are peptides that function as both neurotransmitter and hormone, and decrease ***perception of pain.***

CRITICAL CONCEPT!

Electrical synapse:
In an electrical synapse, the presynaptic and postsynaptic membranes are very close together and are actually physically connected by channel proteins forming gap junctions. Gap junctions allow current to pass directly from one cell to the next. In addition to the ions that carry this current, other molecule, such as ATP, can diffuse through the large gap junction pores.

CRITICAL THINKING

6. Which of the following neuro-modulator also act as neurotransmitter?

A. Cocain B. Nicotine
C. Adrenaline D. Serotonin

There are two types of synapses;

(i) Electrical synapses

(ii) Chemical synapses

Electrical synapses

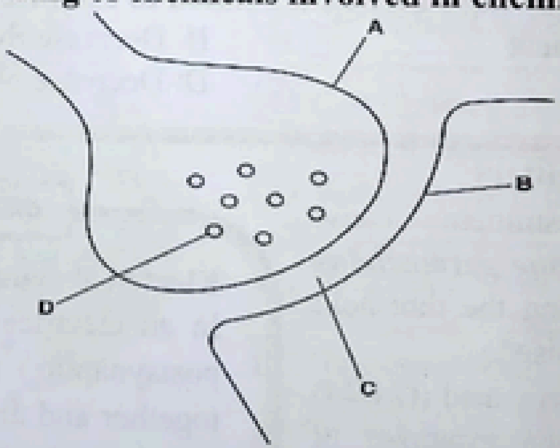
- In electrical impulse, which are specialized for rapid signal transmission, the cells are separated by a gap, the synaptic cleft, of only 0.2nm, so that an action potential arriving at the pre synaptic side of cleft, can sufficiently depolarize the post synaptic membrane to trigger its action potential directly.

Chemical synapses

- The majority of synapses are chemical synapse where synaptic cleft has gap of ***more than 20nm***.
- Through these synapses, information of impulse from one neuron is transmitted to another by means of chemical messengers, the neurotransmitters.

CRITICAL THINKING

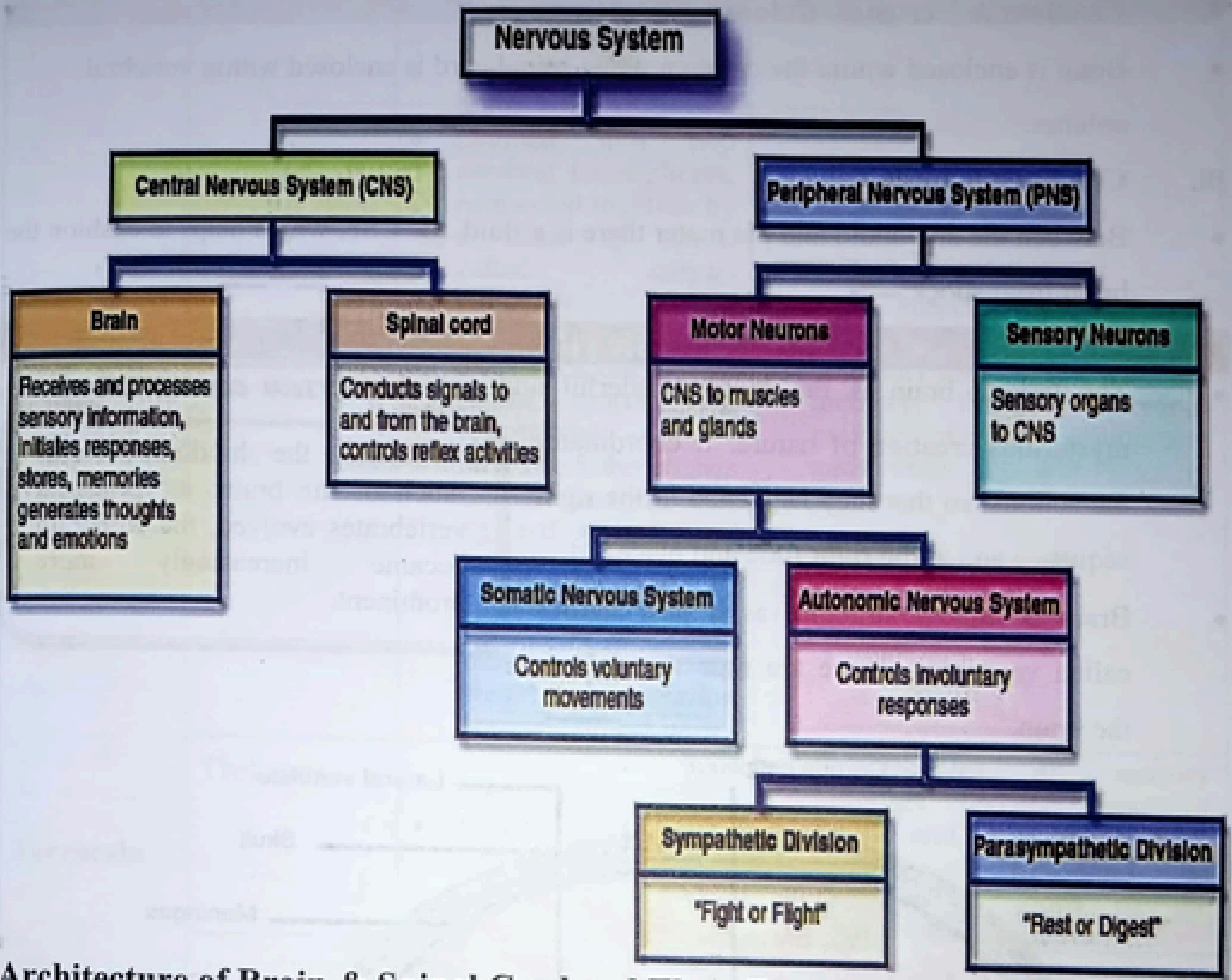
7. Nervous coordination transfers nerve impulse from one cell to another. Which option shows site for binding of chemicals involved in chemical synapse?



BASIC ORGANIZATION OF HUMAN NERVOUS SYSTEM

- The human nervous system consists of ***central nervous system (CNS)*** and ***peripheral nervous system (PNS)***.

The *CNS* is a coordinating center and it lies in the midline of the body, whereas, the *PNS* transmits information from receptors to CNS and transmit orders and commands from CNS to effectors. An outline of divisions of human nervous system is shown in the following diagram.



Architecture of Brain & Spinal Cord and Their Functions

Components of CNS

- Central nervous system consists of brain and spinal cord, and ***both are hollow***. The spinal cord has ***central canal*** and brain has many ***cavities/ventricles*** filled by CSF, which is also present between meninges.

Protection of CNS

i. **Meninges**

The brain and spinal cord are covered with three protective membranes called meninges. The three meninges are

- Dura matter (next to the cranium).
- Arachnoid matter (middle membrane)
- Pia matter (next to the nervous tissue)

CRITICAL CONCEPT!

Meninges:
Meninges are the three membranous envelopes pia mater (innermost), arachnoid mater (middle), and dura mater (outermost), that surround brain and spinal cord. Cerebrospinal fluid fills the ventricles of the brain and the space between the pia mater and the arachnoid mater. The primary function of the meninges and of the cerebrospinal fluid is to protect the central nervous system.

ii. Cranium & Vertebral Column

- Brain is enclosed within the cranium while spinal cord is enclosed within vertebral column.

iii. Cerebrospinal Fluid

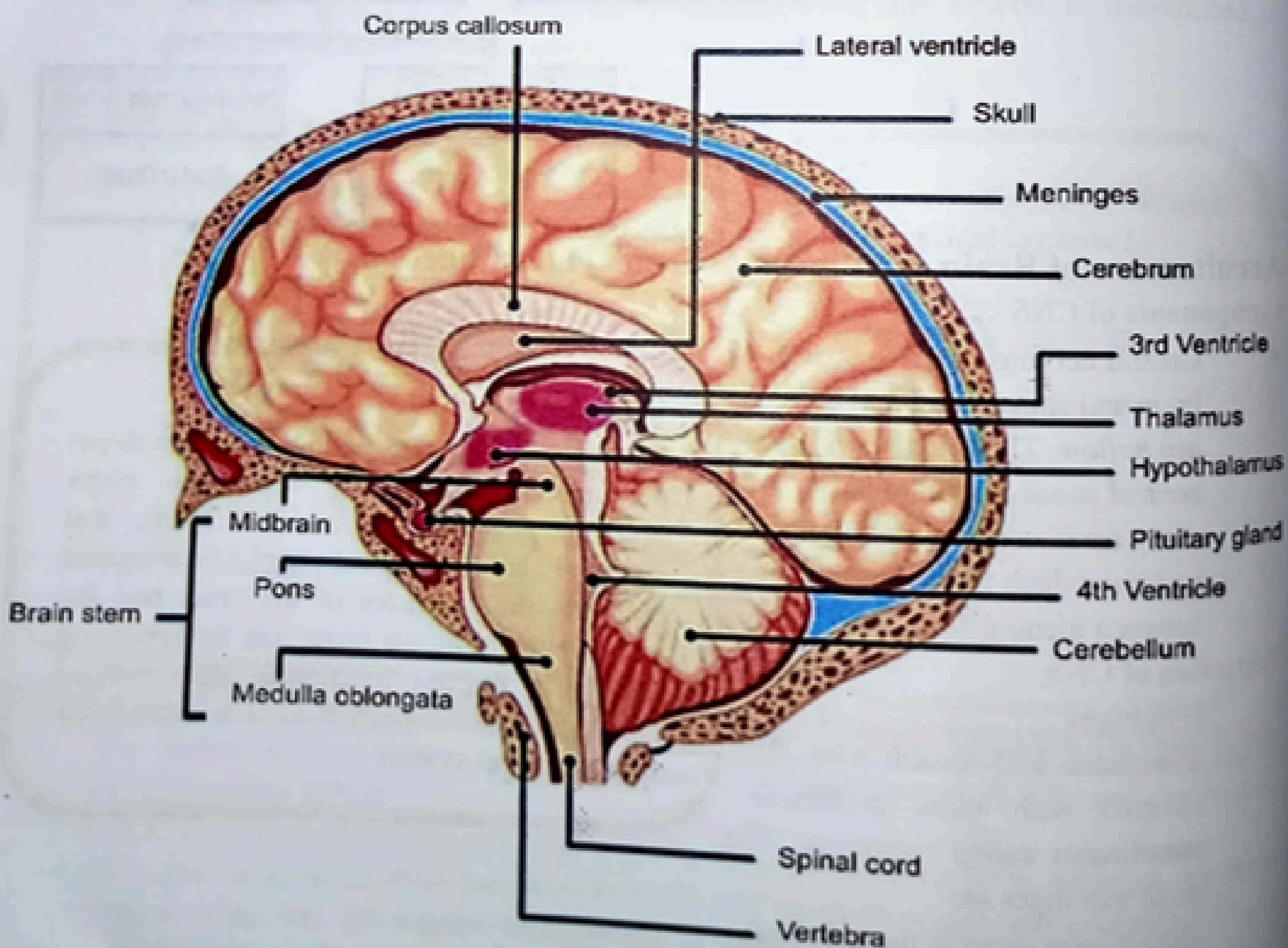
- Between the arachnoid and pia mater there is a fluid, the CSF, which helps to cushion the brain from shock.

BRAIN

- The human brain is the most wonderful and mysterious creation of nature. It coordinates the actions, so that they happened in the right sequence and at the right time and place.
- Brain is hollow structure as it has cavities called ventricles. There are four ventricles in the brain.

CRITICAL CONCEPT!

In fishes, the hindbrain forms much of the brain; as terrestrial vertebrates evolved, the forebrain became increasingly more prominent.



Parts	Subparts	Features	Functions
Forebrain	Cerebrum	• Has many folds • Largest portion of the brain • Divided into two cerebral hemispheres, connected together by a band of axons called ***corpus callosum*** • Each hemisphere contains four surface lobes: frontal, parietal, temporal and occipital lobe • Each lobe further contains different functional areas e.g., auditory and visual area etc. • Each functional area consists of three sub-areas i.e., ***sensory area***, ***association area*** and ***motor area***	• Sight, speech, smell, taste and hearing, conscious sensations, voluntary movements, learning, memory, thinking decision-making, reasoning, judgment and dreams.
	Thalamus	• Situated below cerebrum	• It receives all sensory impulses (except sense of smell) and channels them to limbic system and to appropriate regions of the cortex for interpretation.
	Limbic system	• Complex set of structures that lies on both sides of the thalamus • Divided into 3 further parts	________________
	1. Hypothalamus	• Located on the ventral side of the thalamus is the hypothalamus	• Maintain homeostasis • Contain centers for osmoregulation, thermoregulation, hunger, menstrual cycle and sleep-wake cycle, sexual response, the flight or fight response and biorhythms • Hormones production thus controls pituitary gland.
	2. Amygdala	• Two almond-shaped masses of neurons on either side of the thalamus.	• Control feeling and emotions of pleasure, punishment, love, hate, anger, fear, rage and sexual arousal
	3. Hippocampus	• Consists of two 'horns' that curve back from amygdala	• Formation of long term memory and is thus required for learning

Midbrain		• Reduced in human • Contain reticular formation which is a network of neurons running through medulla in the hindbrain, through the midbrain and up into the thalamus and hypothalamus of the forebrain	• Acts as a relay station for tracts passing between spinal cord and cerebellum, Coordination and relay of visual and auditory information, filters sensory information and sends outputs to higher brain centers
Hind brain	Pons	• Small and lies above the medulla oblongata	• Acts as a bridge for the conduction of impulses between cerebellum, medulla oblongata and cerebrum • Concerned with rate and pattern of heartbeat and breathing • Influences transition between sleep and wakefulness
	Cerebellum	• Second largest portion of the brain. It consists of a central lobe and two lateral lobes • Best developed in birds, which engage them in complex activity of flight	• Coordinates muscle activity and guides smooth and accurate motion. • Body control position and coordination of the actions of individual muscles to produce complex activities such as walking, running, riding bicycles, doing delicate work with hand. • The cerebellum is also involved in learning, memory storage for behaviors • If it is destroyed, the movements become jerky, shaky and disturbed
	Medulla oblongata	• It is broad in front and narrows behind, where it is continuous with the spinal cord	• Highway of communication between the body and the brain. Responsible for special reflexes such as heart beat, respiratory movements, salivary secretions, swallowing, vomiting, coughing and sneezing

CRITICAL THINKING

8. Activity of Judgment, reasoning and thinking is related to which type of organisms?

A. Mammals B. Reptile
C. Birds D. All

SPINAL CORD

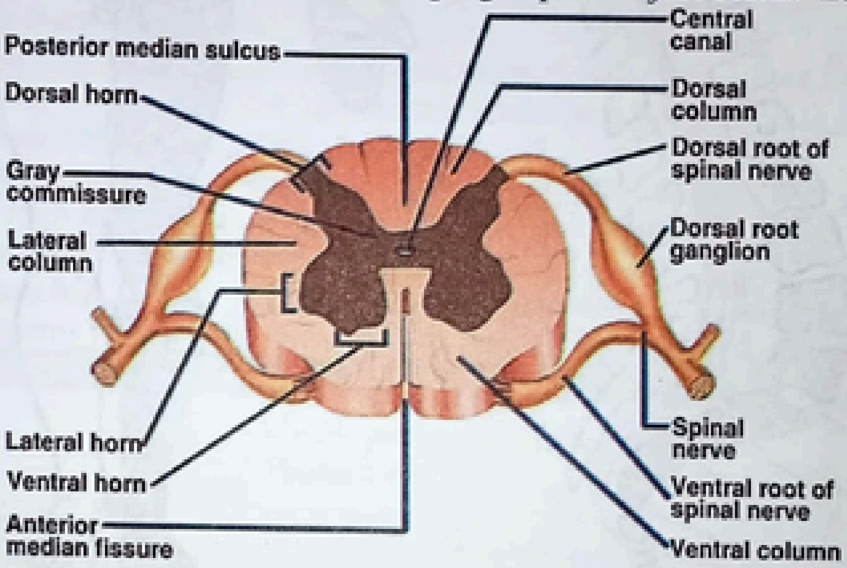
- The spinal cord is the most important structure between the body and the brain.
- The spinal cord extends from the ***foramen magnum*** (a hole in the bottom of skull) where it is continuous with the medulla to the level of the first or second lumbar vertebrae.
- It is a vital link between the brain and the body, and from the body to the brain.

Structure

- A transverse section of the adult spinal cord shows white matter in the periphery, grey matter inside, and a tiny central canal filled with ***CSF*** at its center.

a. Grey Matter

- Grey matter is shaped like the letter ***'H' or a 'butterfly'***.
- As in the other part of the nervous system, the grey matter consists of ***neuron cell bodies and non-myelinated parts of the fibres***.
- Several pairs of spinal nerves originate from ***ventral horn*** of grey matter. Similarly, several pairs of spinal nerves join the spinal cord through dorsal horn of grey matter.
- Dorsal root of spinal nerves, also contain ganglia present just beside the spinal cord.

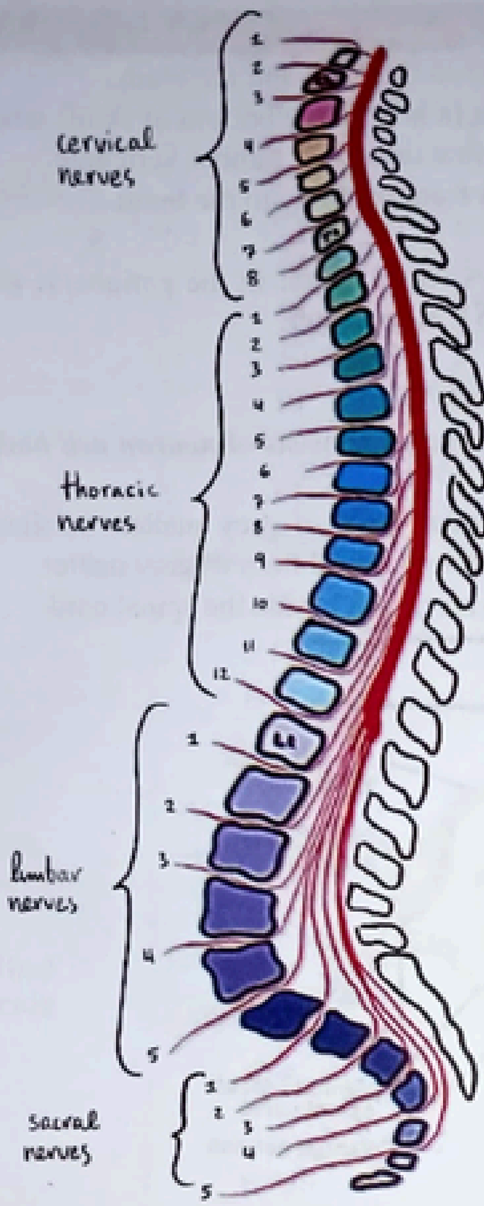


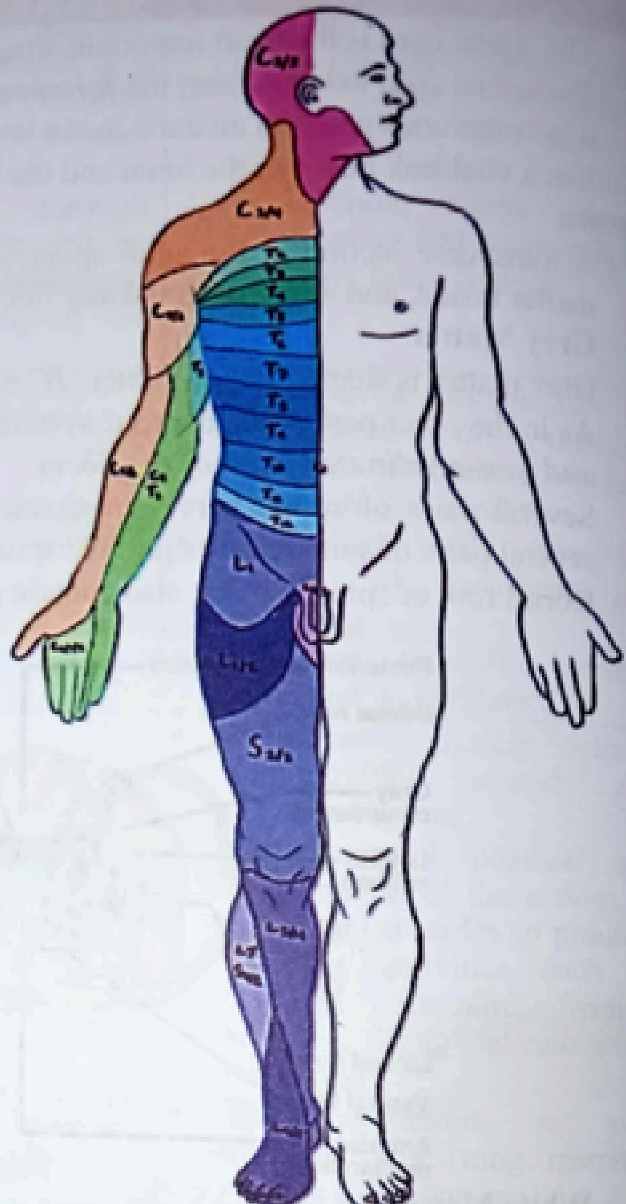
b. White Matter

- The white matter is made up of bundles of myelinated fibres.
- White matter shows deep grooves from both side i.e., from dorsal side to the central canal and from ventral side to the ***central canal***.

c. Segments of Spinal cord

- The spinal cord is divided into four different regions: the cervical, thoracic, lumbar and sacral regions.
- The different cord regions can be visually distinguished from one another. Two enlargements of the spinal cord can be visualized: The cervical enlargement, which extends between C3 to T1; and the lumbar enlargements which extends between L1 to S2.
- The cord is segmentally organized. There are 31 segments, defined by 31 pairs of nerves exiting from the cord. These nerves are divided into 8 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 1 coccygeal nerve. Dorsal and ventral roots enter and leave the vertebral column respectively through intervertebral foramen at the vertebral segments corresponding to the spinal segment.





PERIPHERAL NERVOUS SYSTEM

- PNS comprises sensory and motor neurons. These neurons are distributed throughout the body in the form of ganglia and nerves.
- The collection of neuron cell bodies is called ***ganglia***. It often interconnects with other ganglia to form a complex system of ganglia, known as ***plexus***.
- The bundle of axon fibres (dendrite or axons) covered by the connective tissues are called ***nerves*** and can be classified on the basis of function and origin.

Cranial and Spinal Nerves in Man

- The PNS consists of the nerves that branch out from the CNS and connect it to other body parts. The peripheral nervous system includes;

1. The ***cranial nerves*** which arise from the brain.
2. The ***spinal nerves***, which arise from the spinal cord.

A. Cranial nerves

- There are ***twelve pairs of cranial nerves***. Functionally, three pairs of cranial nerves are sensory (I, II, VIII), five pairs are motor in nature (III, IV, VI, XI, XII) and four pairs are mixed nerves (V, VII, IX, X).

- Cranial nerves are largely concerned with the head, neck and facial regions of the body.

B. Spinal nerves

- ***Thirty-one pairs of spinal nerves*** originate from the spinal cord. They are ***all mixed nerves***, and they provide two-way communication between the spinal cord and parts of the arms, legs, neck and trunk.
- Each spinal nerve emerges from the spinal cord by two short branches or roots, which lie within the vertebral column.

a. Dorsal root

- The dorsal root contains the fibres of sensory neuron, which conduct impulses to the spinal cord.

b. Ventral root

- The ventral root contains the fibres of motor neurons, which conduct impulses away from the cord.
- The two roots join just before a spinal nerve leaves the vertebral column. Each spinal nerve serves the particular region of the body in which it is located.

Somatic and Autonomic Nervous System

- The ***PNS*** can also be subdivided into the somatic and autonomic nervous systems.

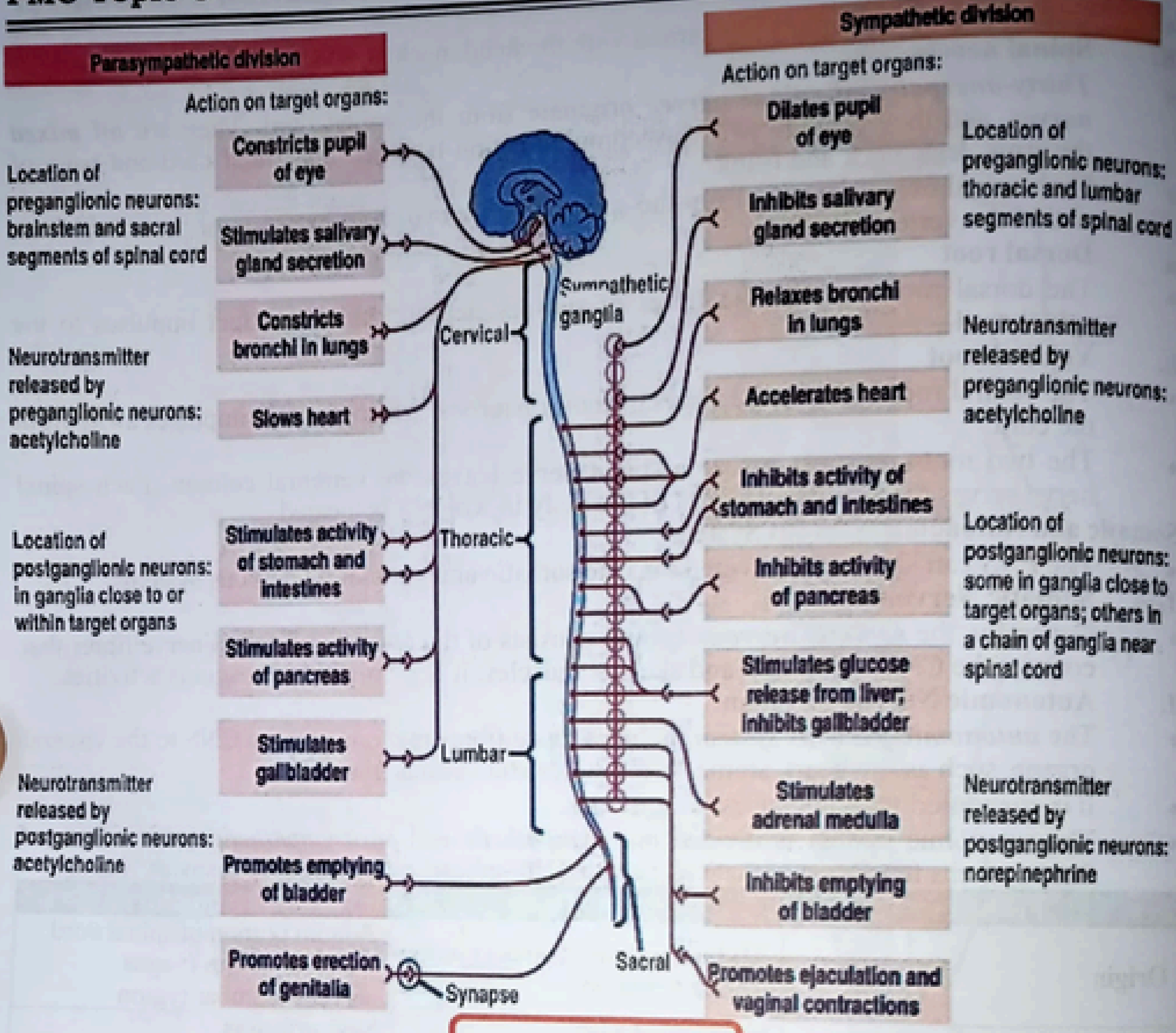
I. Somatic Nervous System

- Generally, the ***somatic nervous system*** consists of the cranial and spinal nerve fibres that connect the CNS to the skin and skeletal muscles; it is involved in conscious activities.

II. Autonomic Nervous System

- The ***autonomic nervous system*** includes those fibres that connect the CNS to the visceral organs, such as the heart, stomach, intestines and various glands.
- It is concerned with unconscious activities.
- The autonomic system is divided into ***sympathetic*** and ***parasympathetic system***. Both of these systems function automatically and usually subconsciously in an involuntary manner.

Features	Sympathetic	Parasympathetic
Origin	Middle portion of spinal cord/ Thoracic region	Bottom portion of spinal cord + cranial nerves (vagus nerves)/ Lumbar region
Position of ganglia	Near spinal cord	Near effectors
Length of pre-ganglionic fibers	Short	Long
Length of post-ganglionic fibers	Long	Short
Functions	Works in emergency, fear and fight situations	Promotes relaxed state
Actions	• Accelerates heartbeat • Dilates pupils • Inhibits digestion of food • Rise in blood pressure	• Retards heartbeat • Constriction of pupils • Promotes digestion of food • Lowering of blood pressure



CRITICAL THINKING

9. Retention of urine in bladder in adults is under control of:

A. Somatic nervous system
B. Autonomic nervous system
C. Sympathetic nervous system
D. Parasympathetic nervous system

NERVOUS DISORDERS

Feature	Parkinson's Disease	Epilepsy	Alzheimer's Disease
Definition	It is a nervous disorder, characterized by involuntary tremors, diminished motor power and rigidity.	It is a convulsive disorder of nerves characterized by abrupt transient symptoms of motor, sensory, psychic or autonomic nature, frequently associated with changes in consciousness.	It is characterized by decline in brain function.
Onset	Late age disease (50's or 60's)& Progressive	Before 30 years of age Organic disease after 30 years	Late age disease & progressive

Cause	Cell death in brain area that produces dopamine that may be due to head trauma	No known cause. Emotional disturbance, alcohol etc. are aggravating factors	Genetic predisposition, High levels of aluminium
Treatment	L-dopa, Use of GDNF	EEG for diagnosis, Anti-convulsive drugs for therapy	Non-curable

CHEMICAL COORDINATION

- The cellular functions needed to be continuously regulated. The nerve fibres do not innervate all the cells of the body; so a special kind of coordination system is thus required.
- The hormonal system is concerned with control of the different metabolic functions of the body, such as the rate of chemical reactions, transport of substances through plasmalemma, growth and secretions. This coordination is called ***chemical coordination***.

Hormone – The Chemical Messengers

- Endocrine glands are ***ductless glands*** and secrete chemical messengers, called ***hormones.***
- Hormones are organic compounds of ***varying structural complexity***.
- They are poured directly in blood and transported to the respective target cells/tissues
- They ***do not initiate new biochemical reactions*** but produce their effects by regulating enzymatic and other chemical reactions already present.
- They may either stimulate or inhibit a function.
- Hormones may also control some long-term changes, such as rate of growth, rate of metabolic activity and sexual maturity.

CRITICAL CONCEPT!

Mechanism of Hormonal Action:
Hormone does not act on the target cell directly. It combines with receptor to form hormone-receptor complex. This complex executes the action through one of the following mechanisms:
1. By altering permeability of cell membrane
2. By activating intracellular enzyme
3. By acting on genes

CRITICAL CONCEPT!

Portal System:
Portal system can be defined as a part of the systemic circulation, in which blood draining from the capillary bed of one structure flows through larger vessels to supply the capillary bed of another structure, before returning to the heart.

Chemical Nature of Hormones

- Chemically hormones may be of following types:

Category	Hormones	Glands
Protein	Insulin, Glucagon	Islets of Langerhans
Polypeptides	ADH, Oxytocin	Produced in hypothalamus and secreted from posterior pituitary
Amino Acids Derivatives	T_3, T_4 (Thyroxin)	Thyroid
Catecholamine	Adrenaline, Nor-adrenaline	Adrenal medulla
Steroid	Estrogen, Testosterone, Cortisone	Gonads, Adrenal Cortex

Mode of Hormone Action

- ***Proteins*** and ***peptide*** cannot pass through cells' plasma membrane because they are ***water soluble***. These hormones (1st messenger) bind with their receptor on the plasma membrane of the target cell, starting a series of events in the cell which generates 2nd messenger e.g. ***cAMP***. The second messenger then triggers various changes in the cells.
- ***Steroid*** and ***thyroid*** hormones can pass through plasma membrane because they are ***lipid soluble***. Receptors for these hormones are located in the cytoplasm or nucleus. Hormone bind with their receptors to form ***hormone-receptor complex*** which then binds with promoter region of a particular gene, thus modify the cellular activities by altering gene expression.

CRITICAL CONCEPT!

The genes for hormone receptors frequently have similar sequences and can be grouped into gene families. Armed with this information, investigators have scanned the human genome sequence looking for homologies to known receptor gene sequences. This method has resulted in the discovery of many "orphan" hormone receptors-receptors that do not appear to bind any known hormone. The existence of orphan receptors raises the possibility that there may be many as-yet undiscovered human hormones, and that determining the effects of these hormones could have profound implications for health.

ENDOCRINE SYSTEM OF MAN AND HYPOTHALAMUS

Glands

- Glands are the tissues which produce and release some products called secretions.
- Endocrine system is the type of glandular system, consists of ***some 20 ductless glands*** lying in different parts of the body.
- These are the organs that are specialized for secretions. Glandular cells are secretory or neurosecretory cells that are abundant in Golgi complex.
- Hormones released from neurosecretory cells are called as neuro-secretions e.g. ADH
- There are mainly two types of glands in the body, ***exocrine*** and ***endocrine glands*** which can be distinguished in the following table.

CRITICAL CONCEPT!

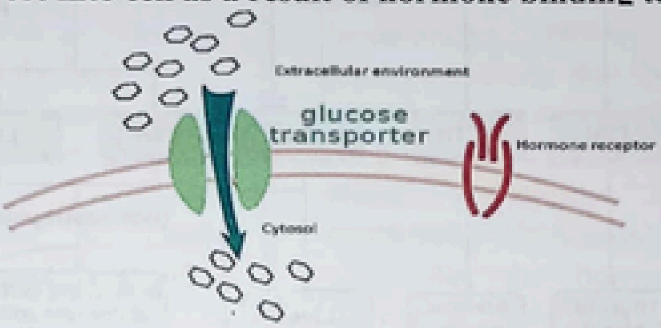
Hormones Secreted by Some Other Organs:

Pineal gland	Melatonin
Thymus	1. Thymosin 2. Thymin
Kidney	1. Erythropoietin 2. Thrombopoietin 3. Renin 4. 1,25-dihydroxycholecalcifero (calcitriol) 5. Prostaglandins
Heart	1. Atrial natriuretic peptide 2. Brain natriuretic peptide 3. C-type natriuretic peptide
Placenta	1. Human chorionic gonadotropin (HCG) 2. Human chorionic somatomammotropin 3. Estrogen 4. Progesterone

Feature	Exocrine Glands	Endocrine Glands
Another Name	Ducted glands	Ductless glands
Secretions	Enzymes, mucus etc.	Hormones
Transportation	Through ducts	Through blood
Examples	Sweat glands, Salivary glands	Adrenal glands, Pituitary gland

CRITICAL THINKING

10. A hormone has bound to its receptor embedded in membrane of its target cell. Movement of glucose into cell as a result of hormone binding to its receptor is:



A. Facilitated diffusion
B. Diffusion
C. Active transport
D. Passive transport

11. Which of the following will not take place as a result of hormone binding to its receptor? (see above diagram)

A. Increased glycolysis
B. Decreased glycogenolysis
C. Increased gluconeogenesis
D. Decreased lipolysis

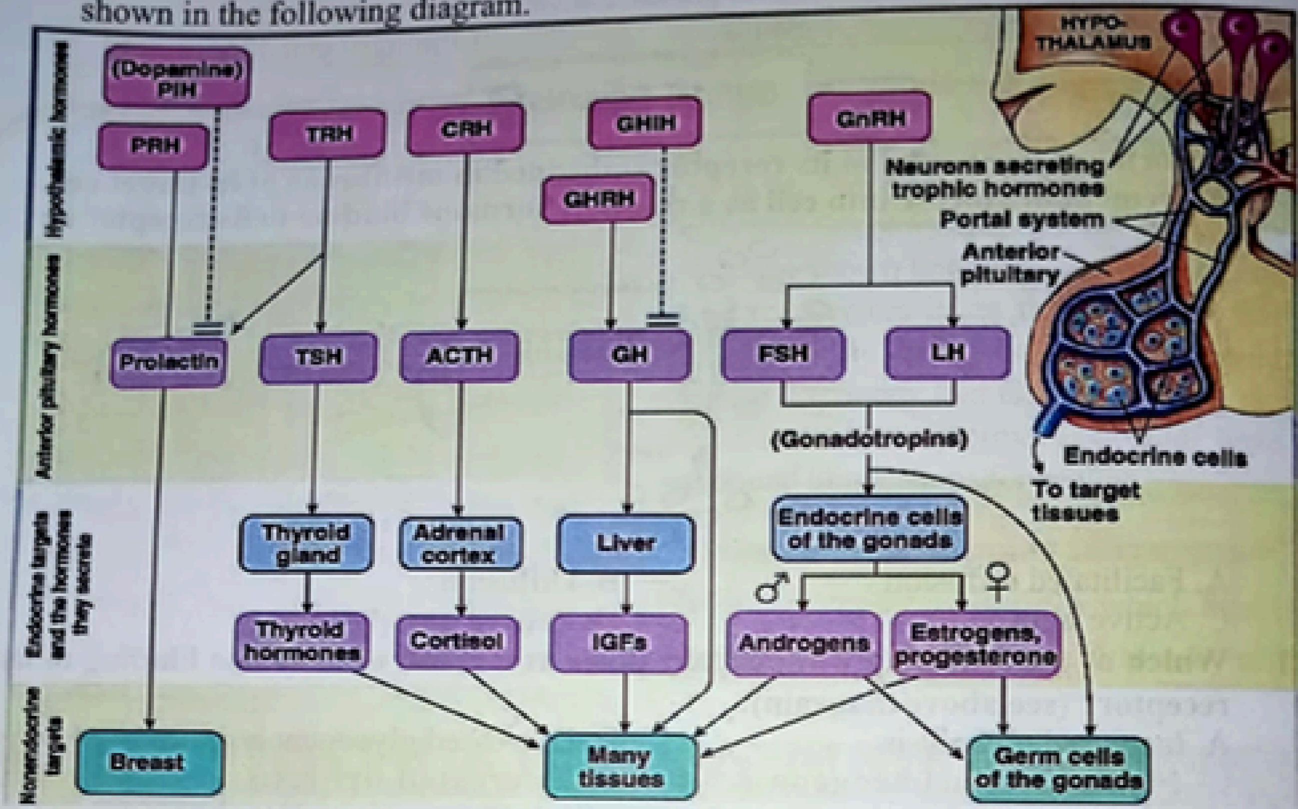
Hypothalamus

- It is a ***part of forebrain***. It acts as ***master control centre*** of the endocrine system. It is here that many of the sensory stimuli of nervous system are converted into hormonal responses.
- Its endocrine signals directly control the pituitary gland. It contains special group of ***neurosecretory cells***. These cells conduct impulses and have developed secretory capacity to a high level. The hormones produced by the hypothalamus are either ***releasing factors*** or ***inhibiting factors.*** The releasing and inhibiting hormones of hypothalamus and their functions are given in the following table:

Sr. No.	Hormone from Hypothalamus	Anterior Pituitary Response
1.	Growth hormone releasing factors (GHRF)	Secretion of GH
2.	Somatostatin	Inhibition of GH
3.	Thyrotrophin releasing factor (TRF)	Secretion of TSH
4.	Adrenocorticotrophin releasing factor (CRF)	Secretion of ACTH
5.	Prolactin inhibiting factor (PIF)	Inhibits secretion of prolactin
6.	Gonadotrophin releasing hormone (GnRH)	Secretion of FSH and LH/ICSH

These are produced in the cell bodies and packed into the granules and are transported down to the axon by ***cytoplasmic streaming***. The axon ending of neuro-secretory cells synapse with blood capillaries and release their hormone into the blood when stimulated.

- The integration of hypothalamus through its hormones with other endocrine glands is shown in the following diagram.



- It is believed that ***oxytocin*** and ***ADH*** are produced in hypothalamus and travel down the nerves to the posterior lobe of pituitary to be stored in nerve endings. They are released from posterior pituitary after receiving nerve impulses from the hypothalamus.

CRITICAL THINKING

12. Portal system is not associated with which of the following organs/tissues?

A. Nephrons B. Liver

C. Pituitary D. Alveoli

PITUITARY GLAND

Pituitary gland or ***hypophysis cerebri*** is located just below the hypothalamus. It is an ***ovoid structure about 0.5gm*** in the adult and is connected to brain through a short stalk, ***the infundibulum***.

It has three lobes viz, anterior, median and posterior.

The anterior lobe is often referred to as the ***master gland***, because in addition to producing primary hormones it produces the tropic hormones which control the secretion of hormones in many of the other endocrine glands.

Anterior Lobe

(i) Somatotrophin Hormone (STH)

- It is also called as growth hormone.
- Hypothalamus → SRF → Anterior Pituitary → STH → Growth
- Somatotrophin releasing factor (SRF) is secreted from hypothalamus throughout life.
- When growth has mostly ceased after adolescence, the hormone continues to promote protein synthesis throughout the body.
- ***Gigantism*** is result of over secretion of GH during childhood in which the bones are still capable of growth and person increase in height abnormally. Over secretion of GH in adult life causes ***acromegaly*** in which bones are no longer capable of increasing in length but grow in thickness. Acromegaly is characterized by enlarging the hands, feet, skull, nose and jawbone.

CRITICAL CONCEPT!

In the 1960s, some children with severe growth hormone deficiencies were treated with GH extracted from the pituitaries of cadavers. The treatments were successful in stimulating growth, but the availability of human pituitaries was a limiting factor. In 1981, the biotechnology pioneer Genentech used recombinant DNA technology to produce bacteria that synthesized human growth hormone. Today GH treatment for pituitary dwarfism is common, but its wider availability has engendered controversy. Is it valid, for example, to administer the hormone to children merely because they are shorter than average? The use of GH as a performance-enhancing drug is also under scrutiny.

- If there is under secretion, ***dwarfism*** results, as well as other symptoms associated with lack of thyroid and adrenal hormone.

(ii) Thyroid Stimulating Hormone (TSH)

- Thyroxine in Blood → Hypothalamus → TRF → Anterior Pituitary → TSH → Thyroid Gland →Thyroxine
- Release of thyrotrophin releasing factor from the hypothalamus is controlled by the levels of thyroxine in the blood.
- In the presence of low levels of thyroxine, there is increasing production of TSH and vice versa.
- It is secreted throughout life but particularly reaches high levels during the periods of rapid growth and development.
- It acts directly on the cells of thyroid gland, increasing both their numbers and secretory activity.

(iii) Adrenocorticotrophic Hormone (ACTH)

- Steroid in Blood → Hypothalamus → CRF → Anterior Pituitary → ACTH → Adrenal Cortex → Corticosteroid
- Release of corticotrophin releasing factor from the hypothalamus is controlled by steroid levels in the blood and by direct nervous stimulation of the hypothalamus as a result of stress e.g. cold, heat, pain, fright, infections.
- Excess and deficiency results in disturbance of normal adrenal functions

(iv) **Gonadotrophic Hormone (GH)**

- These are follicle stimulating hormone (FSH), luteinizing hormone (LH, also called ICSH in male) and prolactin (sometimes inappropriately called luteotrophic hormone, LTH).
- FSH and LH/ICSH share a common hypothalamic releasing factor.
- Prolactin is continuously produced from the pituitary and is inhibited by prolactin inhibiting factor (PIH) from the hypothalamus.
- Prolactin stimulates milk production and acts with LH.
- FSH in females stimulates follicle development and secretion of estrogen from the ovaries; in males it stimulates development of the germinal epithelium of testes and sperm production.
- LH works with FSH to stimulate estrogen secretion and rupture of mature follicles to release egg or ovum.
- It also causes the lutenization of mature follicles and acts synergistically with prolactin to maintain corpus luteum (and hence the progesterone it secretes).
- ICSH in the male stimulates the interstitial cells of the testes to secrete testosterone.

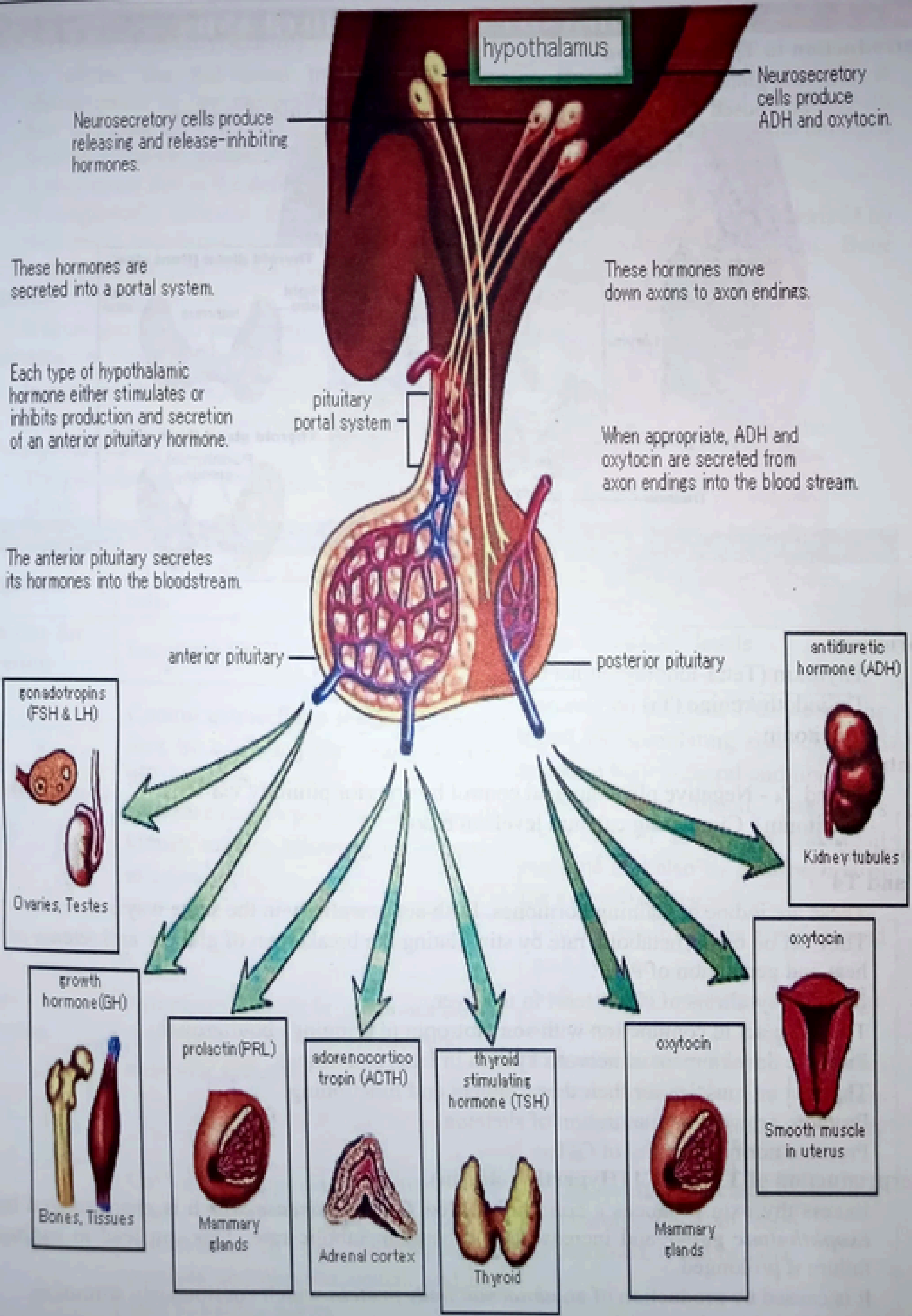
Median Lobe

- Median lobe secretes MSH.
- Its inhibition of secretion is controlled by hypothalamus.
- External light governs its secretion.
- More secretion in pregnancy stimulates melanocytes in skin to produce brown pigment, melanin, which darkens the skin.
- Excess MSH is secreted in Addison's disease. One of the symptoms of which is darkening of skin.

Posterior Lobe

- Posterior pituitary is not glandular by itself. It does not synthesize any hormone.
- It is largely made up of axons of neuro-secretory cells of hypothalamus, which secrete ADH and oxytocin.

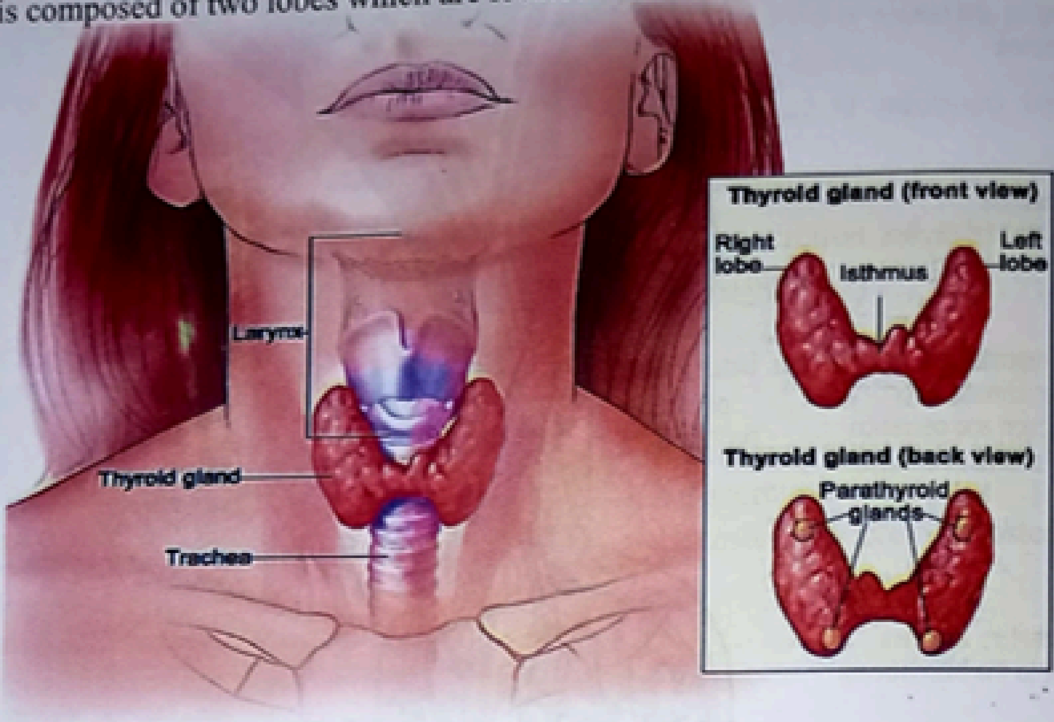
Features	Vasopressin	Oxytocin
Chemical Nature	Polypeptide	Polypeptide
Stimulus for Secretion	Low B.P, decreased blood volume, dehydration	Child birth (Low level of progesterone), Suckling
Target site	Kidneys/Tubules of Nephrons	Smooth muscles of uterus and mammary glands
Functions	Reabsorption of water from kidneys	Stretching of the uterus and cervix, Milk ejection reflex (Letdown reflex). In males, it helps to eject semen during copulation.
Over-secretion	May leads to kidney problem	Rupturing of uterine wall
Under-secretion	Diabetes insipidus	Inhibits normal labour process


hypothalamus
Neurosecretory cells produce ADH and oxytocin.
Neurosecretory cells produce releasing and release-inhibiting hormones.
These hormones are secreted into a portal system.
These hormones move down axons to axon endings.
Each type of hypothalamic hormone either stimulates or inhibits production and secretion of an anterior pituitary hormone.
pituitary portal system
When appropriate, ADH and oxytocin are secreted from axon endings into the blood stream.
The anterior pituitary secretes its hormones into the bloodstream.
anterior pituitary
posterior pituitary
gonadotropins (FSH & LH)
Ovaries, Testes
antidiuretic hormone (ADH)
Kidney tubules
growth hormone(GH)
Bones, Tissues
prolactin(PRL)
Mammary glands
adrenocortico tropin (ACTH)
Adrenal cortex
thyroid stimulating hormone (TSH)
Thyroid
oxytocin
Mammary glands
oxytocin
Smooth muscle in uterus

THYROID AND PARATHYROID GLANDS

Introduction to Thyroid Gland

- Thyroid gland is located below the larynx (voice box).
- It is composed of two lobes which are located on either side of trachea.



Hormones

- Thyroxin (Tetra-iodothyronine/T_4)
- Tri-iodothyronine (T_3)
- Calcitonin

Control

- T_3 and T_4 - Negative physiological control by anterior pituitary via TSH.
- Calcitonin - Circulating calcium levels in blood

Functions

T3 and T4

- These are iodine containing hormones. Both act essentially in the same way.
- They act on basal metabolic rate by stimulating the breakdown of glucose and release of heat and generation of ATP.
- Enhance synthesis of cholesterol in the liver.
- They also act in conjunction with somatotropin in bringing about growth.
- Promote development of nervous system in fetus and infants.
- They act on muscles for their development and functioning.
- Promote growth and maturation of skeleton.
- Promote normal motility of GIT.

Overproduction of T3 and T4 (Hyperthyroidism)

- Excess thyroxin produces a condition called ***Graves' disease*** which is characterized by ***exophthalmic goiter*** and increase in the basal metabolic rate. This can lead to cardiac failure if prolonged.
- It is caused by production of an ***abnormal body protein*** which continuously stimulates thyroid to excessive secretion.

Under-secretion (Hypothyroidism)

- In adults, the full-blown hypothyroid syndrome is called ***myxedema*** which is characterized by low metabolic rate, feeling chilled, puffy eyes, thick and dry skin with hair lost from the scalp and eyebrows, edema, tongue swelling, constipation and enlarged thyroid gland i.e., ***goiter***. All body and mental processes are retarded.
- It may result due to the deficiency of iodine in diet.
- If congenitally deficient, the lack of thyroxin causes ***cretinism***, which is characterized by the mental retardation with poor physical growth and disproportionate body size. Bone maturation and puberty are severely delayed and infertility is common.

Calcitonin

- It is antagonistic to parathormone.

Introduction to Parathyroid Gland

- In humans, there are ***four*** parathyroid glands.
- They are small, light colored masses that stick out from the posterior surface of the thyroid gland.
- The ***parathormone*** is the single most important hormone, produce by the parathyroid gland.

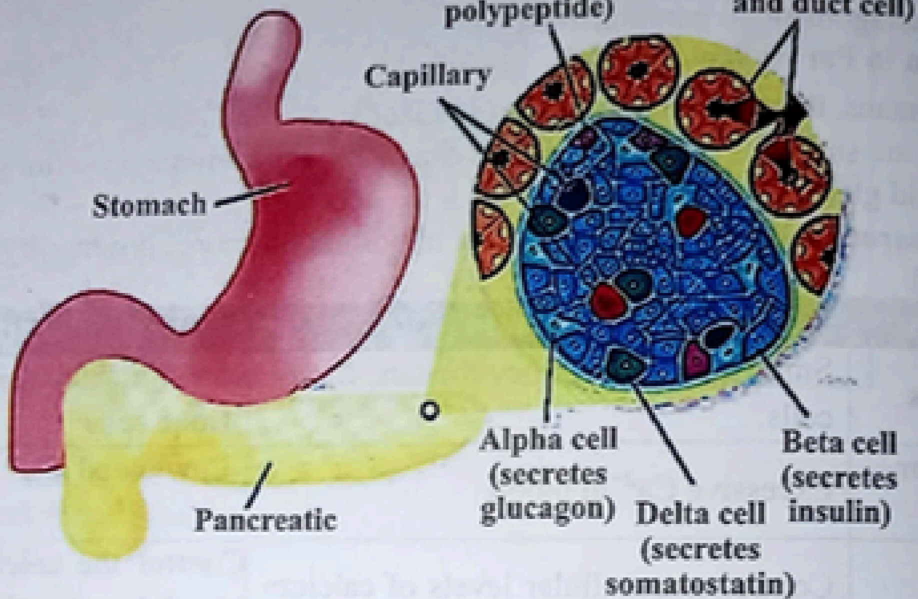
Features	Calcitonin	Parathormone
Target sites	Small intestine, Kidney tubules, Bone cells	Small intestine, Kidney tubules, Bone cells
Stimulus for secretion	Excessive Ca^{2+} in blood	Low blood Ca^{+2} levels
Functions	Control extracellular levels of calcium ions by inhibiting Ca^{2+} absorption by the intestines. Decrease reabsorption of Ca^{2+} from the kidney tubules allowing its excretion in urine	Control the calcium balance of the blood by stimulating osteoclasts to reabsorb bone mineral and liberating calcium into blood, stimulates absorption of calcium in the small intestine and also its reabsorption in the kidney tubules
Over-secretion	Symptoms include brittle bones and disorders related with nervous and muscular systems	Usually results from a parathyroid gland tumor. Soft bones leading to fracture spontaneously Hypercalcemia which depresses nervous system, causes weakness of muscles and leads to kidney stone
Under-secretion	Ca^{2+} are not deposited in bones High blood Ca^{2+} level causes disturbance in the functioning of muscles and nervous system and may lead to kidney stones	Hypocalcemia increases excitability of neurons, muscular tetany. If untreated, it can be fatal.

Introduction

- Pancreas is composed of two types of tissues e.g. ***exocrine tissue*** which produces and secretes ***digestive juice*** and ***endocrine tissue*** which produce hormones.
- The endocrine tissues are distributed in the form of patches which are called ***Islets of Langerhans***.

Hormones

- The Islets contain large number of ***β-cells*** associated with ***insulin*** production.
- The smaller number of ***α-cells secrete glucagon***.



Control

- This is under control of the pituitary trophic hormones, *STH* and *ACTH* and also responds directly to the ***level of blood glucose***.

Metabolic Functions of Insulin

- In general, insulin depresses blood glucose levels, in a variety of ways which include:

(i) Increase the rate of glucose uptake by skeletal muscles and fat cells.
(ii) Increase use of glucose in cellular respiration.
(iii) Increase glycogen synthesis (glycogenesis).
(iv) Promote conversion of glucose into proteins and lipids.
(v) Inhibit the hydrolysis of glycogen (glycogenolysis) in the liver and muscles.
(vi) Inhibits gluconeogenesis.

Abnormalities of Insulin

Under-secretion

- Failure to produce insulin leads to a condition called ***diabetes mellitus***. The symptoms include

(i) High level of blood sugar (***Hyperglycemia***)
(ii) Sugar in the urine (***Glycosuria***)
(iii) A disturbance of the body's osmotic equilibrium
(iv) Derangement of the nervous system
(v) Toxic metabolites from fat (which need 'glucose energy' for their oxidation) also accumulate and are only lost from the kidney with valuable metal cations.
(vi) The body becomes dehydrated

Overproduction

- If excess insulin is produced, the utilization of sugar is too great and its level falls in the blood (hypoglycemia) which upsets nerve and muscle functioning.

Metabolic Functions of Glucagon

- Glucagon is essentially ***antagonistic to insulin*** and causes an increase in blood glucose levels. Sympathetic nervous system also stimulates its secretion while high blood glucose level, insulin and somatostatin suppress its secretion. It plays its role mainly by:

(i) Promoting breakdown of glycogen to glucose in the liver and muscles.
(ii) Increasing the rate of breakdown of fats.

Abnormalities of Glucagon

- Glucagon abnormalities seem to be rare endocrine disorders.
- Tumors on the β-cells will cause excess glucagon secretions and consequently high blood glucose levels. This in turn damages the α-cells.

CRITICAL THINKING

13. Trace down the pathway of Glucagon from its source to its target site:

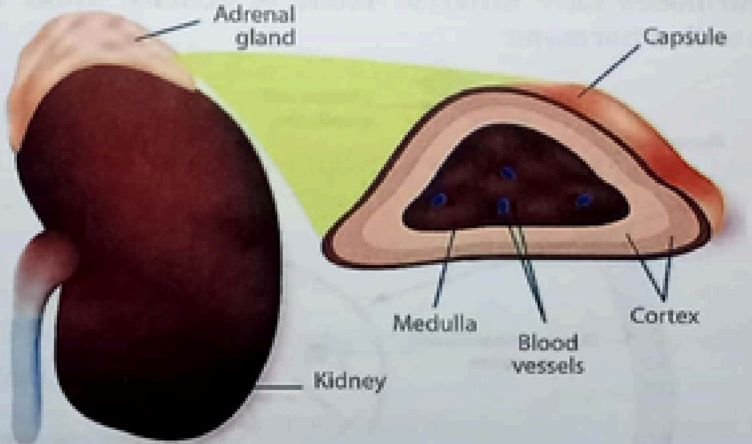
1. Inferior vena cava
2. Heart, lungs, heart
3. Pancreatic vein
4. Aorta
5. Target site

A. 1, 2, 3, 4, 5 B. 2, 1, 3, 4, 5
C. 3, 2, 1, 4, 5 D. 3, 1, 2, 4, 5

ADRENAL GLANDS

Introduction

- A pair of adrenal gland is present, one on top of each kidney. These are also called as glands of emergency or supra-renal glands.
- Each adrenal gland is composed of an inner portion called ***adrenal medulla*** and outer portion is called ***adrenal cortex***.



Adrenal Medulla

- Inner portion of adrenal gland is called adrenal medulla.

Hormones

- The medulla produces the hormones ***adrenaline/epinephrine*** and ***noradrenalin/nor-epinephrine***.

Control

- Both adrenalin and nor-adrenalin are secreted in stress situations.
- They are influenced by sympathetic nervous system.

Functions

- Promote metabolic activities and bronchodilation.
- Essentially adrenaline dilates blood vessels in certain parts of the body such as the skeletal muscles and increases the heart's output.
- Noradrenaline constricts blood vessels but again only in certain areas such as the gut.
- Effects of the two hormones are synergistic in raising blood pressure.
- Adrenaline and noradrenaline promote the release of glucose from liver glycogen and reinforce the effects of the sympathetic system.

Abnormalities

- ***Over-secretion*** of catecholamine may cause hypertension and aggressive behavior during routine life.
- ***Under-secretion*** causes failure to combat with emergency situation. For example, in rats whose adrenal medulla has been removed surgically, the ability to withstand any stress situation such as cold is markedly diminished.

Adrenal Cortex

- Outer portion of adrenal gland is called adrenal cortex.

Control

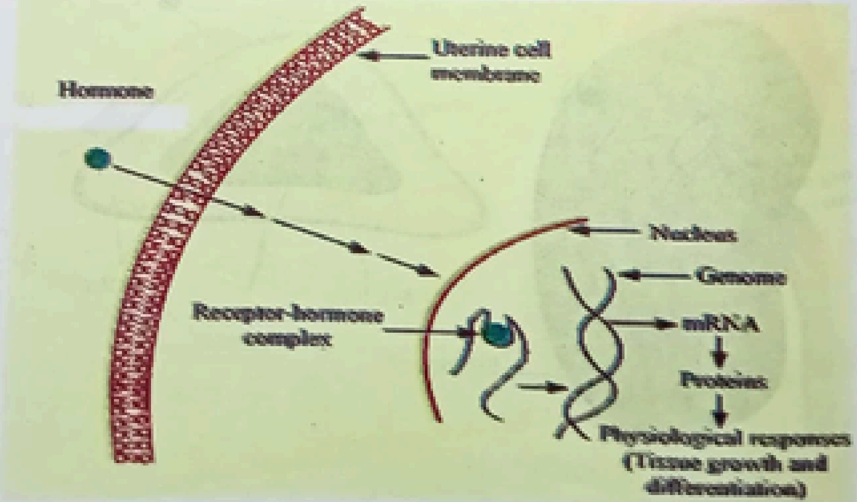
- Hormones of adrenal cortex are secreted under influence of ACTH from adrenal cortex.

Hormones

- The adrenal cortex secretes corticosteroids such as ***cortisol***, ***corticosterone***, ***aldosterone*** and ***androgenic hormones***.
- Cortisol is the glucocorticoid.
- Corticosterone is both a glucocorticoid and a mineralocorticoid.
- Aldosterone is the principal mineralo-corticoid.

CRITICAL THINKING

14. Different hormones have different mode of actions. Make a link of given mechanism with a hormone:



A. Cortisone B. Prolactin
C. Glucagon D. FSH

Functions

- The adrenal cortex is active at all times but especially so following shock or stress situation or infections.
- Cortisol brings about an increase in blood glucose level mainly by its production from protein and antagonizing the action of insulin.
- Corticosterone increases blood glucose levels and regulate mineral ion balance.
- Aldosterone conserves the level of Na^+ in the body by preventing their loss from the kidney tubules.

Abnormalities

Under-secretion of Corticosteroids

- The destruction of the adrenal cortex, such as occurs in ***Addison's disease***, will lead to general metabolic disturbance, in particular weakness of muscle action and loss of salts.
- Stress situations, such as cold, which would normally be overcome, lead to collapse and death.

Over-secretion of Corticosteroids

- The reverse of this is found in ***Cushing's disease*** where too much cortical hormone is produced. Symptoms are an excessive protein breakdown resulting muscular and bone weakness. The high blood sugar disturbs the metabolism as in diabetes.

Overproduction of Androgens

- Androgens cause development of the male secondary sex characteristics.
- Very small amounts of androgens are secreted in both male and female by adrenal glands.
- A tumor on the inner part of the adrenal cortex in a female can cause excess androgens to be produced and thus the development of certain male characteristics. Such cases are very rare.

GONADS

- Gonads are special type of endocrine glands which beside hormone secretions also produce gametes.

Ovarian Hormones

Ovaries are involved in production and secretion of female sex hormones mainly estrogen and progesterone.

Estrogen

Production and Control

- Estrogens are secreted by graffian follicles whose development has been initiated by FSH from the pituitary.
- In many species it is produced by interstitial cells of the ovary.

Functions

- Bring about the development of the ***secondary sexual characters*** in the female.
- Cause thickening of uterine wall.
- At a point during the estrous or menstrual cycle, exert a positive feedback which results in a sharp rise in LH output by the pituitary.
- They also aid in healing and repair of uterine wall after menstruation.
- Under the influence of estrogen, some of the cells of uterine wall become glandular and start secreting proteinaceous secretions which are taken up by the embryo during its early stages of development.

Abnormalities

- Its over secretion leads to the development of fibroids in uterus and polycystic ovaries
- Deficiency of the sex hormones, for one reason or another, leads in the young of failure to mature sexually and sterility in the adult.

Progesterone

Production and Control

- Produced by the *corpus luteum* in response to LH during normal menstrual cycle but it is produced and released from placenta during pregnancy.

Functions

- It inhibits further FSH secretion from the pituitary, thus preventing any more follicles from ripening.
- It also affects uterus, causing further thickening and vascularization of its wall and other areas of the female body, preparing it for maintaining the state of pregnancy.
- It suppresses ovulation that is why it is a major constituent of birth control pill.

Abnormalities

- Under-secretion of progesterone during menstrual cycle ***decreases the chances of pregnancy*** and may cause early menstruation.
- Under-secretion during pregnancy may leads to ***miscarriage***.

Testes

Hormones

- The testes consist of many coiled seminiferous tubules where the spermatozoa develop.
- Between the tubules, regions of interstitial cells produce gonadal hormones called testosterone and 17 β-hydroxytestosterone.
- After the initiation of development, the sex organs in the fetus produce them and their level rises fairly consistently until puberty.
- After puberty the supply of LH/ICSH, and therefore the level of testosterone, remains constant.

Functions

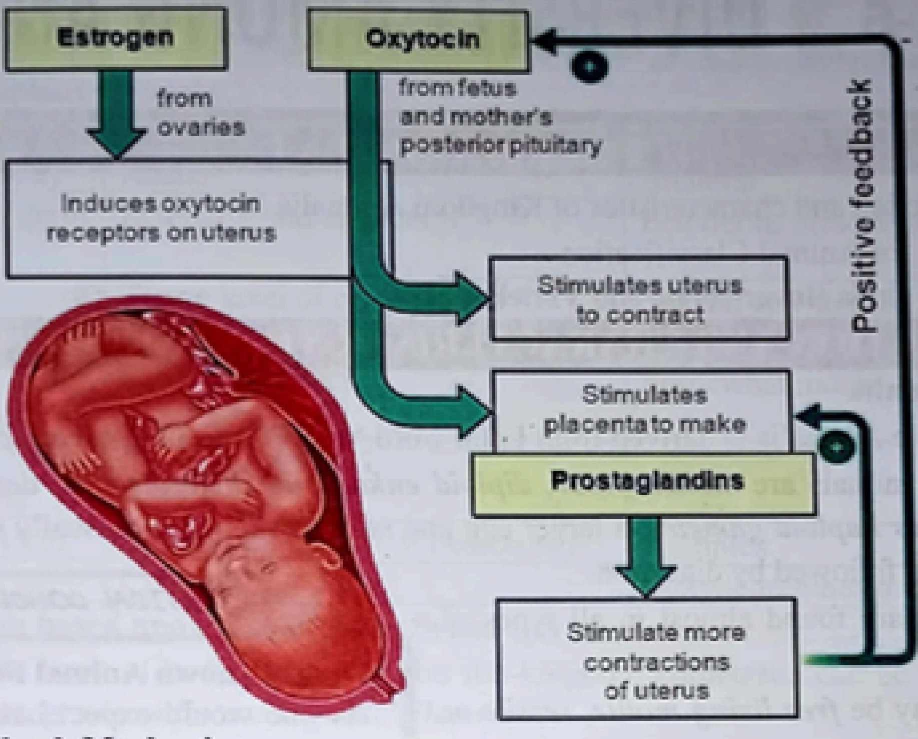
- In the fetus, it initiates the development of the sex organs.
- At puberty, it brings about development of the male secondary characteristics and promotes the sex drive.
- The castrated male fails to develop secondary sexual characteristics and his body tends more towards the form of the immature female.

HORMONAL FEEDBACK MECHANISM

- It is a type of interaction in which a controlling mechanism is itself controlled by the products of reactions it is controlling.
- After receiving the signal, a change occurs to correct the deviation by depressing it with negative feedback or enhancing it with positive feedback.

Positive Feedback Mechanism

- In positive feedback, an end product speeds up its production.
- These responses are not homeostatic and are rare in healthy individuals.
- An example of positive feedback is childbirth.



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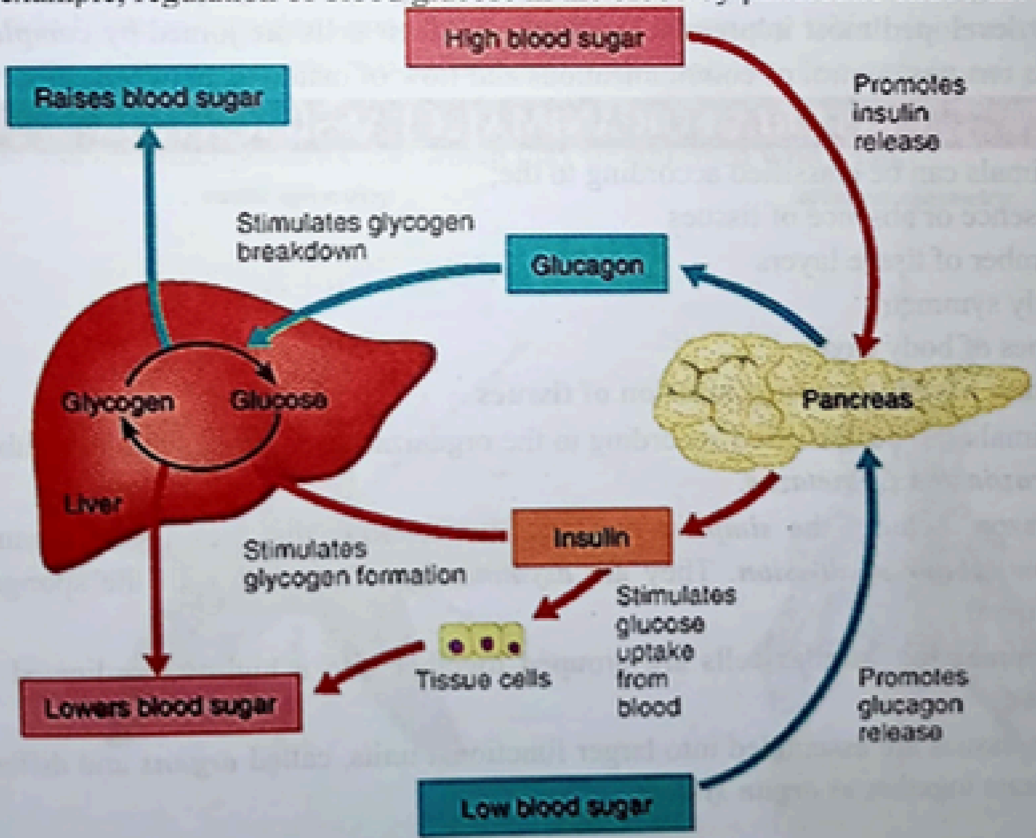
Negative Feedback Mechanism

- In negative feedback, the end products result in the reversal of the direction of change and tends to maintain homeostasis.
- In this system, an endocrine gland is sensitive either to the concentration of a substance it regulates or to the concentration of a product from a process it controls.
- For example, regulation of blood glucose in the blood by pancreatic endocrine cells.



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TOPIC-6 » DIVERSITY AMONG ANIMALS

COURSE CONTENT

- Introduction and characteristics of Kingdom Animalia
- Criteria for Animal Classification
- Animal phyla (Invertebrate and Vertebrate)

INTRODUCTION AND CHARACTERISTICS OF KINGDOM ANIMALIA

Kingdom Animalia

- The name Animalia is derived from Latin word '***anima***' meaning ***breath or soul***.
- All the animals are ***multicellular***, ***diploid eukaryotes***, ***heterotrophs***, ***develop from two dissimilar haploid gametes***, a larger egg and smaller sperm, and usually acquire food by ingestion followed by digestion.
- Animals are found almost in all types of habitat.
- They may be ***free living motile***, ***sessile*** or ***a parasite***.
- They range in size from worms, only seen with a microscope to the largest animal, the blue whales.

> **CRITICAL CONCEPT!**
>
> **Oldest Known Animal Fossils:**
> As one would expect based on their phylogenetic position, fossil sponges are among the oldest known animal fossils.

- Although multi-cellularity is found in all the kingdoms, fungi, plantae and animalia but it has developed most impressively in animals; their cells are joined by ***complex junction***. This ensures control of communications and flow of materials between cells.

CRITERIA FOR ANIMAL CLASSIFICATION

- Animals can be classified according to the;

1. Presence or absence of tissues
2. Number of tissue layers
3. Body symmetry
4. Types of body cavity

Classification based upon organization of tissues

- Animals can be classified according to the organization of tissues into two sub-kingdoms: ***Parazoa*** and ***Eumetazoa***.
- Parazoa includes the ***simplest multicellular animals*** that lack tissue organization but ***show labour of division***. They are ***asymmetrical***. It includes all the sponges (phylum porifera).
- In eumetazoa, similar cells are grouped together into a highly coordinated unit called ***tissue***.
- The tissues are assembled into larger functional units, called ***organs*** and different organs operate together as ***organ system***.

Classification based upon Number of Tissue Layers

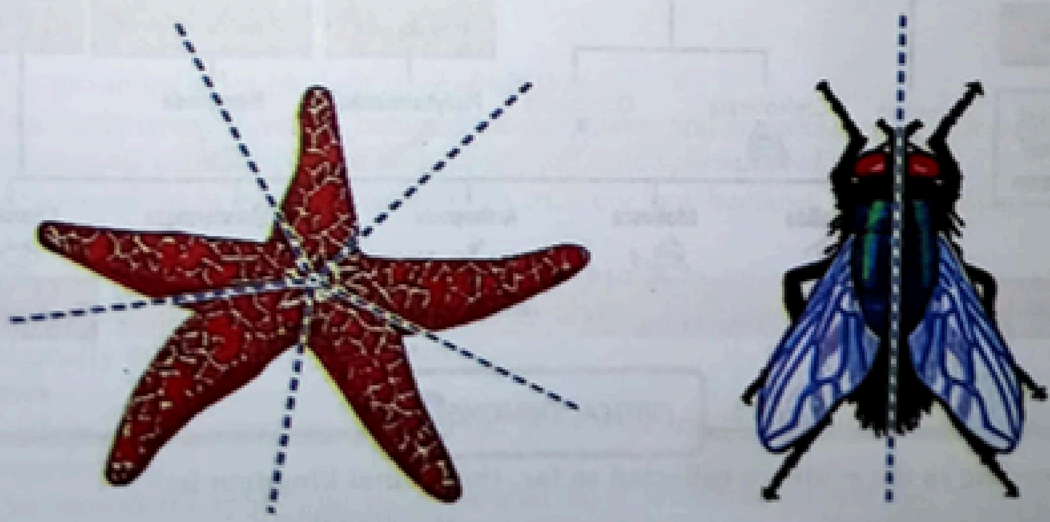
- Animals can be classified according to number of tissue layers as ***diploblastic*** and ***triploblastic*** animals.

Features	Diploblastic Animals	Triploblastic Animals
Body symmetry	Radial	Bilateral
No. of germ layers	Ectoderm and endoderm	Ectoderm, mesoderm and endoderm
Level of organization	Tissue level of organization	Specialized tissue, organ and organ system level of organization
Degree of specialization	Somewhat lesser	Somewhat more
Mesoglea/ Mesenchyme	Present	Absent
Nervous system	Simple and consist of neuron net	Complex
Phylum	Cnidaria	Platyhelminthes to Chordates

Classification based upon type of Body Symmetry

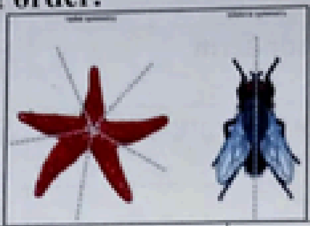
- On the basis of body symmetry, the sub-kingdom eumetazoa can be classified into two groups; ***grade radiata*** and ***grade bilateria***.
- Grade radiata includes all the animals with ***radial symmetry***, which is characterized by the condition in which the parts of the body are arranged around the central axis in such a way that any plane passing through the central axis divides the animal in equal halves that are almost mirror image of each other e.g., jelly fish, sea anemone etc.
- Radial symmetry is considered an adaptation for a sessile life.
- Grade bilateria includes animals with ***bilateral symmetry*** which is characterized by the division of an animal into two equal parts by an imaginary line ***only in one plane***.
- In most multi-cellular animals, there is a clearly differentiated head present at the anterior end and a distinct posterior end which may be equipped with a tail.

radial symmetry bilateral symmetry

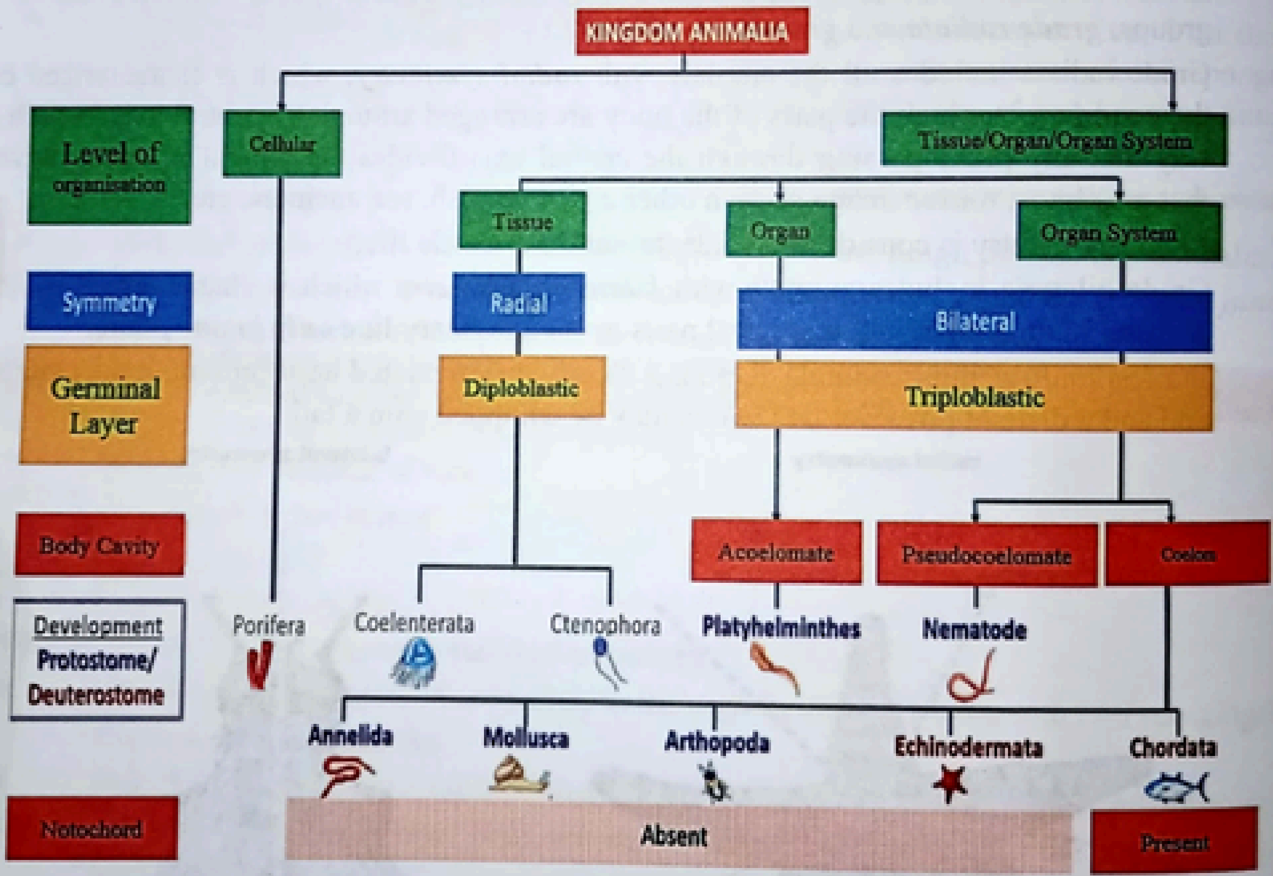


CRITICAL THINKING

1. Two types of symmetries are present in kingdom animalia. Relate feature of these symmetries in correct order.



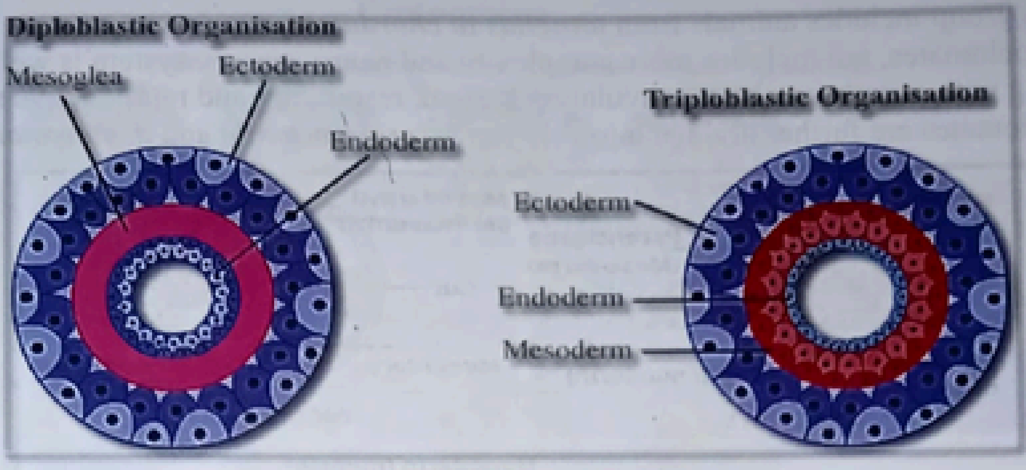
	Grade Radiata	Grade Bilateria
A.	No right- and left-hand sides	No anterior and posterior ends
B.	Anterior and posterior ends	Defined dorsal and ventral surfaces
C.	Defined dorsal and ventral surfaces	Right and left hand sides
D.	No dorsal and ventral surfaces	Triploblastic organization



CRITICAL THINKING

2. According to the evidence collected so far, the animal kingdom is:

A. Monophyletic
B. Paraphyletic
C. Polyphyletic
D. Euphyletic



CRITICAL THINKING

3. Polymorphism and radial symmetry in an adult phase of an organism having triploblastic organization can be related respectively with:

A. Cnidaria, Echinodermata B. Echinodermata, Coelenterata
C. Porifera, Cnidaria D. Arthropoda, Echinodermata

Classification based upon the type of Body Cavity (Coelom)

- Animals can be grouped according to the type of body cavity or ***coelom***, a fluid filled space between the outer body wall and the digestive tube.

Acoelomates

- This group includes phylum ***platyhelminthes***.
- There is ***no body cavity or coelom***.
- Mesoderm forms a loose, cellular tissue ***mesenchyma*** or ***parenchyma*** which fills the space between the ectoderm and endoderm. It forms a packing around the internal organs of the animals to support and protect them.
- The gut is ***sac-type*** and there is no special transport system.
- Only excretory system is developed for the transport of excretory products. This system consists of ***flame cells***, excretory ducts and excretory pores.
- Nervous system is well developed.

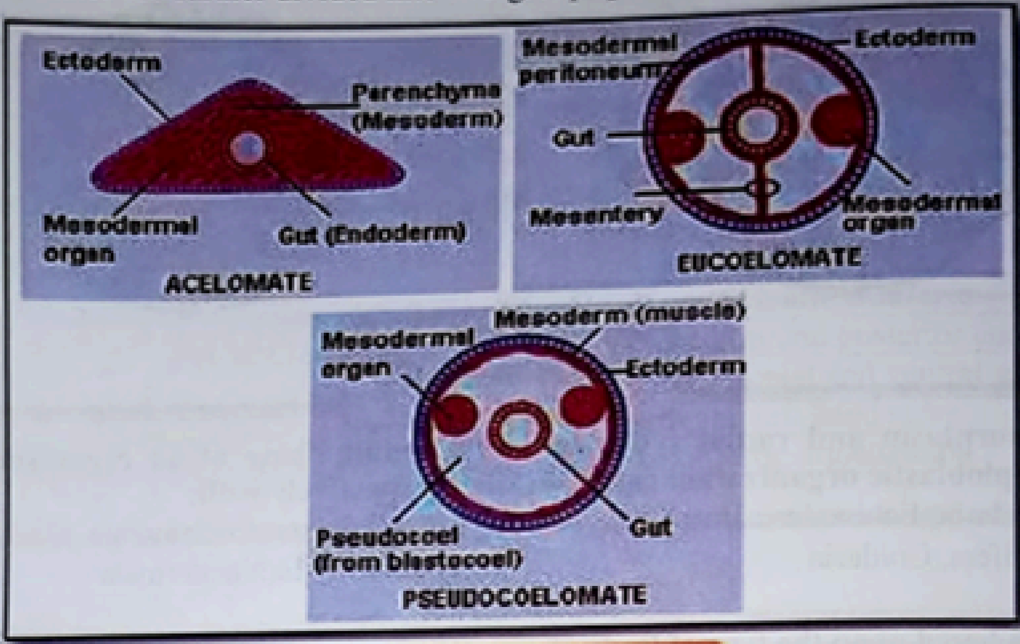
Pseudocoelomates

- This group includes phylum ***Aschelminthes***.
- If the body cavity develops between the mesoderm and endoderm, it is called ***Pseudocoelom***, and animals with this type of body cavity are called ***pseudocoelomates***.
- Pseudocoelom is not homologous to true coelom because it is not lined by coelomic epithelium.
- It has no relation with the reproductive and excretory organs.
- It develops from the blastocoel of the embryo and is bound externally by the muscles and internally by the cuticle of intestine.

Coelomates

- ***Coelom*** is cavity present between the body wall and the alimentary canal and is lined by mesoderm.
- The mesoderm splits into outer parietal layer which underlines the body wall and the visceral layer which covers the alimentary canal and the cavity between them is the true coelom. It is filled with fluid called ***coelomic fluid***.

- This group includes animals from ***annelids to chordates***.
- In coelomates, gut includes more complexity and neuro-sensory system is well developed along with excretory system, circulatory system, respiratory and reproductive system.
- Coelomates are further divided into two groups' ***proterostomia*** and ***deuterostomia***.

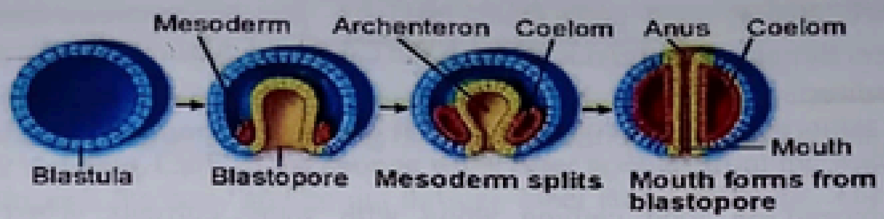


CRITICAL THINKING

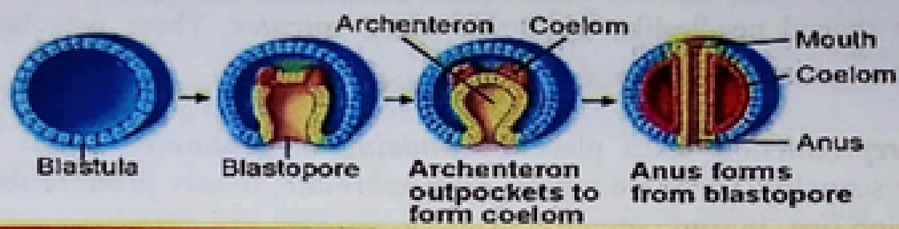
4. **Nematoda is the 1st phylum which evolved tube like digestive system. Epithelial lining of gastrointestinal tract is formed from:**
   A. Mesoderm B. Ectoderm
   C. Endoderm D. Pinacoderm
5. **Among the characteristics, which one is unique to animals:**
   A. Gastrulation B. Multicellularity
   C. Sexual reproduction D. Flagellated sperm
6. **What is the correct sequence of the following four events during an animal's development?**
   1. Gastrulation 2. Metamorphosis 3. Fertilization 4. Cleavage
   A. $4 \rightarrow 3 \rightarrow 2 \rightarrow 1$ B. $4 \rightarrow 3 \rightarrow 1 \rightarrow 2$
   C. $3 \rightarrow 2 \rightarrow 4 \rightarrow 1$ D. $3 \rightarrow 4 \rightarrow 1 \rightarrow 2$

Series Proterostomia (Proterostomes)	Series Deuterostomia (Deuterostomes)
Cleavage/division of the zygote is spiral and determinate.	Cleavage is radial and indeterminate.
The mouth of these animals arises from blastopore or from its anterior margin.	The mouth is formed at some distance anterior to the blastopore and the blastopore forms anus.
Coelom is formed by splitting of mesoderm (Schizocoelous).	Coelom is developed from archenteron (Enterocoelous).
Mesoderm is derived from cells on anterior lip of blastopore.	Mesoderm is derived from wall of developing gut (archenteron).
It includes phylum annelida, Mollusca and arthropoda.	It includes phylum Echinodermata, hemichordata and chordata.

Protostome



Dueterostome



ANIMAL PHYLA (INVERTEBRATE AND VERTEBRATE)

- The animal species that lack a backbone are commonly known as ***invertebrates*** and they account for ***95%***of the known animal species.
- The invertebrates have been divided into eight major phyla: ***porifera***, ***cnidaria***, ***platyhelminthes***, ***aschelminthes***, ***mollusca***, ***annelida***, ***arthropoda***, and ***echinodermata***.

1. Phylum Porifera

General Characteristics:

- The name porifera is derived from Latin ***porous*** = ***Pore*** and ***ferra*** = ***to bear***, so this phylum include 'pore bearing animals', commonly called as ***sponges***.

Evolutionary origin:

- Sponges have evolved from the protists called ***choanoflagellates***.

CRITICAL THINKING

7. What is the direct origin of Porifera?

A. Protista B. Bacteria
C. Plantae D. Fungi

Habitat:

- Sponges are all aquatic. Out of total 5000 species, 150 species live in fresh water while others are marine.

Locomotion:

- Sponges are sessile, attached to the rocks at the bottom of water. Larvae are motile.

Size:

- They range in size from a few millimeters wide to more than a meter long.

Symmetry:

- Asymmetrical.

Organization of Body

- Body is multicellular and not organized as tissue or organs.
- The sponges consist of outer dermal layer called ***pinacoderm***. Inner layer ***choanoderm*** made of

CRITICAL CONCEPT!

Choanoflagellates are having similar cells like choanocytes as in porifera.

flagellated cells called ***choanocytes***. The middle region is called ***mesenchyme***.

- Body is perforated by many pores called ostia.
- Water enters through ***ostia*** travels through the canal and goes out by a large main opening called ***osculum***.
- There is a single cavity inside the body called ***spongocoel***.

Nutrition:

- Sponges depend on food coming along with water currents. Their food includes ***zooplankton*** and ***phytoplankton***. 80% of their food consists of ***detrital organic matter***.

Skeleton:

- Variously shaped needle-like structures called ***spicules***. These may be ***calcareous*** or ***siliceous***.

Reproduction:

- Asexual ***reproduction*** takes place by ***budding*** or ***gemmules***. Some sponge species reproduce sexually. These are mostly ***hermaphrodite***, mostly ***protandrous*** i.e., male sex cells develop first. In some sponges, sexes are separate.

Regeneration:

- Sponges have ***remarkable ability of regeneration*** from a small fragment.

Digestion:

- It is ***completely intracellular*** and occurs in food vacuoles within choanocytes.

Respiration:

- There are no special organelles for respiration.

Transportation:

- It takes place through water current and diffusion. The water current system has greatly enlarged area for the feeding and gaseous exchange.

Excretion:

- It takes place through diffusion and outgoing water-current.

Nervous system:

- A sponge lacks nervous system. Sensory cells probably seem to coordinate the flow of water.

Examples

The examples of Sponges are: *Spongilla*, *Sycon*, *Leucosolenia*, *Euplectella* etc.

Importance of Sponges:

- Skeleton of sponges is **used for washing and bathing**.
- Sponges have great capacity to absorb water. They are **used in surgical operations** for absorbing fluid and blood.
- Sponges are **used for sound absorption** in buildings.

CRITICAL THINKING

8. At which developmental stage should one be able to first distinguish a proterostome embryo from a deuterostome embryo?

A. Fertilization
B. Cleavage
C. Gastrulation
D. Coelom formation

CRITICAL CONCEPT!

Sponges:
Sponges are characterized by the possession of a feeding system unique among animals. Poriferans don't have mouths; instead, they have tiny pores in their outer walls through which water is drawn. Cells in the sponge walls filter goodies from the water as the water is pumped through the body and go out through other larger openings. The flow of water through the sponge is unidirectional, driven by the beating of flagella which line the surface of chambers connected by a series of canals. Sponge cells perform a variety of bodily functions and appear to be more independent of each other than are the cells of other animals.

2. PHYLUM CNIDARIA

General Characteristics:

The name Cnidarian has been given to this group of animals due to the presence of special cells called ***cnidocytes***. These cells give rise to ***nematocysts***-the stinging cells, characteristic of this group.

Symmetry:

- Body shows radial symmetry.

Organization:

- Diploblastic having tissue grading and have organs.

Body Structure

- Cnidarians are diploblastic animals having ectoderm, endoderm and ***mesoglea*** in between the two.
- They have a sac-like internal ***gastrovascular cavity***, which has only one opening the mouth.
- The mouth is often surrounded by ***tentacles***.

Habitat:

- Cnidarians are entirely aquatic, mainly marine, few found in freshwater, e.g. *Hydra*

Locomotion:

- Most of the species are sessile, e.g. *Hydra,* while others are free living and motile e.g. jelly fish. Some are colonial e.g. Obelia.

Size:

- They range in size from microscopic (*Hydra*) to two meters in length (jelly fish).

Digestion:

- They are carnivores and feed upon small organisms which come into contact with them.

Transportation and Excretion:

- Takes place through diffusion

Respiration and Excretion:

- There is no respiratory and excretory system

Nervous System:

- Nervous system consists of nerve net and some sense organs.

Skeleton:

- Colonial coelenterates such as corals produce hard exoskeleton, formed of $CaCO_3$.

Reproduction:

- Asexual reproduction takes place by budding and sexual reduction by gametes.

Importance of Cnidarians:

- ***Coral reefs*** protect shores from erosion by tidal waves.
- Corals are used in jewelry and others are used in aquaria, rock gardens etc.
- Some cnidarians have poisonous stings e.g. jelly fish and sea anemone.

Coral Reefs	Polymorphism
Corals are cnidarians. It is made of $CaCO_3$. The ectodermal cells of the sea water form their exoskeleton. These exoskeleton form coral reefs and even island. Coral reefs are founded in the coastal water of Florida. West indies, east coast of Africa, Australia and island of Coral sea.	Coelenterate may show a number of zooids. They are of different forms. They take up different functions. This is called ***polymorphism***. Polymorphism denotes division of labour among the zooids of the individual. A polymorphic colony contains many individuals called zooids. They are mainly two types: (1) Medusae (2) Polyps. Polyp is sedentary. It shows mouth and tentacles at the free end. The medusa is free swimming. *Hydra* is a monomorphic form. It is represented by polyp form. It performs all functions. *Obelia* like animals Show two forms, polyp, nutritive zooid and medusa reproductive zooid. This is called dimorphic organism. In a colony of Obelia three types of zooids are present: (1) Hydranth (a Polyp stage,) (2) Blastostyle (asexually, reproducing zooid) (3) Medusae are present

3. PHYLUM PLATYHELMINTHES

General Characteristic:

Mode of Life:

- The flatworms are free living, e.g. *Planaria,* or parasite, e.g. Tapeworm.

Habitat:

- They are found in freshwater, marine, animal gut, liver.

Body Structure

- Body is soft and dorsoventrally compressed.
- Platyhelminthes are triploblastic and exhibits a bilateral symmetry.
- Coelom is absent, and the spaces are filled with mesenchyme tissue.
- Eyespots are present in some flatworms.

Locomotion:

- Free-living forms are motile. They move by cilia present on the underside of the animals, e.g. *Planaria.* In parasitic forms, movement is restricted.

Reproduction:

- Asexual reproduction is by ***fission***. The reproductive system is complex, usually with well-developed gonads, ducts and accessory organs. The fertilization is internal.

Digestion:

- Digestive system is incomplete i.e. gastrovascular type, having only one opening to the exterior, the mouth.

Respiration:

- Respiratory system is absent.

Transport:

- Transport system is absent.

Excretion:

- Excretory system consists of two lateral canals with branches bearing flame cells (protonephridia).

Nervous system:

- Consists of a pair of anterior ganglia with longitudinal nerve cord.

Examples

The examples of flatworms are: *Dugesia* (planaria), *Fasciola (*liver fluke), *Taenia* (tapeworm).

Importance of Platyhelminthes:

- The parasitic forms of fluke's and tapeworms are very harmful for man, e.g. tapeworm, liver fluke, the blood fluke of cattle etc.

4. PHYLUM ASCHELMINTHES/NEMATODA

General Characteristics:

Mode of Life:

- The roundworms are free living or parasite, and live in soil, roots, human and animal's intestine and muscles.

Size:

- Most roundworms are less than five cm long and many are microscopic. Some parasitic roundworms are more than one meter in length.

Symmetry:

- The worms exhibit bilateral symmetry, having three germ layers.

Body Structure

- Body is cylindrical, tapered at both ends.
- Muscular layer is not continuous.
- It is divided into four longitudinal quadrants: two – dorsolateral and two – ventrolateral.
- The body cavity is pseudocoelom.

Reproduction:

- Most nematodes are dioecious. Fertilization is internal.

Digestion:

- Digestive tract is a straight tube with mouth and anus at opposite ends of the body.

Respiration:

- Respiratory organs are absent.

Transport:

- Circulatory organs are absent.

Excretion:

- Excretory system consists of canals and protonephridia.

Nervous system:

- Ring of nerve tissue and ganglia around the pharynx with longitudinal nerve cords connected by transverse nerves.

Importance of Aschelminthes:

- *Ascaris lumbricoides* is an intestinal parasite of man.
- Pinworms (*Enterobius vermicularis*) are parasites in the human caecum, colon and appendix causing insomnia and loss of appetite.
- Hook worm (*Ancylostoma duodenale*) is very dangerous parasite because it holds the villi of intestine and sucks the blood and body fluids.

5. PHYLUM MOLLUSCA (soft bodied animals)

General Characteristics:

Mode of Life:

- They are free living or sessile, and live in freshwater, marine and land (in moist places).

Symmetry:

- The molluscs exhibits bilateral symmetry, triploblastic, coelomate, soft and unsegmented animals.

Body Structure

- Body is divided into; head ventral muscular foot dorsal visceral region.
- The whole animal is covered in an envelope called mantle. It secretes the shell.
- The shell may be external (snail), internal (cuttle fish) or even absent (octopus).
- Mouth cavity may have a tongue like structure called radula, e.g. Cuttle fish, snail.
- Coelom is divided into haemocoelic channels or sinuses.

Reproduction:

- Sexes may be separate, e.g. unio or untied, e.g. *Helix*. The development takes place through trochophore larvae.

Digestion:

- Digestive system is complex having rasping organ radula and anus usually emptying into mantle cavity.

Respiration:

- Gaseous exchange takes place by gills, lungs mantle or body surface.

Transport:

- Open circulatory system consists of heart and blood vessels.

Excretion:

- There are one or two metanephridia, which open into the pericardial cavity.

Nervous system:

- Consists of paired cerebral, pleural, pedal and visceral ganglia with nerve cord.

Examples

The examples of molluscs are snail, slug, Oyster, freshwater mussel and Octopus etc.

Economic Importance of Molluscs:

- Shells of freshwater mussels are used in button industry.
- Shells are also used for making ornaments.
- Some oysters make valuable pearls, e.g. *Pearl oyster.*
- Clams, oyster, mussels are source of food in Far East, Europe and America.
- Slugs are injurious in garden and cultivation.
- Toredo a shipworm damage wooden part in ships.

6. PHYLUM ANNELIDA

General Characteristics:

Mode of Life:

- The annelids are called segmented worms. They are free living (Earthworm) or ectoparasite, e.g. (leech).

Habitat:

- They are found in soil, freshwater and marine (*Nereis*).

Body Structure

- Body is metamerically segmented. It is separated into compartments.
- Coelom is a true coelom. The coelomic fluid of the adjacent chamber is mixed. The coelomic fluid serves as a hydrostatic skeleton also.

Locomotion:

- The body wall contains circular and longitudinal muscles which help in locomotion. The organs of locomotion are chitinous chaetae or setae. Parapodia is present in the body wall of *Nereis*.

Reproduction:

- Most of the annelids are hermaphrodite e.g. earthworm, leech. Sexes are separate in some annelids, e.g. *Nereis*. Fertilization is external. Development is direct or indirect through *trochophore* larvae.

Regeneration:

- Common in annelids.

Digestion:

- Digestive system is in the form of an alimentary canal. It extends throughout the body. It has two openings the mouth and the anus. The mouth is surrounded by prostomium.

Respiration:

- Respiratory system is absent and respiration takes place through the moist skin.

Transport:

- Annelids are the first group in the animal kingdom having definite closed blood vascular system which runs throughout the body.

Excretion:

- Takes place by nephridia. These are ciliated organs present in each segment.

Nervous system:

- CNS is present, which extends throughout the body.

Examples

The examples of annelids are *Nereis, Pheritima posthuma* (Earthworm), *Hirudo* (Leech).

Economic Importance of Annelids:

- Polychaetes form an important food item for many edible fish.
- Earthworms help in soil improvement.
- Leech is an ectoparasite to man and cattle.

7. PHYLUM ARTHROPODA

General Characteristics:

Mode of Life:

- The arthropods are called joint footed animals. They are free living or parasites.

Habitat:

- Found in all types of habitat.

Locomotion:

- Some are worm like and others are flying insects.

Symmetry:

- Symmetry is bilateral, having triploblastic organization.

Body Structure

- The body is segmented. Segments are modified, specialized and fused.
- Body is covered by chitin. It is flexible at many places to allow articulation. There are several pairs of appendages.
- Coelom is not present as the main body cavity. It is reduced and is called haemocoel, because it is connected with the blood vascular system.

Digestive System:

- Alimentary canal has two openings, the mouth and anus.

Skeleton:

- Skeleton is exoskeleton, formed chiefly of chitin. Muscles are attached to exoskeleton for locomotion.

Reproduction

- The reproductive organs and ducts are paired. The testes produce sperms and ovaries produce, eggs. Fertilization is mostly internal. Development takes place through metamorphosis

Digestion:

- Digestive system is complete, mouth parts modified from appendages and adapted for different methods of feeding.

Respiration:

Arthropods have a variety of respiratory organs.

- In insect's respiratory system consists of air tubes called trachea. Spiracles are the openings of the main tubes to the exterior.
- Aquatic forms have gills.
- Terrestrial forms have book lungs (e.g. spiders.) or air tubes called trachea.

Transport:

- Circulatory system consists of dorsal contractile heart (blood sinuses)

Excretion:

- In insects, the excretory organs are called Malpighian tubules. The nitrogenous wastes are excreted in the form of solid uric acid.

Nervous system:

- There is a brain and a ventral double nerve cord. There is a ganglion in each segment from which nerves arise.

Economic Importance of Arthropods:

- Lobsters, crayfish and prawns are eatables.
- Some crustaceans act as intermediate hosts for human parasites, e.g. Cyclops carry larvae of a nematode, the Guinea worm.
- Honey and bee's wax are produced by the honeybee.
- Insects aid in the production of fruits, seeds and vegetables by pollinating the flowers.
- Fruit fly (*Drosophila*), cockroach, grasshopper are abundantly used as laboratory animals for scientific learning and research.
- Insects destroy field crops, fruit trees and timber plants.
- They spread diseases among human beings.
- Scorpions and a few spiders are poisonous and sting.

8. PHYLUM ECHINODERMATA

General Characteristics:

Mode of Life:

- The echinoderms are called spiny-skinned animals. They are free living; some are attached to the substratum.

Habitat:

- The echinoderms are exclusively marine. Most are found at the bottom along the shorelines in shallow seas.

Symmetry:

- The echinoderms are triploblastic coelomates and exhibit radial symmetry in adult.

Body Structure

- Body is covered by delicate epidermis.
- The spines, which stick out through the delicate skin, account for their name.
- Coelom consists of canals and spaces, and one of which forms water vascular system.

Locomotion:

- Organs of locomotion are the ***tube feet***.

Reproduction:

- The sexes are separate. The fertilization is external. The larvae such as bipinnaria and brachiolaria are complex and exhibit bilateral symmetry, autotomy and regeneration.

Regeneration:

- The regeneration is shown by the adult and larval stages.

Skeleton:

- Echinoderms have an endoskeleton consisting of a spine bearing calcium rich plates.

Digestion:

- Digestive system is usually complete, axial or coiled anus is absent in ophiuroids.

Respiration:

- Performed by dermal branchiae, tube feet, respiratory tree e.g. sea cucumber and bursae e.g. spiny brittle star.

Transport:

- Blood vascular system is much reduced.

Excretion:

- Excretory organs are absent.

Nervous system:

- Nervous system includes a circumoral nerve ring and radial verve-cords. There is no brain.

Examples

The examples are starfish, sea cucumber, sea lily, brittle star and sea urchin.

- (Cake urchin) The body may be flattened like biscuit.
- (Starfish) Star shaped with short arm.
- (Sea urchin) Globular.
- (Brittle star) Star-shaped with long arms.
- (Sea cucumber) Elongated.

Importance of Echinoderms:

- Many echinoderms are used as food.

- Dried skeleton of echinoderms is used as fertilizer because of their high percentage of calcium and nitrogen.
- Starfishes act as scavengers and thus clean seawater.
- They cause damage to oyster beds.
- The stinging sea urchins are poisonous.

9. **PHYLUM HEMICHORDATA**

- They show characteristics of both echinoderms and chordates and both phyla belong to the group deuterostome branch of animal kingdom.
- Hemichordates are also called **Prochordates** because of their close relationship to chordates.

General Characteristics:

Habitat:

- The hemichordates are called acorn worms. All hemichordates are marine.

Mode of Life:

- Some are solitary, naked and slow moving, others are sedentary.

Body Structure

- Body is soft and unsegmented and has a worm like form.
- Body has three distinct regions: proboscis, collar and trunk.

Symmetry:

- Symmetry is bilateral and hemichordates are triploblastic. Body cavity is a true coelom.

Excretory System:

- Excretory system comprises of a glomerulus situated in the proboscis and connected with blood vessels. There are no nephridia.

Reproduction:

- Sexes may be separate or united. Fertilization is external. Development may include free swimming larval stage.

Respiration:

- Occurs by gill slits connecting the pharynx with outside as in chordates.

Circulatory System:

- It includes a dorsal heart and two longitudinal vessels, a dorsal and a ventral, interconnected by small lateral vessels. Blood is colorless and without corpuscles.

Nervous System:

- It is diffused, consisting of an epidermal plexus of nerve cells and nerve fibers.

Examples:

- *Balanoglossus, Saccoglossus,*

CRITICAL CONCEPT!

Arthropod Vectors:

Vector	Disease	Pathogen type
Mosquitoes	Filariasis	Helminth
	Malaria	Protozoa
	Dengue fever	Virus
	Rift valley Fever	Virus
Ticks	Lyme disease	Bacteria
	Rocky mountain spotted fever	Bacteria
	Relapsing Fever	Bacteria
Deerflies	Tularemia	Bacteria
Tsetse flies	African sleeping sickness	Protozoa
Fleas	Endemic typhus	Bacteria
	Bubonic plague	Bacteria

10. PHYLUM CHORDATA

- The representatives of the phylum chordata called the chordates, are the most familiar, adaptable and successful and the most widely distributing animals, showing diversity of form, habitat and habits.

Characteristics of Chordates:

All the chordates possess four basic characteristics, which are:

1. Notochord
2. Dorsal hollow nervous system
3. Gill slits
4. Postnatal tail

Notochord

- The notochord is a solid un jointed rod located in the mid-dorsal line between the gut and CNS outside the coelom.
- The notochord serves as an axial endoskeleton, giving support to the body and providing space for muscle attachment.
- In some lower chordates the notochord partly or wholly replaced in the adult state by a jointed backbone or vertebral column.

Dorsal Hollow Central Nervous System

- The central nervous system of all the chordates consists of a single, tubular fluid filled, non-gangliated nerve cord.
- It is situated along the mid dorsal line above the notochord and outside the coelom.

Gill Slits

The gill slits (pharyngeal pouches) are paired perforations on the lateral sides of the anterior part of the body, leading from the pharynx to exterior.

Post-anal Tail

It extends beyond anus; present at least in embryo; regresses (passage back, reversion) into tail bone in humans.

Classification of Chordates:

The phylum chordate has been subdivided into two groups:

(a) **Protochordata, (Acrania);** in which brain is not enclosed in bony case.

(b) **Craniata;** in which brain is enclosed in a bony case and notochord has been replaced by vertebral column.

(a) **Group Protochordata (Acrania)**

Protochordata has been divided into two sub-phyla:

(i) Subphylum Urochordata

(ii) Subphylum Cephalochordata

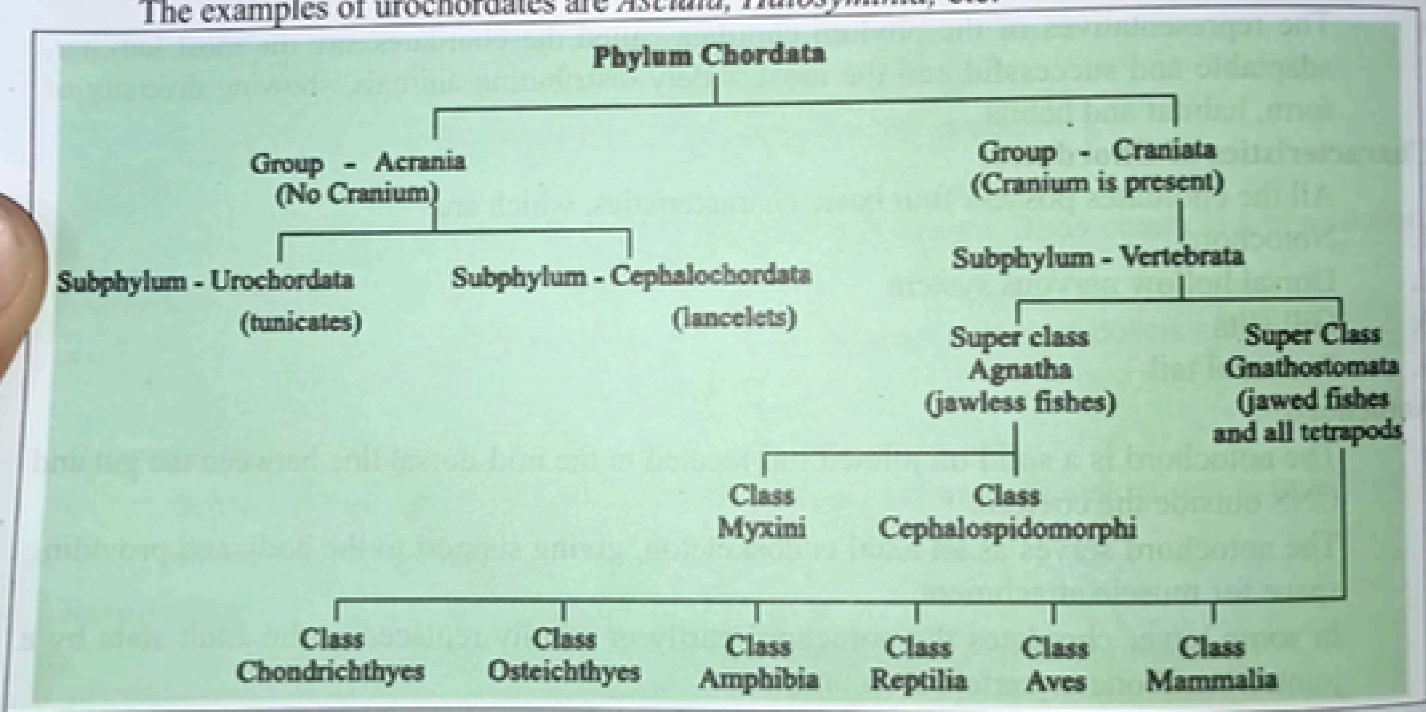
(i) **Subphylum Urochordata**

Characteristics

- The body is covered by a covering called **tunic** so they are called **tunicates.**
- On the outside are two projections: The **incurrent siphon** which corresponds to the anterior end of the body, the **excurrent siphon** that marks the dorsal side.
- Larva has a mid-dorsal supporting rod, the **notochord,** in the tail, so the group has been named urochordata. The notochord usually disappears during metamorphosis, so that adult has no skeleton.

Examples

The examples of urochordates are *Ascidia, Halosymthia,* etc.



(ii) **Subphylum Cephalochordata**

Characteristics

- Body is fish like.
- It has no head but tail is present.
- Notochord extends the entire length of the body.
- There is no organ for respiration.

Examples

The examples of cephalochordate are: *Branchiostoma (Amphioxus)* (lancelet).

(b) **Group Craniata**

Craniata has one subphylum i.e. vertebrata.

Subphylum Vertebrata

The characteristics that give the member of this group the names "vertebrata" and "craniata" are;

- Spinal column of vertebrae, which forms the chief skeletal axis of the body, and a;
- Brain case or cranium.

Classification of Subphylum Vertebrata

Subphylum vertebrata is divided into two super classes;

a. Agnatha
b. Gnathostomata

Ubaid

SUPER CLASS AGNATHA (Jawless Fishes)

General Characteristic of Super Class Agnatha:

Body Structures

Body slender, eel-like, and rounded with naked skin, the caudal fin extends anteriorly along the dorsal surface.

Skeleton

Skeleton is fibrous and cartilaginous and the notochord is persistent.

Reproduction

Sexes are separate. Fertilization is external and there is no larval stage.

Examples

The examples of agnatha are Hagfish, and Lamprey.

Classes in Agnatha

It is divided into classes:

I. Myxini
II. Cephalospidomorphi

I. Myxini

- There are no paired appendages and no dorsal fin in class Myxini.
- Biting mouth with two rows of eversible (to turn outwards) teeth in class Myxini.

II. Cephalospidomorphi

- There are one or two median fins and no paired appendages in class Cephalospidomorphi.
- The oral disk is sucker like and tongue with well-developed teeth in class Cephalospidomorphi.

Evolutionary Adaptations in Super Class Agnatha:

- Buccal funnel and toothed tongue for a device for blood sucking in absence of jaws.
- Dorsal nerve cord with differentiated brain.
- There are five to sixteen gills for respiration in class Myxini.
- There are seven pairs of gills each with external gill opening in class Cephoalospidomorphi.

a. **SUPER CLASS GNATHOSTOMATA**

It is divided into six classes:

1. Chondrichthyes
2. Osteichthyes
3. Amphibia
4. Reptilia
5. Aves
6. Mammalia

1. CLASS CHONDRICHTHYES (Cartilaginous Fishes)

General Characteristics of Class Chondrichthyes:

Body Shape

Body is laterally compressed and spindle (fusiform) shaped.

Location of Mouth

Mouth is ventral.

Olfactory Sacs

Olfactory sacs are not connected to mouth cavity.

Skin

Skin is tough and covered with minute placoid scale.

Fins

The pectoral and pelvic fins are paired. There are two dorsal fins. The caudal fin is heterocercal.

Skeleton

Endoskeleton is entirely cartilaginous.

Digestive Tract

Digestive tract leads into the cloaca. Stomach is j shaped.

Circulatory System

The circulatory system consists of two-chambered heart. There is one atrium and one ventricle. There are 5-7 pairs of aortic arches.

Respiratory System

Respiratory system includes 5-7 pairs of gills, without operculum.

Swim Bladder

Swim bladder is absent.

Reproduction

Sexes are separate. Gonads are paired. Fertilization is internal. Most forms are oviparous or viviparous.

Examples

It includes the sharks, dogfishes, rays, skates and chimaeras.

Evolutionary Adaptations in Class Chondrichthyes:

- Spindle shaped body, slippery skin, presence of scales on the body protect the animal.
- Ventral mouth is suited for capturing prey at the bottom of the sea.
- Internal fertilization, nourishment and protection of the embryo in the mother's body are evolutionary adaptive feature.

2. CLASS OSTEICHTHYES (Bony Fishes)

General Characteristics of Class Osteichthyes:

Body Shape

Body is usually spindle-shaped and streamlined for active movement through water.

Skeleton

Endoskeleton is partly or wholly bony. Vertebrae are numerous. Pelvic girdle is often absent. Notochord persists in a greatly reduced form. Skin usually contains dermal scales embedded in the dermis.

Fins

Both median and paired fins are present. Pelvic and pectoral fins are paired while dorsal fins are single. The caudal fin is homocercal.

Location of Mouth

Mouth is usually terminal, i.e. anterior end often bears numerous teeth.

Jaws

Jaws are well developed.

Digestive Tract

Anus is present and cloaca is absent.

Respiratory System

The four pairs of gills are supported by a bony arch. They are covered by operculum. Spiracles are mostly lacking.

Swim Bladder

Swim bladder is usually present with or without connection with the pharynx. Swim bladder helps in buoyancy.

Circulatory System

Heart is two chambered, having only one atrium and one ventricle. There are four pairs of aortic arches. Red blood cells are oval and nucleated.

Nervous System

Brain has ten pairs of cranial nerves.

Reproduction

Sexes are separates. Gonads are paired. Fertilization is generally external. Most forms are oviparous. Some are ovoviviparous or even viviparous.

Evolutionary Adaptations in Class Osteichthyes:

- Body is laterally compressed spindle shaped and has slimy skin.
- Strong segmental muscle for efficient swimming device.
- Gills help in respiration.
- Air or swim bladder enables the fish to easily shift from one depth to another. Gill rakers check the loss of food.
- Lack of teeth in the jaws is correlated to the herbivorous diet.

3. CLASS AMPHIBIA

General Characteristics of Class Amphibian:

Body Structures

Body varies considerably in forms, is divisible only into head and trunk.

Locomotion

- Most have two pairs of pentadactyl limbs with 4-5 or fewer digits.
- Some are without legs, e.g. caecilians.
- Webbed feet often present, e.g. frogs.

Skin

Skin is often smooth, moist and rich in glands. It is highly vascular. Scales are generally absent. In some glands are poisonous, chromatophore pigment cells are present in the skin.

Respiratory System

In larval stage respiration takes place by gills. In the adult's respiration take place by lungs and skin.

Circulatory System

Heart is three chambered with respect to atria ventricle. Sinus venosus, truncus arteriosus are present. Double circulation takes place through the heart.

Reproduction

Sexes are separate. Gonads are paired. Fertilization may be external or internal. Most forms are oviparous. Development takes place through metamorphosis. Amphibians are an amniotes.

Thermoregulation

Body temperature is variable, i.e. poikilothermic (ectotherms). Most forms undergo hibernation in winter.

Examples

Frogs, toads, salamanders, caecilian, mud puppy etc.

Evolutionary Adaptation in Class Amphibia:

- Limbs for movement on solid substratum.
- Lungs for breathing.
- Internal nares make breathing possible by keeping mouth closed.
- Slimy skin for protection against desiccation.
- Changed in circulatory system to provide respiration by lungs and skin.
- There is reduction in bones to make the body lighter.

4. CLASS REPTILIA

General Characteristics of Class Reptilia:

Locomotion

There are two pairs of pentadactyl limbs, each typically with five digits.

Skin

Skin is rough, cornified and dry, which is adapted to land life.

Circulatory System

Heart is incompletely four chambered, having two atria and partly divided ventricle. Crocodiles have completely four chambered heart.

Thermoregulation

Reptiles are cold blooded animals, i.e. poikilothermic (ectotherms) and hibernate in winter.

Reproduction

Sexes are separate. Gonads are paired. Fertilization is internal. Mostly forms are oviparous. Eggs are large, amniotic and have large yolk eggs. Eggs are enclosed by leather or limy shell for protection. Embryo is protected by three embryonic membranes known as amnion, allantois and chorion.

Example

Tortoise, lizard, snake, crocodile and alligator etc.

Evolutionary Adaptations in Class Reptilia:

- Reptiles show the advancement over the amphibians in having:
- A dry skin which enables them to live away from water.
- Separation of oxygenated and deoxygenated blood in the heart.
- A neck movable independent of the body.
- Better mechanism of breathing.
- Fertilization is internal.
- Egg with shell for protection on land.

5. CLASS AVES

General Characteristics of Class Aves:

Body Shape

Body of aves is streamlined and is boat shaped.

Body Structures

It is divisible into a head, neck, a trunk and a tail. Neck is very long and tail very short. Jaws extend into horny beak. Teeth are absent.

Locomotion

There are two pairs of pentadactyl limbs. The forelimbs are modified to form wings. The hind limbs are large, strong and adapted for perching, walking or swimming. Each foot usually bears four toes armed with horny claws.

Skin

The skin is covered by an epidermal horny exoskeleton of feathers all over the body and scales on the feet.

Skeleton

Due to air spaces skeleton is light. Skull has large sockets.

Circulatory System

Heart is four chambered, having two atria and two ventricles. There is only right aorta.

- It curves to the right side and then bends backward.

Thermoregulation

Birds are endothermic.

Respiratory System

Respiration takes place only by lungs. A system of thin walled air sacs lying among the viscera maintains the supply of fresh air through the lungs. Voice box, the syrinx lies at the trachea and bronchi.

Digestive Tract

Alimentary canal has muscular structure called gizzard, which is used for crushing food.

Excretory System

Excretory system consists of a pair of kidney. The ureter open into the cloaca and the urinary bladder is absent. The urine is semisolid and uric acid is main nitrogenous waste.

Reproduction

Sexes are separate. Fertilization is internal. Eggs are large with much yolk. Only one ovary and oviduct is functional.

Examples

Some birds have secondarily lost the power of flight and are called running birds, e.g. ostrich, kiwi, etc.

Evolutionary Adaptations in Class Aves:

- An insulated covering over the body is present.
- Better aeration of blood in the lungs, taking place during both inspiration and expiration.
- Complete separation of venous and arterial blood in the heart.
- A regulated body temperature keeps the aves equally active all the year round.
- Patterns of behavior, such as care for the young ones, nest building, courtship and affection for the mate and migration, which are practically unknown in reptiles.

6. CLASS – MAMMALIA

Introduction

Mammals give birth to their young ones. Mammals feed them on milk produced by mammary glands of mother.

General Characteristics of Class Mammalia:

Body Structures

Body is variously shaped and divisible into a head, a neck, a trunk and a tail. Coelom is completely divided into anterior smaller thoracic cavity and posterior larger cavity by a muscular partition the diaphragm, which is present only in the mammals. External ear or pinna is present. Voice apparatus is well developed, and consists of larynx and epiglottis.

Locomotion

There are two pairs of pentadactyl limbs. These are variously adapted for walking, running, burrowing and swimming or flying.

Skin

Skin is glandular, mostly covered by hair.

Skeleton

Endoskeleton is fully ossified. Skull has two occipital condyles, large cranium. There is a chain of three bones in the ear incus, malleus and stapes.

Circulatory System

Only left aortic arch is present. Red blood cells are non-nucleated.

Thermoregulation

Mammals are warm blooded (endothermic) animals.

Classification of Mammalia

Mammals are classified into three subclasses:

(1) Prototheria-Egg laying mammals.
(2) Metatheria-Pouched mammals.
(3) Eutheria-Placental mammals.

1. SUB-CLASS PROTOTHERIS – The Monotremes

General Characteristics:

Occurrence

Monotremes are found in Australia. Certain members of this sub-class are adapted for aquatic life, e.g. Duck bill platypus.

Body Structures

Duck bill platypus has a bill similar to that of a duck and has webbed toes.

Evolutionary Relationship

The subclass Prototheria is a connecting link between reptiles and mammals. It provides evidence of evolution and origin of mammals from reptiles.

- The **mammalian features** of the Monotremes are that female has mammary glands and they feed their young's.
- The **reptilian features** include the presence of cloaca and cloacal opening (instead of separate opening for digestive and urinogenital system).

Examples

The **examples** of monotremes are Duckbill platypus and Echidna-spiny ant eater.

2. SUB CLASS METATHERIA – The Marsupials

General characteristics:

Occurrence

The marsupials are found in Australia and America.

Body Structures

The females have an abdominal pouch the marsupium, where they rear their young.

Rearing

The young one's when borne are immature. The nipples are in the pouch. The mother feeds the young ones and carries them in the pouch till they are matured enough.

Examples

The examples of marsupials are: opossum, kangaroo and Koala.

3. SUB-CLASS EUTHERIA – The Placentalis

General characteristics:

Embryological Development

Development of young one takes place inside the body of the mother.

Establishment of Placenta

Developing placental mammals are dependent on placenta an organ of exchange between maternal blood and fetal blood. Nutrients are supplied to the growing offspring, and wastes are passed to the mother for excretion.

Birth

The young's are borne fully developed. The young ones are born at a relatively advanced stage of development. These mammals are called placental mammals. All the placental mammals have mammalian characteristics.

Skin

In some hair have been modified into scales in pangolin, and spines in porcupine

Examples

Examples of the placentalis are man, whale, elephant, horse, rat mice, bat dolphin, cat, tiger, lion monkey, gorilla etc.

Evolutionary Adaptations in Class Mammalia:

- A regulated body temperature. This makes them independent of environmental change, keeping active throughout the year.
- Complete separation of venous and arterial blood in the heart.
- An active life and a high rate of metabolism.
- More efficient mechanism of respiration due to the presence of a diaphragm.
- A separate respiratory passage that avoids interference in breathing during feeding.
- Better developed senses of smell, sight and hearing.
- A more highly developed nervous system.
- Large cerebrum and cerebellum provide for better coordination in all activities and for learning and retentive memory.
- Patterns of behavior, such as care and nursing of the young ones present.

CRITICAL THINKING

9. What is the probable sequence in which the following classes of animals originated, from earliest to most recent?

1. Tetrapods 2. Vertebrates 3. Deuterostomes 4. Amniotes 5. Bilaterians

A. 5 → 3 → 2 → 4 → 1
B. 5 → 3 → 2 → 1 → 4
C. 5 → 3 → 4 → 2 → 1
D. 3 → 5 → 4 → 2 → 1

10. All of the following are related to adaptations for parasitic mode of life except:

A. Formation of resistant cuticle
B. Presence of a specific host
C. Degeneration of nervous system
D. Development of adhesive organs

11. Which of the following can be used to distinguish a nematode worm from an annelid worm?

1. Type of body cavity
2. Number of muscle layers in the body wall 3. Presence of segmentation
4. Number of embryonic tissue layers
5. Shape of worm in cross-sectional view

A. 2 only
B. 2 and 3
C. 1, 2, and 3
D. 1, 2, 3, and 5

12. Which era is known as the "age of reptiles"?

A. Cenozoic
B. Mesozoic
C. Paleozoic
D. Proterozoic

ENZYMES

COURSE CONTENT

- Introduction and Characteristics of Enzymes
- Enzyme Structure
- Mechanism of Enzyme Action
- Factors Affecting the Rate of Enzyme Action
- Enzyme Inhibition
- Classification of Enzymes

INTRODUCTION AND CHARACTERISTICS OF ENZYMES

Introduction of Enzymes

- The sum of all the chemical reactions going on in a cell is known as ***metabolism***. These reactions have to be carried out very quickly so that their products can be utilized in various life activities in the cells. ***Enzymes*** are biological catalysts which speed up the biochemical reaction and remain unchanged after completion of reaction.
- Without enzymes, reactions are possible but they would proceed at very low speed making life impossible.

Characteristics of Enzymes

- All enzymes are globular proteins, having specific chemical composition due to their component amino acids.
- They increase the rate of reaction without themselves being used up, and do not affect the equilibrium of the reaction.
- Their presence ***does not affect the nature or properties*** of end products.
- They are required in very small quantity.
- They are specific for each type of reaction or group of related reactions.
- They ***lower the activation energy*** of the reactants.
- They are highly sensitive to even a minor change in pH, temperature and substrate concentration.
- They ***require aqueous media*** for their activity.
- Some may require co-factor for their proper functioning.
- They can work *in-vivo* as well as *in-vitro*.
- Some enzymes are potentially damaging, if they are manufactured in their active form.

CRITICAL CONCEPT!

Turnover Number:
The turnover number of an enzyme is the maximal number of molecules of substrate converted to product per active site per unit time.

CRITICAL THINKING

1. **An enzyme that is produced in its active form:**
   A. EcoR1 B. Pepsin
   C. Trypsin D. Chymotrypsin

ENZYME STRUCTURE

- With the exception of ***ribozymes***, all enzymes are ***globular proteins*** which are made of one or more polypeptide chains.
- ***Ribozymes*** are the enzymes which consist of RNA and are found in ribosomes. For example, ***peptidyl transferase*** is a ribozyme which forms ***peptide bonds*** during translation.

Shape of Enzyme

- Proteinaceous enzymes are made up of ***hundreds of amino acids***, and have high molecular weight ranging from 10,000 to over one million Daltons, and exhibit tertiary or quaternary structures.
- Most of the amino acids maintain its globular shape while few are involved in catalysis.
- ***Active site*** is a charge bearing, three dimensional cavity of enzymes and is further divided into two functional sites i.e. ***binding site*** and ***catalytic sites.*** Shape of the active site is designed according to the substrate.
- Active site consists of ***3-12 amino acids*** which may be scattered in the polypeptide but are brought together in a particular fashion due to secondary and tertiary folding of the protein molecule.
- The substrate molecule is attached to the active site by ***non-covalent interactions***, like hydrogen bonding, and hydrophobic interactions.
- ***Binding site*** make bonds with substrate, thus involved in recognition and ES complex formation. This reaction activates the catalytic site.
- Activated ***Catalytic site*** is involved in the transformation of enzyme-substrate complex into enzyme and product.

CRITICAL THINKING

2. Which of the following enzyme is attached to an organelle in a cell?

A. NADP reductase B. RNA Polymerase II
C. Phosphofructokinase D. Citrate synthase

Cofactors

- ***Non-protein part*** of enzyme that is required for its proper functioning is called ***co-factor***.
- These cofactor ***acts as bridge*** between enzyme and substrate. It also acts as source of chemical energy, helping to drive reactions which would otherwise be difficult or impossible.
- The cofactor may be ***inorganic*** or ***organic molecules***. Such an inorganic cofactor that is detachable is called ***activator*** e.g. metal ions like Fe^{+2}, Mg^{+2}, Cu^{+2}, Zn^{+2} etc. These are only attached to the enzyme when substrate gets bind.
- The organic cofactors are either co-enzymes or prosthetic groups.
- If a cofactor is organic and loosely attached to the protein part, it is known as ***coenzyme***. Coenzymes are the derivatives of vitamins. For example, ATP, NAD^+ and FAD^+ are common coenzymes.
- If a cofactor is covalently bound to the protein part, then it is called ***prosthetic group***. It is permanently attached to enzyme and does not detach after the completion of reaction. For example, an iron containing porphyrin ring attached to some enzymes like cytochrome.
- An activated enzyme consisting of polypeptide chain and a cofactor is known as ***holoenzyme***.
- An enzyme with its coenzyme or prosthetic group has been removed is called ***apoenzyme***.

CRITICAL CONCEPT!

Vitamins are Raw Material for Co-enzymes.

Vitamin	Coenzyme	Coenzyme Function
Vitamin B_2 (riboflavin)	Flavin mononucleotide or flavin adenine dinucleotide	Oxidation-reduction reactions involving two hydrogen atoms
Vitamin B_3 (niacin)	Nicotinamide adenine dinucleotide or nicotinamide adenine dinucleotide phosphate	Oxidation-reduction reactions involving the hydride ion (H^-)
Vitamin B_{12} (cyanocobalamin)	Methylcobalamin or deoxyadenoxylcobalamin	Intramolecular rearrangement reactions
Biotin	Biotin	Carboxylation reactions

CRITICAL THINKING?

3. Vitamin is a precursor for:

A. Haem
B. ATP
C. FAD
D. Mg^{2+}

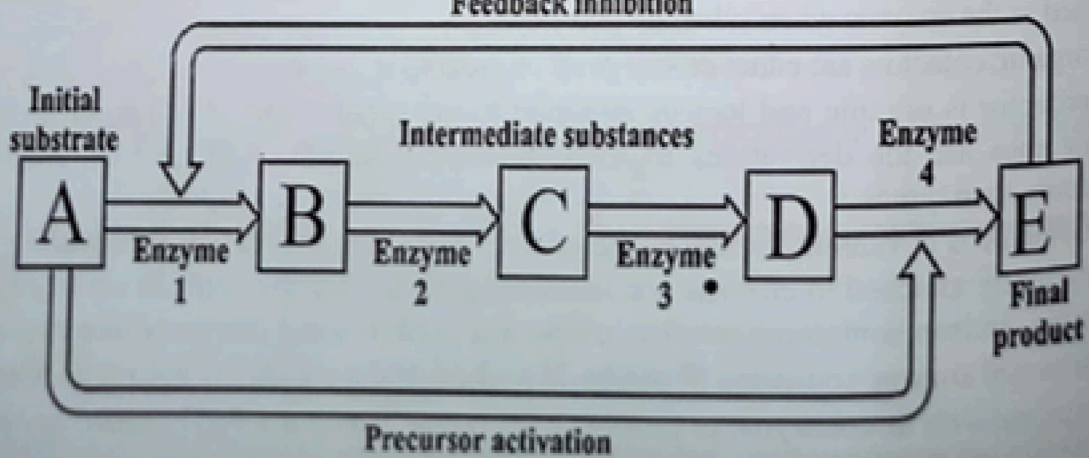
MECHANISM OF ENZYME ACTION

Mechanism

- In an enzyme-catalyzed reaction, the substrate first binds to the active site of the enzyme to form an ES complex, and then the substrate is converted into product while it is attached to the EP complex, and finally the product is released.

$$E+S \rightarrow ES\ Complex \rightarrow EP\ Complex \rightarrow E+P$$

- Actually, the enzyme can make the local conditions inside the active site quite different from those outside, such as pH, H_2O concentration, and charge, so that the reaction is more likely to happen.
- Activity of enzymes in a cell can be regulated by its products. When the activity of an enzyme is inhibited by its own product, it is called ***feedback inhibition*** or end product inhibition.
- Similarly, increase in concentration of substrate can cause increase in rate of reaction. This activation is called ***precursor activation***.

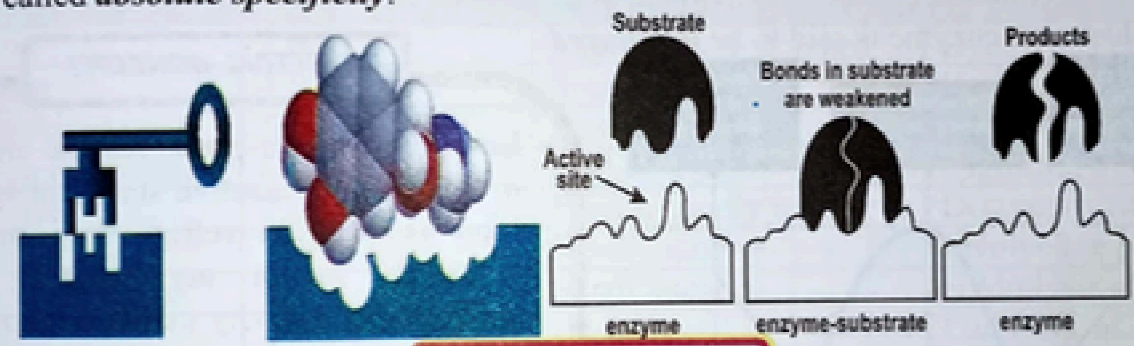


Typically, ***feedback*** loop can be divided into two main types: ***positive feedback*** loops, in which a change in a given direction causes additional change in the same direction, and ***negative feedback*** loops, in which a change in a given direction causes change in the opposite direction.

Models

Lock and Key Model

- ***Emil Fischer*** proposed Lock and Key model in 1894.
- According to this model, the active site of the enzyme has ***definite shape*** and ***rigid structure***. Therefore, a particular substrate can only bind to the active site.
- There is ***no modification or flexibility*** in the active site before, during or after the enzyme action.
- The enzymes which work according to this model are called ***non-regulatory enzymes.*** However, this model is exercised by a very small number of enzymes like ***sucrase, maltase*** etc.
- The ability of enzyme to catalyze one specific reaction is perhaps its most significant property. When one enzyme can catalyze only one substrate and essentially no others, it is called ***absolute specificity***.



CRITICAL THINKING

4. Pick an enzyme that catalyzes two different substrates together but produces a single type of product:

A. Carbonic anhydrase B. DNase
C. Pepsin D. Reverse transcriptase

Induce Fit Model

- D. Koshland proposed Induce Fit Model in 1959 that is the ***modified form of Lock and Key model***.
- According to this model, the ***active site is flexible***; therefore, it can be modified as the substrate interacts with the enzyme and as the reaction is completed, the active site regains its original shape.
- This is the flexibility of active site which allows more than one type of related substrates to be attached on active site and therefore, an enzyme can carry out more than one type of related reactions. For example, ***carbonic anhydrase*** which can adds O_2 to hemoglobin as well as can control the formation of H_2CO_3 and HCO_3^{-1} in the blood.
- Enzymes which follow induce fit mechanism are called ***regulatory*** or ***allosteric enzymes***.

FACTORS AFFECTING THE RATE OF ENZYME ACTION

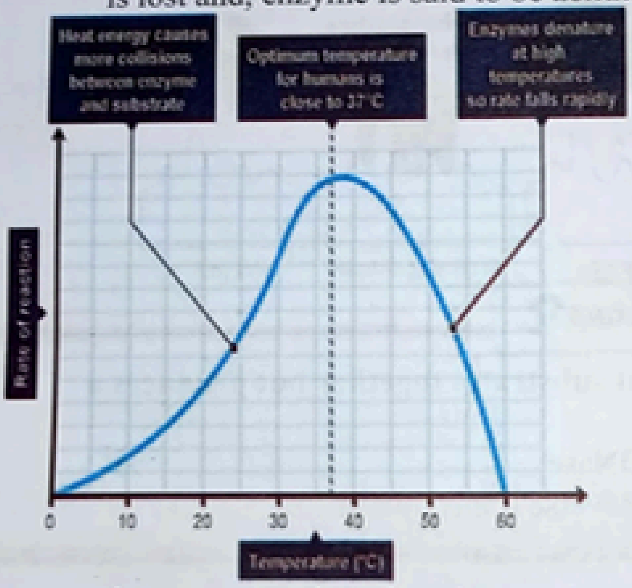
- The rate of enzymatic reaction is measured by the amount of substrate changed or the amount of product formed, during a period of time.

CRITICAL CONCEPT!

Taq polymerase is having same type of bonds just like the normal enzyme of human body but Taq can bear temperature up to 120°C.

Temperature

- Heating increases molecular motions. Thus, the molecules of substrate and enzyme move more quickly, so probability of reactions to occur is increased.
- Increasing temperature affect the rate of reaction in such a way that an increase of just 10°C in existing temperature doubles the rate of reaction but this effect remains up to ***optimum temperature***.
- Optimum temperature is the temperature at which an enzyme works at its maximum rate e.g., for enzymes of human body, 37°C is the optimum temperature.
- If the temperature is increased above the optimum temperature, then a decrease in the rate of reaction occurs despite the increasing frequencies of collision. This is because the atomic vibrations become too violent and, globular structure essential for enzyme activity is lost and, enzyme is said to be ***denatured***.



CRITICAL CONCEPT!

Low temperature preserves the enzyme in temporarily inactive state that is why food is kept in refrigerators so that microbes cannot act well at low temperature; activity can be regained at normal temperature again.
High temperature destroys enzymatic activity because proteins are denatured by heat (Primary structure of protein is however not lost; activity cannot be retained even at normal temperature)

- If temperature is reduced to near or below freezing point, ***enzymes are inactivated***, not denatured. Enzymes will ***regain their catalytic influence*** when higher temperature is restored.

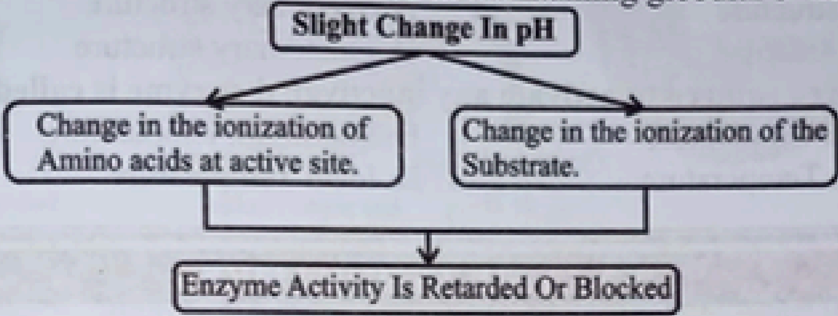
CRITICAL THINKING

5. What is the best reason to explain the high tolerance of temperature by Taq Polymerase?

A. Type of bonds are different than normal enzymes
B. Shape of protein is different
C. Number of bonds are extra ordinarily high
D. Arrangement of bonds to form Protein are different than normal enzymes

pH Value

- Every enzyme functions most effectively over a particular pH range. This narrow range of pH at which the maximum rate of reaction is achieved is called ***optimum pH***.
- ***Enzyme configuration*** is sensitive to pH fluctuations because ***pH influences the charges on the amino acid side chains*** that are involved in maintaining globular structure of enzyme.



- Extreme changes in pH alter the ionic charge of the acidic and basic groups of enzyme and therefore ***disrupt the ionic bonding*** (denaturation) that helps to maintain the specific shape of the enzyme.

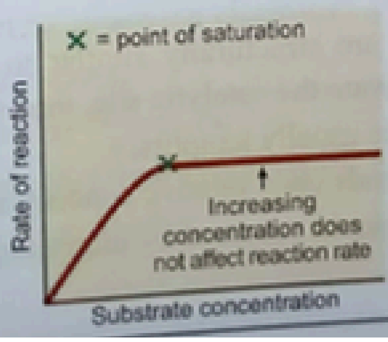
Enzyme	Optimum pH Value	Site of Action	Function
Pepsin	2.00	Lumen of the stomach	Hydrolysis of proteins
Sucrase	4.50	Small intestine	Hydrolysis of sucrose
Enterokinase	5.50	Small intestine	Activation of trypsinogen
Salivary Amylase	6.80	Oral cavity	Digestion of carbohydrate
Catalase	7.60	Predominantly in liver	Decomposition of H_2O_2
Chymotrypsin	7.00-8.00	Small intestine	Involved in proteolysis
Pancreatic lipase	9.00	Small intestine	Hydrolysis of fats
Arginase	9.70	Liver	Catalysis of arginine into urea

Enzyme Concentration

- Rate of reaction is directly proportional to amount of enzyme present, which in turn determines the number of available active sites for that particular catalytic reaction.
- If substrate concentration is unlimited and amount of an enzyme is increased by two-fold the reaction rate will be doubled.
- However, after a certain limiting concentration, the rate of the reaction will no longer depend upon this increase.

Substrate Concentration

- The rate of an enzyme controlled reaction is directly proportional to the substrate concentration provided that active sites on the enzyme are available.
- At higher concentration of enzyme, increase in substrate concentration increases reaction velocity. Reaction reaches to maximum at equilibrium state.
- When all active sites are occupied by substrate and no more available, this state is called ***state of saturation***.



CRITICAL THINKING

6. **Increased temperature above optimum usually does not effect _______ of enzymes.**
   A. Primary structure B. Secondary structure
   C. Tertiary structure D. Quaternary structure
7. **Temperature required to activate any inactivated enzyme is called:**
   A. Minimum temperature B. Maximum temperature
   C. Optimum Temperature D. Ideal Temperature

ENZYME INHIBITORS

- A chemical substance which can react with the enzyme in place of substrate but is not transformed into product/s and thus blocks the active site temporarily or permanently is called ***inhibitors*** and the phenomenon is called ***enzyme inhibition***.
- The molecules which act as inhibitors include ***poisons, cyanide, antibiotics, anti-metabolites, some drugs*** and ***heavy metals.***
- In general, the enzyme inhibition is the normal part of the regulation of enzyme activity within the cells but sometimes when ***external factors cause inhibition***; it may become ***dangerous for life***.
- There are two type of inhibitors i.e. irreversible and reversible inhibitors.

Irreversible Inhibitor

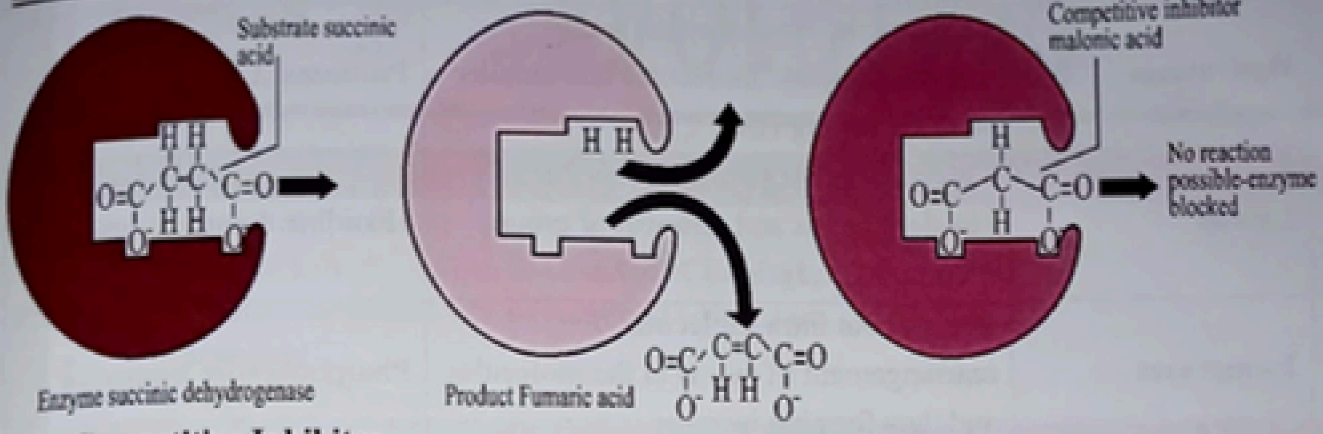
- They occupy the active sites by forming covalent bonds or they may physically block the active sites and they check the reaction rate by occupying the active sites.
- The examples of irreversible non-competitive inhibitors are ***cyanides and ions of heavy metals.***
- Cyanides are potent poisons of living organisms because they can kill an organism by ***inhibiting cytochrome oxidase,*** essential for cellular respiration. On the other hand, ions of heavy metals such as Hg^{2+}, Ag^{+}, Cu^{2+} can combine with '***thiol group***' in the enzymes, thus breaking disulphide bridges.

Reversible Inhibitors

- They form weak linkages with the enzyme.
- Their effect can be neutralized completely or partially by increasing in the concentration of substrate.
- There are two types of reversible inhibitors i.e. competitive and non-competitive.

Competitive Inhibitors

- Competitive inhibitors are structurally similar to the substrate, hence can bind to the active site but can't activate the catalytic site, thus no products are formed.
- Competitive inhibition is usually temporary.
- Level of inhibition depends upon relative concentrations of substrate and inhibitor.
- This type of inhibition can be reversed by increasing concentration of substrate.



Non-Competitive Inhibitor

- Non- competitive inhibitors bind with the enzyme at the site other than active site. The other binding site of enzyme is called ***allosteric site***.
- Structure of an enzyme is altered in such a way that even if the genuine substrate binds the active site, catalysis fails to take place.
- Feedback inhibition is an example of reversible non-competitive inhibition.

CRITICAL THINKING

8. All of the followings are cases of negative feedback inhibition except:
A. Effect of high amount of ATP on Phosphofructokinase
B. Effect of high amount of NADH on Pyruvate decarboxylase
C. Effect of increased amount of thyroxine in blood on TSH release
D. Effect of suckling on release of oxytocin

CLASSIFICATION Of ENZYMES

- Enzymes can be classified either on the basis of reaction types that they catalyzed or on the basis of substrate which are acted upon by the enzyme.

Classification Based Upon Reaction Types

- In 1961, a systemic system of classification of enzymes based on reaction types and reaction mechanism was given by ***International Union of Biochemistry*** and has been classified into six groups:

Enzyme Class	Definition	Examples
Oxidoreductases	Catalyze redox reactions of their substrate and act by removing electrons or H^+ from the substrate.	Cytochrome oxidase
Transferases	Catalyze the transfer of specific functional group other than hydrogen from one substrate to another.	Hexokinase, Glucokinase

Hydrolases	Catalyze the breakdown of large complex organic molecules into smaller ones by adding H_2O.	Proteases, Lipases
Lyases	Catalyze the breakdown of specific covalent bonds and removal of groups without hydrolysis.	Histidine decarboxylase
Isomerases	Bring about intra-molecular rearrangement of atoms in the molecules and thus forming isomers.	Phosphohexose isomerase
Ligases	Bring about joining together of two molecules by utilizing energy	RNA polymerases DNA polymerases

Classification Based Upon Substrate

- Enzymes can be classified on the basis of substrates they use.

Type of Enzymes	Definition	Examples
Proteases	These enzymes act upon proteins	Pepsin, trypsin, amino-peptidase carboxy-peptidase
Lipases	These enzymes hydrolyze lipids into fatty acids and glycerols	Pancreatic lipase
Carbohydrases	These enzymes cause breakdown of carbohydrates	Amylase, cellulase, maltase, sucrase, lactase
Nucleases	These are involved in the breakdown of DNA and RNA	RNase, DNase

TOPIC-8 EVOLUTION

COURSE CONTENT

- Concept of Evolution
- Origin of Life According to Concept of Evolution
- Lamarckism/ Inheritance of Acquired Characters
- Darwinism
- Evidences of Evolution

CONCEPT OF EVOLUTION

- ***Evolution*** refers to the processes that have transformed life on earth from its earliest form to the vast diversity that we observe today.
- Evolutionary change is based mainly on the interactions between populations of organisms and their environments.

  In the earlier 19^{th} century, there were two schools of thoughts.
- Creationists believed on the theory of ***special creation*** while evolutionists believed on the theory of ***natural selection***.

CRITICAL CONCEPT!

Interesting Fact:
No two animals are the same, even if they belong to the same species.

(i) Theory of Special Creation

According to this theory, all living things came into existence in their present forms ***especially and specifically created by nature***. Among the scientists who believed in divine creation was ***C. Linnaeus***. He grouped similar species in the same genus and similar genera in one family. But as a natural theologian, he believed that species were permanent creations.

(ii) Theory of Natural Selection

According to this theory, organisms evolved through time e.g. one type of organism giving rise to another type of organism.

- It is ancient one starting from days of Aristotle to Darwin.
- However, the present-day concept of evolution is based on history.

CRITICAL CONCEPT!

Soul is an intangible thing that cannot be studied in biology because biology deals only with tangible things.

Scientist's Name	Life Span	Achievements
Linnaeus	1707-1778	Order in diversity of life, binomial nomenclature
Lamarck	1744-1829	Theory of evolution
Malthus	1766-1834	Essay on 'Principle of Population'.
Cuvier	1769-1832	Science of Paleontology, earth's history by catastrophism.
Lyell	1797-1875	Principles of Geology
Darwin	1809-1882	1. Voyage of Beagle. 2. Books on origin of species. 3. Essay on origin of species.
Mendel	1822-1884	Papers on inheritance
Wallace	1823-1913	Sent his theory to Darwin
Hutton	1726-1797	Theory of Uniformitarianism

CRITICAL THINKING

1. **Study of soul can be done in:**
   A. Chemistry
   B. Biology
   C. Metaphysics
   D. Ethics

ORIGIN OF LIFE ACCORDING TO CONCEPT OF EVOLUTION

Hydrothermal Vent Hypothesis

Origin of First Life Form

- Life may have originated in the oceans, in underwater hot springs called ***hydrothermal vents***. These vents could have supplied the energy and raw materials for the origin and survival of early life forms.
- ***Archaebacteria*** are considered as first life form, which support this vent hypothesis because they can tolerate ***temperature up to 120°C*** and undergone less evolutionary changes than any other living species.
- As bacteria are prokaryotes, so prokaryotes are considered as first life form on earth.

CRITICAL THINKING

2. **Simplest organism would be:**
   A. *Nostoc*
   B. *Escherichia*
   C. *Bacillus*
   D. *Thermus*

Evolution of Photosynthetic Organisms

- Nutrients produced in primitive environment would have limited early life. Photosynthesis probably feed living organisms from a dwindling supply of nutrients.
- First photosynthetic organisms probably used ***hydrogen sulfide*** as a source of hydrogen for reducing carbon dioxide to sugars.
- Later water served this same purpose and oxygen liberated by photosynthetic reaction begun to accumulate in the atmosphere.

Evolution of Aerobic Respiration

- Accumulation of oxygen in atmosphere changed the primitive environment.
- Ozone developed by oxygen in upper atmosphere began to filter ultraviolet radiations from the sun. It is considered that about ***4.2 billion*** (420 million) years ago, enough protective ozone had built up to make life on land possible.
- Some living organisms began to utilize oxygen.
- Ironically, the change from a reducing atmosphere to an oxidizing atmosphere also means that life could no longer arise abiotically.

Evolution of Prokaryotes into Eukaryotes

- The prokaryotes may have arisen more than ***3.5 billion years ago***.
- Eukaryotes may have evolved ***1.5 billion years ago***.

  It is considered that prokaryotes converted into eukaryotes. Major change is development of organelles. Two hypotheses are considered in this context.

Endosymbiont Hypothesis

- This hypothesis was presented by Lynn Margulis.
- According to this hypothesis, eukaryotes and their organelles had been produced by some symbiotic relation with prokaryotes. Origin of some organelles has been described below.

(i) **Origin of Mitochondria**

According to this hypothesis, mitochondria might have evolved when large anaerobic amoeboid prokaryote ingested small aerobic bacteria and stabilized them instead of digesting them. This idea is known as the endosymbiont hypothesis.

These aerobic bacteria then converted into mitochondria, which are the sites of aerobic respiration and energy conversion in eukaryotic cells.

(ii) **Origin of Flagella**

Flagella might have evolved through the ingestion of prokaryotes similar to spiral-shaped bacteria.

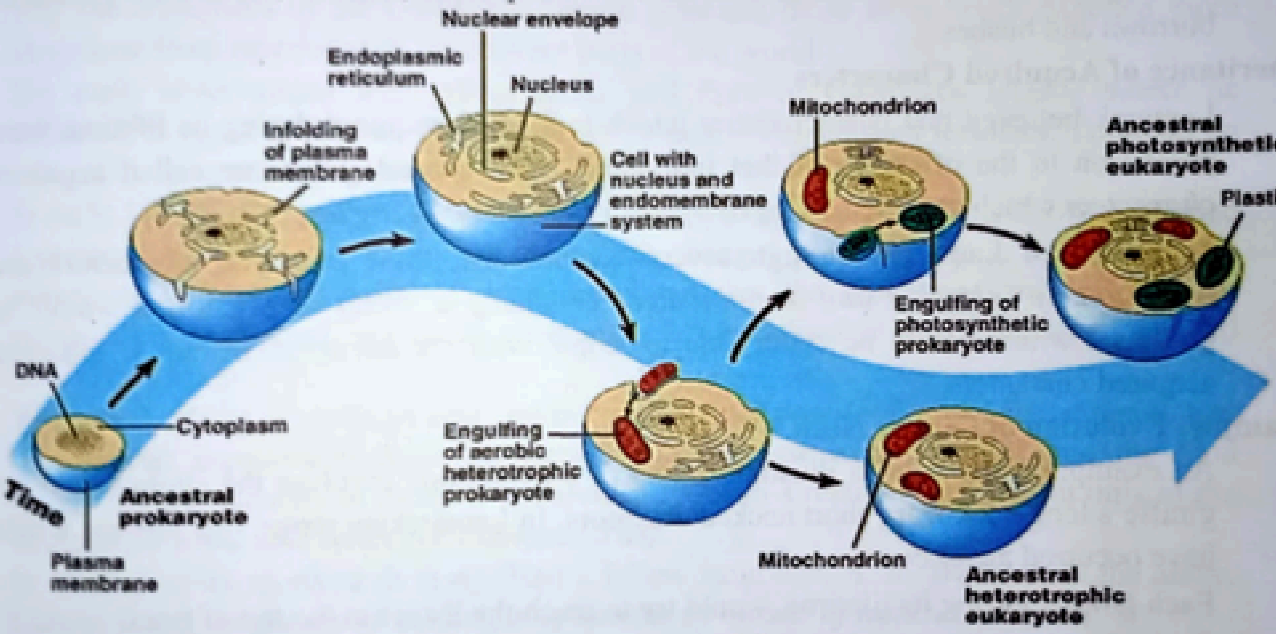
(iii) **Origin of Chloroplast**

Ingestion of prokaryotes that resembled present day cyanobacteria could have led to the endosymbiotic development of chloroplast in plants.

Cell Membrane Invagination Hypothesis

According to this hypothesis, cell membrane of prokaryotes invaginates (folded inward) to enclose copies of its genetic material.

This invagination resulted in the formation of several double membrane-bounded entities (organelles) in single cell. These entities could then have evolved into the eukaryotic mitochondrion, nucleus, chloroplast etc.



Evolution of Multicellular Eukaryotic Organism and Diversity

- Formation of eukaryotic cell led to a dramatic increase in the complexity and diversity of life forms on earth.
- During evolution, eukaryotic cell became specialized into tissues, which in turn formed organs for many different functions. These multicellular forms then adapted themselves to life in a great variety of environment.

CRITICAL THINKING ?

2. **Origin of life is explained by all except:**
   A. Endosymbiont hypothesis B. Creationism
   C. Hydrothermal vent hypothesis D. Chemical evolution

LAMARCKISM / INHERITANCE OF ACQUIRED CHARACTERS

Lamarck's Theory

- ***J. B. de La Lamarck*** (1744-1829) was a ***French naturalist*** and soldier. He was an early proponent of the idea that evolution occurred and proceeded in accordance with the natural laws. In 1809, he published his book *Philosphie Zooloqique*.

Main Points of Lamarckism

- The ideas about evolution presented by Lamarck are known as ***Lamarckism***. He pictures evolution as ***ladder of life*** from simplest to the most complex animals. Man was at top rung of the ladder.
- Lamarck's explanation of evolution revolved around two basic assumptions; ***use and disuse of organs*** and ***inheritance of acquired characters***.

Use and Disuse of Organs

- Lamarck argued that those parts of the body used extensively to cope with the environment become larger and stronger e.g. blacksmith developing a bigger biceps in the arm that works the hammer.
- Those parts that are not used deteriorate e.g. loss of legs in snakes due to their habitat of burrows and bushes.

Inheritance of Acquired Characters

- Lamarck believed that characteristics which individual acquired during its lifetime were passed on to the offspring of that individual. Such characteristics are called ***acquired characters*** which are often emerged by the use or disuse of organs.
- According to Lamarck, through several generations, these ***acquired characters are continuously inherited and accumulated***. Gradually a group of organisms would be produced which would be better able to 'cope' with the environment due to inherited acquired characters.

Example: Evolution of Giraffe Neck

An example often used to illustrate Lamarck's hypothesis involves the evolution of the giraffe's long neck from short necked ancestors. In Lamarckian terms, this process would have occurred as follows.

- Each giraffe, during its lifetime, would try to reach the leaves at the top of trees.
- Each animal would constantly stretch its neck in order to attain this goal.
- As these individuals reproduced, the results of neck stretching (an acquired characteristic) would be passed on to future generation.
- Each offspring would be born with a slightly longer neck than those of its parents. Thus, long necked giraffes gradually evolved.

Demerits of Lamarck's Theory

1. There is no experimental proof of Lamarckism.
2. The idea of use and disuse of proposed by Lamarck has no genetic bases and therefore, cannot be inherited to the next generation.
3. It is not necessary that the acquired characters transmit into the next generation.
4. Organs are not modified by the wish or requirements of an organism.

DARWINISM

- In 1831, Darwin accepted the position of naturalist abroad on the ***HSM beagle***, a British Naval ship about to sail around the world. His major mission was to expand the navy's knowledge about natural resources e.g., water and food in foreign lands.

Darwin's Observations during His Voyage

- The Beagle spent almost 2 months at the Galapagos Islands, where Darwin collected and catalogued thousands of plant and animal specimens and kept notes of his observations that were most important in the development of his ideas about evolution.

Observations about South American Mainland

- Darwin noticed that flora and fauna of different region of the continent had a definite South American stamp, very distinct from the life form of Europe.
- Further the South American fossils that Darwin found, though clearly different from modern species, were distinctly South American in their resemblance to the living plants and animals of the continent.

Observations about Galapagos Islands

- Darwin compared the animals and plants of Galapagos Islands with those of the South American mainland. He was particularly impressed by their similarities and wondered why the organisms of the Galapagos should resemble those from South America more than those from other islands in different parts of the world.
- His main observations were about fauna and flora of Galapagos Islands where he collected 13 types of finches. He also observed saddle shaped shell tortoises. Tortoises on other islands were having dome shaped shell.
- In early 1830's, ***C. Lyell*** published a book '***Principle of Geology***'. This books presented arguments to support a theory of geological changes proposed by ***J. Hutton***, called ***theory of uniformitarianism***. Lyell pointed out that the mountains, valleys, deserts, rivers, lakes, and coastlines could have come through the action of existing forces and natural conditions.
- ***Thomas R. Malthus*** wrote an essay on the; principle ***of populations'*** where he mentioned that ***human populations have the capacity to increase exponentially***, and the food supply has the capacity in increase arithmetically. Such a relation could result only in the ***struggle for food and hence for existence itself***.
- In 1858, Darwin received as essay from a fellow naturalist, ***A. R. Wallace***. In the essay, Darwin found the ***theory of the origin of species by means of natural selection***.
- A. R. Wallace was the man who motivated Darwin to publish his book, ***the origin of species by the means of natural selection.*** It appeared in 1859, and twelve years later, Darwin's ***Decent of man*** was published.
- According to Darwin, new species would arise from an ancestral form by the gradual accumulation of adaptations to different environments, separated from original habitat by geographical barriers. Over many generations, the two populations could become dissimilar enough to be designated as separate species.

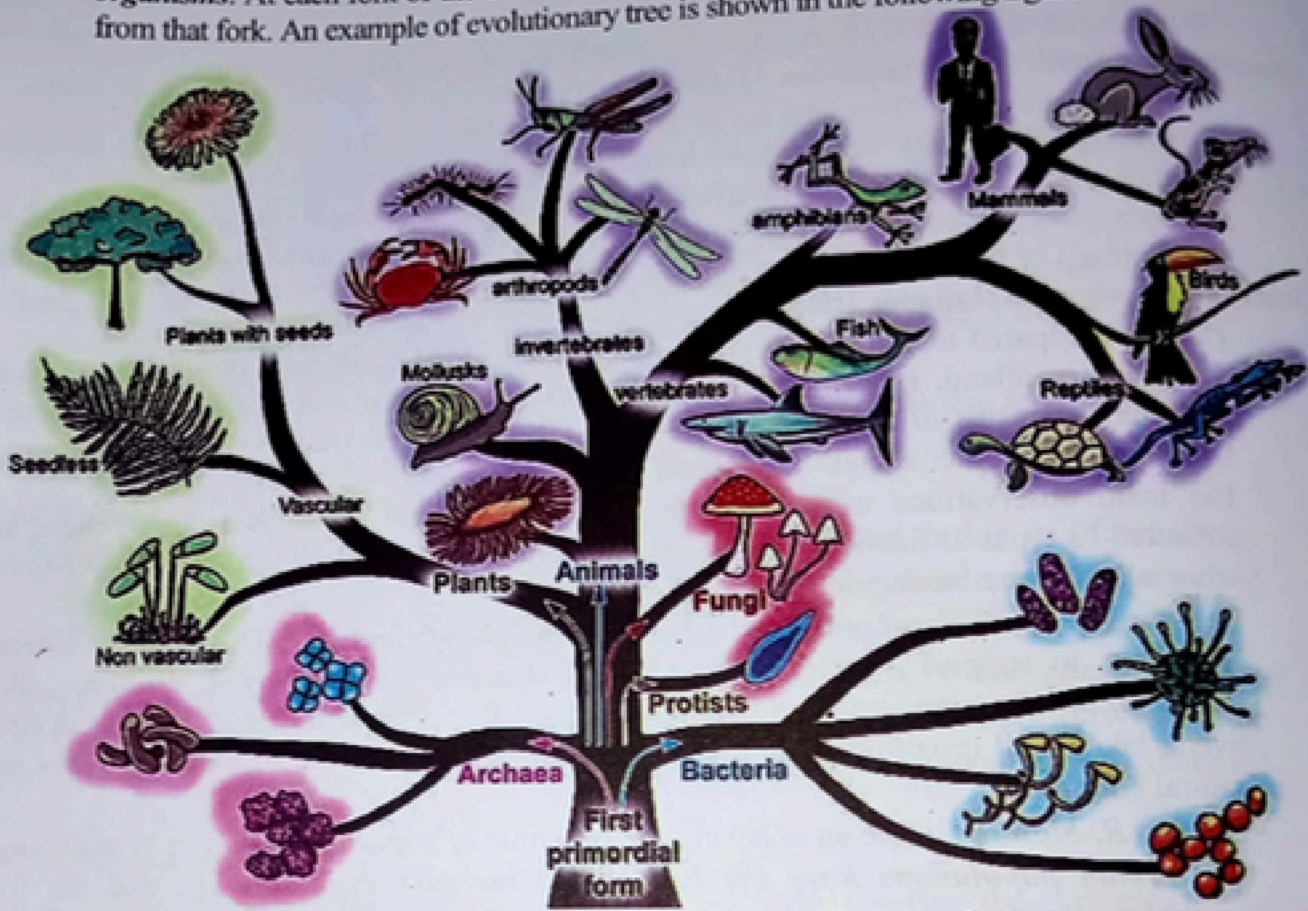
Darwin's Theory of Natural Selection

In his Book ***'the origin of species'*** Darwin developed two main points i.e.,

1. Descent with modification
2. Natural selection and adaptations.

Descent with Modification

- Darwin believed in ***perceived unity in life***, with all organisms related through descent from some common ancestor that lived in the remote past.
- According to Darwin, history of life is like a tree, with multiple branching and re-branching from a common trunk all the way to the tips of the living twigs, symbolic of the ***current diversity of organisms***. At each fork of the evolutionary tree is an ancestor to all line of evolution branching from that fork. An example of evolutionary tree is shown in the following figure:



Natural Selection and Adaptation

- Darwin suggested that populations of individual species become better adapted to their local environments through ***natural selection***. Natural selection refers to the 'differential reproductive capacities among individuals of a population which indicated that some individuals of a population are capable to reproduce while others are not.
- Darwin's mechanism of evolution by natural selection consists of four observations about natural world.

(i) Overproduction

- Production of more individuals than the environment can support.

(ii) Variations

- The individuals in a population exhibit variation in their traits. Some of these traits improve the chances of an individual's survival and reproductive success, whereas other traits do not.

(iii) Struggle for Existence

- Over-production leads to the competition among individuals for limited resources like food, water, light, growing space etc. The struggle may be:

1. ***Intra-specific:*** Competition among organisms of same species.
2. ***Inter-specific:*** Competition among organisms of different species.
3. ***Environmental Struggle:*** Struggle against various environmental conditions.

(iv) Survival of the Fittest

- Those individuals that possess the most favorable combination of characteristics are most likely to survive and reproduce, passing their heritable traits on to the next generation.
- It is not random but depends in part on the heredity constitution of the surviving individuals. Those organisms whose inherited characteristics fit them best to their environment are likely to leave more offsprings than the less fit individuals.

(v) Evolution

- This unequal ability of individuals to survive and reproduce will lead to a gradual change in a population, with favorable characteristics accumulating over the generations thus leading to the evolution of new species.

Neo-Darwinism

- When Lamarck and Darwin put forward their ideas, practically nothing was known about heredity. The origin of species convinced most biologists that ***species are product of evolution***.
- An important turning point for evolutionary theory was the birth of population genetics which emphasizes the extensive genetic variation within population and recognized the importance of quantitative characteristics.
- The emergence of population genetics has provided a clear understanding of inheritance and variations among the individuals of a population and firm support to Darwinian theory.
- With progress in population genetics in the 1930s, ***Mendelian and Darwinism were reconciled***, and the genetic basis of variation and natural selection was work out. Thus, a comprehensive theory of evolution that became known as the ***modern synthesis or Neo-Darwinism*** was developed in the early 1940s.
- It is called a synthesis because it integrated discoveries and ideas from many different fields, including biochemistry, ecology, paleontology, taxonomy, biogeography, and of course, population genetics.
- Advances in these fields have enabled scientists to identify mutation, genetic drift and gene flow as other natural forces of evolutionary change.

EVIDENCES OF EVOLUTION

- Evolution leaves observable signs. Darwinism was mainly based on the evidences from the geographical distribution of species and from the fossil record.
- However, there have been many evidences as biology progressed. New discoveries continue to validate the evolutionary view of life.

Evidences from Biogeography

- It is the ***geographical distribution of species***. It was first evidence that suggested idea of evolution to Darwin.
- According to Darwin, islands have many species of plants and animals that are endemic but closely related to species of the nearest mainland or neighboring island.
- ***Armadillos*** (armored mammals) live only in America. The evolutionary view of biogeography predicts that contemporary armadillos are modified descendants of earlier species that occupied these continents and fossil records also confirm existence of such ancestors.

- Similarly, Darwin noticed that South America lacked rabbits, even though the environment was quite suitable to them. He concluded that there are no rabbits in South America because rabbits originated somewhere else and they had no means to reach South America.
- This distribution is due to geological barriers, harsh environmental conditions or presence of organisms that can compete.

Evidences from Paleontology

- The succession of fossil forms is ***strong evidence in the favor of evolution***.
- It provides a visual record in a complete series showing the evolution of an organism.
- ***Fossils*** are either the actual remains or traces of organisms that lived in ancient geological times.
- Most fossils are found in ***sedimentary rocks.***
- Modern biological sciences places prokaryotes as ancestors of all life and predict that prokaryotes should precede all eukaryotic life. In the fossil record, indeed, the ***oldest known fossils are of prokaryotes***.

> **CRITICAL CONCEPT!**
>
> **Oldest Known Fossils:**
> The oldest known fossils, in fact, are of bacteria from Archaean rocks of Western Australia, dated 3.5 billion years old. This may be somewhat surprising, since the oldest rocks are only a little older: 3.8 billion years old.

- They show chronological appearance of the different classes of vertebrate animals as shown by fossils. It shows following evolutionary arrangement:
- Fishes → Amphibians → Reptiles → Mammals + Birds
- Sometimes, the fossil record allows us to trace the history of one particular organism, such as modern day horse *Equus*. The earliest horses had four toes. Over the time the number of toes reduced to three, in the modern horses to one, a large central toe that ends in a hoof. The evidences of fossil record support the common descent hypothesis.

> **CRITICAL THINKING**
>
> **3. Bacterial fossils may be present in which form?**
>
> A. Humus B. Cast as an impression
>
> C. Spore D. Petrified tissues

Evidences from Comparative Anatomy

- Anatomical similarities between species grouped in the same taxonomic category bring another support to the theory of the descent with modification.
- Comparative anatomy supports that evolution is a remodeling process in which ancestral structures that functioned in one capacity become modified as they take on new functions.

Homologous Structures

- Such organs, which are functionally different but structurally similar, are called homologous organs. Similarity in characteristics resulting from common ancestry is known as ***homology***.
- This pattern of evolution in which different species have been evolved from common ancestors at different habitats is known as ***divergent evolution.***

> **CRITICAL CONCEPT!**
>
> **Interesting Fact:**
> At one point in time, whales walked on land!

- For examples, same skeletal elements make up the forelimbs of human, cats, whales, bats and all other mammals although they have different functions.
- The limb-bone pattern of all tetrapods from amphibian to mammals has the same structural plan. It is called ***pentadactyle limb***.
- The basic similarity of these forelimbs is the consequence of the descent of all functions.
- The flower parts of a flowering plant are homologous. They are considered to have evolved from leaves, to form sepals, petals, stamens and carpals.

Analogous Structures

- Such organs, which are functionally alike but structurally different, are called analogous organs.
- These structures are of evolutionary interest because they demonstrate that population with separate ancestries may adapt in similar ways to similar environmental demands.
- This pattern of evolution in which different species have been evolved from different ancestors at a common habitat is known as ***convergent evolution***.
- For example, wings of birds and insects are examples of convergent evolution.

Vestigial Structures

- Such organs, which are historical remnants of structures that had important functions in ancestors but are no longer essential presently, are called ***vestigial organs***.
- These are oldest homologous structures.
- For example, skeleton of whales and some snakes retain vestiges of the pelvis and leg bones of walking ancestors, vermiform appendix in carnivores, ear muscles in man etc.
- There are about ***90 such structures present in the human body***.

CRITICAL CONCEPT!

Tail in Humans:
All humans develop a tail in the womb that eventually dissolves.

CRITICAL THINKING

4. This is a historical hypothesis that the development of the embryo of an animal, from fertilization to gestation or hatching, through stages resembling or representing successive adult stages in the evolution of the animal's remote ancestors:

A. Theory of natural selection
B. Theory of modern synthesis
C. Theory of catastrophism
D. Theory of recapitulation

Evidences from Molecular Biology

- Evolutionary relationships among species are reflected in their ***DNA*** and ***proteins*** - in their ***genes and gene products***. If two species have genes and proteins with sequences of monomers that match closely, the sequences must have been copied from a common ancestor.
- Molecular biology provides ***strong evidence*** in support of evolution as the basis for the unity and diversity of life.

CRITICAL CONCEPT!

Junk DNA:
The term "Junk DNA" refers to regions of DNA that are non-coding or, in other words, they do not code for a protein.

Examples

- Organisms utilize the same triplet code and the same twenty amino acids in their proteins. Organisms even share the same type of introns.
- Humans and bacteria have some common proteins e.g., ***cytochrome 'c'***, a respiratory protein, is found in all aerobic species.
- There is obviously no functional reason why these elements need to be similar, but their similarity can be explained by descent from a common ancestor.

CRITICAL THINKING

5. It should not be present in *Spirochete*:

A. Cytochrome 'c'
B. Glucokinase
C. Elongation factors
D. Primase

CRITICAL CONCEPT!

One really extraordinary hint of evolution is actually found within our arms. There is a tendon that 10 – 15% of our human population has evolved out. This tendon is attached to an ancient muscle called the palmaris longus, which was primarily used by tree-dwelling apes (lemurs and monkeys, for instance) to help them move from branch to branch. Humans and ground-central apes, like gorillas, no longer have a need for this muscle or tendon, so both species have started to lose this internal function.

However, evolution is a slow-going process, so almost 90% of humans still have this useless trait carried down from our monkey ancestors.

To see if you have the tendon, lay your forearm down on a table, palm up. Touch your pinky to your thumb and lift your hand just a little off the surface. If you see a raised band in the middle of your wrist, you have the tendon connected to your still-intact palmaris longus.

If you don't – congrats, you're evolving.

TOPIC-9

LIFE PROCESSES IN ANIMALS & PLANTS

COURSE CONTENT

Nutrition

- Carnivorous Plants
- Digestive System
- Digestion in Oral Cavity
- Digestion in Stomach
- Digestion in Small Intestine
- Role of Liver and Pancreas in Digestion
- Large Intestine
- Some Common Disorders Related to Human Digestive System

Gaseous Exchange/Respiratory system

- Anatomy of Human Respiratory System
- Mechanism of Breathing
- Transport of respiratory gases
- Role of Respiratory Pigments
- Respiratory volumes
- Respiratory disorders

Ubaid

Transport in Plants

- Uptake and Transport of Minerals
- Water Potential
- Uptake of Water by Roots
- Ascent of Sap
- Translocation of Organic Solutes

Transport in Man/Cardiovascular system

- Blood
- Structure of Human Heart
- The Cardiac Cycle
- Mechanism of Heart Excitation and Contraction
- Electrocardiogram
- Blood Vessels
- Blood Pressure and Rate of Blood Flow

Lymphatic System

Immune System

CARNIVOROUS PLANTS

Modes of Nutrition

- Organisms can be divided into two classes on the basis of their mode of nutrition.

Autotrophs	Heterotrophs
Autotrophic organisms can exist in an exclusively inorganic environment because they can- manufacture their own organic compounds from the inorganic raw material taken from the surrounding media. This means that they produce their own sugars, lipids, proteins etc. from CO_2, H_2O and nitrates.	Heterotrophic organisms are incapable of manufacturing organic compounds from simple inorganic nutrients and so they obtain organic molecules from the environment in the form of food
Example: Plants, Algae, Some bacteria.	**Example:** Animals, Fungi

Carnivorous Plants

- There are a few plants that supplement their inorganic diet with organic compounds. These organic compounds are obtained by trapping and digesting insects and small animals.
- All of the insectivorous plants are ***true autotrophs***, but when they capture prey, their growth becomes rapid.
- Apparently, nitrogenous compounds of animal body are of benefit to these plants. In some plants, the trapped insects are ***decomposed by bacteria***.
- In others, the trapped insects are ***digested by enzymes secreted by the leaves***. The plants absorb the nitrogenous compounds thus formed.

	Pitcher Plant	Venus-Fly Trap	Sundew
Scientific Name	*Sarracenia pupurea*	*Dionaea muscipula*	*Drosera intermedia*
Leaf Modification	Leaves modified into a sac or a pitcher, partly filled with water. Leaf end is modified to form a hood, which partly covers the open mouth of the pitcher.	Leaf is bilobed with midrib between them. There is a row of long stiff bristles along the margins of each lobe. Bristles interlocked upon touch of insects.	Tiny leaves bear numerous hair-like tentacles, each with a gland at its tip. The insects, attracted by the plant's odour are entangled.
Digestion	Bacteria or enzymes break protein of insects that are prevented climbing out of pitcher by stiff hairs.	Digestion by the enzymes secreted from the glands on the leaf surface and the products are then absorbed.	Proteins of insects are digested by enzymes.

HUMAN DIGESTIVE SYSTEM

Digestion

- The breakdown of complex organic compounds of food into simpler diffusible molecules by the action of enzymes is called ***digestion***.
- Digestion may be either ***intracellular*** or ***extracellular***. In intracellular digestion, breakdown of food occurs within the cells. In extracellular digestion, enzymes are secreted outside the cell into the gut cavity or lumen where then digestion takes place.

Digestive System

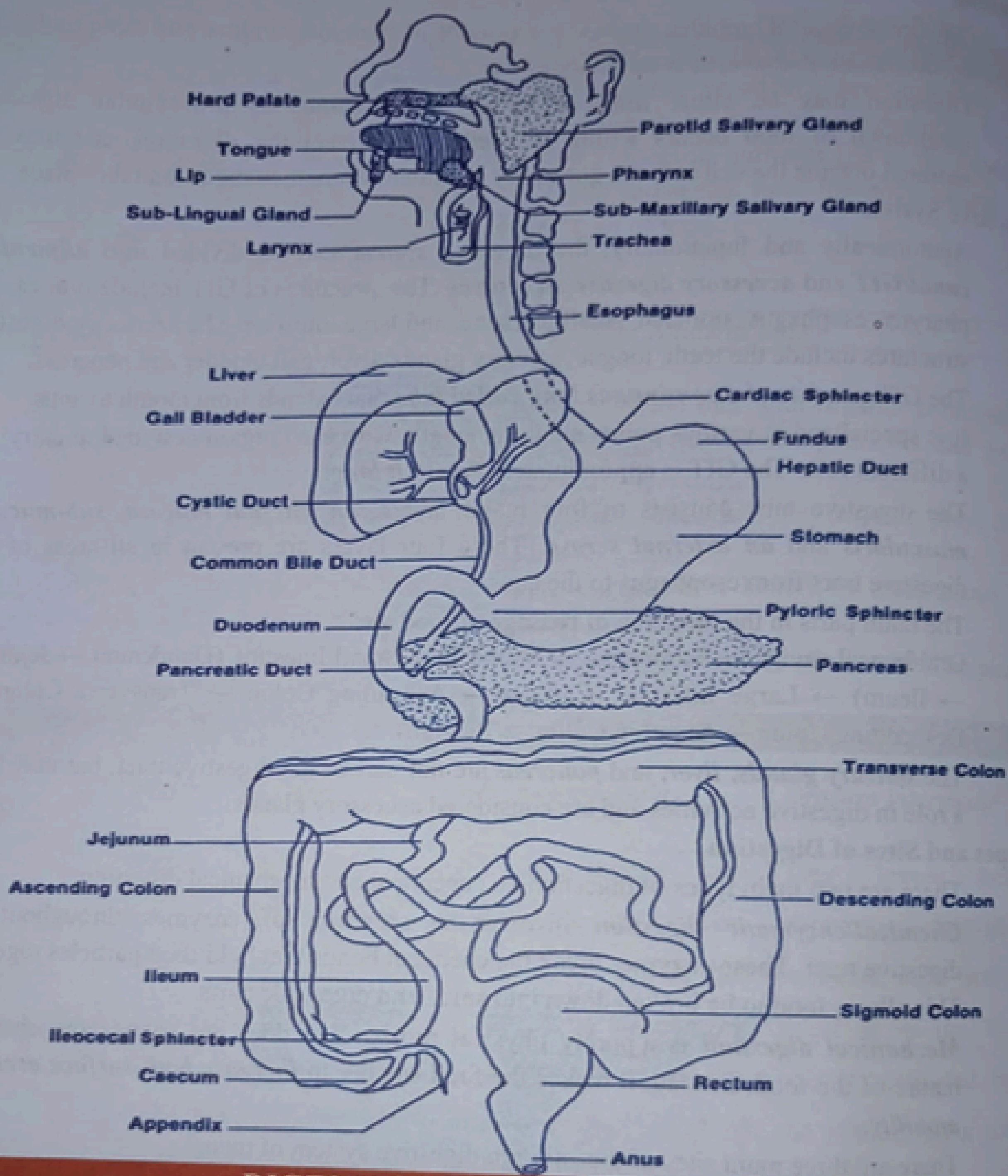
- Anatomically and functionally, the ***digestive system*** can be divided into ***alimentary canal/GIT*** and ***accessory digestive structures***. The structures of GIT include oral cavity, pharynx, esophagus, stomach, small intestine, and large intestine. The accessory digestive structures include the teeth, tongue, salivary glands, liver, gall bladder and pancreas.
- The GIT consists of a ***continuous long coiled tube*** that extends from mouth to anus.
- It is specialized at various points along its length, with each region designed to carry out a different role. The GIT is approximately ***9m/30 ft long***.
- The digestive tube consists of four major layers: ***an internal mucosa***, ***sub-mucosa***, ***muscularis*** and ***an external serosa***. These four layers are present in all areas of the digestive tract from esophagus to the anus.
- The main parts in the direction of passage of food are:
  Oral/buccal cavity → Esophagus → Stomach → Small Intestine (Duodenum → Jejunum → Ileum) → Large Intestine (Caecum → Ascending Colon → Transverse Colon → Descending Colon → Sigmoid Colon → Rectum)
- The ***salivary glands, liver***, and ***pancreas*** are not part of the digestive tract, but they have a role in digestive activities and are considered accessory glands.

Types and Sites of Digestion

- There are two main types of digestion i.e., chemical and mechanical digestion.
- ***Chemical/enzymatic digestion*** involves the secretion of enzymes throughout the digestive tract. These enzymes break the chemical bonds that hold food particles together. This allows food to be broken down into small and digestible parts.
- ***Mechanical digestion*** is a purely physical process that does not change the chemical nature of the food. Instead, it makes the food smaller to ***increase both surface area and mobility***.
- There are three main sites of digestion in digestive system of man:

Parts	Chemical Digestion	Mechanical Digestion
Oral Cavity	Salivary amylase	Mastication by teeth
Stomach	Gastric juice	Churning by gastric smooth muscles
Small intestine	Pancreatic and intestinal juices	Emulsification by bile salts

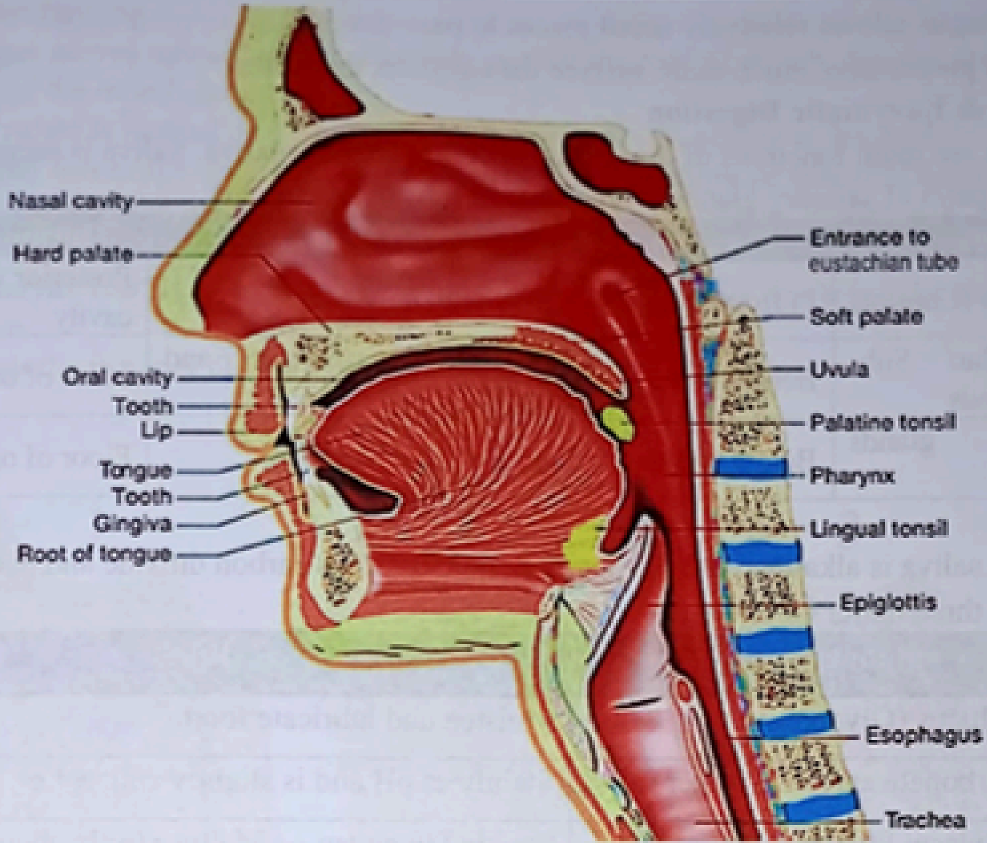
HUMAN DIGESTIVE SYSTEM



DIGESTION IN ORAL CAVITY

Oral Cavity

- The mouth is surrounded by the lips, cheeks, tongue and a palate and includes a chamber between the palate and tongue called ***oral cavity***. The tongue nearly fills the oral cavity when the mouth in closed. It is the ***site for entrance of food*** in alimentary canal.
- Rough projections called ***papillae*** on the surface of the tongue cause friction; which is ***useful in handling of food***. These papillae also contain ***taste buds***.
- The palate forms the ***roof of the oral cavity***. It consists of a hard anterior part, ***the hard palate*** and soft posterior part, the ***soft palate***.



- In adult human beings, the oral cavity is equipped with 32 teeth. Different teeth are adapted to handle food in different ways.

Name of Teeth	Shape of Teeth	Function
Incisors (Front teeth)	Chisel shaped with sharp edges	Used to bite off relatively large pieces of food
Canines	Cone-shaped	Useful in grasping or tearing of food
Pre-Molars and Molars	Flattened surfaces	Specialized for grinding of food particles.

Functions of Oral Cavity

It performs four important functions:

1. Selection of food
2. Grinding or mastication of food
3. Lubrication of food
4. Enzymatic digestion of food

Selection of Food

- When food enters in oral cavity, it is tasted, smelled and felt. If the taste or smell is unpleasant or if hard objects like bone or dirt are present in the food, it is rejected.
- Oral cavity is aided in selection by the senses of smell, taste and sight.
- Tongue being ***sensory*** and ***muscular organ*** plays the most important role in the selection of food through its taste buds.

Grinding or Mastication

- After selection, the food is ground by means of molar teeth into small pieces. This is useful because:

- Esophagus allows relatively small pieces to pass through.
- Small pieces have much more surface for enzymes to attack.

Lubrication & Enzymatic Digestion

- These are main functions of oral cavity accomplished by saliva. Saliva is secreted by three pairs of salivary glands. Three pairs of salivary glands are:

Glands	Location	Secretions	Opening of Ducts
Parotid glands (Largest)	In front of ears	Saliva with amylase	Posterior part of oral cavity
Sub-mandibular/ Sub-maxillary glands	Behind jaws	Saliva with amylase and mucus	Floor of oral cavity
Sublingual glands (Smallest)	Below tongue	Saliva with mucus only	Floor of oral cavity

Saliva

- Fresh saliva is alkaline with pH nearly 8, quickly loses carbon dioxide and gets to pH 6.
- It has three major components:

Components	Role
Water and Mucus (Glycoprotein)	Moisten and lubricate food
Sodium bicarbonate and some other salts	Stabilizes pH and is slightly antiseptic
Salivary Amylase/ Ptyalin	Starch/ Glycogen → Maltose (only about 3% -5%)

- Saliva prevents bacterial infection in the mouth as it contains ***lysozyme*** and ***antibodies/immunoglobulins***.

Anatomy of Oral Cavity	Physiology of Oral Cavity
Teeth	Mastication/ Mechanical digestion of food
Lips	Communication, Hold food in position
Tongue	Manipulation of food, hold food, Cleansing of teeth, Taste, Communication, Swallowing, mucus and serous fluid production.
Soft Palate	Prevents entry of food in nasal cavity
Salivary Glands	Chemical digestion of food mainly carbohydrates
Hard Palate	Palatine bones

Pharynx

- The pharynx is a cavity behind the mouth. It is ***common passage*** for digestive system and respiratory system. It is lined by mucus.

Swallowing

- As a result of mastication, softened, partly digested and slimy food mass is rolled into small oval lump called ***bolus***, which is then pushed to the back of the mouth by the action of tongue and muscles of pharynx.
- Transfer of bolus from buccal cavity to pharynx and then to esophagus is called ***swallowing/ deglutition***.
- Beginning of swallowing is voluntary action and then it becomes involuntary. The swallowing procedure is regulated by nerves in the medulla oblongata and pons.

Events of Swallowing

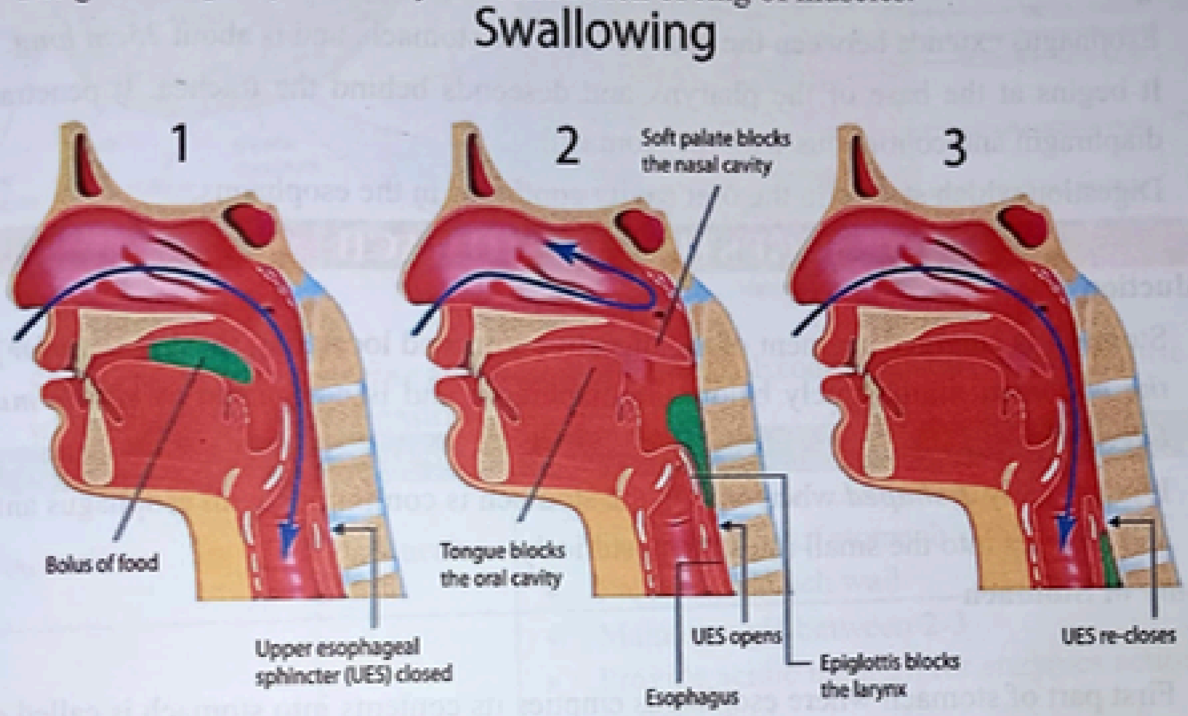
(i) Tongue moves upwards and backwards against the roof of mouth, forcing the bolus to the back of the mouth cavity.

(ii) Soft palate is pushed up by tongue which closes nasal opening at the back.

(iii) Tongue forces the epiglottis (***flap of cartilage***) into more or less horizontal in position, thus closing the opening of windpipe (glottis). Epiglottis diverts the bolus toward esophagus.

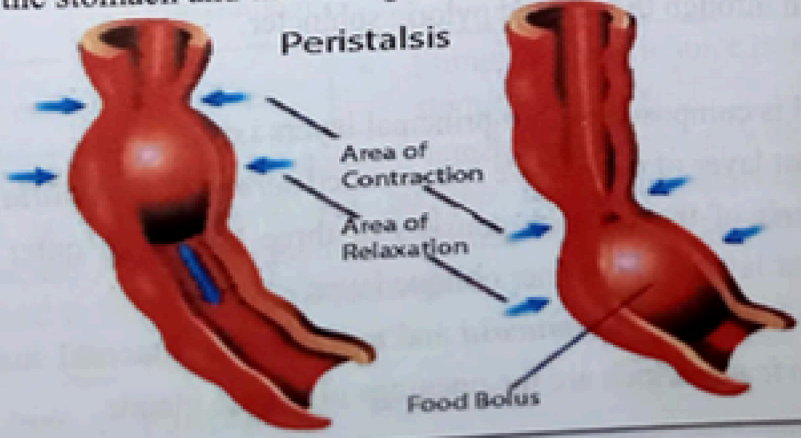
(iv) The larynx (cartilage box round the top of windpipe) moves upward under the back of the tongue.

(v) The glottis is partly closed by the contraction of ring of muscles.



Peristalsis

- ***Peristalsis*** is characteristic movement of digestive tract due to alternate contractions and relaxations of smooth muscles by which food is pushed along the digestive tract.
- It consists of the wave of contraction of circular and longitudinal muscles preceded by the wave of relaxation thus squeezing the food down along the canal.
- Relaxation of circular muscles in front of food is followed by a wave of strong contraction of circular muscles behind food.
- Peristalsis starts just behind the mass of food, from the buccal cavity, along the esophagus to the stomach and then along the whole alimentary canal.



- ***Anti-peristalsis*** is reverse peristaltic movements due to which food is passed from intestine back into stomach and even in mouth. It may lead to vomiting.
- Hunger contractions are peristaltic contractions caused by low blood glucose level. These create an uncomfortable sensation often called ***hunger pangs***.
- Hunger pangs usually begin 12-24 hours after the previous meal.
- ***Gravity*** assists the movement of material through the esophagus, especially when liquids are swallowed.

Esophagus

- Esophagus extends between the pharynx and the stomach, and is about ***25cm long***.
- It begins at the base of the pharynx and descends behind the trachea. It penetrates the diaphragm and continuous with the stomach.
- Digestion which started in the oral cavity continues in the esophagus.

DIGESTION IN STOMACH

Introduction

- Stomach is enlarged segment of the digestive tract and located in the ***left superior part of the abdomen***, immediately below the diaphragm and is designated as ***elastic muscular bag***.
- It is typically ***J-shaped*** when empty, the stomach is continuous with esophagus anteriorly and empties into the small intestine posteriorly.

Anatomy of Stomach

Parts

- First part of stomach where esophagus empties its contents into stomach is called ***cardiac region***.
- At the junction between esophagus and the stomach, there is a special ring of muscles called ***cardiac sphincter.*** It is also called as lower esophageal sphincter (LES). When the sphincter muscles contract, the entrance to the stomach closes and prevents backward movement of food. It opens when a wave of peristalsis coming down the esophagus reaches it.
- Point where stomach joins duodenum is called ***pyloric sphincter***. Stomach empties into the duodenum through the relaxed pyloric sphincter.

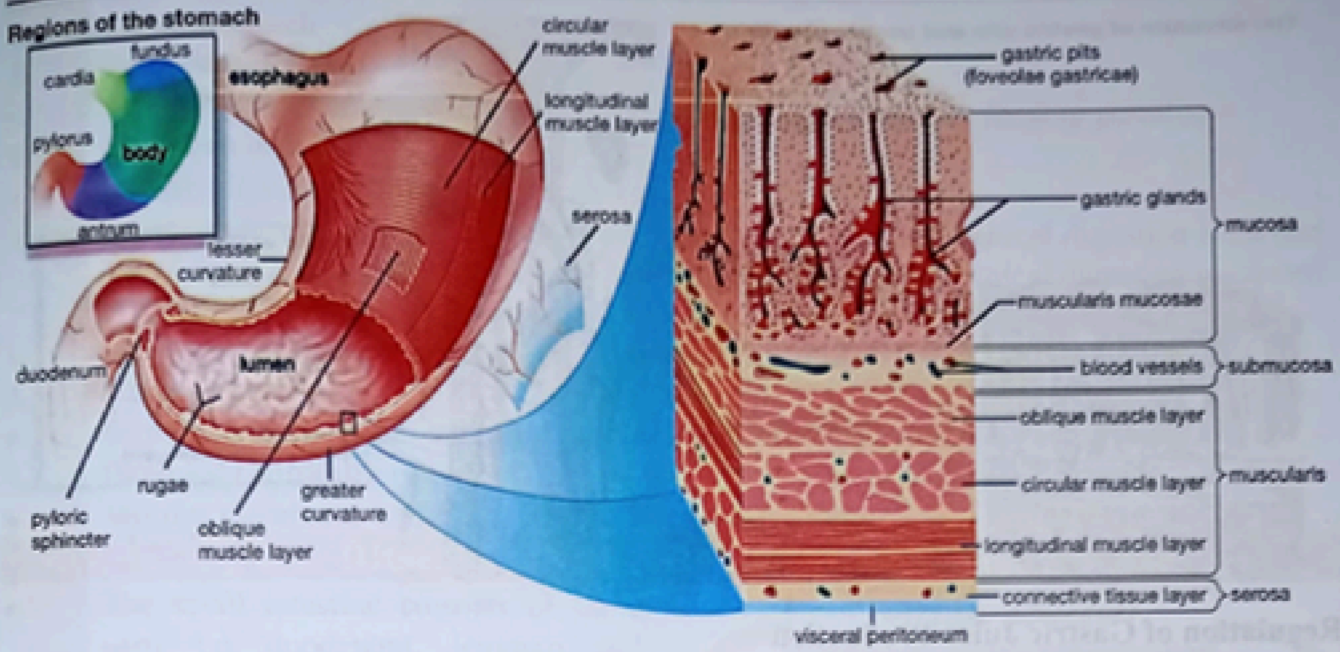
Layers

- Stomach wall is composed of four principal layers i.e.

(i) The outer most layer of connective tissue called ***serosa*** or ***adventitia***.

(ii) The ***muscularis*** of the stomach consists of three layers; an outer longitudinal layer, a middle circular layer and an inner oblique layer.

(iii) The next two layers are ***sub-mucosa*** and ***mucosa***. The mucosal surface forms numerous tube-like ***gastric pits*** which are the openings of gastric glands.



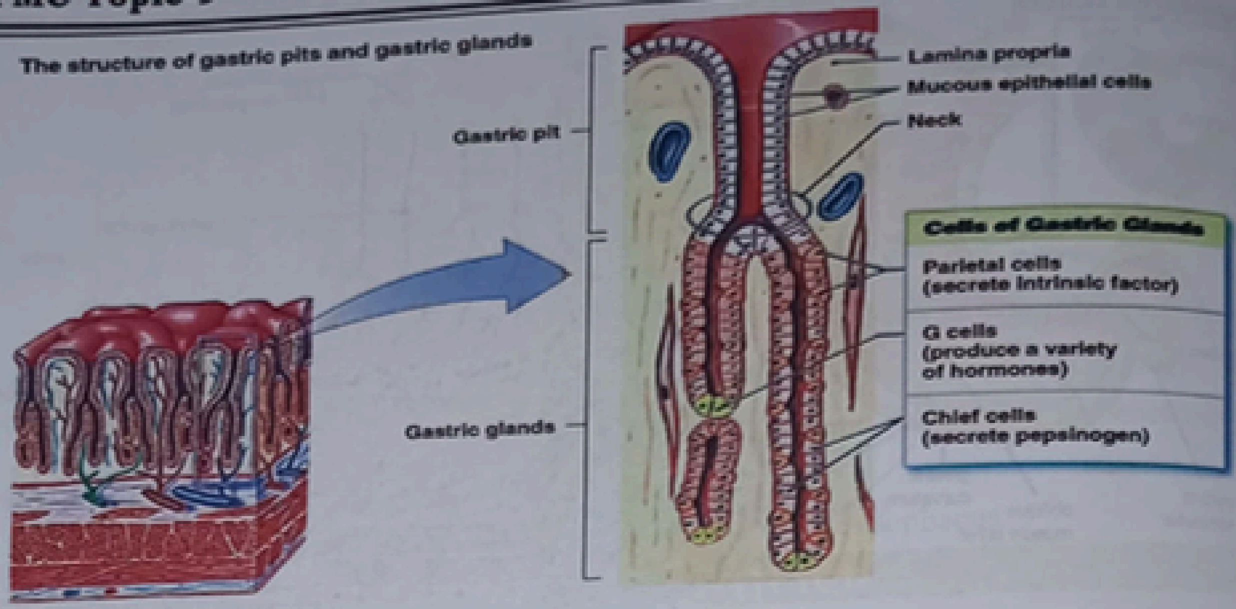
Gastric Glands

- Stomach has both ***exocrine*** and ***endocrine glands***. Exocrine glands secrete gastric juice while endocrine secrete gastrin.

Cells	Secretions	Functions
Mucous cells	Mucus	• Thick secretion • Covers inside of stomach • Protects stomach wall
Parietal/Oxyntic cells	HCl and Intrinsic factor	• Maintains pH between 2-3 • Provide acidic medium for enzymes action • Softens food • Kills microorganisms • Converts inactive pepsinogen into pepsin • Inactivates salivary amylase • Low pH denatures/mis-fold many proteins which helps in their digestion • Intrinsic factor helps in the absorption of vitamin B_{12} in the ileum.
Zymogen/Chief/Principal cells	Pepsinogen	• Hydrolyzes proteins into peptones and polypeptides.
G-cells/Endocrine cells	Gastrin	• Stimulates gastric juice production, secretion & stomach motility

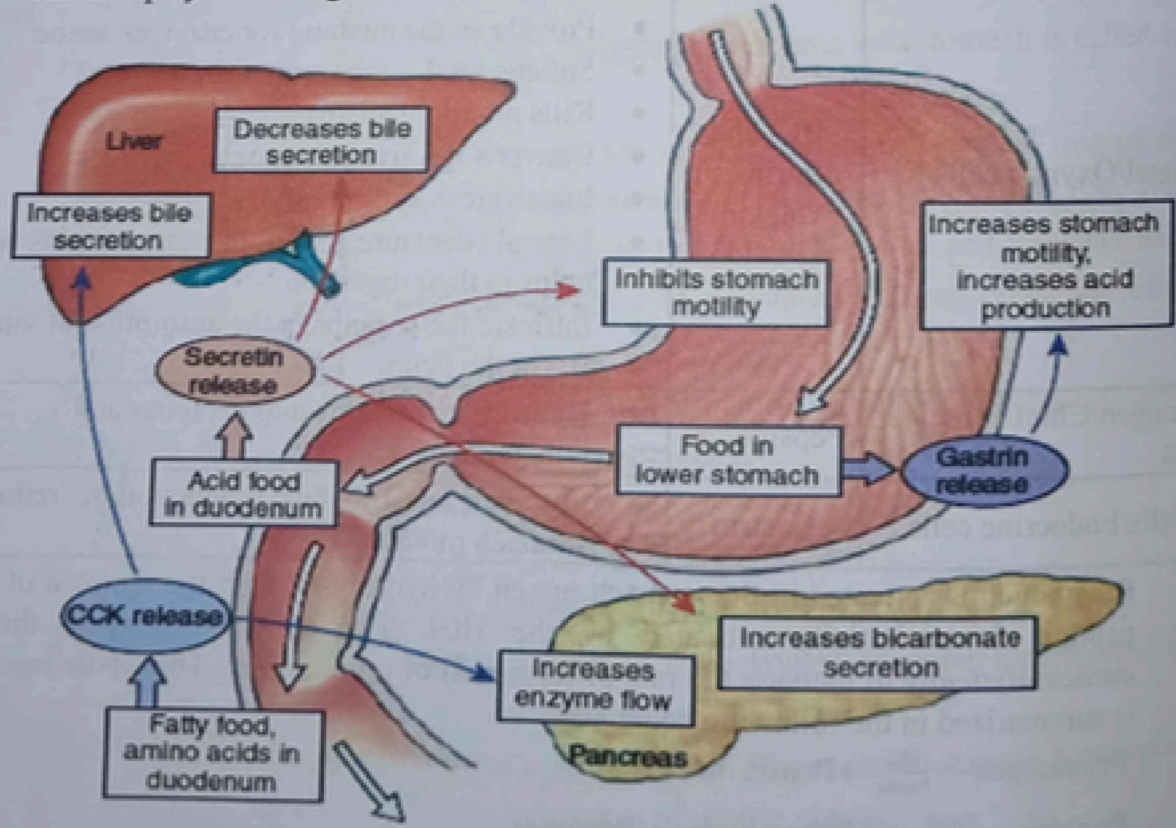
- Pepsinogen is activated in the stomach lumen by hydrolysis, with the removal of a short peptide. It is initially activated by the HCl. The activated enzyme then ***acts autocatalytically*** to increase the rate of formation of more pepsin. The whole mechanism is summarized in the following equations:
- Pepsinogen $\xrightarrow[\text{Pepsin}]{\text{HCl}}$ Pepsin
- Proteins $\xrightarrow{\text{Pepsin}}$ Polypeptides + Peptones

The structure of gastric pits and gastric glands



Regulation of Gastric Juice Production

- Both nervous and hormonal mechanisms regulate gastric secretions. Gastric juice secretion is regulated by smell, sight and quality of food.
- Main hormones that regulate gastric secretions are ***gastrin*** and ***secretin***.
- If more protein is present in food, it stimulates production of ***gastrin*** from gastric endocrine ***lining of pyloric region of stomach***.
- It is carried by ***blood*** to the gastric glands and stimulates them to produce more gastric juice (positive hormonal feedback mechanism).
- The interplay between gastrin and secretin is shown in the following diagram:



Functions of Stomach

1. **Food Storage**
- It stores food from meals for some time, making ***discontinuous feeding*** possible.

2. **Digestion of Food**
- It partly digests protein food.
- Stomach shows both chemical and mechanical digestion. Mechanical digestion is carried out by middle muscular layer and is called ***churning***, while chemical digestion is carried out by gastric glands. Muscular walls thoroughly mix up the food with gastric juice.
- End result of digestion in stomach is formation of semi-solid mass called ***chyme***.

3. **Absorption**
- Stomach is involved in the absorption of some chemicals like aspirin and ethanol.

4. **Defense/ Immunity**
- Mucous membrane and HCl act as barriers against germs.

DIGESTION IN SMALL INTESTINE

- The small intestine consists of three parts i.e. duodenum, jejunum and ileum.
- The entire small intestine is about ***6-7m long***.

CRITICAL CONCEPT!

Proteolytic Enzymes:
Pepsin, trypsin, chymotrypsin, carboxypeptidase, aminopeptidase all act on the proteins but having different amino acids as their target site, for example
Pepsin: Act on acidic and aromatic amino acids
Trypsin: Act on arginine and lysine
Chymotrypsin: Act on tryptophan, phenylalanine, tyrosine, leucine
Carboxypeptidase: Carboxyl group of terminal amino acids
Aminopeptidase: Amino group of terminal amino acids

Duodenum
- Duodenum is first and the shortest part of small intestine and is about ***20-30 cm long***.
- When food enters the duodenum, the secretions of pancreas and liver poured into it.
- Duodenum also has its own secretions.
- It acts both as exocrine and endocrine gland.
- Exocrine function of duodenum is secretion of intestinal juice and endocrine function is release of secretin and small amount of gastrin hormone.
- ***Secretin*** is hormone produced by the action of acidic food on internal mucosa of duodenum. It inhibits production of gastric secretions and promotes production of secretions of liver and pancreas.
- Chyme after neutralization by secretions from liver, pancreas and duodenum is called ***chyle*** (liquid).

Jejunum and Ileum
- Jejunum is the second portion of small intestine extending from duodenum to the ileum.
- It is about ***2.5 m long*** comprising about ***$2/5^{th}$ of small intestine***.
- Ileum is the third and the longest part with length of ***3.5 m long*** comprising ***$3/5^{th}$ of small intestine***.
- The food which escaped undigested from duodenum is completely digested in the jejunum and ileum by a group of enzymes contained in the intestinal juice.

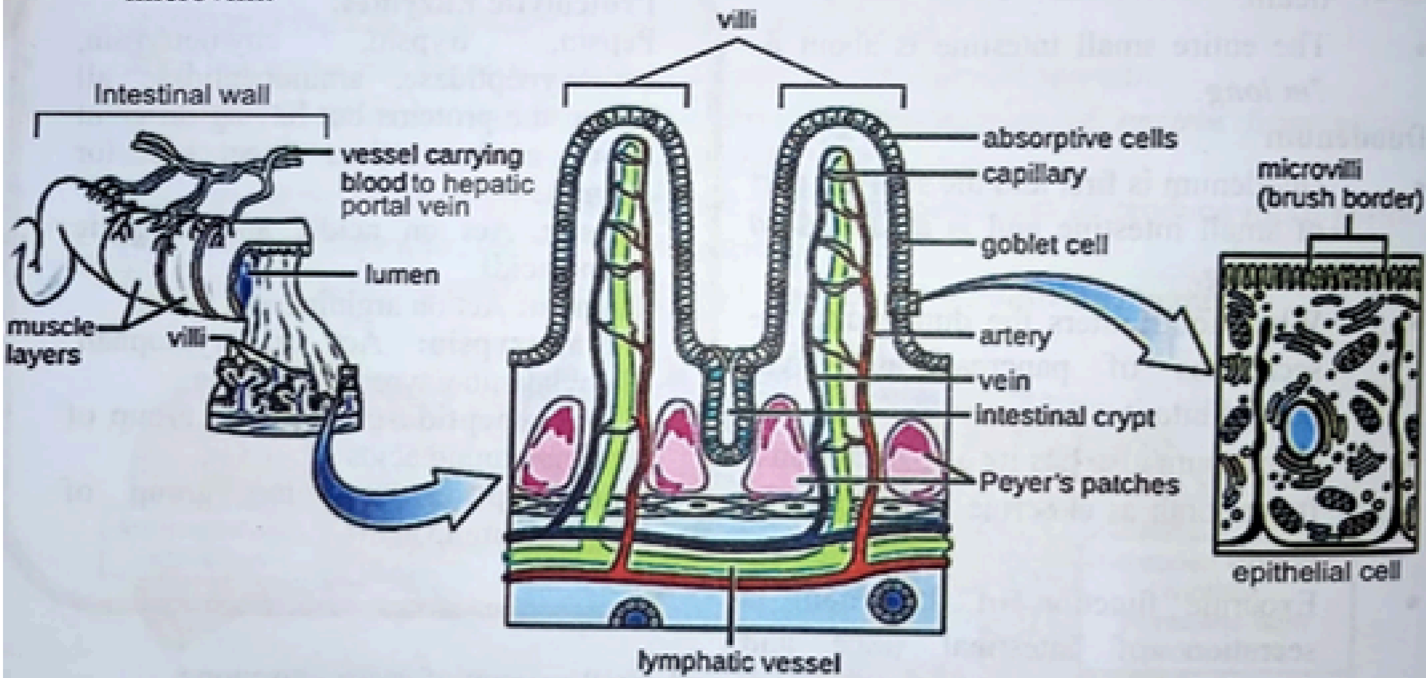
Enzymes of Intestinal Lining

- The overall picture of enzymes, their substrate and the final products is as follows:

Enzymes	Substrates	Products
Amino peptidase	Polypeptides	Dipeptides
Erypsin	Dipeptides	Amino acids
Lipase	Fats	Fatty acids and glycerol
Maltase	Maltose	Two glucose molecules
Lactase	Lactose	Glucose & galactose

Absorption of Food

- Nearly all the absorption of the products of digestion takes place in the ileum. The internal surface of ileum has many folds, which exhibits ***velvety appearance*** due to the presence of numerous finger-like outgrowths called ***villi***, which are ***0.5-1.5 mm*** in length.
- Each villus is covered by ***simple columnar epithelium***, blood capillary network and a lymph capillary, called as ***lacteals***.
- Epithelial cells of villi have countless, closely packed cylindrical processes, ***microvilli***. The total area of absorption becomes incredibly large due to the infoldings, villi and microvilli.

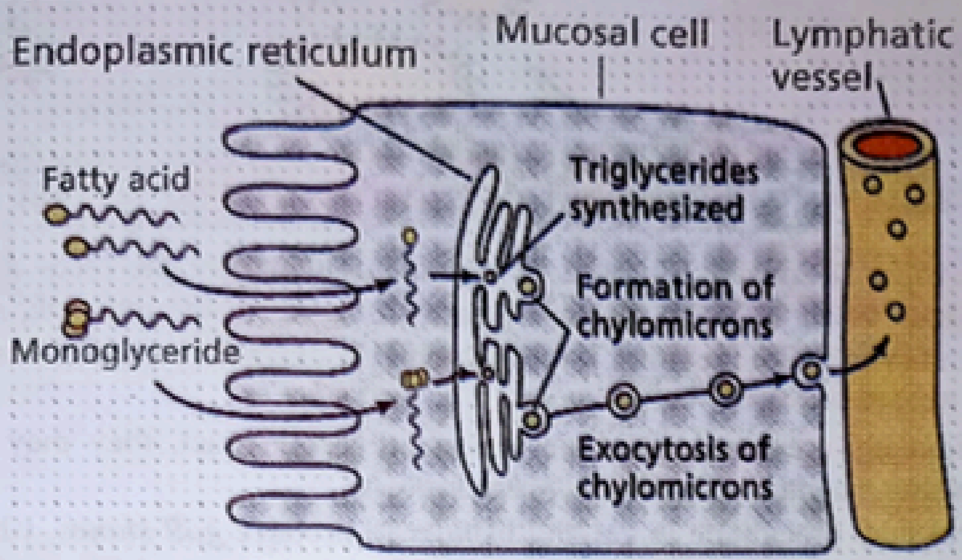


- The absorption of ***simple sugars*** occurs by a combination of ***simple diffusion*** and ***active transport***. The absorbed sugar molecules are transferred to the capillaries in intestinal villi and are carried by the ***hepatic portal system*** to the liver, where non-glucose sugars are converted to glucose.
- Individual ***amino acids*** are absorbed in the epithelial cells of villi and enter in the ***hepatic portal system***, which transport them to liver. The amino acids may be modified in the liver or released into the bloodstream and distributed throughout the body.

CRITICAL CONCEPT!

Some epithelial cells of ileum release lipase that can be the part of intestinal juice.

- Lipids digested into their components are absorbed by the ***epithelial cells***. They are recombined into fats within these cells. The fats are then mixed with cholesterol and proteins, forming small globules called ***chylomicrons***, most of which are transported by ***exocytosis*** out of the epithelial cells into the lacteals. These pass into blood stream via ***thoracic lymph duct***. The lipoproteins are hydrolyzed by blood plasma enzyme and enter body cells, where they may be used in respiration or stored as fat in the liver, muscles or under the skin.



End Result

- After absorption, the intestinal contents are pushed along the alimentary canal by normal peristaltic activity.
- At the end of ileum, there is an ***ileocolic/ileocecal sphincter*** that opens and closes time to time to allow a small amount of residue from the ileum to enter the large intestine.

CRITICAL THINKING

1. **Digestion complete in:**
   A. Duodenum B. Jejunum
   C. Ileum D. Colon

ROLE OF LIVER AND PANCREAS IN DIGESTION

Role of Liver

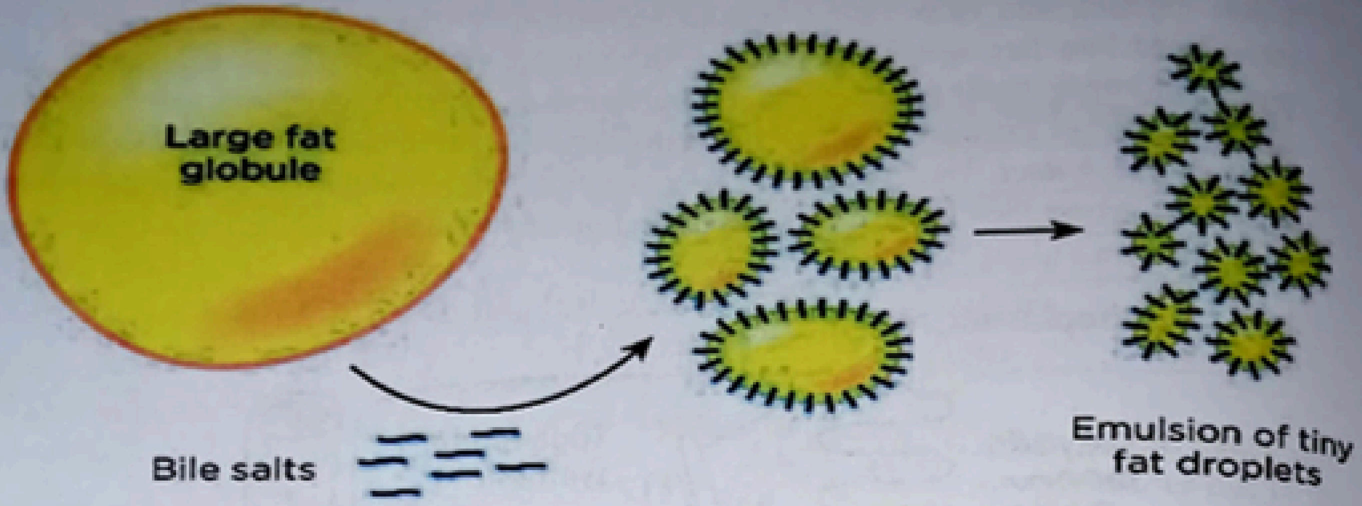
- The liver is the largest internal organ of the body. It has a wide range of functions, including ***detoxification*** and ***production of bile*** to help digestion.
- Liver secretes ***bile***, which may be temporarily stored in the gall bladder and release into duodenum through ***bile duct***.

Composition of Bile

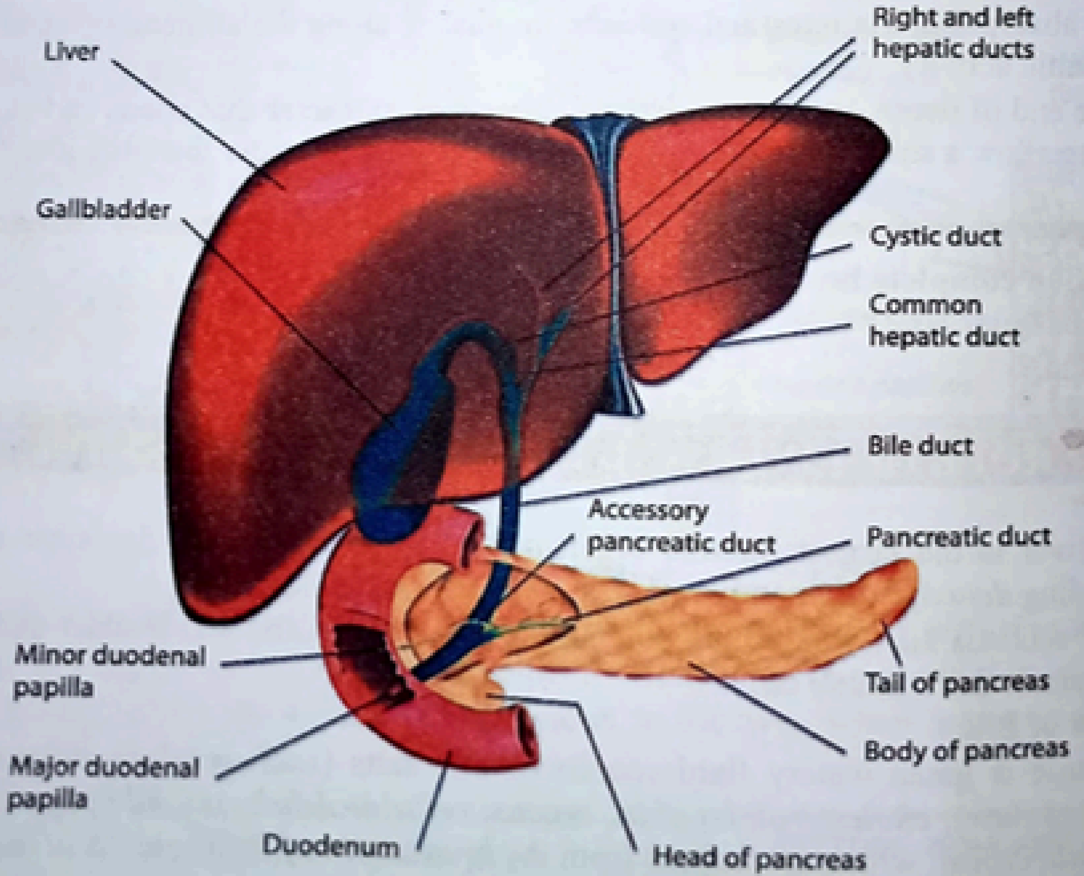
- The bile is green watery fluid consist of bile salts (***sodium glycocholate*** and ***sodium taurocholate***), ***cholesterol, lecithin, mucus, cellular debris*** and ***bile pigments (bilirubin*** and ***biliverdin)***, which are formed from the ***breakdown of hemoglobin in the liver***.

Role of Constituents of Bile

- ***Bile salts*** reduce surface tension of the fat globules and ***emulsify*** them into small droplets and thus increase their total surface area. It is then easily ***digested by water-soluble lipase***.



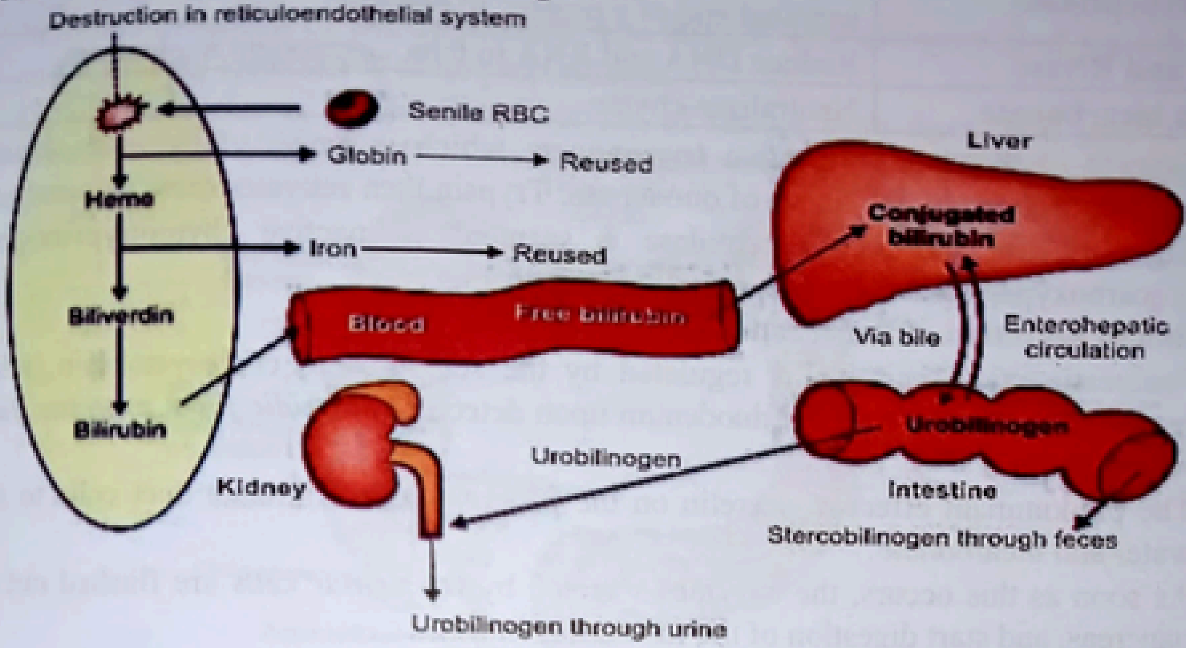
- Intestinal bacteria convert bilirubin into pigments that give the feces its characteristic brown colour. Some of these pigments are absorbed from the intestine, modified in the kidneys and excreted in the urine, contributed to the characteristic yellowish colour of the urine.
- If bile pigments are prevented from leaving digestive tract, they may accumulate in blood, causing a condition known as ***jaundice***.
- Cholesterol may precipitate in the gall bladder to produce ***gall stones***, which may block the release of bile.



- The ***gall bladder is a sac-like structure*** on the inferior surface of the liver that is about ***8 cm long*** and ***4 cm wide***. It is connected to the common bile duct by the ***cystic duct***. Bile is secreted by the liver and ***stored in the gall bladder***.

CRITICAL CONCEPT!

Formation and Circulation of Bile Pigments:



Regulation of Secretion of Bile

- Acidic chyme in the lumen of the duodenum stimulates other endocrine cells to release ***secretin*** which is carried through circulatory system to the liver and ***stimulates liver to release bicarbonate*** into the bile.
- Fatty acids in the lumen of duodenum stimulate endocrine cells of release ***Cholecystokinin.*** This hormone stimulates contractions in the smooth muscles of the gall bladder allowing bile release into the duodenum.

Role of Pancreas

- The ***pancreas*** is complex organ composed of both ***endocrine*** and ***exocrine tissues*** that performs several functions.
- The pancreas consists of a head, located within the curvature of duodenum, a body and a tail, which extend to the spleen.
- As an ***endocrine gland*** (Islets of Langerhans), it produces several important hormones, including insulin and glucagon.

Pancreas as an Exocrine Gland

- The exocrine secretion of pancreas is called pancreatic juice and has two major components: an aqueous component and an enzymatic component.
- Pancreatic juice is ***slightly alkaline***. Its ***pH is about 8***. Included in this juice are the enzymes that digest all the principal components of food i.e., carbohydrates, lipids and proteins.

Components of Pancreatic Juice

Component	Role
Pancreatic Amylase/ Amylopsin	Continues the polysaccharide digestion that was initiated in the oral cavity. It hydrolyzes polysaccharides (starch/glycogen) into maltose and even to glucose.
Pancreatic Lipase	Principal enzyme for the hydrolysis of fats and hydrolyze them into free fatty acids, glycerides, glycerol and cholesterol.

Trypsin	Protein digesting enzyme (Proteins → Polypeptides + Peptones)
Chymotrypsin	Protein digesting enzyme (Proteins → Polypeptides + Peptones)
Carboxypeptidase	It is a protease enzyme that hydrolyzes a peptide bond at the C-terminal end of a protein or peptide.
DNase and RNase	Reduce DNA and RNA to their component nucleotides
Sodium bicarbonate	Neutralizes chyme

- Trypsin is secreted as inactive trypsinogen, which is activated by ***enterokinase***, an enzyme secreted by the lining of duodenum. Trypsin then activates more trypsinogen.
- Chymotrypsin and carboxypeptidase is secreted as inactive chymotrypsinogen and procarboxypeptidase, which is activated by trypsin.

Regulation of Secretion of Pancreatic Juice

- Pancreatic juice secretion is regulated by the secretin and cholecystokinin, which is produced by the walls of the duodenum upon detection of ***acidic food, proteins, fats*** and ***vitamins***.
- The predominant effect of secretin on the pancreas is to stimulate duct cells to secrete water and bicarbonate.
- As soon as this occurs, the enzymes secreted by the ***acinar cells*** are flushed out of the pancreas, and start digestion of the food components.

CRITICAL THINKING

2. A protease which is protein in nature:
A. Lipase B. Enterokinase
C. Gastrin D. Amylase

3. Which of the following glandular secretions involved in digestion would be most likely released initially as inactive precursors?
A. Protein-digesting enzymes B. Fat-solubilizing bile salts
C. Acid-neutralizing bicarbonate D. Carbohydrate-digesting enzymes

LARGE INTESTINE

- Large intestine is last part of alimentary canal. It is divided into caecum, colon and rectum.
- The junction between ileum and large intestine is ***ileocecal junction*** gaurded by ***ileocecal sphincter***.

Caecum

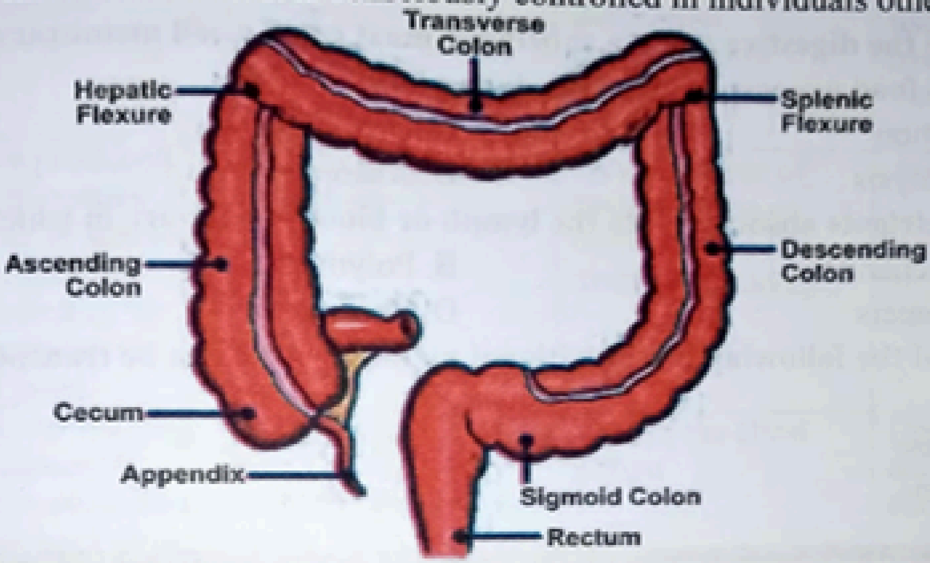
- ***Caecum*** is a blind sac and proximal end of the large intestine. It is the structure the small and large intestines meet.
- Attached to the caecum is a small, blind and finger-like tube which is called ***appendix***. It is measured about ***9-10cm in length*** and its wall contains many ***lymph nodules***. Inflammation of appendix is called ***appendicitis***.

Colon

- Colon is longest part of large intestine ***measuring about 1.5-1.8 m***. It is further divided into ascending, transverse, descending and sigmoid colon.
- The materials that pass from small intestine to large intestine contain a large amount of water, dissolved salts and undigested material.

Rectum

- It is the last part of large intestine where feces are temporarily stored and rejected through anus at intervals.
- Anus is surrounded by ***two sphincters***. The internal anal sphincter is of smooth muscles and outer anal sphincter is of striped muscles.
- ***Defecation reflex*** is involved in emptying of rectum from feces. It is generated when rectum is filled with feces. It is consciously controlled in individuals other than infants.



Functions of Large Intestine

- The proximal half of the large intestine functions to absorb water and electrolytes.
- The fecal matter contains a large number of bacteria, plant fibers, sloughed off mucosal cells, mucus, cholesterol, bile pigments and water.
- The large intestine also helps in absorption of vitamins made by the bacteria that normally live in large intestine as mutualistic resident. These bacteria produce large amounts of vitamins, the most important of which are ***vitamin K*** and ***biotin***.
- The mucosa of the large intestine ***secretes bicarbonates*** to neutralize the increased acidity and also acts as ***mucosal barrier*** and ***protects from microbial infections and invasions***.
- Less absorption leads to ***diarrhea*** and then dehydration. If this condition is unchecked, it leads to dehydration and even death. Excessive absorption of water leads to ***constipation***.

CRITICAL CONCEPT!

Vitamin-K is produced by *E. coli* bacteria in large intestine. *E. coli* is anaerobic facultative bacteria.

Defecation Reflex in Adults and Infants

- When it is appropriate, an ***adult person*** usually can initiate the defecation reflex by holding a deep breath and contracting the adnominal muscles. The action increases the internal pressure and forces the faeces into the rectum.

CRITICAL THINKING?

4. **Absorption of Vitamin-K occurs at:**

   A. Ileum
   B. Rectum
   C. Colon
   D. Caecum

- When the rectum is filled, its wall is distended and the defecation reflex is triggered. As a result, peristaltic waves in the descending colon are stimulated, and the internal and external anal sphincter is signaled to relax and the fecal matter is forced to the outside.

- The defecation reflex persists only for a few minutes and quickly dies. A person usually can inhibit defecation voluntarily by keeping the external anal sphincter contracted.
- In *infants*, the defecation reflex causes automating emptying of the lower bowel at inconvenient times during the day because of lack of conscious control exercised through voluntary contraction of the external anal sphincter.

CRITICAL THINKING?

5. To leave the digestive tract, a substance must cross a cell membrane. During which stage of food processing does this take place?

A. Ingestion B. Digestion
C. Hydrolysis D. Absorption

6. Most nutrients absorbed into the lymph or bloodstream are in which form?

A. Disaccharides B. Polymers
C. Monomers D. Enzymes

7. Which of the following is a nutritional monomer that can be transported in the blood?

A. Sucrose B. Maltose
C. Alanine D. Dipeptide

SOME COMMON DISORDERS RELATED TO HUMAN DIGESTIVE SYSTEM

Disorder	Description	Cause/s	Symptoms and Complications	Treatment
Dyspepsia	Incomplete or imperfect digestion	Acidity in stomach, faulty function of stomach, insufficient quantity and quality of bile	Abdominal discomfort, flatulence, heartburn, nausea, vomiting	Antibiotics, Cimetidine
Food Poisoning/ Botulism	Illness from indigestion of food contaminated with toxins Severe form of food poisoning	*Clostridium botulinum, Salmonella spp, Compylobacter spp.* Entering through unpasteurized milk or improperly cooked meat.	Abdominal pain, nausea, vomiting, diarrhea, fatigue, dizziness, double vision, headache	Maintain good hygienic conditions, use ORS, Loperamide antibiotics are prescribed
Obesity	Accumulation of abnormal fats in the body	Over-eating, Eating too much fatty food, hormonal	May cause hypertension, Cardiac diseases, diabetes mellitus, stomach disorders	Reducing fatty food, regular exercise, eat balanced dies, hormonal therapy
Anorexia Nervosa	Loss of appetite due to fear of becoming obese	Psychological with the onset of puberty and sexuality	Weight loss, metabolic disturbance	Psychiatric therapy, feeding through some alternative route
Bulimia Nervosa	It is characterized by	Neurotic disorder	Self-induced vomiting, fasting,	Overcome effects of weight loss

	the bouts of over-eating fattening food		purging, serum electrolyte imbalance, recurring infections	and malnutrition
Piles	Masses of dilated tortuous veins in anorectal mucosa	Unhygienic conditions	Bleeding, constipation, depressed urge to defecation, distention of rectum	Improve hygiene, increase roughage in food, use of laxatives, avoid sitting on hard surfaces, surgical removal
Ulcer	Sore produced by the eating away of walls of stomach or duodenum by the digestive enzymes	Excess gastric HCl secretion	Development of hole, spilling of contents into the abdominal cavity	Antacid, milk,
Pyrosis	Painful burning sensation in chest associated with back flush of acidic chyme into esophagus	Over-eating, eating fatty food, lying down immediately after meal, alcohol and caffeine consumption, smoking	Pain in the chest region	Decrease in acidity, avoid eating spicy food

GASEOUS EXCHANGE/RESPIRATORY SYSTEM

- Like other life processes, the respiration process also occurs at ***cellular level*** and ***organismic level***. The process of respiration that occurs at cellular level is also called ***internal respiration*** which is a catabolic process. On the other hand, the process of respiration that occurs as organismic level is called ***external respiration***.
- Both the processes are interlinked as the oxygen, required for cellular respiration, is inhaled from the environment while the carbon dioxide, which is produces in cellular respiration, is exhaled into the environment.

Properties of Respiratory Surface

- The area where gaseous exchange with the environment actually takes place is called ***respiratory surface.*** It must have the following properties so that diffusion can occur effectively:

i. Must be moist.
ii. Must be permeable so that gases can pass through.
iii. Must be thin, because diffusion if only efficient over distance of ***1mm or less***.
iv. Should possess a large surface area.
v. Should possess a good blood supply.
vi. There should be a good ventilation mechanism to maintain steep diffusion gradient across respiratory surface.

Anatomy of Human Respiratory System

- The human respiratory system can be divided into two regions e.g., upper respiratory tract and lower respiratory tract.

1. *Upper respiratory tract* includes nostrils, nasal cavity and pharynx
2. *Lower respiratory tract* includes the larynx, trachea, bronchi, and lungs.

- Many structures of human respiratory system form the ***air passage way*** which provide the path through which air enters or leaves the lungs.
- It consists of following components in sequence:
Nostrils → Nasal Cavities → Pharynx → Larynx → Trachea → Bronchi → Terminal Bronchioles → Respiratory Bronchioles → Alveolar Ducts → Alveolar Sacs

Components	Anatomy	Physiology
Nostrils (2)	• Bone and cartilage • Hair • Mucous membrane	• Filtration of larger particles. • Moistening • Warming (about 30°C)
Nasal Cavities (2)	• Each cavity subdivided into 3 passage ways. • Ciliated epithelium • Mucous membrane	• Filtration • Moistening • Warming (about 30°C)
Pharynx/ Throat	• Cone-shaped muscular passage • Divided into nasopharynx, oropharynx, and laryngopharynx • Mucous membrane	• Common part of digestive system and respiratory system • Channelizes air to larynx
Larynx/ Voice box	• Composed of cartilage and muscles • Glottis • Epiglottis • Vocal cords	• Air passage way • Voice production
Trachea/ Windpipe (1) (ventral to oesophagus)	• 15-20 C-shaped cartilage rings • Ciliated epithelium • Mucous cells/ Goblet cells	• Air passage way • Filtration • Moistening
Primary Bronchi (2)	• C-shaped cartilage rings • Ciliated epithelium • Mucous cells	• Air passage way • Filtration • Moistening
Secondary & Tertiary Bronchi.	• Irregular cartilage plates • Ciliated epithelium • Mucous cells	• Air passage way • Filtration • Moistening
Terminal Bronchioles	• Diameter of 1 mm or less • No cartilage • Ciliated epithelium • Mucous cells	• Air passage way • Filtration • Moistening
Respiratory Bronchioles	• No cartilage • No Ciliated epithelium • Mucous cells	Gaseous exchange with blood
Alveolar Ducts & Alveolar Sacs	• Single layered surrounded by blood capillaries • Lined by surfactant	Gaseous exchange with blood

CRITICAL THINKING

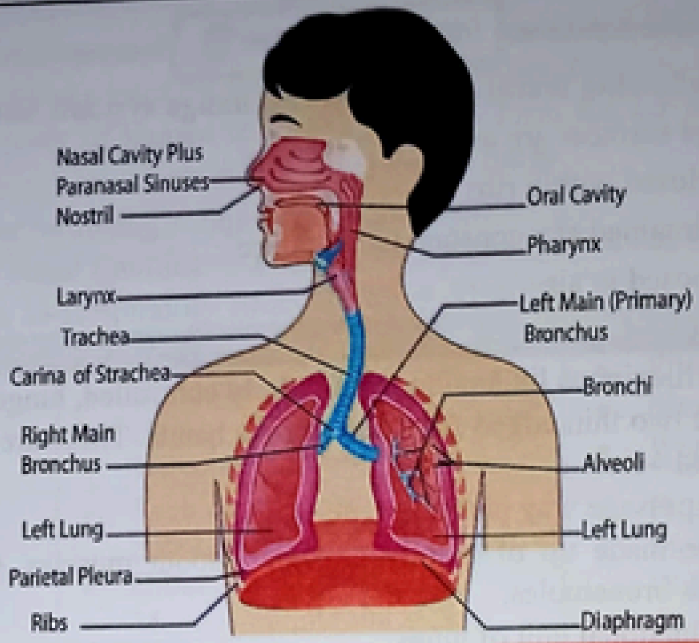
8. **Which of the following features do all gas exchange systems have in common?**
A. The exchange surfaces are moist
B. They are enclosed within ribs
C. They are maintained at a constant temperature
D. They are exposed to air

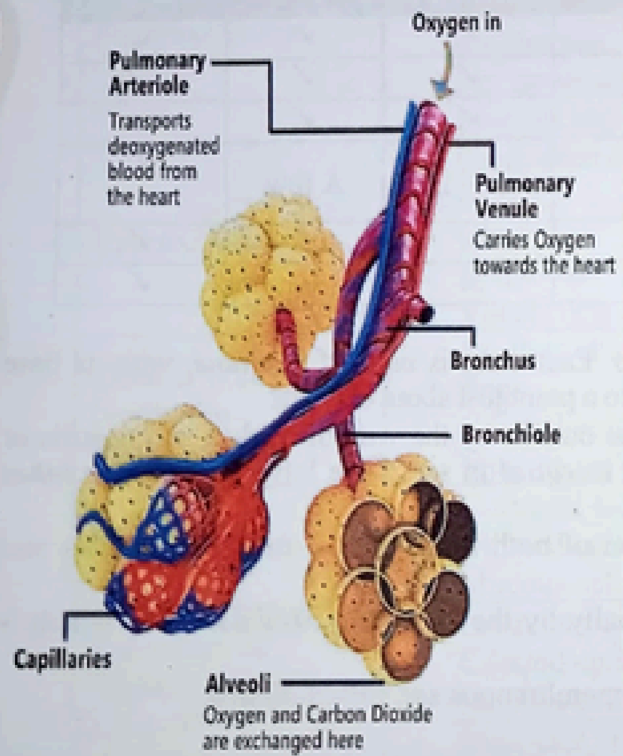
- Epiglottis is cartilaginous lid having a muscularly controlled, hinge-like action.
- Vocal cords are two thin edged stretched fibrous bands. These are larger in male so male have low pitched voice.
- Cartilage in air passage way prevents collapse.
- Bronchioles are made up of mainly circular smooth muscles. Change in diameter is possible through bronchioles.
- Air sac is the functional unit of lungs.

Components	Cartilage	Goblet cells	Smooth muscles	Cilia	Exchange of gases
Trachea	✓	✓	✓	✓	×
Bronchi	✓	✓	✓	✓	×
Terminal Bronchiole	×	×	✓	✓	×
Respiratory Bronchiole	×	×	×	A few	×
Alveolar Duct	×	×	×	×	✓
Alveoli	×	×	×	×	✓

Lungs
- The lungs are principle organs for respiration. Each lung is ***conical in shape***, with its base resting on the diaphragm and its apex extends to a point just about clavicle.
- They are closed sacs that are connected to the outside by the way of trachea and nostrils or mouth. The right and left lungs are ***slightly unequal*** in size. The left lung has ***two lobes*** while the right lung has ***three lobes***.
- The ***hilum*** is a triangular shaped depression of both lungs where the blood vessels and airways pass into the lungs.
- The right and left lungs are separated medially by the heart and ***Mediastinum***, which is the area between the lungs.
- Lungs are covered by a double layered thin membranous sac called ***pleura***.

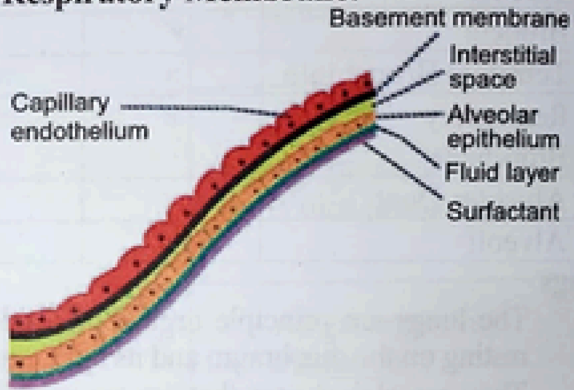
Surfactant
- It is the mixture of lipoproteins ***secreted by alveolar epithelium*** which forms a layer over the surface of the fluid within the alveoli to reduce surface tension.
- It speeds up the transport of respiratory gases and helps to kill bacteria, which reach the alveoli.
- In premature infants, ***respiratory distress syndrome*** is common due to its deficiency. It is more common in infants with a gestation age of ***less than 7 months***.





CRITICAL CONCEPT!

Respiratory Membrane:



Respiratory membrane is a membranous structure through which exchange of respiratory gases takes place. It is formed by Epithelium of respiratory unit and Endothelium of pulmonary capillary. Epithelium of respiratory unit is a very thin layer.

MECHANISM OF BREATHING

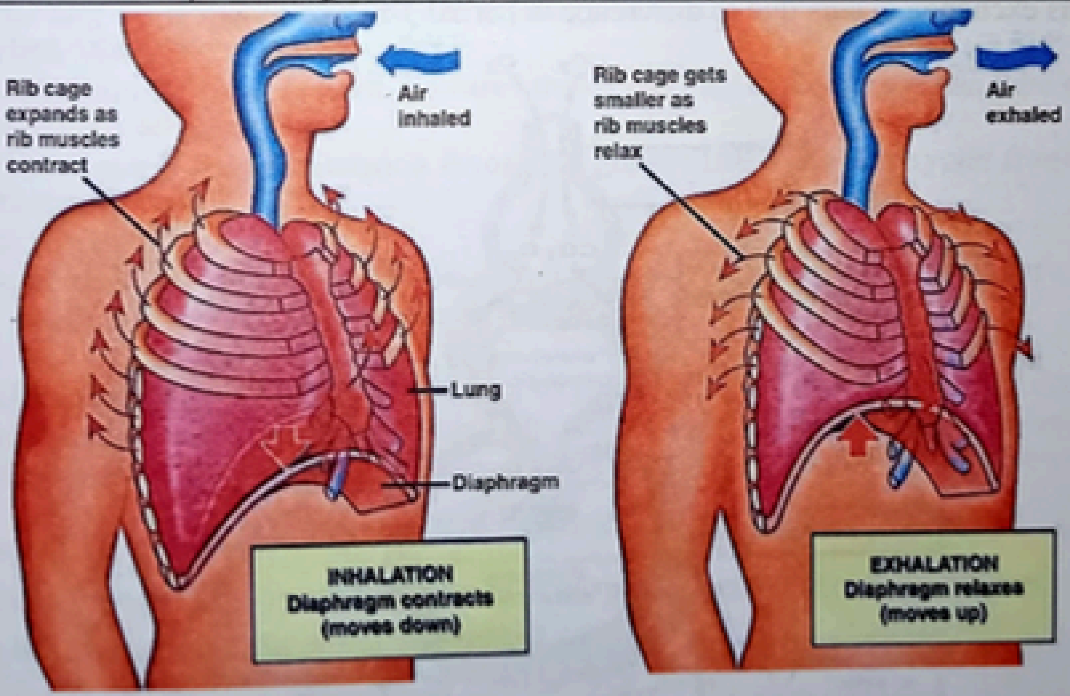
- Breathing is a process by which fresh air containing oxygen is pumped into the lungs and air with more carbon dioxide is pumped out of lungs.
- During rest, breathing occurs rhythmically at the ***frequency of 15-20 times/min*** in humans and it can increase to ***30 times/min during exercise***.
- ***Lungs are spongy in nature***. They themselves neither draw in air nor push it out.
- The floor of the ***chest cavity*** is ***diaphragm*** which is a ***sheet of skeletal muscle***. It separates the thoracic cavity from abdominal cavity.

- Walls of the ***chest cavity*** are composed of ***ribs*** and ***intercostal muscles***. There are two sets of intercostal muscles between each pair of ribs: the ***external intercostal*** and ***internal intercostal muscles***. The muscle fibres run diagonally but in opposite direction.

Phases of Breathing

- Breathing is a ***mechanical process*** consisting of two phases; ***inspiration*** and ***expiration***.

Features	Inspiration	Expiration
Definition	It is the process of taking in of the air (rich in O_2 and poor in CO_2)	It is the process of taking out of the air (rich in CO_2 and poor in O_2)
Another Name	Inhalation	Exhalation
Status of Lungs	Passive expansion of lungs	Passive recoiling of lungs
Status of Diaphragm	• Contracts • Moves down • Becomes less dome shaped	• Relaxes • Moves up • Become more dome shaped
Intercostal/Rib Muscles	• External intercostal →Contract • Internal intercostal → Relax	• External intercostal → Relax • Internal intercostal → Contract
Rib cage	Moves • Upward • Forward • Outward	Moves • Downward • Inward • Backward
Volume of Thoracic Cavity	Increases	Decreases
Changes in Pressure in the Thorax	Decreases	Increases
Air Moves	Into lungs	Out of lungs

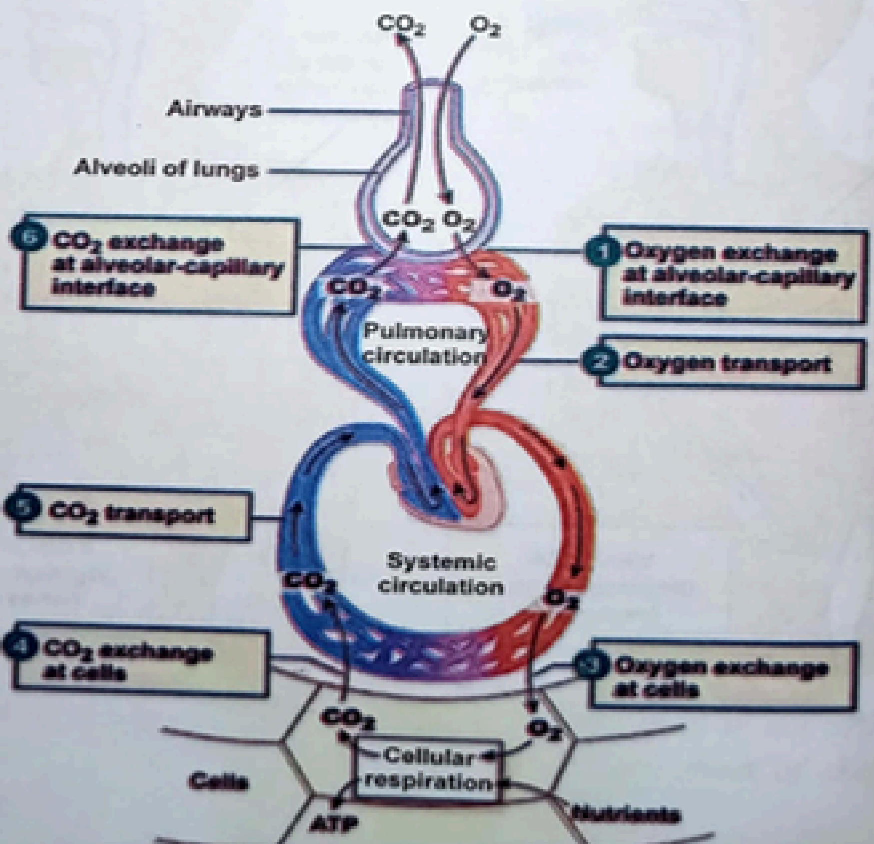


Control of Breathing

- Normally, breathing is ***controlled involuntarily*** but within limits the rate and depth of the breathing are also under ***voluntary control*** as shown by the ability to hold the breath.
- ***Involuntary control*** of breathing is carried out by a breathing centre located in ***medulla oblongata*** of the brain.
- The ***ventral (lower) portion*** of the breathing centre acts to ***increase the rate*** and ***depth of inspiration*** and is called ***inspiratory centre.***
- The ***dorsal (top) and lateral (side) inhibit*** inspiration and stimulate expiration. These regions form the ***expiratory centre***.
- The breathing centre communicates with the intercostal muscles by way of the ***intercostal nerves*** and with the diaphragm by way of the ***phrenic nerve***. Rhythmic nerve impulses to the diaphragm and intercostal muscles bring about ventilation movements.
- ***Voluntary control*** is also used during ***forced breathing, speech, singing, sneezing*** and ***coughing***. When such control is being exerted, impulses originating in the ***cerebral hemisphere*** pass to the breathing centre which then carries out the appropriate action.

TRANSPORT OF GASES

- Intake of oxygen and release of carbon dioxide by blood passing through capillaries of alveoli is brought about by the following factors:
- Diffusion of oxygen in and carbon dioxide out occurs because of the difference in partial pressures of these gases.
- Within the rich network of capillaries surrounding the alveoli. Blood is distributed in extremely thin layers and therefore, exposed to large alveolar surface.
- Blood in lungs is separated from alveolar air by extremely thin membranes of the capillaries and alveoli.
- Gaseous exchange follows principles of diffusion.
- This exchange occurs due to difference in partial pressure of gases.



Transport of Oxygen

- In humans, the transport of oxygen is done by two ways:
- Approximately, *97%* of the oxygen is carried by RBCs as ***oxyhaemoglobin.*** Haemoglobin is one of the most important respiratory pigment and acts as an ***efficient oxygen carrier***.
- *3%* is transported as dissolved oxygen in the plasma.

At the Level of Lungs

- Haemoglobin readily combines with oxygen to form ***bright red oxyhaemoglobin***.
- $Hb + 4O_2 \rightarrow Hb4O_2$
- The ability of hemoglobin to bind with oxygen is called ***oxygen carrying capacity*** of blood. It is ***directly proportional to the pO_2***.
- ***Maximum capacity*** of haemoglobin to carry oxygen is about 20ml/100ml of blood at sea level. At this, blood will be 100% saturated and is achieved at 100mmHg pO_2.
- Under normal conditions, blood of alveoli of lungs is not completely oxygenated. ***At 115 mmHg*** oxygen tension, there is 19.6ml of O_2/100ml of blood, where hemoglobin is 98% saturated.

At the Level of Aerobic Tissue

- ***Oxyhaemoglobin is unstable*** and splits into the normal purple red haemoglobin and oxygen in the condition of low oxygen concentration and low pressure. ***Carbonic anhydrase*** present in RBCs facilitates this activity.

$$HbO_2 \xrightarrow{\text{Carbonic Anhydrase}} Hb + O_2$$

- When oxygen pressure falls ***below 60 mmHg***, as in many cells and tissues. The oxygen saturation of hemoglobin decreases very sharply, which results in the liberation of large quantities of oxygen from hemoglobin.
- In this way in the aerobic tissues where the oxygen tension is low, oxyhemoglobin dissociated rapidly.
- Under normal conditions every 100ml of blood gives ***5ml O_2*** to aerobic tissue.

Factors Affecting O_2 Holding Capacity of Hemoglobin

1. **Carbon Dioxide**
   - When carbon dioxide pressure increases the oxygen tension decreases and the capacity to hold oxygen becomes less.
   - Increased carbon dioxide tension favors the greater liberation of oxygen from the blood to the tissue.
2. **Temperature**
   - Rise in temperature causes a decrease in oxygen carrying capacity of blood/Hb.
   - For example, in increased muscular activity.
3. **pH**
   - With decrease in pH of blood amount of oxygen bound to haemoglobin also declines.
   - Decreased pH results from increase in hydrogen ions. Hydrogen ions combine with the protein part of hemoglobin molecules causing a decrease in its ability to bind oxygen.

CRITICAL THINKING

9. **Heamoglobin is having a function of transport of gases and metal ion, what could be any other function of haemoglobin?**

A. Act as Buffer B. Oxygen storage
C. Nitrogen binding D. Act as enzyme

Transport of Carbon Dioxide

- Carbon dioxide is ***more soluble*** than oxygen and dissolved freely in the tissue fluid surrounding the cells. Its path from aerobic cells to blood is given below:

  CO_2 produced by the aerobic cell → Dissolved in tissue fluid → Passes to blood
- CO_2 which is ***much more important than oxygen*** as a regulator of normal alveolar ventilation/breathing. Under certain circumstances, however, a reduced pO_2 in the arterial blood does play an important stimulatory role, especially during the conditions of shock.

Ways of Transport of CO_2

- CO_2 is transported in the blood in three main ways:

Sr. No.	Percentage	Transported As
1.	70%	Bicarbonate ions
2.	23%	Carboxyhemoglobin/Carbaminohemoglobin
3.	7%	Dissolved in blood plasma

As Bicarbonate Ions

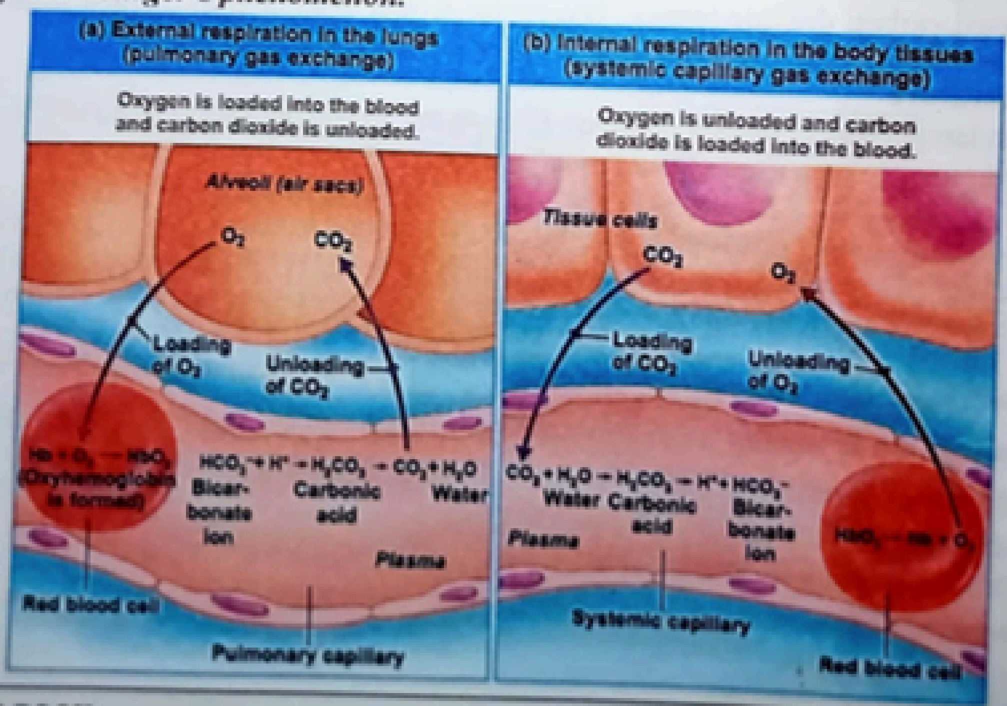
- Approximately, **70%** of CO_2 is carried in the blood as HCO_3^{-1}.
- CO_2 diffuses into the blood, enters the RBCs and combines with water to form carbonic acid in the presence of carbonic anhydrase.
- $CO_2 + H_2O \xrightarrow{\text{Carbonic Anhydrase}} H_2CO_3$
- H_2CO_3 is an unstable compound and dissociates to form H^+ and HCO_3^{-1}.

$$H_2CO_3 \rightarrow H^+ + HCO_3^-$$

- Accumulation of H^+ increases acidity in the blood, hence pH decreases. The H^+ readily associates with the $Hb4O_2$ to form hemoglobinic acid and O_2 is releases to the tissue as shown below:

$$Hb\,4O_2 + H^+ \rightarrow HHb + 4O_2$$

- From inside of the RBCs, negatively charged HCO_3^{-1} diffuse to the blood plasma. This is balanced by the diffusion of Cl^- in the opposite direction.
- The movement of both of the negatively charged species is achieved by special ***HCO_3^{-1}-Cl^- carrier protein*** that exists in the membrane of RBCs and moves the ions in opposite direction, maintaining the balance of ions on either side. This is called ***chloride shift/Hamburger's phenomenon.***



- The Cl^- that enters the RBCs combines with K^+ to form ***KCl***, whereas HCO_3^{-1} in the blood plasma combines with Na^+ to form ***$NaHCO_3$***. The blood pH is thus maintained at approximately ***7.4 by the buffer mechanism*** that exists in the blood.
- In lungs, process reverses and HCO_3^{-1} combine with H^+ to release CO_2 and H_2O.

As Carboxyhaemoglobin/Carbaminohaemoglobin

- About ***23%*** of CO_2 is carried as carboxyhaemoglobin/carbaminohaemoglobin. It is formed when CO_2 combines with ***amino group of globin part*** of haemoglobin.
- When PCO_2 is higher in the tissues than blood, formation of carboxyhaemoglobin/carbaminohaemoglobin occurs.
- When the PCO_2 is higher in the blood than tissues as in case of lungs carboxyhaemoglobin/carbaminohaemoglobin releases its CO_2.

As Dissolved CO_2 in Plasma

- Only ***7%*** of CO_2 is carried this way. This is rather inefficient way to carry CO_2, but it does occur.

Capacity of Blood for CO_2

- ***Arterial blood*** contains about ***50ml*** of CO_2/100ml of blood, whereas ***venous blood*** contains ***54ml*** of CO_2/100ml of blood.
- In this way, each 100ml of blood takes 4ml of CO_2 as it passes through the tissues and gives 4ml of CO_2 as it passes through lungs.

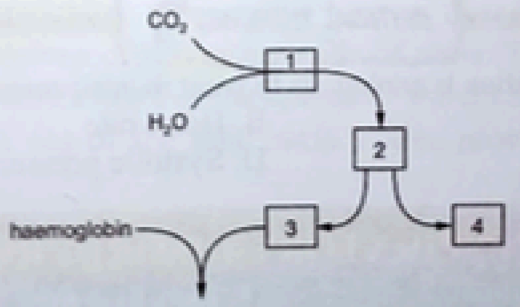
CRITICAL CONCEPT!

Hemoglobin as a Buffer

Hemoglobin is the principal protein inside of red blood cells and accounts for one-third of the mass of the cell. During the conversion of CO_2 into bicarbonate, hydrogen ions liberated in the reaction are buffered by hemoglobin, which is reduced by the dissociation of oxygen. This buffering helps maintain normal pH. The process is reversed in the pulmonary capillaries to re-form CO_2, which then can diffuse into the air sacs to be exhaled into the atmosphere.

CRITICAL THINKING

10. The diagram shows the pathway for the transport of carbon dioxide that occurs in red blood cells.



Which row is correct?

	1	2	3	4
A.	Carbaminohaemoglobin	Haemoglobinic acid	Hydrogen ions	Bicarbonate ions
B.	Carbonic anhydrase	Carbonic acid	Hydrogen ions	Bicarbonate ions
C.	Carboxyhaemoglobin	Carbonic anhydrase	Carbonic acid	Carbon dioxide
D.	Haemoglobinic acid	Carbonic acid	Bicarbonate ions	Hydrogen ions

ROLE OF RESPIRATORY PIGMENTS

- Respiratory pigments are ***colored molecules***, which acts as oxygen carriers by binding reversibly to oxygen. The most important respiratory pigments in humans are ***haemoglobin*** and ***myoglobin***.

Features	Haemoglobin	Myoglobin
Found in	RBCs/Blood	Muscles
Structure	• It consists of four polypeptide chains • Each molecule possesses four iron containing haem groups • It exhibits quaternary structure	• It consists of one polypeptide chain • Each molecule possesses one iron containing haem group • It exhibits tertiary structure
Capacity for Oxygen	More	Less
Affinity with Oxygen	Less	More
Loses Oxygen	At 60 mmHg PO_2	At 20 mmHg PO_2
O_2 molecules Bound	4	1
Main Function	It transports oxygen	It stores oxygen

RESPIRATORY VOLUMES

- Breathing occurs in cyclic manner due to the movements of the chest wall and the lungs. The resulting changes in pressure, causes changes in lung volumes i.e., the amount of air, the lungs are capable of occupying.
- ***Respiratory volume*** is the amount of air inhaled, exhaled and stored within the lungs at any given time.
- In an adult human being, when the lungs are fully inflated the total inside capacity of lungs is about ***5- 6 liters***. This is called ***total lung capacity***.
- The amount of air which is inhaled or exhaled at rest is called ***tidal volume***. Its average value is about ***500ml***.
- The amount of extra air inhaled during a deep breath is called ***inspiratory reserved volume***. This can be as high as ***3000ml***.

CRITICAL THINKING

11. Tidal volume in respiration is analogous to what measurement in cardiac physiology?

A. Cardiac output B. Heart rate
C. Stroke volume D. Systolic pressure

RESPIRATORY DISORDERS

Features	Tuberculosis	Emphysema	Cancer
Disease	Infectious disorder of respiratory system	Breakdown of alveoli	Malignant tumor in lungs and show potentially unlimited growth
Cause	*Mycobacterium tuberculosis* (air-born droplets) Malnutrition Poor living conditions	Smoking	Smoking (90%) Other pollutants

Pathogenesis	Contagious disease Lung damage Cough & fever	• Smoke chemicals → Weaken walls of alveoli • Irritants → Smokers cough → Bursting of weak alveoli → ↓ Absorptive area → ↓ Gaseous exchange → Breathlessness & exhaustion • Inflammation of bronchioles → Obstruction → ↑ airway resistance	Malignant tumor Local expansion by invasion and systemic by metastasis Occlusion of respiratory passage
Treatment	Medicine/Antibiotics	Quitting smoking, Bronchodilator, Antibiotics	Pneumonectomy Chemotherapy & radiotherapy

TRANSPORT IN PLANTS

Uptake and Transport of Minerals

- The roots of a plant not only ***anchor*** the plant body in the soil, but also *absorb minerals* and ***water*** from the soil. These nutrients are first absorbed by roots epidermal cells from where these are moved to the xylem and then through xylem, these materials are ultimately reached to the leaves.
- There are three types of nutrients needed by the plants, carbon dioxide, water and minerals besides light to carry out photosynthesis.
- The rate of absorption of individual mineral which is independent of rate of absorption of water molecules is determined by:

(i) Concentration both inside and outside of the root cells.
(ii) The ease with which it can passively penetrate cell membrane.
(iii) Extent to which carrier molecules and active absorption is involved.

- To get these materials, roots must provide large surface area for absorption, which is achieved by extensive branching. The roots bear a dense cluster of tiny hair-like structures, which are extensions of epidermal cells of roots. These are called ***root hairs***, which are in fact the sites where most of the uptake of water and minerals takes place.
- It has been estimated that out of the total surface area provided by the roots, ***67% is provided by the root hair***.
- Plants are able to synthesize all their required compounds, with the help of the minerals and H_2O from soil, CO_2 from air, and light energy.
- Most of the minerals enter the root hairs or epidermal cells of roots ***along with water in bulk flow***, but some are taken in by diffusion, facilitated diffusion, or active transport.

Mineral Absorption by Roots

- The minerals available to plants for absorption are dissolved in the soil water. Their ***concentration varies according to the fertility*** and the acidity of the soil, besides other factors.
- When the soil minerals are not in solution but are bound by ionic bonds to soil particles, they are not available to plants.

Processes Involved in Absorption by Roots

- The uptake of minerals by root cells is a combination of passive uptake and active uptake, involving the use of energy in the form of ATP.

- The passive uptake involves diffusion. The minerals also move down their concentration gradient through plasmodesmata to cells of cortex, endodermis, pericycle and then to sap in xylem cells. From here they are ***pulled up by transpiration pull*** to different parts of plant.
- The ***diffusion*** of ions along with water also takes place by mass flow along the apoplast pathway. Ions moving in the apoplast can only reach the endodermis, where casparian strips prevent further progress.
- To cross the endodermis, ions must pass by diffusion or active transport into endodermis cells, entering their cytoplasm, and possibly their vacuoles. The ions then reach the xylem cells.
- ***Diffusion of ions can also take the vacuolar pathway*** where the ions move along their concentration gradient through the cell membranes, cytoplasm, and tonoplast (the membrane of vacuoles), and reach the dead xylem cells.
- Most of ions are taken up by the roots by the process of ***active transport***. By this method plants can take a mineral that is in higher concentration inside the root cells than in the soil solution.
- In this process molecules and ions move from their low concentration to their higher concentration (i.e. against the concentration gradient), through cell membrane, by the use of energy in the form of ATP.
- Some nutrients are carried from the soil to the epidermal cells of roots through their cell membrane by ***facilitated diffusion***.
- In this type of diffusion, carrier molecules within the cell membrane transport nutrients across the membrane.
- These carrier molecules are proteins which are present within cell membrane of epidermal and other root cells.

WATER POTENTIAL

- Water molecules ***possess kinetic energy*** which means that in liquid or gaseous form, they move about rapidly and randomly from one place to another. So, greater the concentration of the water molecules in a system, the greater is the total kinetic energy of water molecules. This is called ***water potential*** and is represented by ***Ψw***.
- Ψw of a medium is directly proportional to the concentration of water in that medium; therefore, pure water has highest value of Ψw which is designated a value of ***zero***.
- Ψw of all the solutions or the cells must be less than zero i.e., in negative range.

Factors Effecting Ψw:

- The Ψw in plant solutions is mainly influenced by the solute concentration (***osmotic or solute potential = Ψs***) and the pressure potential (***Ψp***). The pressure potential is generated when water enters and inflates plant cells.

Osmotic (Solute) Potential = Ψs

- Solutes reduce Ψw by consuming some of the potential energy available in the water. This measure of decrease in Ψw of a medium due to the addition of solutes is called ***solute/osmotic potential***.
- It can also be defined as 'the measure of the change in water potential of a system due to the presence of solute molecules'.
- Ψs is negative in a plant cell and zero in distilled water. More solute molecules present, lower (more negative) is the Ψs.

Pressure Potential (Ψs)

- The measure of increase in water potential of a medium due to the addition of water or due to the pressure greater than the atmospheric pressure is ***pressure potential.***
- If pressure greater than atmospheric pressure is applied to pure water or a solution, its water potential increases. It is ***equivalent to pumping water*** from one place to another. Such a situation may arise in living systems.
- When water enters plant cells by osmosis, pressure may be built up inside the cell making the cell turgid and increasing the water potential.
- Thus the total water potential is sum of Ψs and Ψp.

Ψw	=	Ψs	+	Ψp
Water potential		**Solute potential**		**Pressure potential**

- If we use the term water potential, the tendency for water to move between any two systems can be measured; not just from cell to cell in a plant but also from soil to root from leaf to air or from soil to air. The steeper the potential gradient the faster is the flow of water along it.
- As the individual component change, they raise or lower the total Ψw of a system. When this happens, water moves to equilibrate.
- Therefore, for water to move through the plant from the soil to the air ***(transpiration)*** the conditions must exists as:

Ψw of soil > Ψw of the roots > Ψw of the leaf > Ψw of the atmosphere

CRITICAL THINKING

12. All of the following have an effect on water potential (Ψ) in plants except:

A. Physical pressure   B. Organic solutes
C. Inorganic solutes   D. DNA

UPTAKE OF WATER BY ROOTS

- The cell wall of epidermal cells of roots is ***freely permeable*** to water and other minerals, while cell membrane is differentially permeable. From root hairs, water molecules enter the epidermal cells by ***osmosis*** i.e., along the concentration gradient.
- Is passes through cortex, endodermis, Pericycle, and reach the xylem vessel.
- The movement of water into the cells in called ***endosmosis*** while the movement of water out of the cell is called ***exosmosis.***
- There are three pathways taken by water to reach the xylem tissues i.e. ***apoplast, symplast*** and ***vacuolar pathway***.

Apoplast Pathway

- This involves system of adjacent cell walls, which is continuous throughout the plant roots.
- In the roots, apoplast pathway becomes discontinuous in the endodermis due to the presence of ***casparian strips*** which is a ***band of suberin*** and ***lignin***, bordering four sides of root endodermal cells.

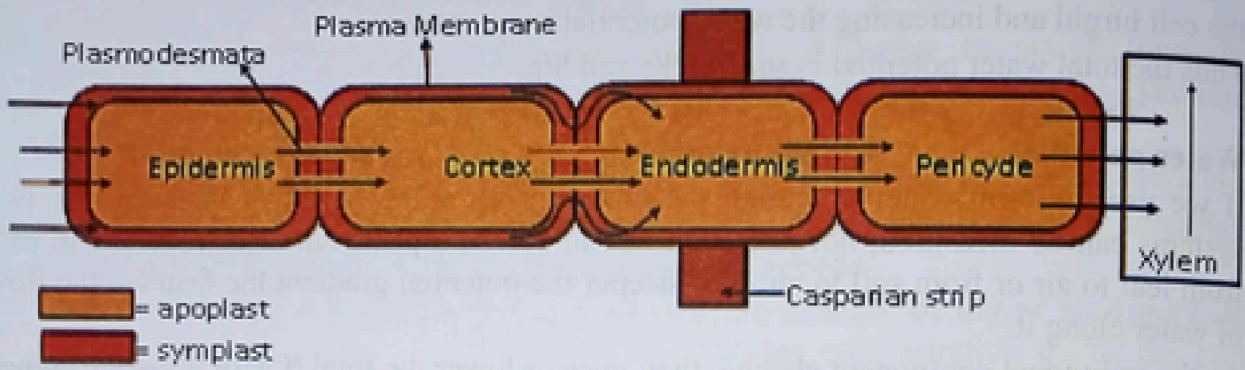
Symplast Pathway

- It is an important pathway of water movement in which movement of cell sap involves the ***cytoplasmic connection*** of adjacent cells.
- The cytoplasm of neighboring cells (protoplast) is linked with one another by ***plasmodesmata***.

- Once water and any solutes it contains are taken into the cytoplasm of one cell, it can move through the symplast without having to cross further membranes. This movement might be ***aided by cytoplasmic streaming***.

Vacuolar Pathway

- In this pathway, water moves from vacuole to vacuole through neighboring cells, crossing the symplast and apoplast and moving through membranes and tonoplast by osmosis. It moves down a water potential gradient.



ASCENT OF SAP

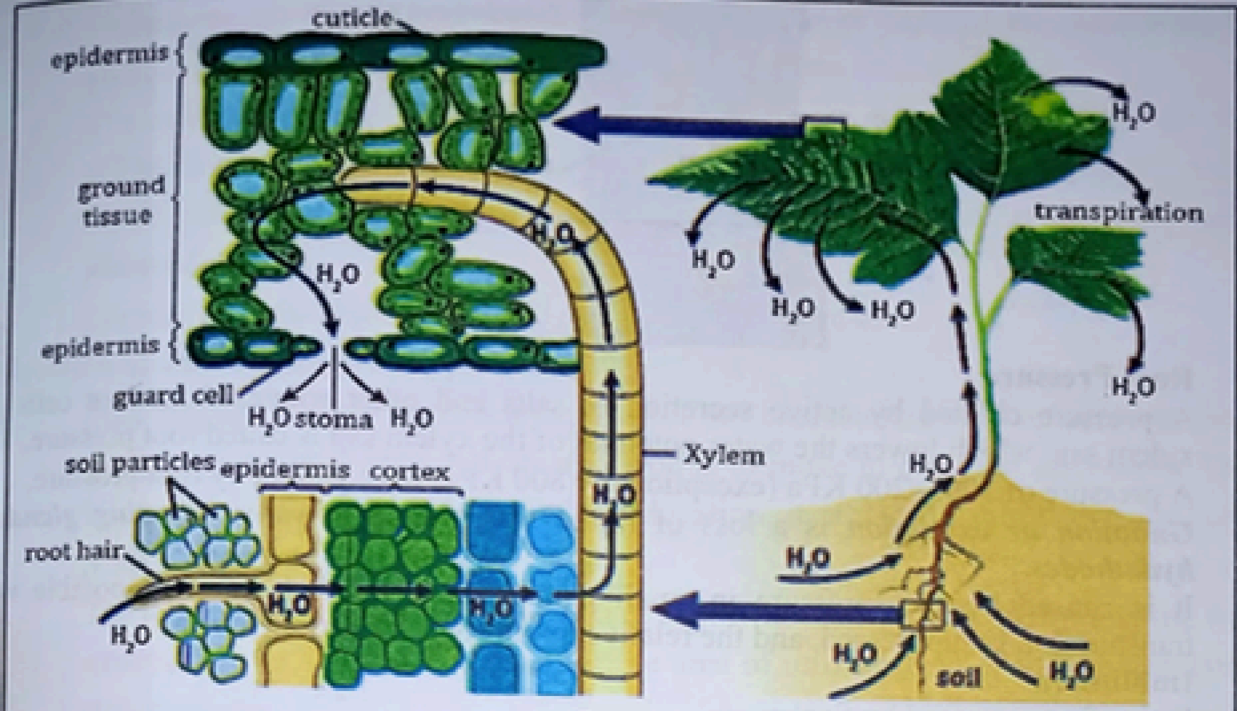
- Water and minerals are absorbed by the roots epidermal cells from where these substances are first move to the root xylem and then to the leaves. This upward movement of water and dissolved minerals towards the leaves through the xylem tissue is called ***ascent of sap***.
- Since this movement occurs against the gravity therefore, a considerable force is required to conduct water and minerals in tall heighted plants.
- It is explained through ***TACT theory***, ***root pressure*** and ***imbibition***.

1. TACT Theory

- According to this theory, four factors such as *T*ranspiration pull, *A*dhesion, *C*ohesion and *T*ension are combined to form a collective force that is mainly responsible for ascent of sap.

i. Transpiration

- The ***evaporation of water*** from aerial parts of plant especially through stomata of leaves is called transpiration.
- As a leaf transpires the water potential of its mesophyll cells drop. This drop causes water to move by osmosis from the xylem cells into dehydrating mesophyll cells.
- The water molecules leaving the xylem are attached to other water molecules in the same xylem tube by hydrogen bonds. Therefore, when a water molecule moves up the xylem, the process continues all the way till the root, where water is pulled from the xylem cells.
- This pull causes water to move down its concentration gradient transversely from the root epidermis to the cortex by endosmosis and to pericycle. This pulling force is called ***transpiration pull*** and is so strong that it also reduces the water potential of root epidermal cells.
- Thus water in the soil moves from its higher potential to lower water potential of epidermis of root by osmosis.



Transpiration Pull

Types of transpiration

Features	Cuticular	Lenticular	Stomatal
Component involved	Cuticle	Lenticel	Stomata
Structure	Present on upper & lower epidermis, impermeable to water, water lost from thin areas.	Aerating pores formed from bark from cork, in stem of some plants, externally scars or protrusions	Guard cell, dumbbell shaped.
%	5-7%	1-2%	90%

ii. **Adhesion**

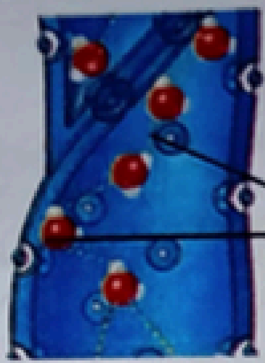
- Adhesion develops between water molecules and cell wall of xylem cells. The composition of cell wall provides necessary adhesion to water molecules that helps water creep up.
- The ***cellulosic component*** of cell wall especially has great affinity for water.
- Adhesion also helps to hold water in xylem when transpiration is not occurring.

iii. ***Cohesion***

- It is the attraction among water molecule (H-bond) forming a solid chain like column within the xylem tubes.

iv. ***Tension***

- It is provided when water chain is pulled up in the xylem. ***Transpiration*** provides the necessary energy or force. This xylem tension is strong enough to pull water up to **200 meters in plants**.
- It is essential that the xylem walls should have high ***tensile strength***. The lignin and cellulose provides strength to cell wall of xylem vessels.
- Large quantities of water are carried at relatively high speed, ***upto 8m/h*** being recorded in tall trees, and commonly in ***other plants at 1m/h***.
- The total water pulled up in the leaves is transpired, except about 1%which is used by plants in various activities including photosynthesis.



2. **Root Pressure**

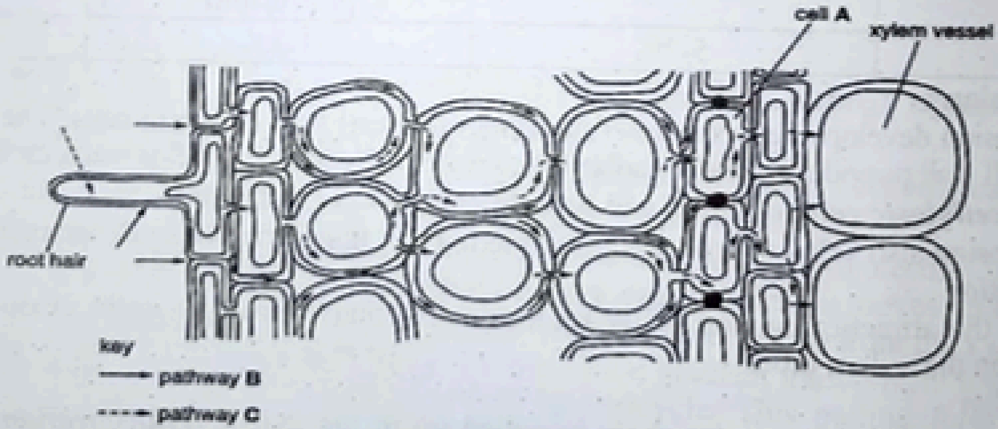
- A pressure created by active secretion of salts and other solutes from root cells into xylem sap, which lowers the water potential of the xylem sap is called root pressure.
- A pressure of 100 – 200 KPa (exceptionally 800 KPa) is generated by root pressure.
- ***Guttation or exudation*** is a loss of liquid water through ***water secreting glands or hydathodes***.
- It is caused by root pressure in small plants like grasses. It is more notable when transpiration is suppressed, and the relative humidity is high at night.

3. **Imbibition**

- It was first proposed by Sacks.
- The cell walls components especially ***cellulose, pectin and lignin*** can take up water and as a result increase in volume, but the components do not dissolve in water, this is called imbibition.
- The root cell walls imbibe water from the soil, and this water moves by apoplast pathway.
- It is a ***reversible process***.

CRITICAL THINKING

13. Water absorbed by plant roots travels by different pathways from root hairs to the xylem. Figure shows these pathways in the root of *Ranunculusacris*.



Name Cell A and Pathway B:

	Cell Name	Pathway Name
A.	Endodermis	Apoplast
B.	Cortex	Symplast
C.	Pericycle	Vacuolar
D.	Endodermis	Symplast

TRANSLOCATION OF ORGANIC SOLUTES

- The movement of prepared organic solutes to different parts of the plant body through phloem tissue is called translocation of organic solutes.
- The cells of phloem that transport sugars and organic material throughout the plant are called ***sieve elements***. These cells are associated with one or more ***companion cells***.
- Sieve tube and companion cells are ***in communication with each other by plasmodesmata***.
- Companion cells ***supply ATP*** and ***proteins*** to the sieve tube.

Direction of Translocation

- Like ascent of sap, translocation cannot be characterized as upward or downward movement, because prepared organic food is to move in ***different directions.*** Therefore, in order to define the direction of translocation, it is usually said that it always ***occurs from a source towards a sink***.
- The term ***source*** is applied to the area of supply of food such as food preparing or storage structures. The term ***sink*** is used for the area of utilization of food like metabolizing or storage organ.
- ***Leaf*** is purely a source while ***fruit*** is particularly a sink. On the other hand, ***roots and stem act as both source and sink***.

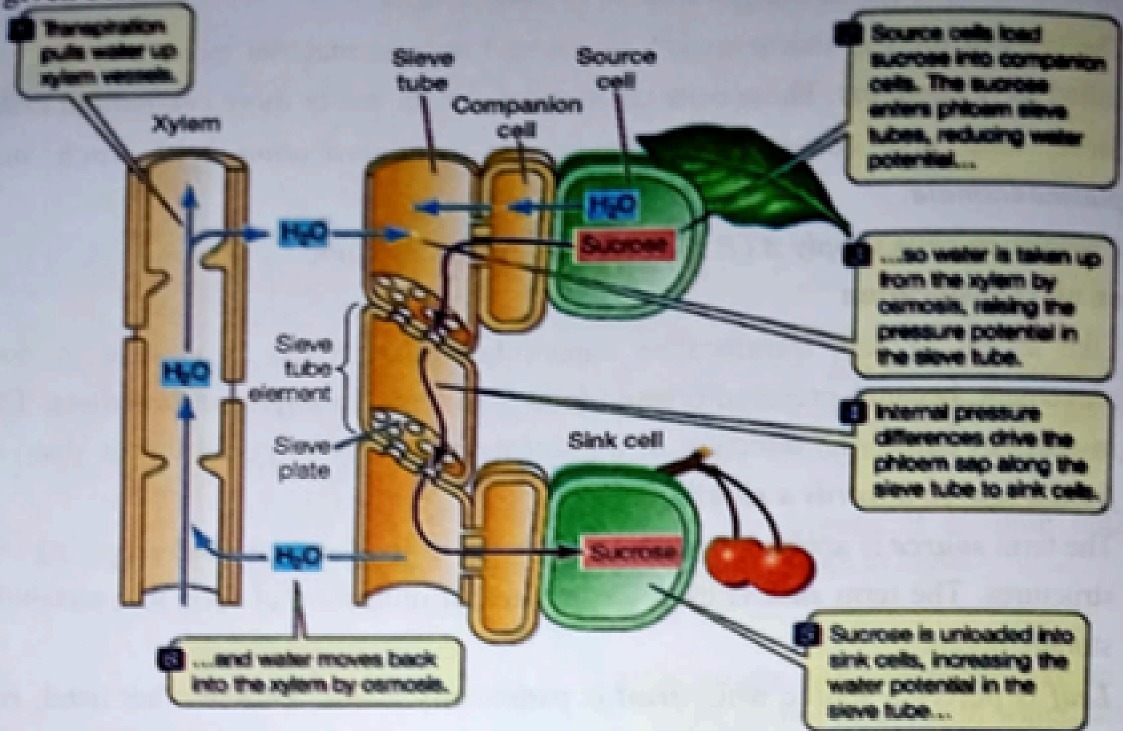
Composition of Phloem Sap

- Phloem sap is composed of 10-25% dry matter. The 90% of this dry matter is sucrose/cane sugar, while remaining are other organic compounds including hormones.

Mechanism of Translocation

- A hypothesis was first proposed by ***Ernst Munch*** in 1930. It states that the flow of solution in the sieve elements is driven by an osmotically generated pressure gradient between source and sink.
- The most acceptable theory that explains the mechanism of translocation of organic solutes is the ***pressure flow/mass flow theory***.
- According to this theory, the sugars are loaded into the phloem's sieve tube elements by the companion cells.
- The active transport ***increases the concentration of sugars in the phloem***, thus ***water potential decreased***.
- As a result, ***water moves to phloem*** by osmosis from nearby xylem cells and ***increases hydrostatic pressure in the phloem***, which pushes forcibly the sap away from the source.
- The ***pressure gradient*** from source to sink causes translocation from the area of higher hydrostatic pressure (at the source) to the area of lower hydrostatic pressure (at the sink).
- When this solution reached to the sink, the sink cells actively absorb the organic solutes from the sap.

- The ***loss of solutes in phloem sap causes an increase in water potential*** so the water moves from phloem back to the xylem tube. The mechanism is shown in the diagram given below:



- In biennials e.g. root of beet is a sink in first growing season but becomes source in the next growing season, when sugars are utilized in growth of new shoots.
- The movement in phloem is from source to sink in most of the plant during active photosynthesis.

CRITICAL THINKING

14. Arrange the following five events in an order that explains the mass flow of materials in the phloem.
1. Water diffuses into the sieve tubes.
2. Leaf cells produce sugar by photosynthesis.
3. Solutes are actively transported into sieve tubes.
4. Sugar is transported from cell to cell in the leaf.
5. Sugar moves down the stem.

A. 2, 1, 4, 3, 5 B. 1, 2, 3, 4, 5
C. 2, 4, 3, 1, 5 D. 4, 2, 1, 3, 5

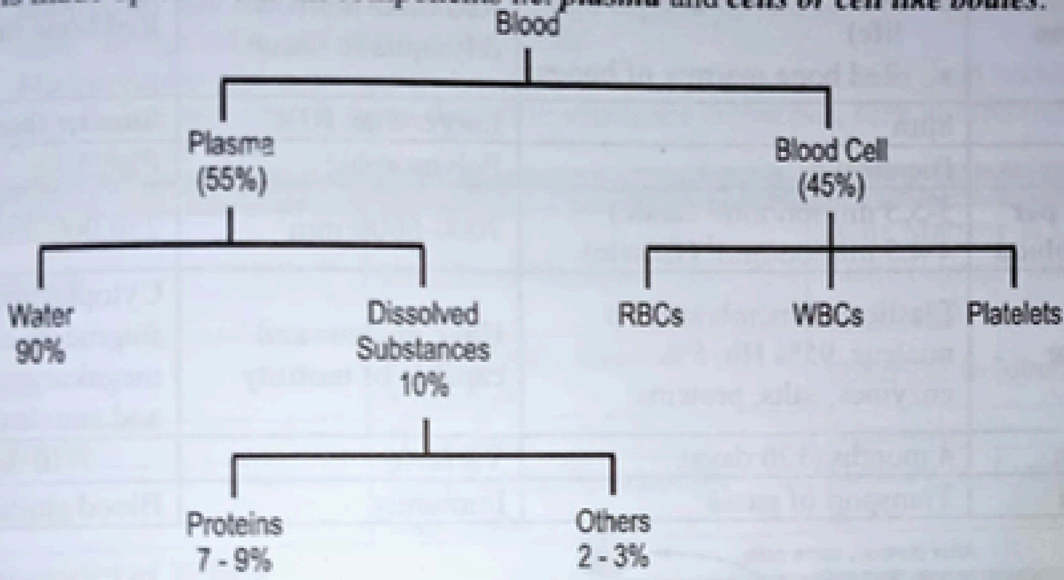
TRANSPORT IN MAN/CARDIOVASCULAR SYSTEM

- All the cells of our body need food from small intestine and oxygen from lungs. Carbon dioxide and waste chemicals have to be removed from the lungs and kidney, respectively.
- Human body is too large for materials to simple diffuse in and out. So, humans have a system of internal transport that transport respiratory gases, distributes nutrients to the body cells and conveys the waste products of metabolism to specific site for disposal.
- In humans, the internal transport is accomplished by ***cardiovascular system*** and the ***lymphatic system***.

- The cardiovascular system consists of three basic components:
  i. Circulatory fluid- The Blood
  ii. Pumping organ- The heart
  iii. Blood vessels

BLOOD

- Blood is the form of ***fluid connective tissue*** in which dissolved nutrients, respiratory gases, hormones, and wastes are transported through the body.
- The weight of blood in our body is about ***1/12th of our body***.
- The normal pH of blood is 7.4.
- It is made up of two main components i.e. ***plasma*** and ***cells or cell like bodies***.



Composition of Plasma

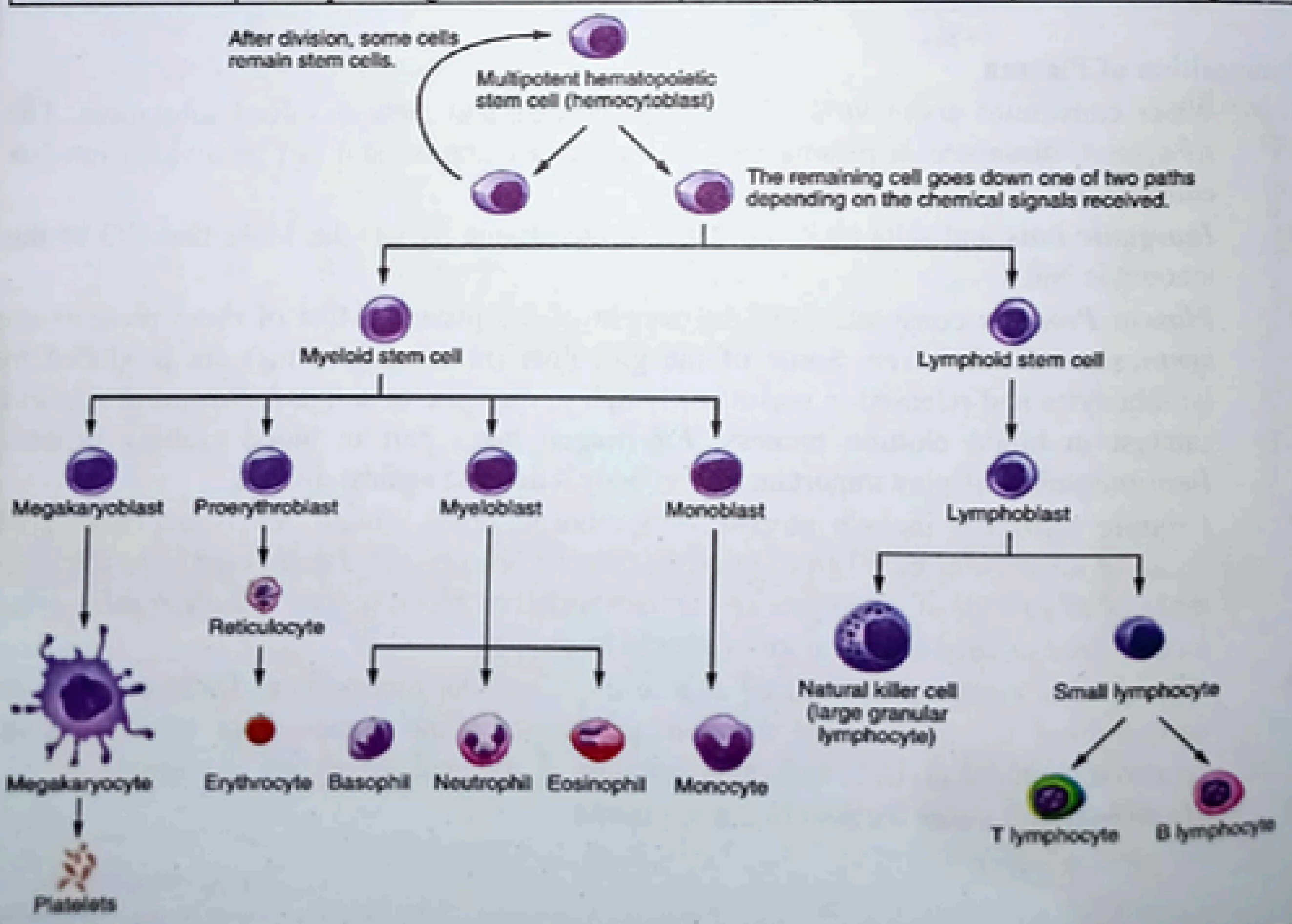
- Water constitutes about ***90%*** of the blood plasma, and ***10%*** dissolved substances. The substances dissolved in plasma vary in their concentration and can be divided into ***six categories***:
- ***Inorganic ions*** and salts make up 0.9% of the plasma by weight. More than 2/3 of this amount is NaCl.
- ***Plasma Proteins*** constitute 7-9% by weight of the plasma. Most of these proteins are ***synthesized in the liver***. Some of the globulins (immunoglobulins) are produced by lymphocytes and released in plasma or lymph in response to antigen. ***Thrombin*** acts as a catalyst in blood clotting process. ***Fibrinogen*** takes part in blood clotting process. ***Immunoglobulins*** play important role in body's defense against disease
- ***Organic nutrients*** include glucose, fats, phospholipids, amino acids and lactic acid. Some of them enter blood from intestine (during absorption). ***Lactic acid*** is produced in muscles as a result of glycolysis and is transported by blood to liver. ***Cholesterol*** is either metabolized or used as precursor of steroid hormones.
- ***Nitrogenous wastes*** are produced as a result of cellular metabolism. These products are carried from the liver where they are produced, to the organs from where they are removed i.e. kidneys. Urea and small amounts of uric acid are present in plasma.
- ***Hormones*** and ***gases*** are also found in plasma.

Types of Blood Cells

Red Blood Cells

- These are most numerous of the cells in the blood.
- These cells when formed have nucleus, but it is lost before they enter the circulatory fluid or blood.
- The red blood cells once mature do not divide.

Features	RBCs	WBCs	Platelets
Name	Erythrocytes	Leucocytes	Thrombocytes
Colour	Red	Colorless	Colorless
Formation	• Liver & spleen (embryonic life) • Red bone marrow of bones	Red bone marrow &lymphatic tissue	Red bone marrow
Size	8µm	Larger than RBC	Smaller than RBC
Shape	Biconcave	Polymorphic	Plate like
Number per mm^3 of blood	5-5.5 million/mm^3 (male) 4-4.5 million/mm^3 (female)	7000-8000/mm^3	250,000/mm^3
Structure	Elastic cell membrane, no nucleus, 95% Hb, 5% enzymes, salts, proteins	Have nucleus and capable of motility	Cytoplasmic fragments of megakaryocytes and anucleated
Life span	4 months (120 days)	Variable	7-10 days
Function	Transport of gases	Immunity	Blood clotting



White Blood Cells

- There are five different types of WBCs which can be distinguished on the basis of the shape of the nucleus and density of granules in the cytoplasm.
- They can be grouped into two main types, ***granulocytes*** and ***agranulocytes***.
- ***Monocytes*** stay in blood for 10-20 hours then enter tissues and become tissue macrophages.
- ***Lymphocytes*** have life spans of months or even years; but this depends on the body's need for these cells.
- ***Monocytes*** and ***neutrophils*** travel through capillaries and feed on bacterial invaders or other foreign cells, including cancer cells.
- ***Macrophages*** and ***neutrophils*** typically die in a process and their dead bodies accumulate and contribute to the white substance called pus, seen at infection sites.

CRITICAL CONCEPT!

Transmigration, or diapedesis, is the process by which large White blood cells migrate across blood vessel walls to enter various tissues and organs.

Main Categories of WBC

Feature	Granulocytes	Agranulocytes
Formation	Red Bone Marrow	Bone Marrow & Lymphoid tissue (Lymph nodes, spleen, tonsils, adenoids, thymus)
Nucleus	Incompletely divided/ Spherical	Spherical to lobed
Cytoplasm	Granular	Agranular
Examples	Neutrophils, Eosinophils, Basophils	Monocytes, Lymphocytes (B & T)

Subcategories of WBCs

Feature	Neutrophils	Eosinophils	Basophils	Monocytes	Lymphocytes
Size in relation of RBC	Twice	Twice	Twice	Twice to thrice	Slightly larger
Nucleus	2-5 lobes	Bilobed	Bilobed	Round to lobed	Round, nearly filling cell
%age	62%	2%	<1%	3%	32%
Function	Destruction of small particles by phagocytosis	Inactivate inflammation producing substances & attack parasites	Release heparin to prevent blood clots & histamine to cause inflammation	Destroy large particles by phagocyto-sis	Immune response by producing antibodies

Platelets

- These are not cells but are fragments of large cells called ***megakaryocytes***.
- Platelets help in conversion of ***fibrinogen***, a soluble plasma protein, into soluble form, ***fibrin***. The fibrin threads enmesh RBCs and other platelets in the area of damaged tissue, ultimately forming a ***blood clot***.
- The ***clot*** serves as temporary seal to prevent bleeding until the damaged tissue can be repaired.

CRITICAL THINKING

15. Which of the following cell cannot cross the capillary pore?

A. Monocyte B. Lymphocyte
C. Neutrophil D. Red blood cell

Functions of Blood

1. **Maintenance of Osmotic Balance**
- Plasma proteins maintain colloid osmotic pressure of blood.
- 75% role is played by albumins, 25% by globulins and almost none by fibrinogen.

2. **Transportation**
- Blood helps to transport nutrients, water, salts and waste products.
- Hormones are transported by blood from the endocrine tissues to the target cells.
- Gases (O_2 and CO_2) are transported by blood.

3. **Homeostasis**
- Blood acts as a buffer to maintain the acid-base balance i.e. concentration of H^+ and OH^- ions in the body.
- Blood helps in maintaining the body temperature, concentration of water and salts, thus helps in homeostasis.
- Blood helps the body in maintaining the internal environment, by producing heparin, histamine and also by maintaining the amounts of chemicals.

4. **Defense/ Immunity**
- Blood helps in body defenses against disease. Neutrophils and monocytes engulf and destroy invading microorganisms e.g. bacteria.
- Blood provides immunity by the lymphocytes.
- Blood produces interferons and antitoxins which are proteins and protect our body from nucleic acids and toxins of invading organisms.

5. **Blood Clotting**
- It helps in blood clotting process and seals the wounds that stop entry of pathogens into the body.

6. **Exchange of Materials**
- Walls of capillaries help in exchange of materials between blood and body tissue through blood capillaries via interstitial fluid.

STRUCTURE OF HUMAN HEART

Introduction
- The human heart is ***located in the chest cavity*** between lungs slightly left of the sternum.
- The heart contracts automatically with rhythmicity, under the ***control of the autonomic nervous system***.
- Human heart is ***hollow, fibromuscular organ***. Adult heart has shape of cone.
- Base of heart extends to ***second*** intercostal space and apex of heart is in ***fifth*** intercostal space, approximately ***9 cm to left of midline***.

Pericardium
- It is a closed sac that surrounds heart. Consists of 2 parts; outer and inner part.
- Outer part is inelastic white fibrous tissue. Inner part is made up of 2 membranes.
- Inner membrane is attached to heart and outer one is attached to fibrous tissue.
- ***Pericardial fluid*** is secreted between them and ***reduces friction*** between heart wall and surrounding tissues when heart is beating. Inelastic nature of pericardium as whole prevents heart from being ***overstretched*** or overfilled with blood.

Heart Walls

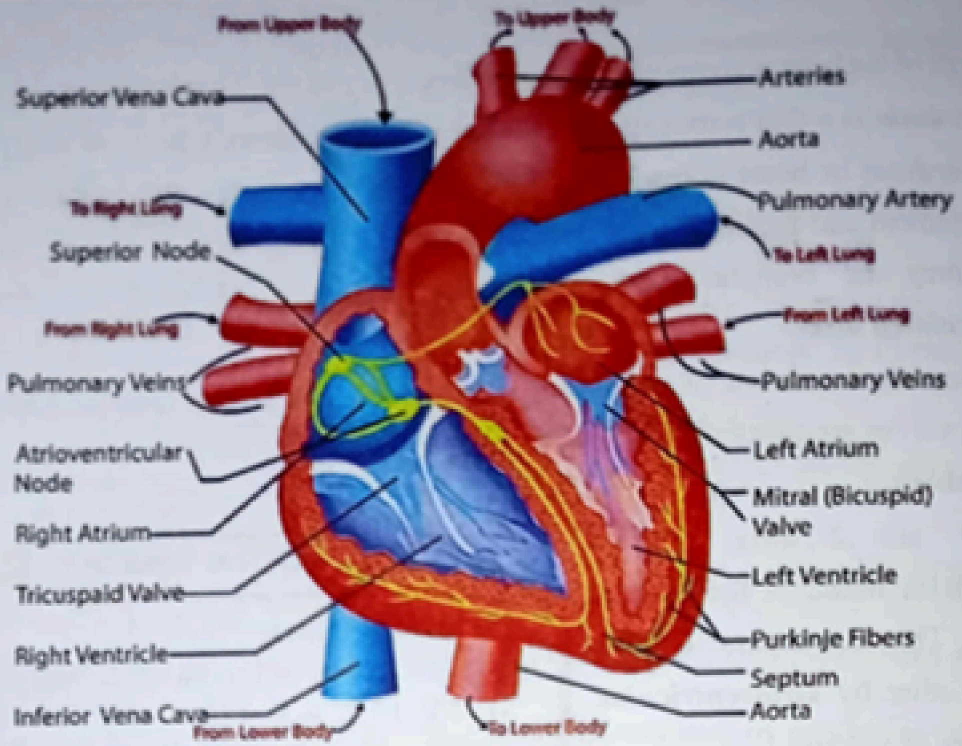
- The wall of the heart is composed of ***three layers***: Epicardium, Myocardium and Endocardium.
- ***Epicardium*** is a thin serous membrane comprising of smooth outer surface of heart
- ***Myocardium*** of heart is made up of special type of muscles, the cardiac muscles. Their arrangement and mechanism of contraction is essentially same as skeletal muscles except that they are branched cells. Successive cells are separated by junctions called ***intercalated discs***.
- ***Endocardium*** consists of simple squamous epithelium over a layer of connective tissue. Heart valves are formed by fold of endocardium.

Heart Chambers

- There are 2 atria and 2 ventricles found in the human heart. They are separated from each other by ***atrioventricular groove*** or ***sulcus***.
- Interatrial groove separates atria and interventricular groove separates ventricles. In normal intact heart the sulci are covered by fat.

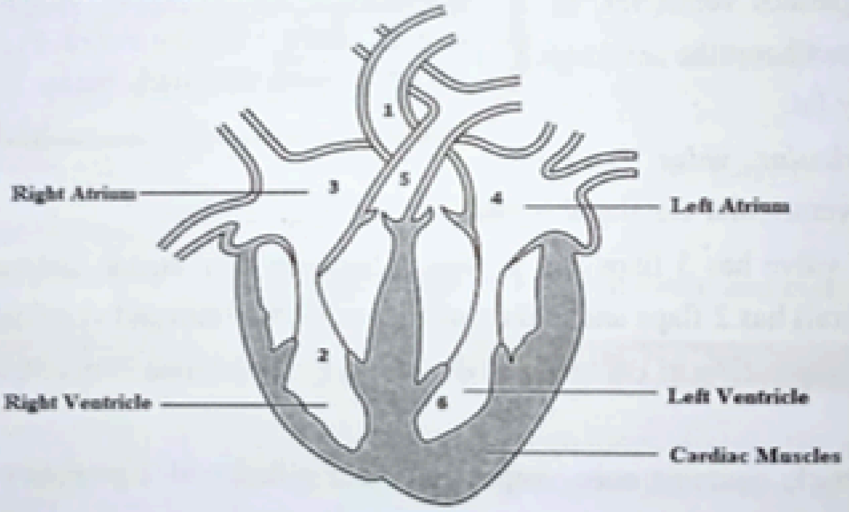
> **CRITICAL CONCEPT!**
>
> **Peripheral Heart:**
> Together, the calf's muscles and deep vein system form a complex array of valves and pumps, often referred to as the "peripheral heart," that functions to push blood upward from the lower leg against gravity. In upright posture, the soleus (a calf muscle) is responsible for pumping *venous* blood back into the heart from the periphery, and is often called the skeletal-muscle pump.

- ***Atrioventricular valve*** is on each atrioventricular canal and is composed of cusps or flaps.
- ***Tricuspid*** valve has 3 flaps and is present between right atrium and ventricle. ***Bicuspid*** valve (Mitral) has 2 flaps and is present between left atrium and ventricle.
- Complete separation of deoxygenated and oxygenated blood is maintained by formation of ***septa***.
- Each ventricle contains cone shaped muscular pillars called ***papillary muscles*** that are attached by thin, strong connective tissue strings called ***chordae tendineae*** to cusps of atrioventricular valves.
- Aorta and pulmonary trunks have aortic and pulmonary valves. Each valve consists of 3 pockets, free inner borders of which meet in center of artery to block blood flow.
- ***Semilunar valves*** are present at base of aorta and pulmonary trunk. Each valve consists of three pockets like semilunar cusps.



CRITICAL THINKING

16. **Trace down flow of blood in heart:**

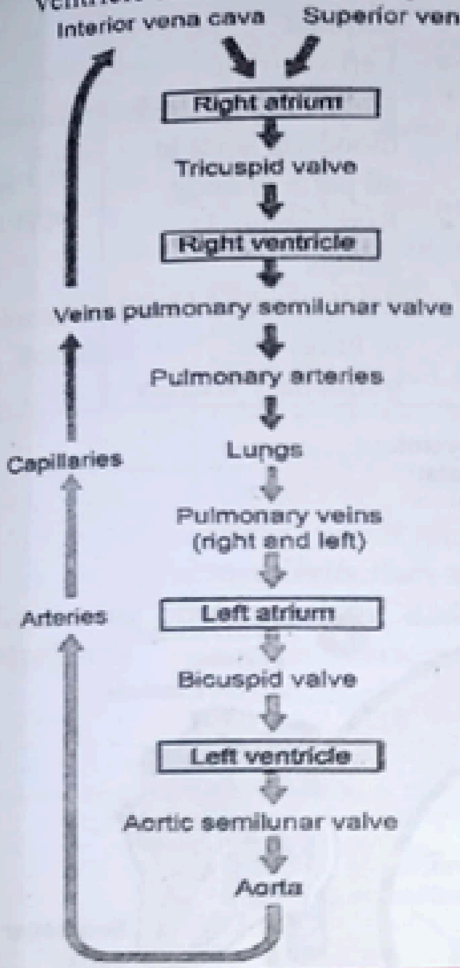


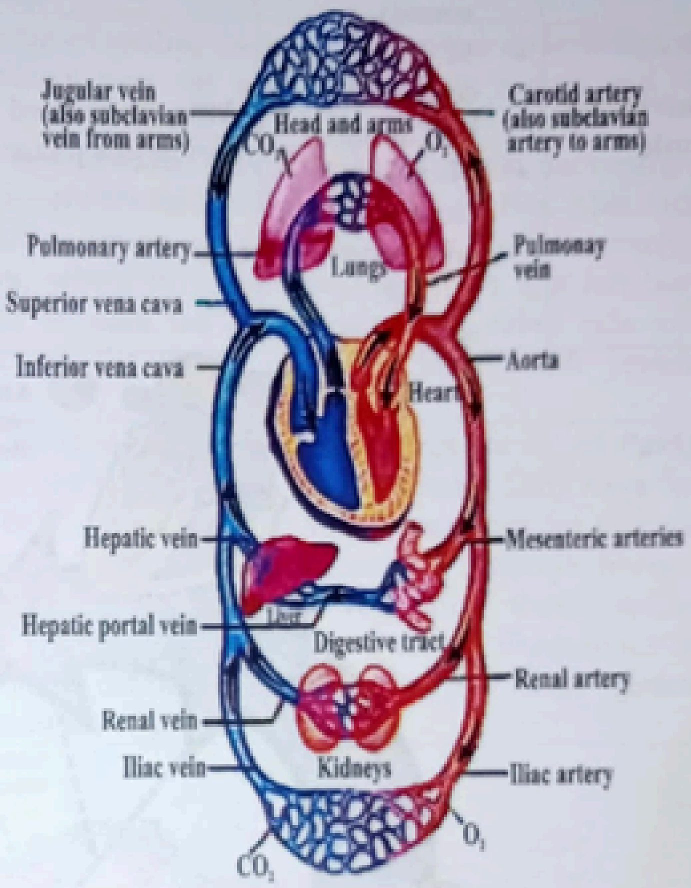
A. 1, 2, 3, 4, 5, 6
B. 2, 3, 4, 5 1, 6
C. 3, 2, 5, 4, 6, 1
D. 4, 5, 6, 3, 2, 1

Passage of Blood through Heart

- The ***superior vena cava*** and ***inferior vena cava***, both carrying deoxygenated blood, enter the right atrium.
- The right atrium sends blood through the tricuspid valve to the right ventricle. The right ventricle sends blood through pulmonary semilunar valve into the pulmonary trunk and two pulmonary arteries to lungs.
- ***Four pulmonary veins***, carrying oxygenated blood from the lungs, enter the left atrium.

- The left atrium sends blood through bicuspid valve to the left ventricle. The left ventricle sends blood through aortic semilunar valve into the aorta to the body.
- The heart is a ***double pump*** because the right ventricle sends blood to the lungs, and left ventricle sends blood throughout the body.





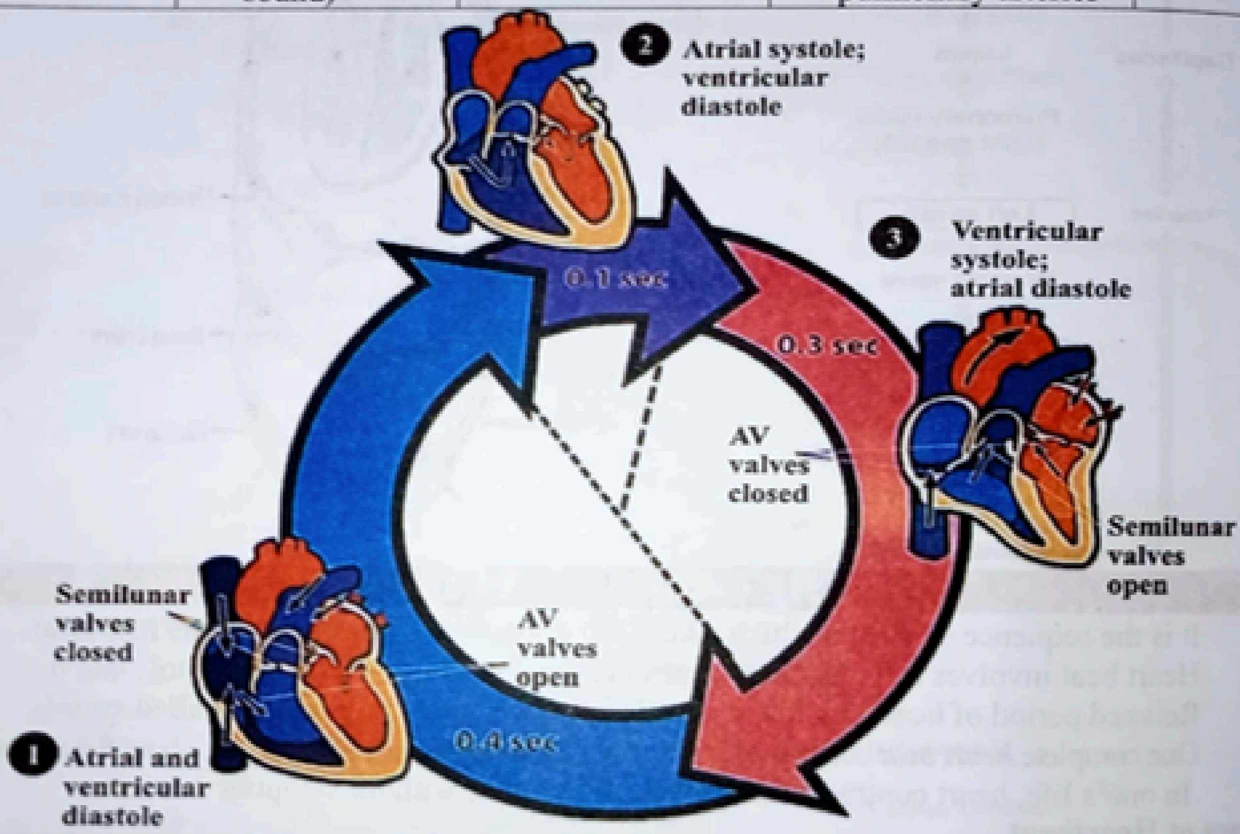
THE CARDIAC CYCLE

- It is the sequence of events which take place during the completion of one heartbeat.
- Heart beat involves three distinct stages i.e. atrial systole, ventricular systole and diastole.
- Relaxed period of heart chambers is called ***diastole*** and contraction is called ***systole***.
- One complete ***heart beat*** consists of one systole and one diastole and lasts for about ***0.8 seconds***.
- In one's life, heart contracts about 2.5 billion times, without stopping.

Phases of Heartbeat

Phase	Valves	Events in Atria	Events in Ventricles	Duration
Diastole (Relaxation)	• AV valves open • SL valves closed	• Atria relaxed • Deoxygenated blood enters right atrium by vena cava • Oxygenated blood enters left atrium by pulmonary veins	• Ventricles relaxed • Deoxygenated blood enters right ventricle through right atrium • Oxygenated blood enters left ventricle through left atrium.	0.4 sec

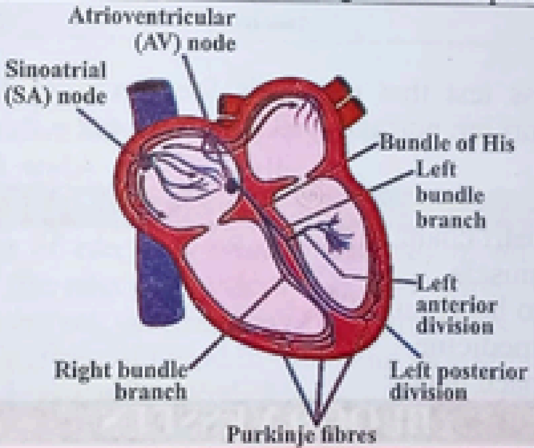
Atrial Systole	• AV valves open • SL valves closed	Muscles of atria contract and pump blood to ventricles	Ventricles are relaxed and receive blood from atria.	0.1 sec
Ventricular systole	• AV valves close (LUBB sound) • SL valves open at the beginning • SL valves close at the end of systole (DUBB sound)	Atria are relaxed during this phase	• Both ventricles contract • Left ventricle pumps oxygenated blood via aorta to all parts of body • Right ventricle pumps deoxygenated blood to lungs via pulmonary arteries	0.3 sec approx.



MECHANISM OF HEART EXCITATION AND CONTRACTION

- The heart will go in beating after it has been cut right out of the body. Cardiac muscles are myogenic i.e., its rhythmic contraction arise from within the muscle itself.
- Specialized strands of interconnecting cardiac muscle tissue that coordinate cardiac contraction constitute the ***conduction system***. The conduction system constitutes the cardiac cycle. Cardiac muscle has an ***intrinsic rhythmicity***.
- Heartbeat starts when the sino-atrial node (***pacemaker***) sends out electrical impulses to the atrial muscles, thus causing both atria to contract. It is ***located at the upper end of right atrium.***
- (0.04 seconds for nerve potential to reach AV node & 0.11 sec delay from AV node to AV bundles

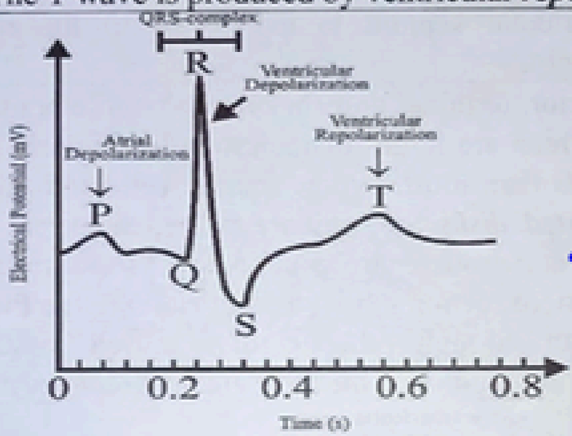
Components	Structure
Sinoatrial Node	It consists of **i)** Diffusely oriented cardiac fibers **ii)** Few myofibrils **iii)** Few nerve endings from autonomic nervous system in the upper wall of the right atrium. It is close to where vena cava enter the atrium. SA node is developed from the ***sinus venosus*** and has become a part of the atrium, so it is called sinoatrial node
Atrioventricular Node	Another specialized group of cardiac muscle fibers called ***atrio-ventricular node***. AV node is present near the junction of right atrium and right ventricle
Atrioventricular Bundle	AV node is connected to a strand of specialized muscles (in the ventricular septum) known as atrioventricular bundle or bundle of His. This bundle passes through a small opening in the fibrous skeleton to reach the interventricular septum, where it, divides to form right and left bundle branches which extend beneath the ***endocardium*** on either side of the interventricular septum to the apices of the right and left ventricles respectively.
Conducting Myofibrils	The inferior, terminal branches of the bundle branches are called ***Purkinje fibres***, which are large- diameter cardiac muscle fibres. They have fewer ***myofibrils*** than most cardiac muscle cells and do not contract forcefully. ***Intercalated disks*** are well developed between the Purkinje fibres and contain numerous gap junctions. As a result of these structural modifications, action potentials travel along the Purkinje fibres much more rapid than through other cardiac muscle tissue. SA node generates spontaneous action potentials of greater frequency.



ELECTROCARDIOGRAM

Introduction	The electrical impulses that pass through the conduction system of the heart during cardiac cycle
Electrocardiograph	The electrical changes from depolarization and repolarization of cardiac muscle fibres and can be detected on surface of the skin using an instrument called the *electrocardiograph*
P Wave	***Depolarization*** of the atrial fibres of the SA node produces the P wave. The ventricles of the heart are in diastole during the expression of the P wave

P-R Interval	On the ECG recording, the P-R interval is the period of time from the start of the P wave to the beginning of the QRS complex. This interval indicates the amount of time required for the SA depolarization to reach the ventricles
QRS Complex	The QRS complex begins as a short downward deflection (Q), continues as a sharp upward spike (R), and ends as a downward deflection (S). The QRS complex indicates the ***depolarization*** of the ventricles
S-T Segment	During this interval, the ventricles are in ***systole*** and blood is being ejected from the heart. The time duration known as the S-T segment represents the period between the completion of ventricular depolarization and initiation of ***repolarization***
T Wave	The T wave is produced by ventricular ***repolarization***



Ubaid

Uses of ECG

- An ECG is a painless test that measures the electrical activity of the heart to show whether or not it is working normally. ECG can detect:

i. Cardiac arrhythmias
ii. Conduction defects
iii. Size and position of heart chambers
iv. Damage to the heart muscle
v. Impaired blood flow to heart muscle
vi. The effect of cardiac medicine
vii. Function of artificial pace maker

BLOOD VESSELS

- Blood vessels are involved in the transportation of blood. They are three types of blood vessels i.e. arteries, veins and capillaries.

Feature	Arteries	Veins	Capillaries
Direction of Blood Flow	They transport blood away from heart to various parts of body	They collect blood from various parts of body and transport it towards heart	They link arteries with veins
Type of Blood	All carry oxygenated blood except pulmonary and umbilical arteries	All carry deoxygenated blood except pulmonary and umbilical veins	They have mixed blood

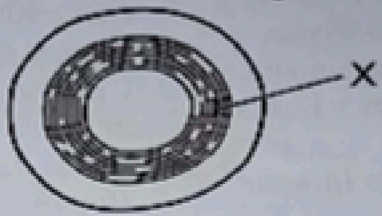
Structure	• Three layers • ***TunicaAdventitia***: Connective tissue + Elastic fibers • ***TunicaMedia***: Circular smooth muscles + Elastic fibers • ***Tunica Intima***: Simple squamous epithelium and elastic fibers composed of elastin	• Three layers • ***Tunica Adventitia***: Collagenous Connective Tissue • ***Tunica Media***: Circular smooth muscles + Thin elastic membrane + Collagen fibers • ***Tunica Intima***: Endothelium + Elastic fibers + Smooth Muscle	Only one cell thick endothelium
Elasticity	Elastic	Less elastic	Inelastic
Pulsatile Nature	Pulsatile	Non-pulsatile	Non-pulsatile
Valves	No valves except at the base of aorta & pulmonary trunk	Semilunar Valves are present to prevent the backflow of blood	No valves
Blood Pressure	High blood pressure	Low blood pressure	Falling pressure in these
Rate of Blood Flow	Rapid blood flow 400-500 mm/sec in aorta and decreasing in arteries and arterioles	Increases from smaller to larger veins	Blood flow is slowest less than 1mm/sec
Exchange of Material	No	No	Yes
Bore and Thickness	Have smaller bore and thick walls	Have larger bore and thin walls	Larger bore; wall one cell in thickness

Some Other Features

Arteries	Contraction of ***circular smooth muscles*** of arteries and arterioles is under control of the nervous system and endocrine system. When stimulated the muscles contract, constricting the arterioles (vasoconstriction) and thus ***reducing*** the flow of blood in them and vice versa. Several substances, called ***kinins,*** can cause powerful vasodilation, are formed in the blood and tissue fluids of some organs e.g., ***histamine***.
Veins	In veins, muscle contraction also assists (squash blood vessels) in blood flow return towards heart along with the valves. ***Portal veins*** carry blood to any organ other than the heart. For example, hepatic portal vein carries blood from intestine to liver.
Capillaries	In liver, every cell is in direct contact with capillary. The diameter of a capillary can be altered by nervous stimulation, which tends to close them and by chemicals, such as ***histamine***, which dilate them. The change in diameter is brought about by change in shape of cells. The ***pre-capillary sphincters*** also regulate the amount of blood flowing in capillaries. Exchange of materials between blood and cells occurs through with extracellular fluid. It involves diffusion, active transport and endocytosis

CRITICAL THINKING

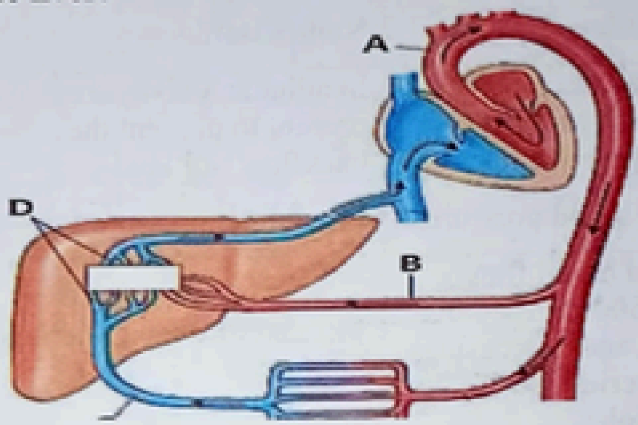
17. The diagram shows a transverse section through an artery:



Which statement describes the tissues present in layer X?

A. Collagen and smooth muscle only
B. Elastic fibres and collagen only
C. Elastic fibres and smooth muscle only
D. Elastic fibres, collagen and smooth muscle

18. Select an option of blood vessel which carry diffusible food particles from small intestine to liver:



BLOOD PRESSURE AND RATE OF BLOOD FLOW

Blood Pressure

- "It is the measure of force with which blood pushes up per unit area against the walls of blood vessels".
- It is measured in mmHg.
- Blood pressure is detected by mechanoreceptors called ***baroreceptors***.
- It is the force that keeps blood flowing from the heart to all the capillary networks in the body.
- The blood pressure is generated by the contraction of ventricles. This is called *systolic pressure*.
- When the ventricles relax, the atrial pressure is lowest and is called ***diastolic pressure***.
- Blood pressure consistently decreases in the following pathway:

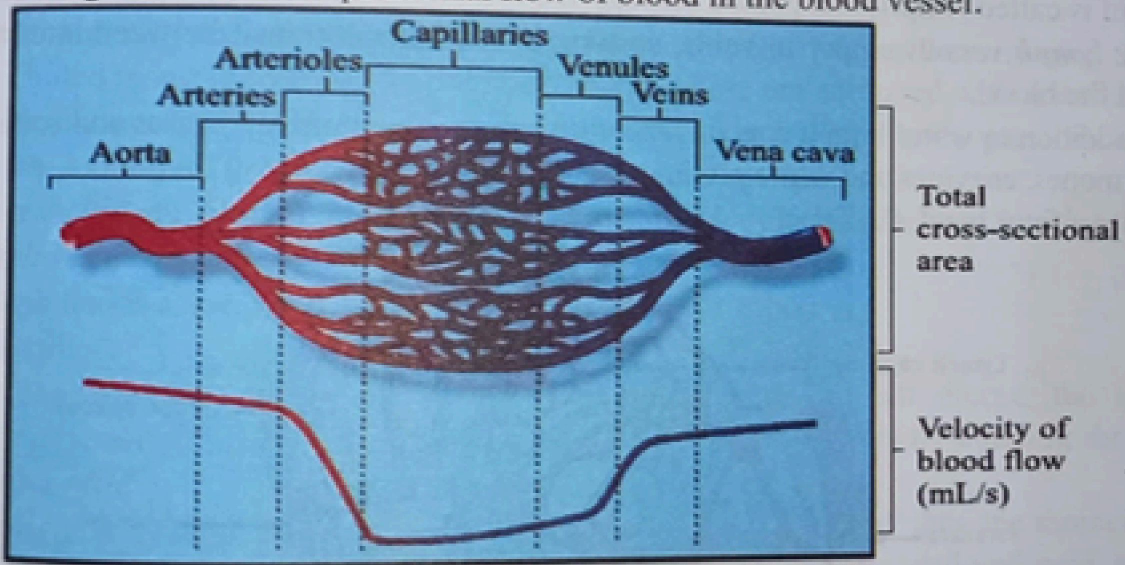
  Aorta → Arteries → Capillaries →Veins → Vena cava
- The normal systolic blood pressure is ***120 mm Hg*** which is during ventricular systole.
- The normal diastolic blood pressure is ***75-85 mm Hg*** which is during diastole of the heart.

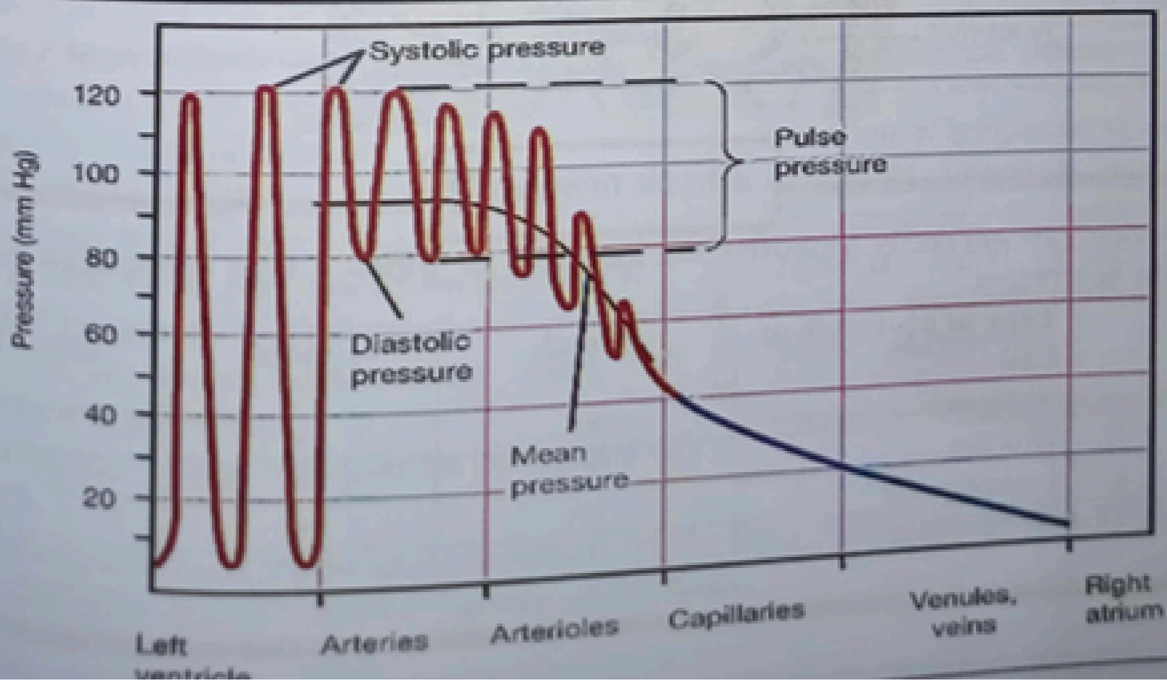
CRITICAL THINKING

19. Which of the following is correct for a blood pressure reading of 130/80?
(i) The systolic pressure is 130.
(ii) The diastolic pressure is 80.
(iii) The blood pressure during heart contraction is 80.
A. I only
B. III only
C. I and II only
D. II and III only

Rate of Blood Flow

- The rate of blood flow tends to fall as the blood moves through the branching arteries and arterioles, the rate is lowest in the capillaries; and increases again in the venules and veins.
- These changes in rate of blood flow result from changes in the total cross sectional area of the vessel system.
- The flow of blood in veins is maintained by the contraction of surrounding muscles, the action of semilunar valves which prevent back flow of blood, Muscular activity including breathing movements helps normal flow of blood in the blood vessel.





LYMPHATIC SYSTEM

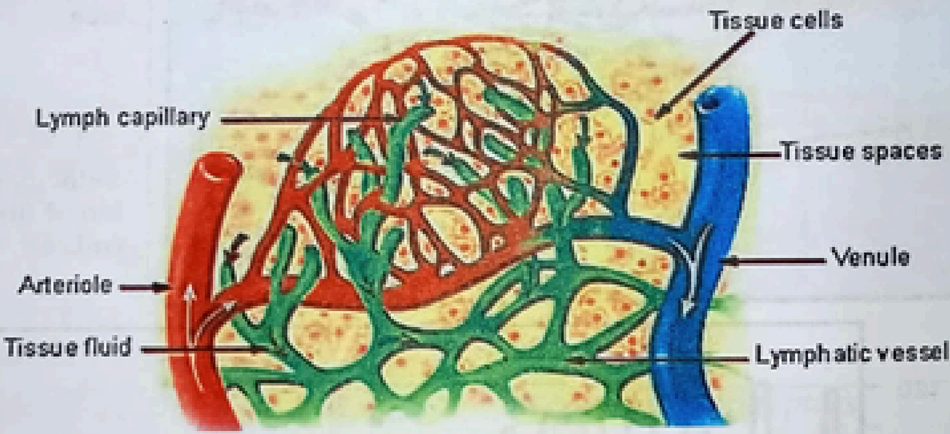
Introduction

- This system is responsible for the ***transport and returning of material*** from the tissues of the body to the blood.
- It comprises of lymph capillaries, lymph vessels, lymphoid masses, lymph nodes, lymph and lymphocytes.

Components of Lymphatic System

Lymph

- ***Lymph*** is the fluid which flows in the system. The fluid in the interstitium is derived by ***filtration*** and ***diffusion*** from the capillaries. The ***intercellular spaces*** in the walls of lymph vessels are larger than those of the capillaries of blood vascular system.
- This fluid is mainly entrapped in the minute space among the proteoglycan filaments. This combination of proteoglycan filaments and the fluid entrapped within them has the characteristics of gel and therefore is called ***tissue gel***.
- Approximately ***30 liters*** of fluid pass from the blood capillaries into the interstitial space each day. Whereas only ***27 liters*** pass from the interstitial space back into blood capillaries. The remaining ***3 liters*** of fluid enters the lymphatic capillaries, where the fluid is called ***lymph***, and passes through the lymphatic vessels back to the blood.
- The ***lymph vessels*** empty in veins; so lymph is a fluid in transit between interstitial fluid and the blood.
- In addition to water lymph contains solutes such as ions, nutrients, gases and some proteins, hormones, enzymes and waste products.
- After a fatty meal, the fat globules may make up 1% of the lymph.



CRITICAL THINKING

20. Which row correctly identifies the locations in which a type of molecule or cell can be present?

	Type of Molecule or Cell	Blood	Lymph	Tissue Fluid
A.	Antigens	✓	×	×
B.	Glucose	✓	×	✓
C.	Lymphocyte	×	✓	✓
D.	Neutrophils	✓	✓	✓

Lymph Capillaries

- The lymphatic system begins in the tissues as lymph capillaries, which differ from blood capillaries as they ***lack a basement membrane***.
- The lymph capillaries are far ***more permeable*** than blood capillaries and nothing in the interstitial fluid is excluded from the lymph capillaries.
- The lymph capillary epithelium functions as a series of ***one-way valve (blind ended)*** that allows fluid to enter the capillary, but prevent it from passing back into the interstitial spaces.

Lymph Vessels

- The lymph capillaries join to form larger lymph vessels that ***resemble small veins***. Small lymphatic vessels have a beaded appearance because of the presence of one-way valves along their lengths that are similar to the valves of veins.
- ***Lacteals*** are the branches of lymph capillaries inside villi of intestine.
- Largest lymph vessel is ***thoracic duct***.
- Lymph vessels which carry lymph towards lymph nodes are called ***afferent lymph*** vessels while the vessels that carry lymph away from lymph nodes are called ***efferent lymph*** vessels.

Lymph Nodes

- These are ***masses of connective tissue*** and round, oval, or bean-shaped structures distributed along the various lymphatic vessels. These are equipped with ***lymphocytes***.
- In the human body, the lymph nodes are present in various body parts such as ***neck region, axilla*** and ***groin***.
- Several afferent lymph vessels enter a lymph node, which is drained by ***single efferent lymph vessel***.
- Lymph nodes act as filter for lymph as do spleen for blood.

Flow of Lymph

- The ***thoracic duct*** drains the lower limbs, abdomen, the left thorax, the left upper extremity, and the left side of the head and neck. The duct ends by entering the ***left sub-clavian vein***.
- The ***right lymphatic duct*** is much short and smaller in diameter than the thoracic duct. It drains the right thorax, right upper limb, and right side of the head and neck and opens into the right sub-clavian vein.
- The flow of lymph is maintained by:

1. Activity of skeletal muscles
2. Movement of viscera
3. Breathing movements
4. Semilunar valves that prevent backward flow

> **CRITICAL CONCEPT!**
>
> **Location of lymphatic system:** Lymphatic system is responsible for returning of material that leaves the blood capillaries. It is absent in few body parts i.e. CNS, cornea and bones.

Functions of Lymphatic System

- Return of excess extracellular fluid and proteins to the blood.
- Absorption of large fat globules by lacteals of villi.
- Play important role in the defense system of the body. Lymphocytes and macrophages present inside lymph nodes kill bacteria and viruses.

CRITICAL THINKING

21. The role of lymph in CNS is played by:

A. Tissue fluid B. CSF
C. Blood plasma D. Serum

IMMUNE SYSTEM

Immunity

- The capacity to recognize the intrusion of any material foreign to the body and to mobilize cells and cell products to help remove the particular sort of foreign material with greater speed and effectiveness is called ***immunity***.
- The body's response to foreign particles, such as the production of antibodies directed against a specific antigen, is called an ***immune response***.

Defense Lines

- The human body has ***three lines of defence*** against microbial attack.
- First and second defense lines are non-specific while 3rd defense line is specific.
- Skin, mucous membrane and blood clot are physical barriers.
- HCl and lysozyme are examples of chemical barriers.
- Phagocytes and lymphocytes are example of cellular/ biological barriers.

(i) First Defense Line

- The human body has two surfaces exposed to the environment: the ***skin*** and the ***mucous membranes*** of the digestive and respiratory tracts.
- Since these barriers inhibit all kind of microbial invasion thus, first line of defence is supposed to be a ***non-specific defence***.

Skin

- It acts as impenetrable barrier against microbial invasion and is made up of two layers i.e. ***epidermis*** and ***dermis***.
- Epidermis is superficial multicellular thickened layer. Most cells of epidermis are ***keratinocytes***, which produce a protein mixture called ***keratin***. The outer surface of the skin also consists of ***dry dead cells***. Consequently, most microbes that land on the skin cannot obtain the water and nutrients they need.
- Epidermis is also equipped with ***epidermal dendritic cells*** that actively patrol the skin to phagocytize pathogens.
- Dermis is the inner, ***comparatively thick layer*** containing ***glands, hair follicles, receptors, nerves*** and ***blood vessels***.
- ***Sebaceous glands*** produce sebum whereas ***sweat glands*** secrete sweat. Secretions from these glands usually cover the skin. These secretions contain certain chemicals such as ***lactic acid*** that ***inhibit the growth of bacteria and fungi***.

Mucous Membrane

- The gastrointestinal tract and inner surface of nasal cavities is covered by mucous membrane.
- ***Mucus*** secreted by the mucous membrane is involved in trapping of microbes.

Role of Acid

- Acids such as ***gastric HCl*** kills the bacteria present in food.

(ii) *Second Defense Line*

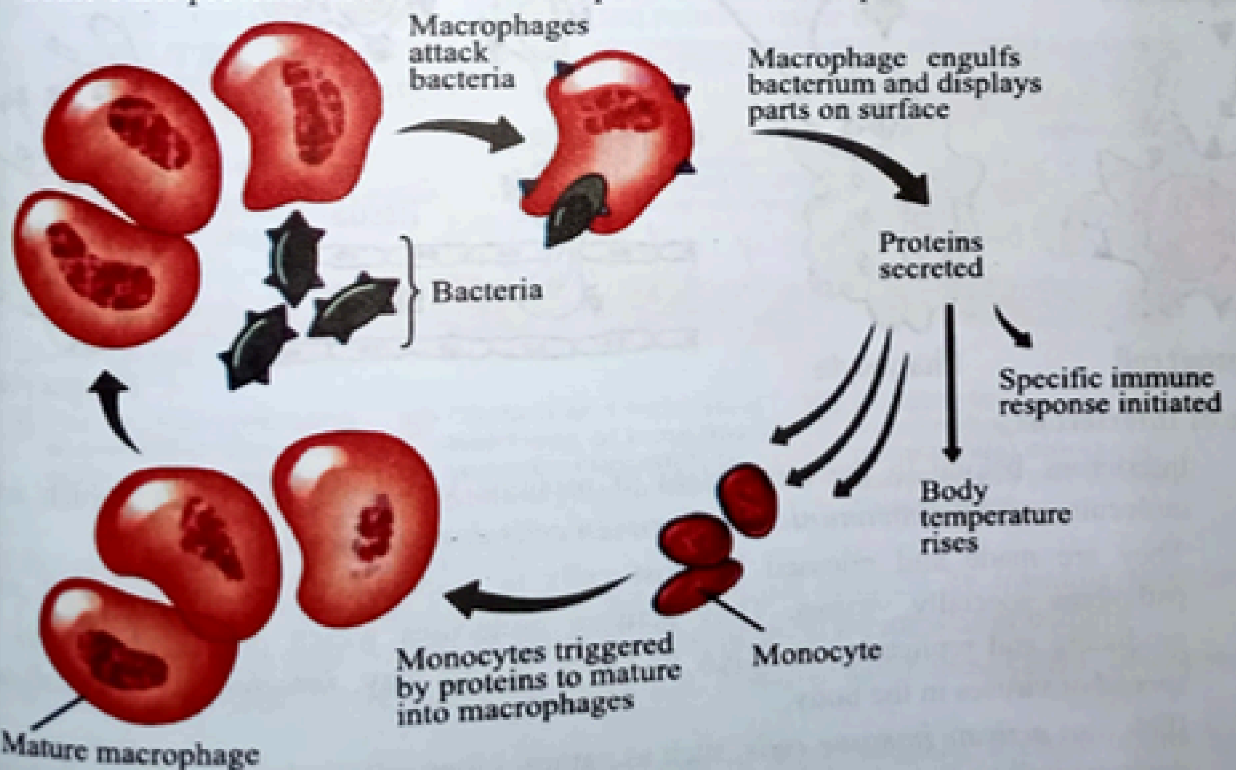
- If microbes become successful to penetrate the skin or mucous membranes, then second line of defence takes action against these foreign invaders. This defense line includes response by ***phagocytes***, ***natural killer cells***, ***inflammatory response*** and ***fever***.
- This defence is ***non-specific*** because they attack wide variety of microbes, rather than targeting specific invaders as the immune response does

Role of Phagocytes in Defense

- A phagocyte is a cell that destroys other ***abnormal body cells/cancerous cells*** or ***invaded microorganisms*** by engulfing them by ***phagocytosis.*** Two types of blood cells are phagocytes i.e., ***macrophages*** and ***neutrophils***.
- Macrophages are ***derived from monocytes*** and generally found in the organs such as the ***lungs, liver, spleen, kidney*** and ***lymph nodes***, rather than remaining in the blood. In these organs, they patrol within the free spaces among the cells and provide protection by trapping and destroying microorganisms entering the tissue.

Role of Macrophages

- They act as ***antigen presenting cells*** and display some parts of microbes on their surface so that other body cells may also be informed.
- The macrophages also ***secrete many different proteins*** when they perform phagocytosis of the microbes. Some of these proteins trigger the maturation of monocytes into macrophages, thereby increasing their numbers.
- Another protein ***interleukin-I*** signals the brain to raise the body temperature, producing fever.
- Some other proteins also stimulate the specific immune response.



Role of Neutrophils

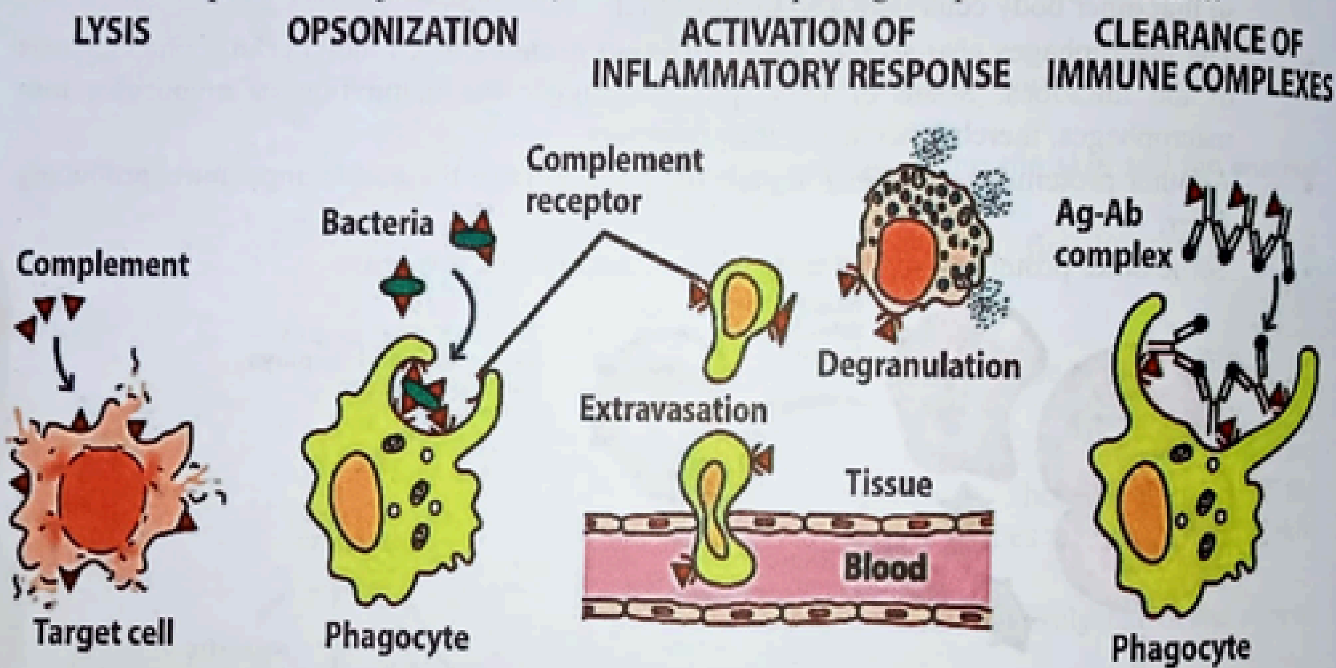
- ***Neutrophils*** are short lived. They are highly mobile and ***move like amoeba***. Neutrophils also release ***lysosomal*** enzymes and certain chemicals that kill microorganisms and cause ***inflammation***.

Role of Natural Killer cells

- ***Natural killer cells*** are a type of T-cell. These cells do not directly attack invading microbes. Instead, natural killer cells strike at the cancerous cells or body cells that have been invaded by viruses.
- These cells kill their target by releasing ***perforins***, which punch holes through the membranes of the infected cells. The pores formed by these proteins allow for the passive diffusion of certain apoptotic proteases, known as the ***granzymes***, into the target cell. The cell dies by apoptosis.

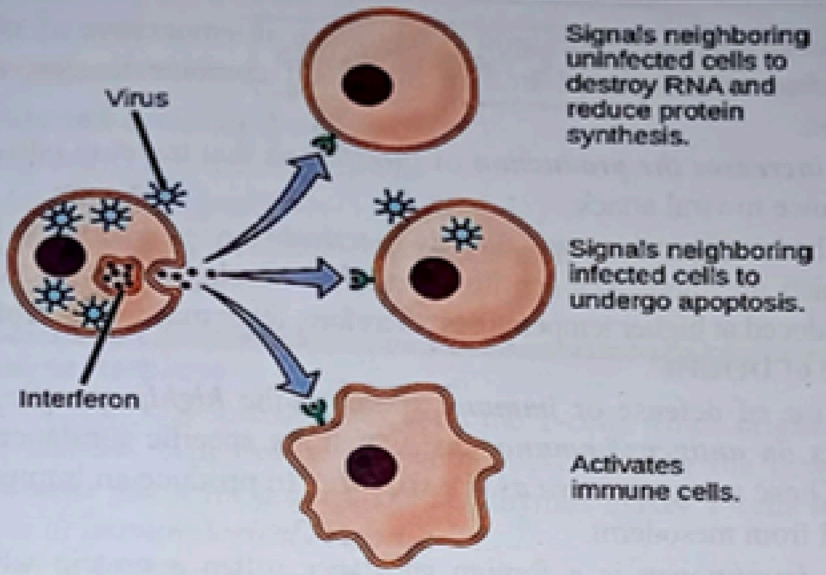
Protective Proteins of Complement System

- The complement system consists of ***over thirty types of small proteins*** found in the blood, in general ***synthesized by the liver***, and normally circulating in ***inactive state***. They are activated on the entry of foreign particles.
- The result of complement activation is ***stimulation of phagocytes*** to clear foreign and damaged material by acting as an ***important supporter of the immune system***.
- It also causes the development of inflammation to ***attract additional phagocytes*** at the site of infection and activation of the cell killing membrane attack complexes.
- It also ***promotes inflammation***, and attacks the pathogen's plasma membrane.



Role of Interferons

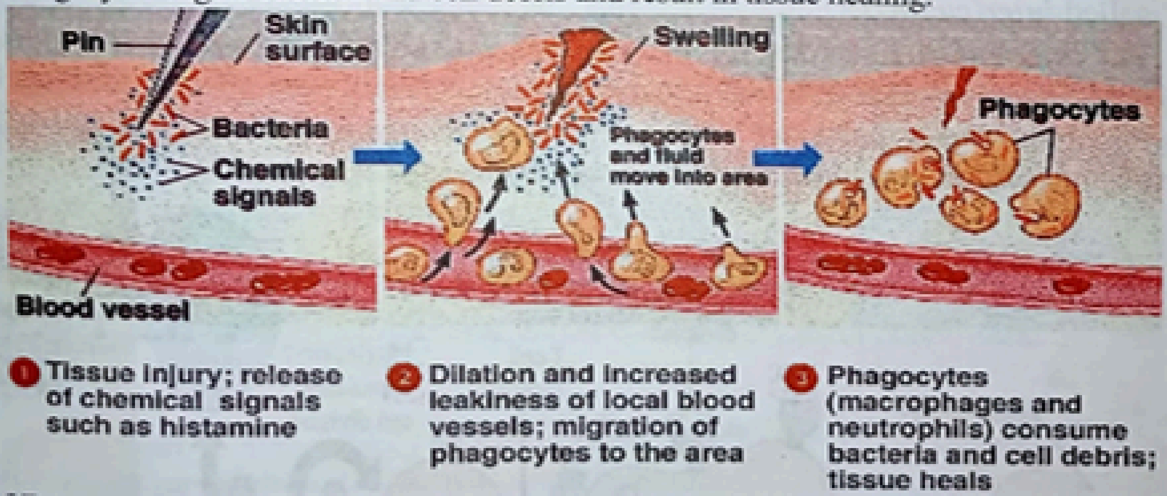
- Interferons belong to the large class of proteins known as ***cytokines***, which are the molecules used for ***communication between cells during infection***.
- They are made and released by host cells in response to the presence of several pathogens specially viruses. They activate molecules which prevent the virus from producing and replicating its RNA or DNA. In this way, ***interferons limit cell-to-cell spread*** of viruses in the body.
- IFNs also ***activate immune cells***, such as natural killer cells and macrophages that in turn destroy virally infected cells.



Inflammatory Response

- It is a major component of the non-specific defence. Any damage to tissue, whether caused by an infectious microorganism or by physical injury, even just a scratch or an insect bite triggers this response.
- Inflammation can be *localized* or *systemic*.
- The classical signs of inflammation are ***heat***, ***pain***, ***redness***, ***swelling***, and ***loss of function***.
- In case of injury or pathogenic infection, the sequence of events are mentioned below:

i. The damaged cells release chemical signals such as ***histamine***
ii. Histamine mediated ***vasodilatation*** and ***blood vessels start leaking***.
iii. Phagocytes engulf bacteria and cell debris and result in tissue healing.



Role of Fever as Second Line of Defense

- ***Fever/pyrexia*** is due to pyrogens that are chemicals released by invading organisms. ***Pyrogens*** increase temperature set point of hypothalamic thermostat of body.
- White blood cells in response to infection produce hormones called ***endogenous pyrogens***.
- These pyrogens increase temperature set point of ***hypothalamus*** because higher body temperature than normal increases the activity of phagocytic WBCs that attack upon bacteria. The endogenous pyrogens also cause other cells to reduce the concentration of iron in the blood.

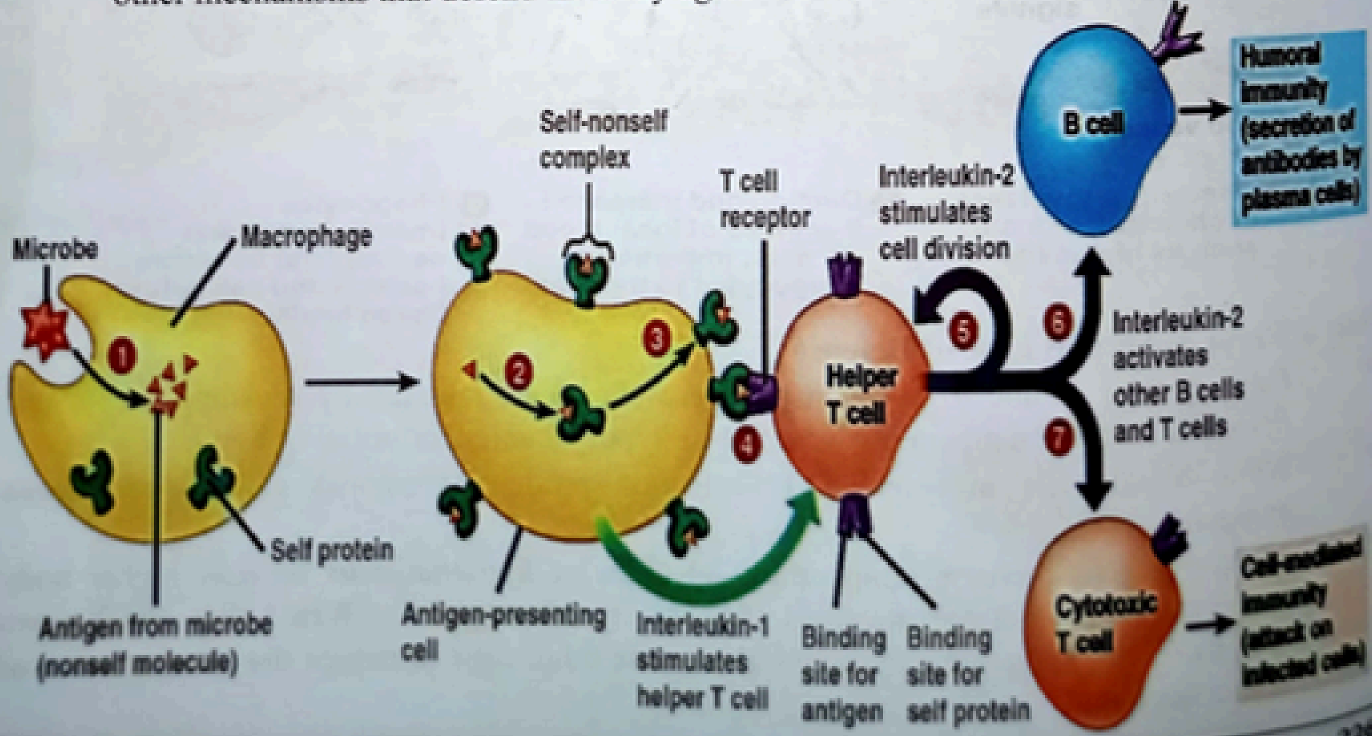
- As many bacteria require more iron to reproduce at temperature of 38°C or 39°C than at 37°C. So, fever and reduced iron in the blood combine to slow down their rate of reproduction.
- Fever also ***increases the production*** of ***interferons*** that travel to other cells and increase their resistance to viral attack.
- The higher body temperature may directly ***inactivate*** the virus particles; particularly envelop viruses, which are more heat-sensitive than non-enveloped viruses. Replication of some viruses is reduced at higher temperatures; therefore, fever may inhibit replication.

(iii) Third Line of Defense

- The third line of defense or ***immune system*** is the ***highly specific defense/resistance*** which ***relies on antigens/immunogens***, which are specific substances found in foreign microbes. These antigens ***serve as the stimulus*** to produce an immune response.
- It is derived from mesoderm.
- ***Antigen*** or ***immunogen*** is a foreign substance, often a protein which stimulates the formation of antibodies.
- In 3rd line of defense, the immune response can be of two types: ***humoral/antibody mediated immune response*** which is carried out by ***B-lymphocytes/plasma clone cells*** and ***cell-mediated immune response*** which is carried out by ***T-lymphocytes***.
- However, the activation of these lymphocytes depends upon the participation of monocytes/macrophages.

Role of Monocytes in Third Line Defense

- When macrophages perform phagocytosis of invaded microorganisms, they digest them and ***display microbial antigens on their surfaces***, and also begin to ***secrete about 100 different compounds*** including various enzymes, interferons and a protein called ***interleukin-1***.
- The ***interleukin-1*** secreted by macrophages ***activates the T cells***. That in turn begins to secrete ***interleukin-2***, which then ***activates the B cells***.
- Interleukin-1 also promotes a general response to injury, causing fever and activating other mechanisms that defend the body against invasion.



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CRITICAL THINKING

22. Both lysozyme and cytotoxic T cells
A. Kill cells through chemical interactions
B. Kill cells by inducing apoptosis
C. Kill cells by generating a membrane attack complex
D. Are part of innate immunity

Cell Mediated Immune Response

(i) This type of immune response depends upon the T-cells which originate from stem cells in the bone marrow. After early embryonic development, the newly formed T-cells migrate to ***thymus gland*** for processing. The thymus makes T-cells ***immuno-competent*** that is capable of ***immunological response***.

- T-lymphocytes are further divided into following categories:

(ii) ***Helper T-lymphocytes* (CD4):** These cells secrete ***interleukin- 2***, which stimulates cell division of T-cells and B-cells. In other words, these cells recruit even more cells to help fight the pathogen.

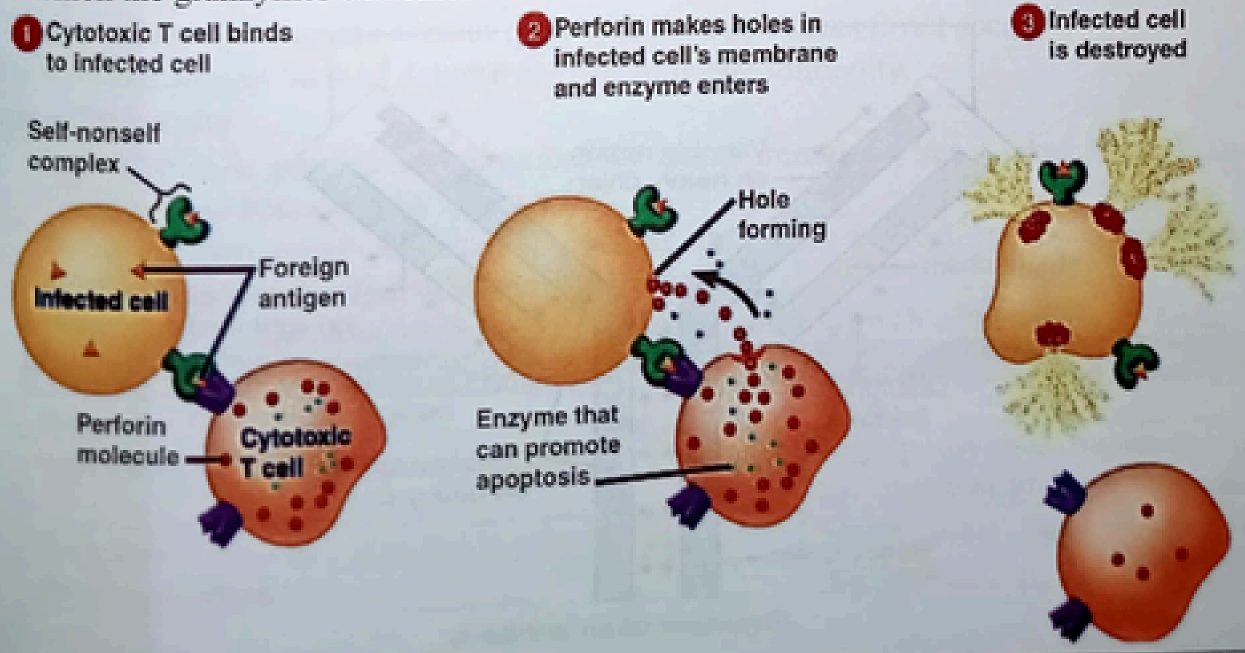
(iii) ***Suppressor T-lymphocytes* (CD8):** When infection is successfully removed, these cells begin to secrete certain proteins that inhibit further proliferation of T cell. Therefore, they shut down the immune response.

(iv) ***Cytotoxic T-lymphocytes*** (CD8) are involved in direct killing or destroying of antigens. For destruction, they usually depend upon lysosomes and peroxisomes.

(v) ***Memory T-lymphocytes***: These cells remain dormant after the initial exposure to an antigen. If the same antigen presents itself again, even if it is years later, the memory cells are stimulated to convert themselves into helper T-cells and help fight the pathogen.

Mode of Action of Cytotoxic T Cells

- Cytotoxic T-cells carry out their killing function by releasing two types of preformed cytotoxic protein: the ***granzymes***, which seem able to induce apoptosis in any type of target cell, and the ***perforin***, which punches holes in the target-cell membrane through which the granzymes can enter.



Humoral Immune Response

- Humoral immune response or antibody medicated immune response is shown by the B-lymphocytes which are differentiated in ***bone marrow***.

(vi) B-lymphocytes have been given name due to their 1st discovery from ***Bursa of Fabricius***, which is a lymphoid tissue in birds around cloaca.

- In humans, these are produced and released in mature form from bone marrow. After stimulation by antigen, they are activated and start dividing and form:

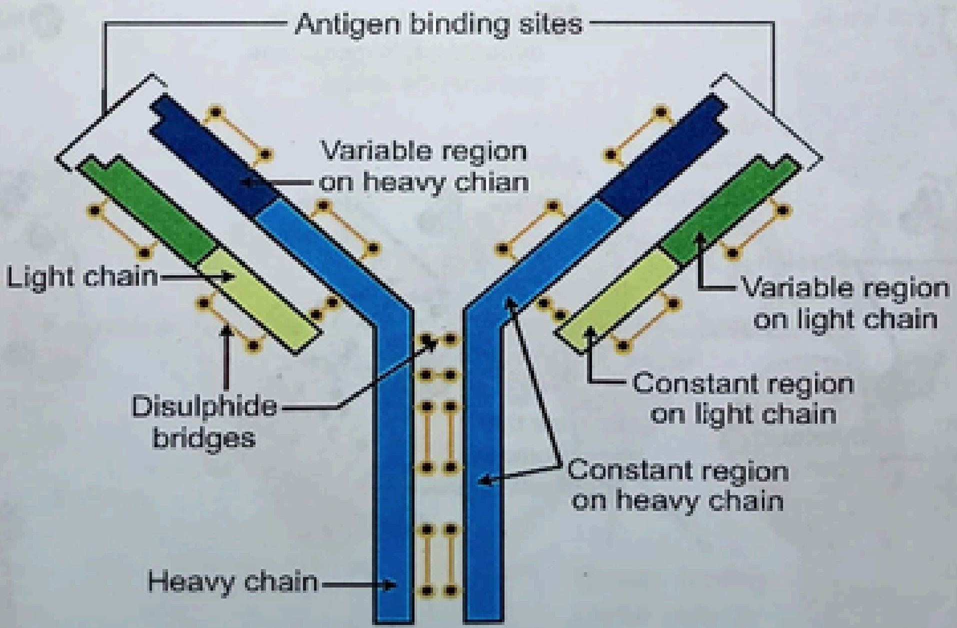
(i) ***Plasma cells clone*** which synthesize and secrete antibodies in plasma and other body fluids.
(ii) ***Memory B-cells*** which keep information/ memory of antigen encountered.

- B-cells express specific receptors on their cell membrane, the ***B-cell receptors*** (BCRs). BCRs allow the B-cell to bind a specific antigen, against which it will initiate an antibody response.

Antibodies

- ***Antibodies/Immunoglobulins*** are globular proteins, manufactured by B-lymphocytes, then secreted into the lymph and blood where they circulate freely.
- These are ***Y-shaped molecules*** and ***possess quaternary structure***.
- Each antibody consists of four polypeptide chains; ***two heavy chains*** and ***two light chains***.
- Each chain has a ***constant region*** and ***variable region***. In constant region, the amino acid sequence is constant within a particular immunoglobulin class.
- On the other hand, variable segment consists of different amino acid sequence in every antibody. Therefore, they act as antigen binding sites. Each antibody has two antigen binding sites.

> **CRITICAL CONCEPT**
>
> **Classes of Antibodies and their Important Functions:**
>
> **IgA** plays a role in localized defense mechanism in external secretions like tears.
>
> **IgD** is involved in recognition of antigens by B-lymphocytes.
>
> **IgE** is involved in allergic reactions.
>
> **IgG** is responsible for complement fixation.
>
> **IgM** is also responsible for complement fixation.

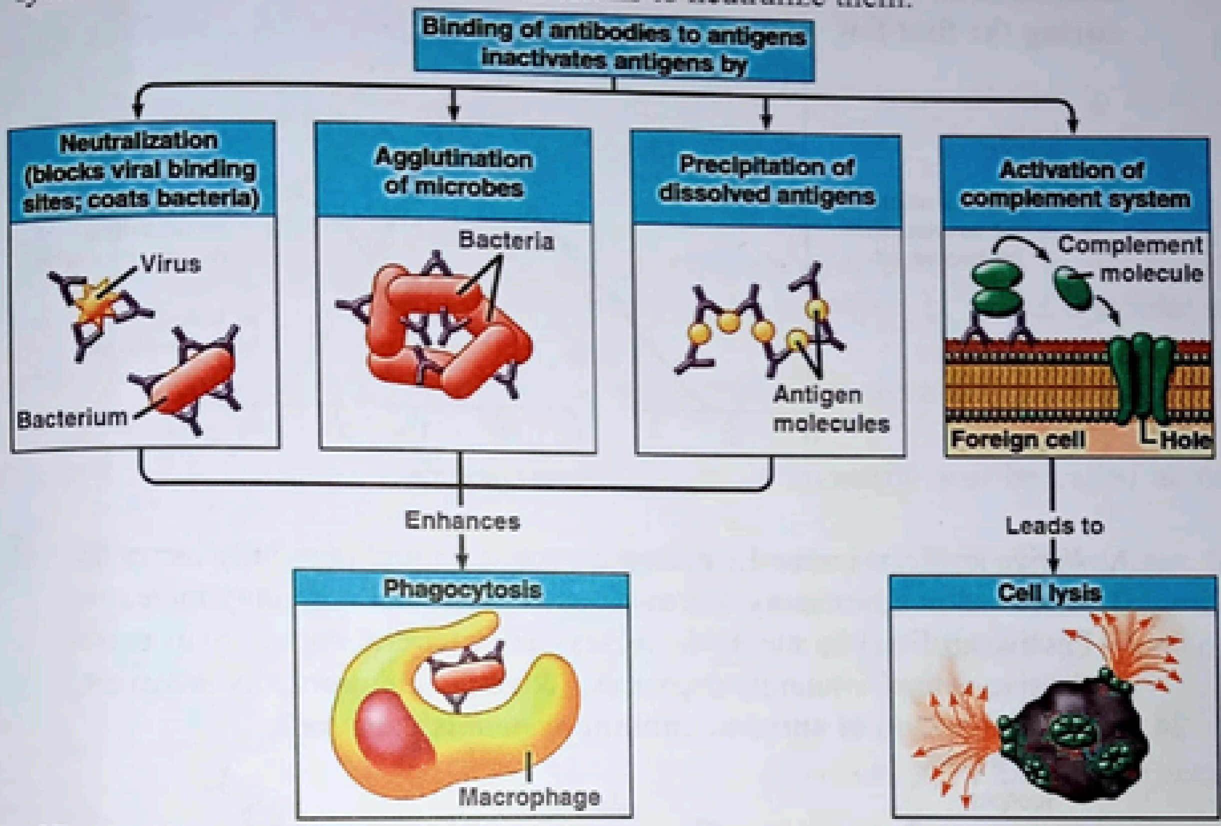


Structure of an antibody

- The polypeptide chains of an antibody molecule are linked with each other through ***disulfide bonds***. Typically, there are two disulfide bonds between two heavy chains and two disulfide bonds are present between heavy and light chains.

Modes of Action of Antibodies

- Antibodies work in different ways: the antibody can bind to an antigen, forming an ***antigen-antibody complex thus promote phagocytosis***. They also ***activate complement system***. Antibodies can combine with toxins to neutralize them.



Types of Immunity

- There are two basic types of immunity: ***inborn*** or ***innate immunity*** and ***acquired*** or ***adaptive immunity***.

Innate Immunity

- The ability of the innate immunity to kill microorganisms is not specific.
- First and second lines of defense are part of innate immunity.

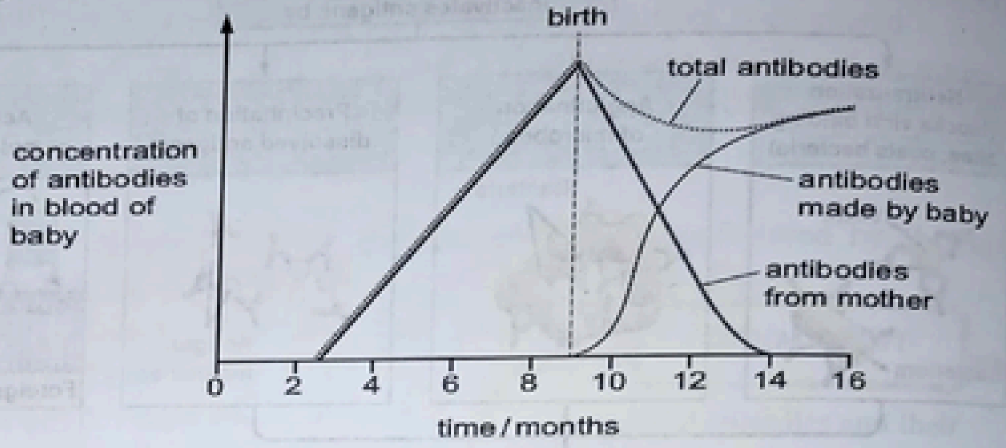
Acquired Immunity

- Highly specific protection is provided by innate immunity, but it takes several days for this system to become fully functional.
- There are two types of acquired immune responses i.e. cell-mediated response and antibody-mediated or humoral immune response.
- The comparison between inborn and acquired immunity is given in the following table:

Features	Inborn/Innate Immunity	Acquired/Adaptive Immunity
Response Time	Hours	Days
Specificity	Limited and fixed	Highly diverse, improves during the course of immune response
Response to Repeated Infection	Identical to primary response	Much more rapid than primary response

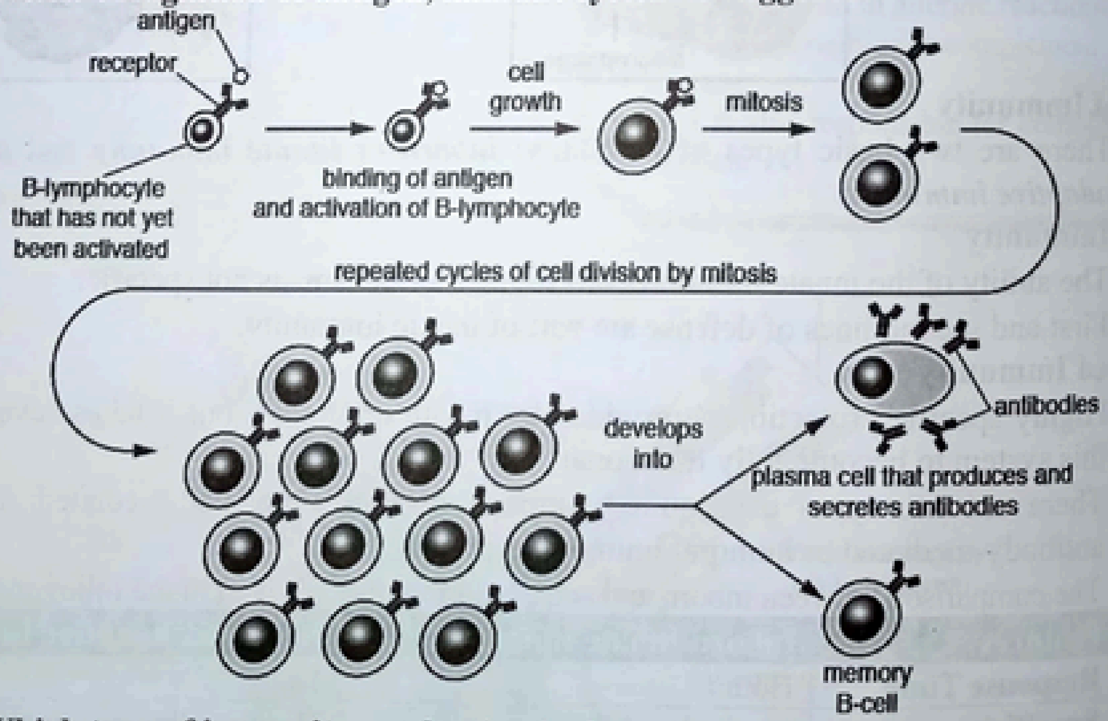
CRITICAL THINKING

23. The graph shows the changes that occur in the concentration of antibodies in the blood of a baby before birth and during the first few months after birth. Which description about the changes in immunity during the first few months after birth is correct?



A. Active artificial immunity decreases, active natural immunity increases
B. Active natural immunity decreases, active artificial immunity increases
C. Passive artificial immunity decreases, active natural immunity increases
D. Passive natural immunity decreases, active natural immunity increases

24. After recognition of antigen, immune system is triggered.



Which type of immunity production is shown?

A. Innate immunity
B. Active immunity
C. Cell mediated Immunity
D. Passive immunity

Types of Acquired Immunity

- There are two types of acquired immunity:
  (i) Active Immunity
  (ii) Passive Immunity
- The method of passive immunization is used to combat active infections of tetanus, infectious hepatitis, rabies, snakebite venom etc.
- These are further divided into ***natural*** and ***artificial immunity***.

Natural Active Immunity

- When a person is exposed to an infection (antigen) becomes ill and in most cases survives, then this immunity developed against that disease is called ***natural active immunity***.

Artificial Active Immunity (Vaccination)

- The use of vaccines, which stimulates the production of antibodies in the body, and making a person immune against the diseases or infection, is called ***artificial active immunity***. The process is called vaccination.
- This active immunity has been achieved by artificially introducing antigens in the body.

Natural Passive Immunity

- If the source of antibodies is natural, then type of immunity will be called as natural passive immunity.
- For example, antibodies from a mother can cross the placenta and enter her fetus. In this way they provide protection for the baby until its own immune system is fully functional.
- This immunity may also be provided by ***colostrum***, the first secretion of the mammary glands. The baby absorbs the antibodies through its gut.

Artificial Passive Immunity

- Antibodies which have been formed in one individual are extracted and then injected into the blood of another individual.
- In the case of snakebite venom, passive immunity is produced by antitoxins, so the serum is called ***anti-venom serum***.
- Similarly, specific antibodies used for combating tetanus and diphtheria are cultured and injected into humans.
- The comparison between active and passive immunity is given in the following table:

Features	Active Immunity	Passive Immunity
Production of Immunity	Produced because of entry of antigen.	Produced because of entry of antibodies.
Source of Antibodies	Body is stimulated to produce antibodies.	Antibodies are introduced from other source.
Substance Entering the Body	Antigen	Antiserum
Response	Delayed immune response	Immediate immune response
Duration of Protection conferred	Prolonged	Short
Development of Immune Memory	Yes	No
Role	Preventive	Preventive and curative

TOPIC-10 PROKARYOTES (KINGDOM MONERA)

COURSE CONTENT

- Size and Shape of Bacteria
- Bacterial Cell Structures
- Importance and Control of Bacteria

SIZE AND SHAPE OF BACTERIA

- Kingdom prokaryotae consists of organisms with ***prokaryotic cells.*** These organisms are simply called as ***bacteria*** which are microscopic, single-celled and thrive in diverse environments.

Size of Bacteria

- Bacterial cells are about one-tenth the size of eukaryotic cells. However, a few species are visible to the unaided eye.

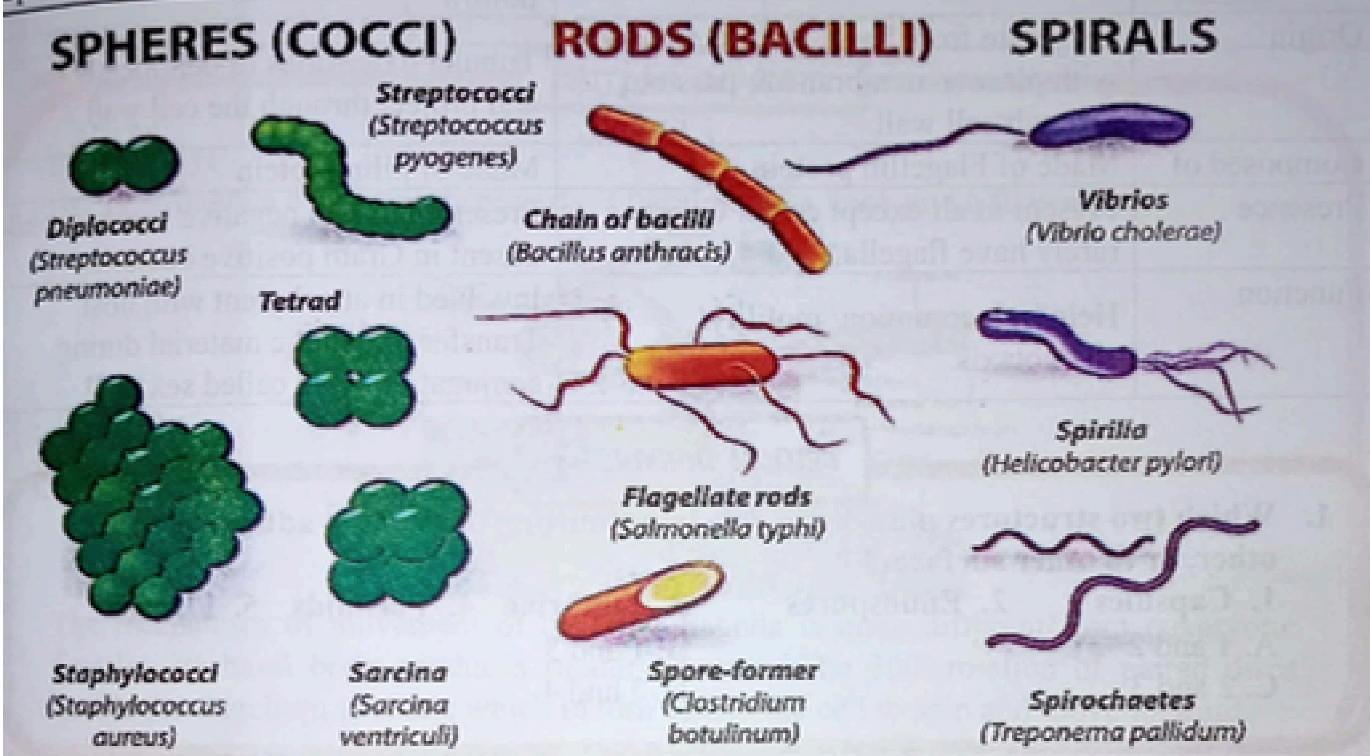
Type	Size
Range	0.1-600 μm
Mycoplasma (Smallest)	100-200 nm
Escherichia coli	1.1-1.5 μm (width), 2.0-6.0 μm (length)
Spirochete	500 μm in length
Staphylococci & Streptococci	0.75-1.25 μm in diameter
Epulopiscium fishelsoni	600 μm long, and 80 μm thick

Shapes of Bacteria

- On the basis of general shape, bacteria are classified into three categories which may be ***Cocci*** (spherical or oval in shape), ***Bacilli*** (rod shaped) and ***Spiral*** (curved/ spring shaped).
- Most of the bacterial species have fairly constant characteristic cell shape. However, it has been shown that certain bacteria are capable of dramatically changing shape. Such bacteria are called as ***pleomorphic***. For example, ***H. pylori*** exist in both a helix-shaped and a spherical form.

Type	Arrangement	Division	Examples
Coccus	Spherical	No	*Streptococcus pneumoniae, Neisseria meningitidis, Staphylococcus aureus*
Diplococcus	Two cocci	Single plane of division	
Streptococcus	Cocci in chain	Single plane of division	
Staphylococcus	Irregular arrangement	Random planes	
Tetrad	Square of four cocci	Two planes of division	
Sarcina/Octate	Cube of eight cocci	Three planes of division	
Bacillus	Rod shaped	No	*Escherichia coli, Bacillus subtilis, Pseudomonas*
Diplobacillus	Two bacilli	Single plane of division	
Streptobacillus	Chain of bacilli	Single plane of division	
Coccobacilli	Rod shaped with	No	

(Pleomorphic)	spherical ends		*Haemophilus influenzae*
Spirals	Spirally coiled	No	*Vibrio cholerae* *Hyphomicrobium,* *Helicobacter pylori* *Treponema pallidum*
Vibrio	Comma shaped	No	
Spirillum	Thick, rigid spiral	No	
Spirochete	Thin, flexible spiral	No	

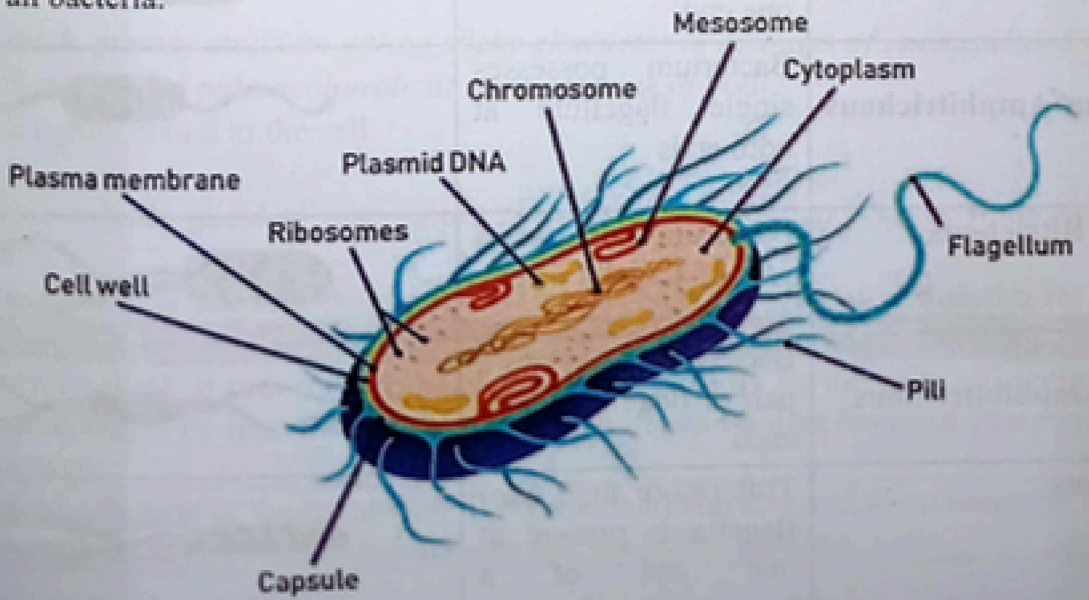


BACTERIAL CELL STRUCTURE

All bacterial cells invariably have a cell membrane, cytoplasm, ribosomes and chromatin bodies.

The majority have cell wall, which gives shape to the bacterial cell.

Specific structures like capsule, slime, flagella, pili, fimbriae and granules are not found in all bacteria.



Bacterial Appendages

- The structures that project from the surface of the bacterial cell are called *bacterial appendages* and include ***flagella***, and ***pili/fimbriae***.

Flagella and Pili

Features	Flagella	Pili/ Fimbriae
Appearance	Thin, long, flexible and helical	Thick, short, rigid, non-helical, and hollow
Origin	Originate from basal bodies, attached with plasma membrane & pass out through cell wall.	Tubular extensions of cell membrane and project through the cell wall
Composed of	Made of Flagellin protein	Made of pilin protein
Presence	Present in all except cocci. Cocci rarely have flagella.	Present in Gram negative bacteria while absent in Gram positive bacteria.
Function	Help in locomotion/ motility/ chemotaxis.	Involved in attachment with host Transfer of genetic material during conjugation (also called sex pili)

CRITICAL THINKING

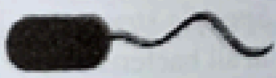
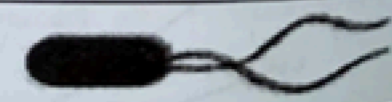
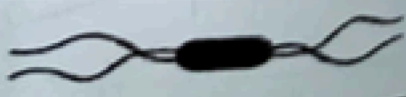
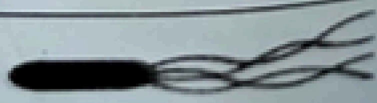
1. Which two structures play direct role in permitting bacteria to adhere to each other, or to other surfaces?

1. Capsules 2. Endospores 3. Fimbriae 4. Plasmids 5. Flagella

A. 1 and 2
B. 1 and 3
C. 2 and 3
D. 3 and 4

Classification on Basis of Flagella

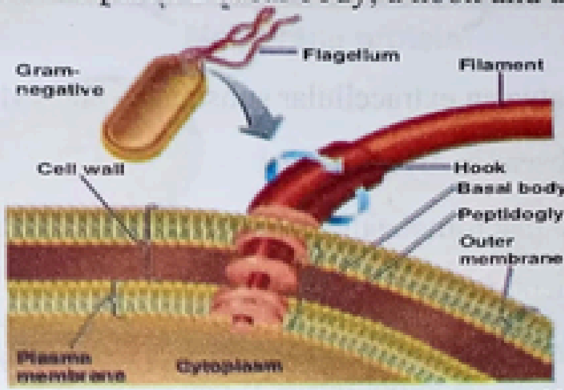
- On the basis of presence or absence of flagella, pattern of attachment of flagella and the number of flagella present, the bacteria are classified into different taxonomic group.

Type	Flagella	Appearance
Mono-polar Monotrichous	Bacterium possesses single flagellum at one end	
Bi-polar Monotrichous/Amphitrichous	Bacterium possesses single flagellum at both ends	
Mono-polar Bitrichous	Bacterium possesses a pair of flagella at one end	
Bi-polar Bitrichous/Amphibitrichous	Bacterium possesses a pair of flagella at both ends	
Lophotrichous	Tuft (more than two) flagella is present at one end of a bacterium	

Amphilophotrichous	Tuft of flagella is present at both ends of a bacterium	
Peritrichous	Flagella arise randomly over the entire surface of the cell	

CRITICAL CONCEPT!

Basal Body:
Bacterial flagella consist of three parts: a basal body, a hook and a filament.



The mechanism of movement of bacterial flagella is quite different from eukaryotic flagella. Its basal body produces rotatory motion. The 360° rotation of paired discs enable the flagellum to rotate which in turn causes the cell to spin and move forward.

Cell Envelope

- The detailed studies of bacterial structure by the electron microscope revealed that the cell envelop is the outer wrapping of bacterial cell.
- Complexes of layers external to the cell protoplasm are collectively called cell envelope and commonly include capsule, slime and cell wall.

Capsule

- A ***thick, gummy*** structure giving ***sticky character to colonies of encapsulated bacteria***.
- It is made up of ***polysaccharide*** units or ***proteins*** or both.
- It is tightly bound to the cell.

Slime

- ***Loose soluble*** shield of macromolecules outside capsule and can be removed from cell easily.
- Slime **protects bacteria from environmental dangers such as antibiotics etc.**

Functions of Glycocalyx
In the form of slime, it prevents the phagocytosis of bacteria by the cells of immune system called ***macrophages*** by increasing diameter of bacteria and hiding bacterial components from immune system
Promotes the adhesion of the bacteria to living and inert surfaces and the subsequent formation of adherent, glycocalyx-enclosed populations that are called biofilms

CRITICAL THINKING?

2. **Bacteria that cause nosoco[...]duce extra cellular substances that allow them to stick firmly to medical devices, such as intra venous catheters. Which one of the following is the name of this extra cellular substance?**

A. Axial filament B. Endotoxin
C. Flagella D. Glycocalyx

3. **Which of the following requires ATP to function, and permits some species to respond to taxes (plural of taxis)?**

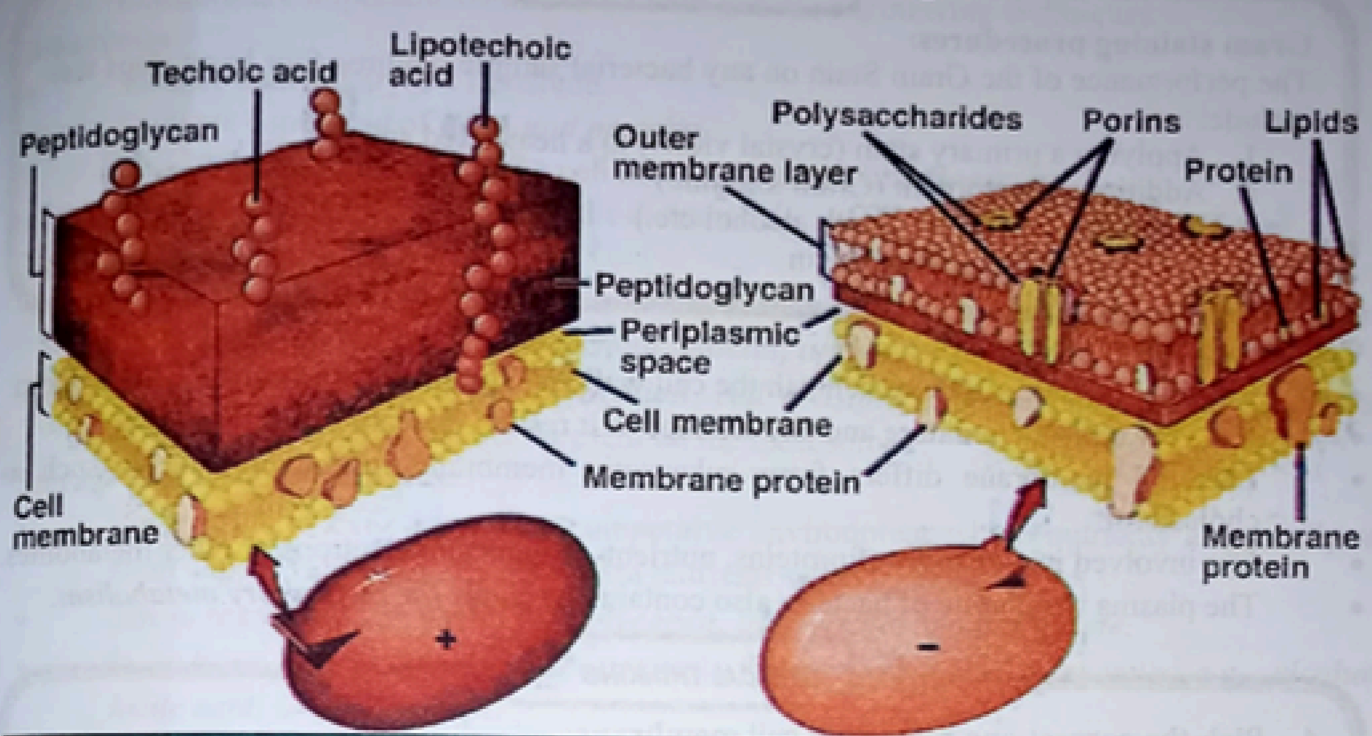
A. Endospore B. Sex pilus
C. Flagellum D. Capsule

Cell Wall

- A rigid structure between extracellular substances and cytoplasmic membrane.
- Cell wall is only absent in ***Mycoplasma***.
- It is composed of a macromolecule called ***peptidoglycan*** consisting of long glycan chains cross linked with peptide fragments.
- ***Sugar, teichoic acid, lipoproteins and lipopolysaccharides*** are also present which are linked with peptidoglycan.
- Teichoic acid fibers protrude outside the peptidoglycan.
- Cell wall of archaebacteria does not contain peptidoglycan; rather contain proteins, glycoproteins and polysaccharides.
- It determines the ***shape of bacteria*** and ***protects*** the cell from ***osmotic lysis***.
- It provides ***identity to different bacteria***, depending upon their staining characteristics i.e., Gram positive and Gram-negative bacteria.
- The Gram-negative cell wall also contains a protein, the ***porins*** in outer membrane which act like pores for particular molecules.

CRITICAL CONCEPT!

Peptidoglycan:
Chemically, Peptidoglycan is a conjugated molecule, consisting of two alternating amino sugars make up the crystal lattice structure of peptidoglycan; they are N-acetylglucosamine (NAG) and N-acetylmuramic acid (NAM). Amino sugars are sugar molecules that have an amine group ($-NH_2$) replacing one of their hydroxyl groups. Each NAM molecule has an attached chain of four or five amino acids. Crosslinking between these amino acids gives peptidoglycan its strong structure.



Characteristics	Gram Positive	Gram Negative
Stain Retained	Primary dye (Crystal violet & Gram's iodine)	Secondary dye (Safranin)
Final Color After Staining	Purple	Pink
Number of Major Layers	1	2
Peptidoglycan	More (50% of dry weight)	Less (10% of dry weight)
Lipids	Less (only 1-4%)	More (11-12%)
Additional Substances	Teichoic acid and lipoteichoic acid	Lipopolysaccharides, lipoproteins
Overall Thickness	Relatively thicker (20-80nm)	Relatively less thick (8-11nm)
Outer Membrane	Absent	Present
Periplasmic Space	Present in some species	Present in all species
Permeability of Molecules	More penetrable	Less penetrable
Resistance to molecules	Less	More
Porins	Absent	Present

- Periplasmic space lies between peptidoglycan layer of cell wall and cytoplasmic membrane. It is the site having certain enzymes.

CRITICAL CONCEPT!

Gram staining procedures:
The performance of the Gram Stain on any bacterial sample requires four basic steps that include:

1. Applying a primary stain (crystal violet) to a heat-fixed smear
2. Addition of a mordant (Gram's Iodine)
3. Rapid de-colorization (with alcohol etc.)
4. Counterstaining with safranin

Cell Membrane

- It is thin, flexible structure beneath the cell wall and completely surrounds the cytoplasm.
- It is very delicate in nature and any damage to it results in death of the organism.
- Bacterial membrane differs from eukaryotic membrane in ***lacking sterols*** such as cholesterol.
- It is involved in ***transport*** of proteins, nutrients, sugars and electrons or other metabolites.
- The plasma membrane of bacteria also contains ***enzymes for respiratory metabolism***.

CRITICAL THINKING

4. Pick the correct one regarding cell membrane:

	Features	Prokaryotes	Eukaryotes
A.	Help in flow of nerve impulse	Yes	Yes
B.	Lacks cholesterol	Yes	Yes
C.	Helps in transport of material	Yes	Yes
D.	Proteins are embedded in membrane	No	Yes

Cytoplasmic Matrix

- A ***gel-like*** substance present between the plasma membrane and the nucleoid.
- Plasma membrane and everything present within it is called ***protoplast***.
- Cytoplasmic matrix lacks membrane bounded organelles and cytoskeleton; however, chromatin/ nuclear body, ribosomes, mesosomes, granules and nucleoid are present in it.

Nucleoid

- Other names for nucleoid are nuclear body, chromatin body and nuclear area.
- Nucleoid is the nuclear region of bacteria which is not separated from the cytoplasm by nuclear membrane. It consists of a single, large circular, double stranded DNA molecule, aggregates as an irregular shaped dense area in the centre of bacterial cell. Due to this single chromosome, bacteria are considered ***haploid organisms***.
- A short duration of diploid state comes in their life cycle just before cell division when they replicate their DNA.
- It is visible in the light microscope after staining with ***Feulgen dye***.
- The nucleoid DNA ***controls growth and metabolic activities*** of bacteria.
- *E. coli* closed circle chromosome measures approximately 1,4000 μm.

Plasmid

- Circular, double stranded DNA molecules, ***self-replicating*** but not essential for the bacterial growth and metabolism

- Contains genes of ***drug resistance, heavy metal resistance, disease, and insect resistance***.
- Plasmids are important vectors in modern genetic engineering techniques.

Ribosomes

- ***Smaller*** than eukaryotic ribosome.
- They are composed of ***RNA and proteins***.
- May be loosely attached to the cell membrane or plasma membrane.
- They are involved in protein synthesis/translation.

Mesosomes

- The cell membrane invaginates into the cytoplasm forming structure called as ***mesosomes***. They occur in the form of ***vesicles, tubules or lamellae***.
- They are involved in ***DNA replication***, ***cell division***, ***export of exo-cellular enzymes***. ***Respiratory enzymes*** are also present on the mesosomes.

Storage Bodies and Granules

- Since bacteria exist in a very competitive environment where nutrients are usually in short supply. They tend to store extra nutrients when possible.
- The nutrients may be useful e.g., ***glycogen, sulphur, fat*** and ***phosphate***.
- In addition, cells contain waste materials that are subsequently excreted e.g., ***alcohol***, ***lactic acid***, and ***acetic acid***.

Spores

- These are ***metabolically dormant*** bodies, resistant to adverse physical environmental conditions such as light, high temperature, desiccation, pH and chemical agents.
- They may be ***exospores*** (external to vegetative cell) or ***endospores*** (inside vegetative cell/ inside cell wall).
- Endospores are more resistant structures and can survive for years.
- They ***germinate*** to form vegetative cell under favorable conditions. They normally develop at ***end stage of growth*** of bacteria.

Cysts

- They are ***dormant, thick walled, desiccation resistant*** form but not heat resistant structures.
- They develop during ***differentiation of vegetative cells*** which can germinate under suitable conditions.

Spore	Cyst
Inside (Endospores)	Outside
Resistant to light, temperature, desiccation, pH and chemical agents	Desiccation resistant
Develops at end stage of bacterial growth	Develops during differentiation of bacterial cell.
Actinomycets	*Azotobacter*

IMPORTANCE AND CONTROL OF BACTERIA

Importance of Bacteria

- Bacteria are very important members of biodiversity from ecological, economical, biotechnological and research view point.

1. Ecological Importance of Bacteria

Ecological importance refers to the role of bacteria in environment, such as;

- Decomposition of dead/complex organic matter
- Humus formation to increase the fertility of soil
- Bioremediation etc.

Role of Bacteria as Recyclers

- Bacteria serve as *recyclers* of nature as they are involved in decomposition of dead and complex organic matter in the environment.
- If the dead bodies are not decomposed, the organic nutrients present in their bodies would not be released in the environment. The organic carbon present in dead bodies might diminish all the CO_2 from the atmosphere if there were no decomposers present on earth.
- Through this process, other organisms also get benefited, who can use the simple forms of organic compounds/nutrients released from the dead matter of various bacteria.

Role of Bacteria to Increase Soil Fertility by Humus Formation and N_2-Fixation

- The partially decaying organic matter of dead organisms is called ***humus***. It contains nutrients and increases soil fertility for the growth of plants.
- It also increases the water retaining capacity of the soil. ***Bacteria and fungi are the only organisms that decompose dead animals and plants*** and thus, take part in humus formation.
- Soil is the only source of nitrogen for plants as they cannot inhale nitrogen directly from the atmosphere. Nitrogen from the atmosphere can be available to the plants through the process of ***nitrogen fixation***.
- This process takes place with the help of nitrogen fixing bacteria like ***Rhizobium*** and ***Cynobacteria*** in the soil. These species of bacteria ***convert the atmospheric nitrogen into nitrates and nitrites*** as a part of their metabolism, and make it available to the plants.
- Leguminous plants have a ***mutualistic association*** with the bacteria living into their tissues for this purpose.

Role of Bacteria in Bioremediation

- Removal or degradation of environmental pollutants by using living organisms is called ***bioremediation***.
- It involves the use of many bacteria that either naturally loves to eat contaminants or have been ***genetically altered*** to give them the taste for toxins.
- Scientists are designing or deploying microbes to purge sites of contaminants such as oil, radioactive waste, gasoline, mercury.

2. Economic Importance of Bacteria

- The economic importance of bacteria refers to the role of bacteria in research and technology, plant diseases and in human diseases.

Role of Bacteria in Research and Technology

- Bacteria play an important role in many technological fields, mainly in biological research, mining, medicine, production of food products, plastics synthesis and sewage treatment. The overall commercial worth of bacteria in these operations is immense.

Use in Genetics & Genetic Engineering

- Bacteria have been used and being continuously used in the study of genetics and genetic engineering.
- Bacteria were used as model organism in number of famous experiments such as the discovery of DNA as heredity material, discovery of semi conservative replication of DNA and central dogma of life etc.
- Many components of bacterial cell are also being used as tool in genetic engineering experiments.

Use in Mining

- The miners can extract metal from low grade ores in a relatively ecologically friendly way by using certain bacteria.
- The bacterium *Thiobacillus ferrooxidans* is the important organism here. It works by catalyzing the oxidation of metal sulphides, particularly copper sulphate so that they are soluble in water i.e. Cu_2S to $2Cu^{2+}$ and SO_4^{2-}. This allows the copper to be leached out of the rock.
- *T. ferrooxidans* is also used in the organic leaching of gold and uranium with the help of other bacteria such as *T. thiooxidans* and *Leptospirillum ferrooxidans*.

Use in Production of Complex Organic Molecules

- Bacteria are useful to mankind in the production of complex organic molecules that are of use in small amounts as part of the normal process of living, these include antibiotics, vitamins, amino acids and enzymes.
- In addition to these compounds, the dairy products such as yogurt cheese, butter etc. are also produced with the help of bacteria.

Use in Production of Biodegradable Plastic

- Now a day, ***biodegradable plastic*** is made by using two bacterially produced molecules, ***Poly-B-hydroxybutyrate*** and ***Poly-B-hydroxyvalerate***.
- These molecules make a polymer just like ordinary plastic but having the essential difference that once left out in the compost or in a landfill they can be broken down by bacteria and fungi to become part of the cycle of life again.

Use in Treatment of Waste Water

- Owing to their characteristics of degrading harmful chemicals and pollutants, bacteria naturally help in treatment of waste water.

Role of Bacteria in Causation of Diseases and Spoilage of Food

- Parasitic bacteria attack plants and cause various diseases, e.g. fire blight in apple, ring diseases in potatoes and crown gall etc.
- Many human diseases are caused by bacteria e.g. diphtheria, tetanus, leprosy, meningitis, sore throat, whooping cough also called pertussis etc.
- Bacteria cause decay of wood, leather, fabrics etc.
- Bacteria spoil the food materials by decomposition.

Control of Bacteria

- Bacterial control is required to prevent diseases and food spoilage.
- Modes of action of different physical and chemical agents of control vary. Damage can result malfunctions in the cell wall, cell membrane, cytoplasmic enzymes or nucleic acids.

Physical Methods

- The process in which physical agents are used to control bacteria/microorganisms is known as ***sterilization*** and it involves destruction of all life forms.

> **CRITICAL CONCEPT!**
> Sterilization is the complete killing of all life form.

- In physical methods, steam, dry heat, gas, filtration and radiations are used to control bacteria.

Type of Physical Method	Description
Use of heat	• Used in microbiological labs for control of microbes. • Both ***dry heat*** and ***moist heat*** are effective. • Moist heat causes ***coagulation of proteins*** and kills the microbes. • Dry heat causes ***oxidation of chemical constituents*** of microbes and kills them
Use of radiations	• Certain electromagnetic radiations ***below 300 nm wavelength are effective*** in killing of microorganisms. • ***Gamma rays*** are in general used for the sterilization process
Use of Membrane Filters	• Heat sensitive compounds like ***antibiotics, seras, vaccines, enzymes*** etc. can be sterilized by means of membrane filters.
Pasteurization	• Use to kill non-spore forming bacteria e.g., milk pasteurized by heating at ***71 °C for 15 seconds*** and at 62 °C for 32 minutes. • More effective method of pasteurization of milk is through ***UHT*** in which milk is treated at ***140 °C for 3 seconds*** and then cooled suddenly in vacuum chamber
Dehydration	• Food is dehydrated so that in dry condition bacteria may not grow.
Addition of Preservatives	• Acid is added to lower the pH. • By dehydration salt contents increased so that water in food in not enough for bacterial growth. • Some chemicals like ***potassium metabisulphite*** are added to preserve pickles, candies, jam and breads.

Chemical Methods

- Antiseptics, disinfectants and chemotherapeutic agents are used as chemical methods for microbial control

Type of Chemical Method	Description
Antiseptics	• Procedure to eliminate or reduce the possibility of infection is called ***antisepsis***. • Chemical substances used on living tissues that inhibit the growth of microorganism are called ***antiseptics***.
Disinfection	• Process that eliminates many or all pathogenic microorganisms, except bacterial spores, on ***inanimate objects***. • It involves killing of most but not all life forms. • Important chemicals used for disinfection are ***oxidizing*** and ***reducing*** agents e.g., halogens, phenols, H_2O_2, $KMnO_4$, alcohol and formaldehyde etc.
Chemotherapeutic Agents	• Chemotherapeutic agents and antibiotics work with natural defense and stop the growth of bacteria and other microbes. • They destroy or inhibit the growth of microorganisms in living tissues. • These are sulfonamides, tetracycline and penicillin
Vaccination	• It is an important method of prevention and treatment to control microbial diseases in humans.

CRITICAL THINKING

5. Which of the following is most effective method to kill all life form from any non-living surface?

A. Disinfectants B. Sterilization

C. Antiseptics use D. Filtration

TOPIC-11 REPRODUCTION

COURSE CONTENT

- Male Reproductive System
- Female Reproductive System
- Menstrual Cycle
- In Vitro Fertilization
- Sexually Transmitted Diseases

Ubaid

MALE REPRODUCTIVE SYSTEM

- The male reproductive system includes: ***gonads***, ***accessory ducts***, ***accessory glands*** and ***copulatory organ***.

Gonads

- The testes are male gonads which are situated outside the abdomen within a skin pouch, called ***scrotum***.
- Each testis is divided into ***250-300 lobules*** each lobule contains one to four tightly coiled and highly complex duct system called ***seminiferous tubules***, in which cells of germinal epithelium divides to produce spermatogonia.
- ***Seminiferous tubules*** are the sites for spermatogenesis.
- Testes are also acts as endocrine glands because they produce male sex hormones, most important of which is ***testosterone***.
- Seminiferous tubules also contain ***sertoli cells/nurse cells***, which provide liquid medium, protection and nourishment to sperms while they are in the tubules. These cells also secrete inhibin hormone which serves to control the spermatogenesis at normal rate.
- ***Interstitial cells/leydig cells*** are present between the seminiferous tubules and secrete testosterone, essential for production of sperms and development of male secondary sexual characteristics during puberty.
- Both germinal epithelial cells and sertoli cells are under the control of FSH while interstitial cells are under the control of ICSH.

Accessory Ducts

- Once spermatozoa are produced, they move through the seminiferous tubules and enter a tubular network called the ***rete testis*** for further maturation.
- The spermatozoa are transported

> **CRITICAL CONCEPT!**
>
> **Role of Accessory Glands in Male Reproductive System:**
>
> Seminal vesicles: The seminal vesicles provide an alkaline fluid containing fructose, ascorbic acid and a coagulating enzyme called vesiculase, as well as other substances that enhance the sperm motility thus improve their fertilizing power.
>
> Prostate gland: The prostate encircles the urethra just below bladder, it secretes milky and slightly acidic fluid that contain citrate as a nutrient source and several enzymes specially hyaluronidase.
>
> Bulbourethral gland (Cowper's gland): It secretes mucus and alkaline fluid into urethra. This fluid neutralizes the acidity of urine in urethra.

out of the testis by a series of ***efferent ductules***.

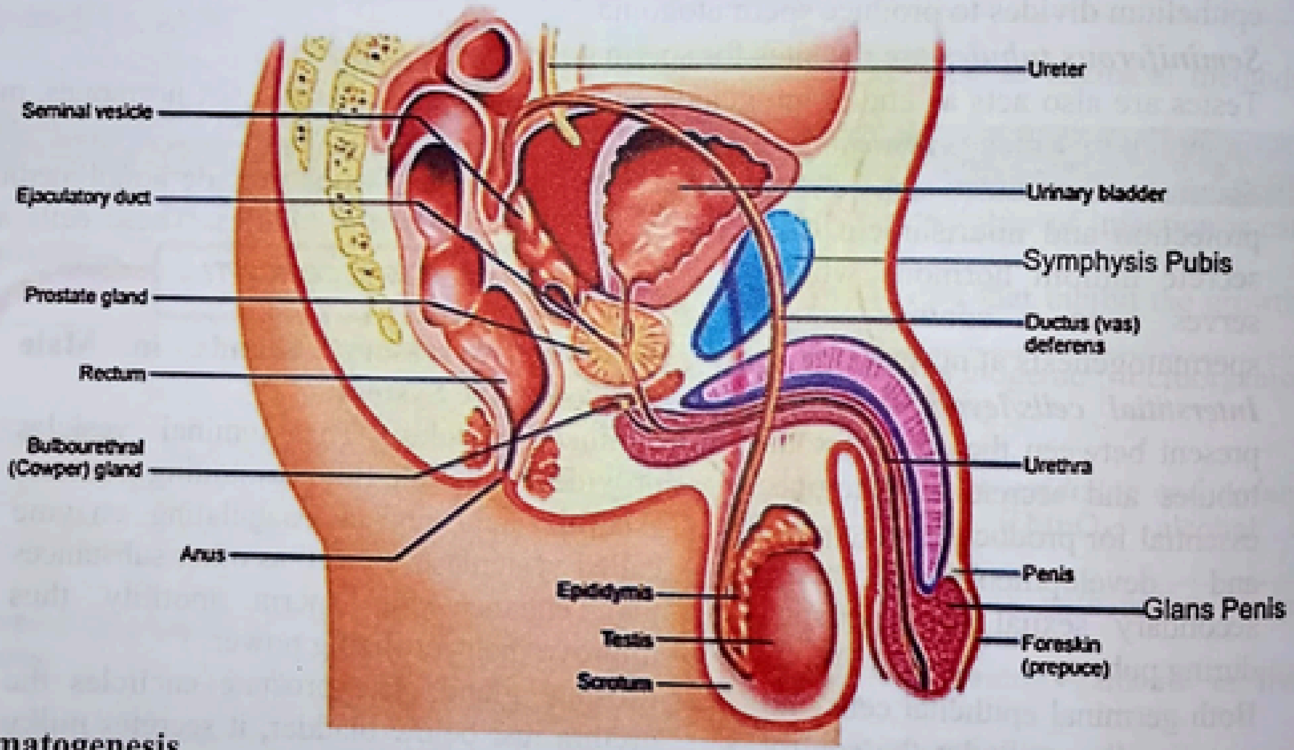
- ***Epididymis*** is the proximal and highly convoluted portion of ***vas deferens***. Its function is to transport and storage of sperms.
- Epididymis opens into another duct celled ***Vas deferens*** (sperm duct) and is the main duct of male reproductive tract.
- It joins with the duct of the seminal vesicles to form the short ***ejaculatory duct***. Here, ejaculatory duct enters the ***prostate gland***; then it empties into the urethra.
- In male, ***urethra*** is also called as urinogenital duct because it transfers both urine and semen outside the body.

Copulatory Organ

- ***Penis*** is copulatory organ is used to transfer sperm into female reproductive tract.
- It consists mainly of tissues that can fill with blood to cause an ***erection***.

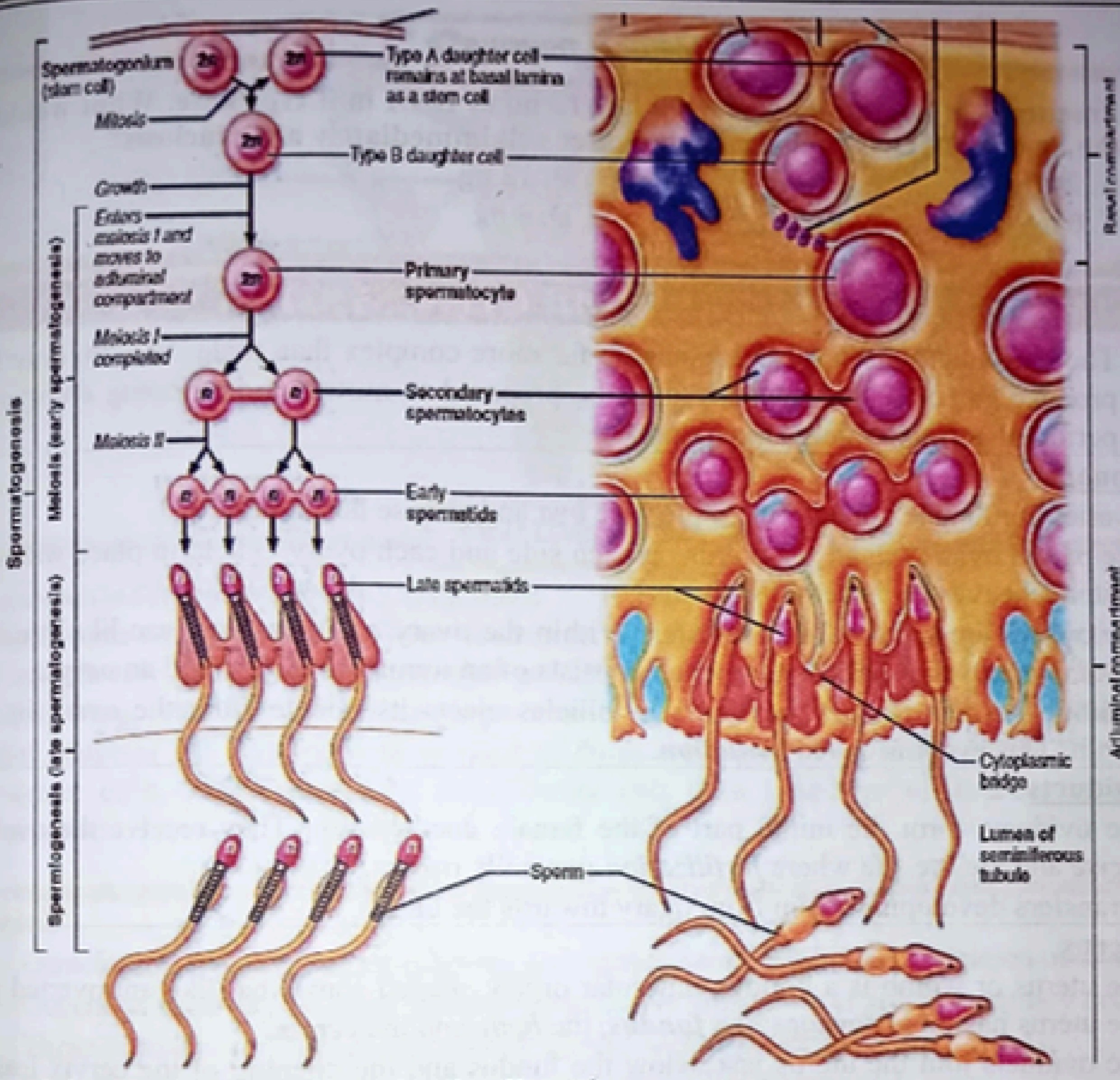
Accessory Glands

- These are exocrine in nature and include seminal vesicles, prostate and bulbourethral/Cowper's glands.
- A pair of ***seminal vesicles*** is located at the junction of sperm duct and ejaculatory duct.
- The ***prostate gland*** encircles the urethra just below the bladder.
- A pair of ***bulbourethral gland/Cowper's gland*** is situated at the junction of ejaculatory duct and urethra.



Spermatogenesis

- It is the process of sperm formation in males. This process takes place in the ***inner/germinal epithelium*** of seminiferous tubules.
- The spermatogonia divide by mitosis, forming a ***primary spermatocyte*** which undergoes ***meiosis-I***, forming two smaller haploid daughter cells, called ***secondary spermatocytes***.
- Each secondary spermatocyte after ***meiosis-II*** produces two daughter cells, called ***spermatids***. Each spermatid is a round, non-motile, and haploid cell.
- ***Spermiogenesis*** is a process in which spermatids change into motile and active sperms. During this process, a ***spermatid elongates, sheds its excess cytoplasm***, and ***form a tail***.



Hormonal Control of Male Reproductive Function

- The process of spermatogenesis is controlled by various hormonal secretions, which are mention in the following table:

Features	Hormones				
	GnRH	FSH	LH/ICSH	Testosterone	Inhibin
Released From	Hypothalamus	Anterior pituitary	Anterior pituitary	Leydig cells	Sertoli cells
Chemical Nature	Polypeptide	Glycoprotein	Glycoprotein	Steroid	Protein
Role	Control the release of pituitary gonadotropins	Stimulate spermatogenesis Stimulate sertoli cells	Stimulates Leydig cells to release testosterone	Growth and development of germinal epithelium	Control the spermatogenesis at normal rate

CRITICAL THINKING

1. **Precursor of an animal germ cell has 12 ng of DNA in it G_1 Phase. What would be the amount of DNA in its each daughter cell immediately after meiosis?**

A. 24 ng
B. 12 ng
C. 6 ng
D. 3 ng

FEMALE REPRODUCTIVE SYSTEM

- The reproductive role of the female is far more complex than male. She not only has to produce gametes, but her body must be prepared to nurture a developing embryo for a period of approximately nine months.

1. Gonads

- Ovaries are female gonads which produce ***ova*** and release hormones.
- The paired ovaries flank the uterus on each side and each ovary is held in place within the peritoneal cavity by several ligaments.
- The ovaries are solid, ovoid structures. Within the ovary are many tiny sac-like structures called ***ovarian follicles*** each of which consists of an immature egg, called an ***oocyte***.
- In adult women, one of the ripening follicles ejects its oocyte from the ovary in each month. This event is called ***ovulation***.

2. Oviducts

- The oviducts form the initial part of the female duct system. They receive the ovulated ***oocyte*** and are the site where ***fertilization*** generally occurs.
- It transfers developing ovum from ovary towards the uterus.

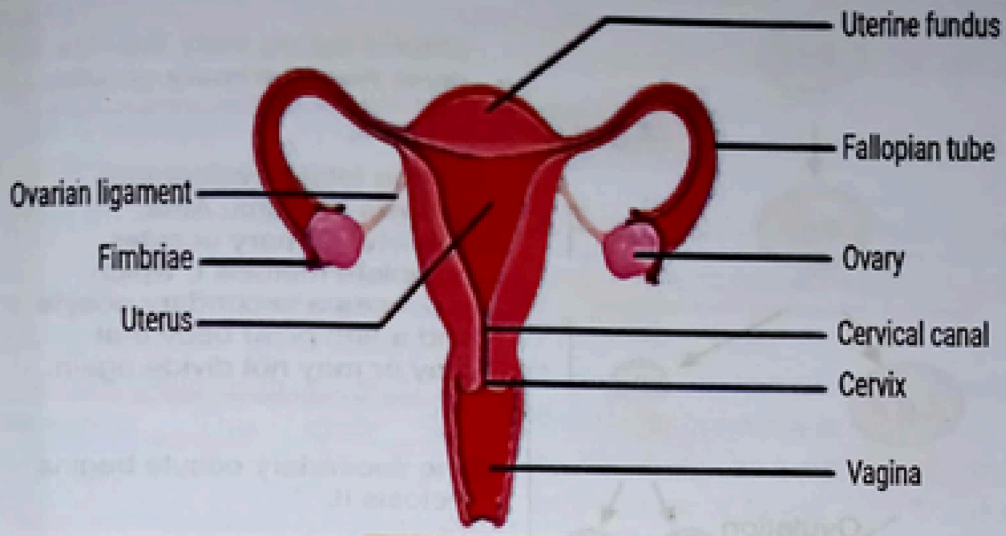
3. Uterus

- The uterus or womb is a hollow, muscular organ, shaped somewhat like an inverted pear. The uterus has three portions: the ***fundus***, the ***body*** and the ***cervix***.
- The oviducts join the uterus just below the fundus and the opening of the cervix leads to the vaginal canal.
- ***Cervix*** is a narrow entrance to the uterus from the vagina. It is normally blocked by a plug of mucus.
- The wall of the uterus is composed of three layers;

Perimetrium	The perimetrium is the outermost thin covering layer of the uterus.
Myometrium	The myometriumis the middle thick muscular layer composed of bundles of smooth muscle, which contracts rhythmically during childbirth to expel the baby from the mother's body.
Endometrium	The endometrium is the inner spongy lining of the uterine cavity. If fertilization occurs, the young embryo is implanted into the endometrium and resides there for the rest of its development. The main functions of uterus are to receive, retain, and nourish a fertilized ovum.

4. Vagina

- The vagina (opening is called vulva) is a thin-walled long tube and extends from the cervix to the body exterior.
- Vagina is often called the ***birth canal*** as it provides a passageway for delivery of an infant and for menstrual flow. The urethra is embedded in its anterior wall.



CRITICAL CONCEPT!

Asymmetric Segregation During Oogenesis:

Asymmetric segregation of cellular determinants is based on the asymmetric localization of cytoplasmic molecules, e.g., proteins and RNAs, within a cell before it divides. During cell division, one daughter cell receives most or all of the localized molecules, while the other daughter cell receives less or none of these molecules. This result in two different daughter cells, which then take on different cell fates based on differences in gene expression.

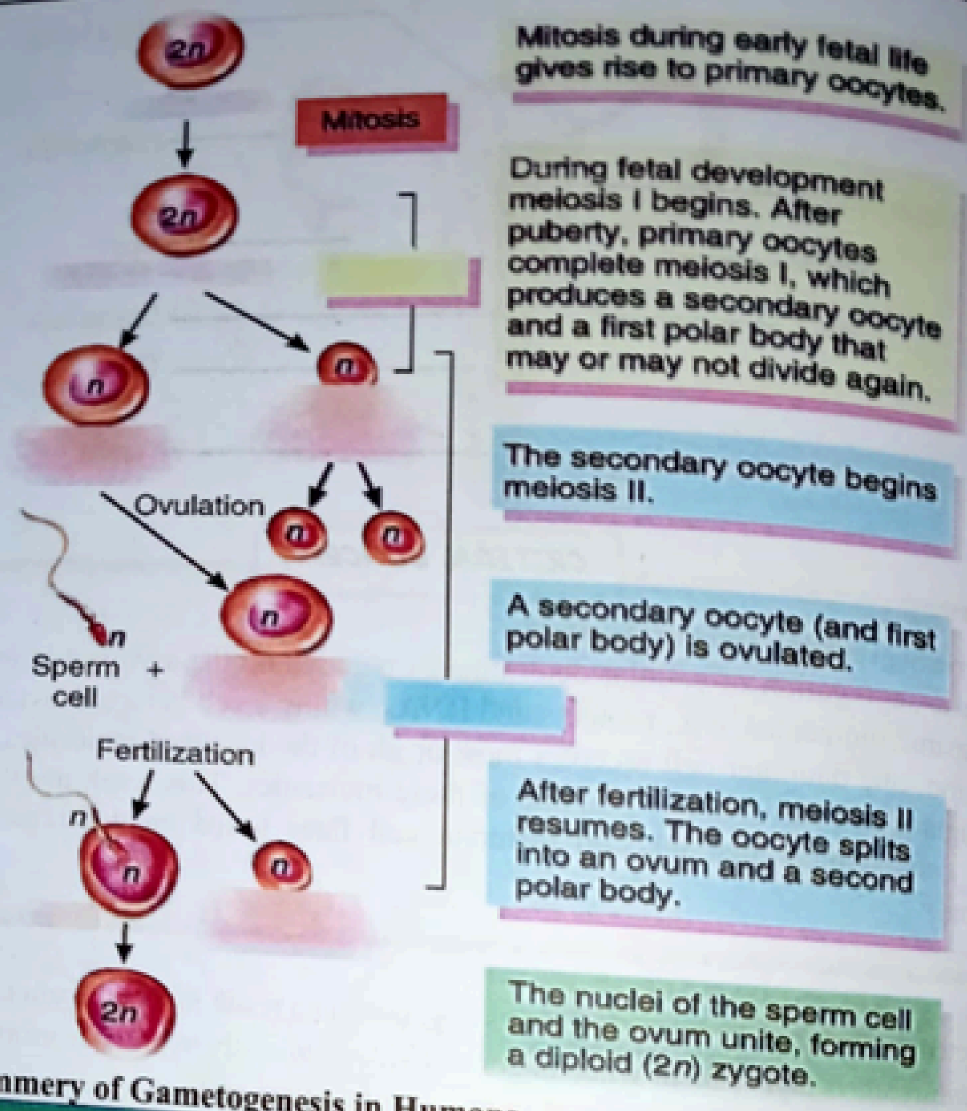
Oogenesis

- Gametogenesis in the female is known as oogenesis and result in the formation of ova/egg.
- Oogenesis ***starts before birth*** when oogonia divide mitotically to produce primary oocytes.
- These primary oocytes are enclosed in groups of ***follicle cells***.
- Primary oocytes undergo meiosis-I but are ***arrested at prophase-I***.
- At puberty, primary oocyte completes meiosis-I and gives rise to haploid secondary oocyte along with ***1st polar body***.
- Secondary oocyte undergoes meiosis-II but ***arrested in metaphase-II***. It is released in this stage from ovary and does not proceed further until fertilization.
- If fertilization occurs, then secondary oocyte divides to form ovum and 2nd polar body.
- In human female only one ovum is usually discharged from the ovary at one time, this phenomenon is called ovulation.

CRITICAL THINKING

2. Conversion of primary oocyte into secondary oocyte results in:

A. Reduction in amount of DNA only
B. Reduction in DNA and chromosomes
C. Reduction in chromosomes only
D. Reduction in chromatids only



Overview/Summery of Gametogenesis in Humans

Features	Spermatogenesis	Oogenesis
Location	Occur in testes	Occur mainly in ovaries
Meiotic Division Results in	Equal division of cytoplasm	Unequal division of cytoplasm
Number of Gametes Produce	Four	One and two to three polar bodies
Size of the Gamete	Relatively smaller	Relatively larger
Duration	Un-interrupted process	Interrupted process
Onset	Begins at puberty	Begins during fetal life
Release of gametes	Continuous	Monthly (From puberty till menopause)
End	Lifelong (But reduces with age)	Terminates with menopause
Growth phase	Short	Prolonged
Gamete Motility	Yes	No

MENSTRUAL CYCLE

In female, production of egg is a cyclic activity as compared to male.

Oestrous cycle is reproductive cycle in all mammalian female except humans. In human female, it is called ***menstrual cycle***.

Menstrual cycle involves changes in the structure and function of the whole reproductive system.

1st ovulation and menstruation occur at puberty. Start of menstrual cycle is called ***menarche***. Its complete stop or end is called ***menopause***. This cycle is completed in approximately 28 days (average of 21-35 days).

The events of the menstrual cycle involve the ovaries (***ovarian cycle***) and the uterus (***uterine cycle***). Events of menstrual cycle are regulated by ***pituitary gonadotropins***.

Based upon changes and hormonal regulation, the cycle can be divided into three phases i.e., ***menstrual phase, proliferative phase*** and ***secretory phase***.

CRITICAL CONCEPT!

Pregnancy Test:

A pregnancy test can tell whether a female is pregnant or not. It is done by checking for a particular hormone in the urine or blood. This hormone is called human chorionic gonadotropin (hCG). hCG is synthesized by the trophoblasts, cells that formed outer layer of blastocyst.

Menstrual Phase (Days 1–5)

- In this phase, the uterus sheds all but the deepest part of its ***endometrium***.
- The thick, hormone-dependent functional layer of the endometrium detaches from the uterine wall, a process that is accompanied by bleeding for 3–5 days.
- The detached tissue and blood pass out through the vagina as the ***menstrual flow***.
- At the beginning of this stage, ovarian hormones are at their lowest normal levels and gonadotropins are beginning to rise. Then ***FSH level begins*** to rise.

Proliferative/Pre-Ovulatory Phase (Days 6–14)

- Follicle stimulating hormone (FSH) during the first days of the cycle stimulates few ovarian follicles.
- Only ***one follicle develops***. Rest stop to grow and finally disintegrate (***follicle atresia***), while one dominant follicle in the ovary continue to mature and becomes ***mature follicle*** (Graffian or vesicular follicle), in which ***oogenesis*** occurs.
- FSH also stimulates the graffian follicle to secrete estrogen which in turn governs the vascularization of endometrial lining of uterine wall.
- Estrogen has ***negative feedback*** upon FSH, therefore, as the concentration of estrogen rises the level of FSH falls. This is a signal for anterior pituitary to release ***LH***.
- At the end of the proliferative stage (day 14) LH causes ***ovulation*** which takes less than five minutes.
- LH also converts the ruptured follicle to a yellowish glandular mass called ***corpus luteum***.

Secretory/Post-Ovulatory Phase (Days 15–28)

- During the secretory phase, the endometrium prepares for implantation of an embryo.
- Rising levels of progesterone from the corpus luteum act on the endometrium, causing the arteries to extend and converting the functional layer to a glandular secretory layer.
- The uterine glands enlarge, coil and begin secreting nutritious glycogen into the uterine cavity.
- ***If fertilization has not occurred***, the corpus luteum begins to degenerate towards the end of the secretory phase as LH blood levels decline.
- Progesterone levels tall, depriving the endometrium of hormonal support and endometrial cells die, setting the stage for menstruation to begin on 28th day.

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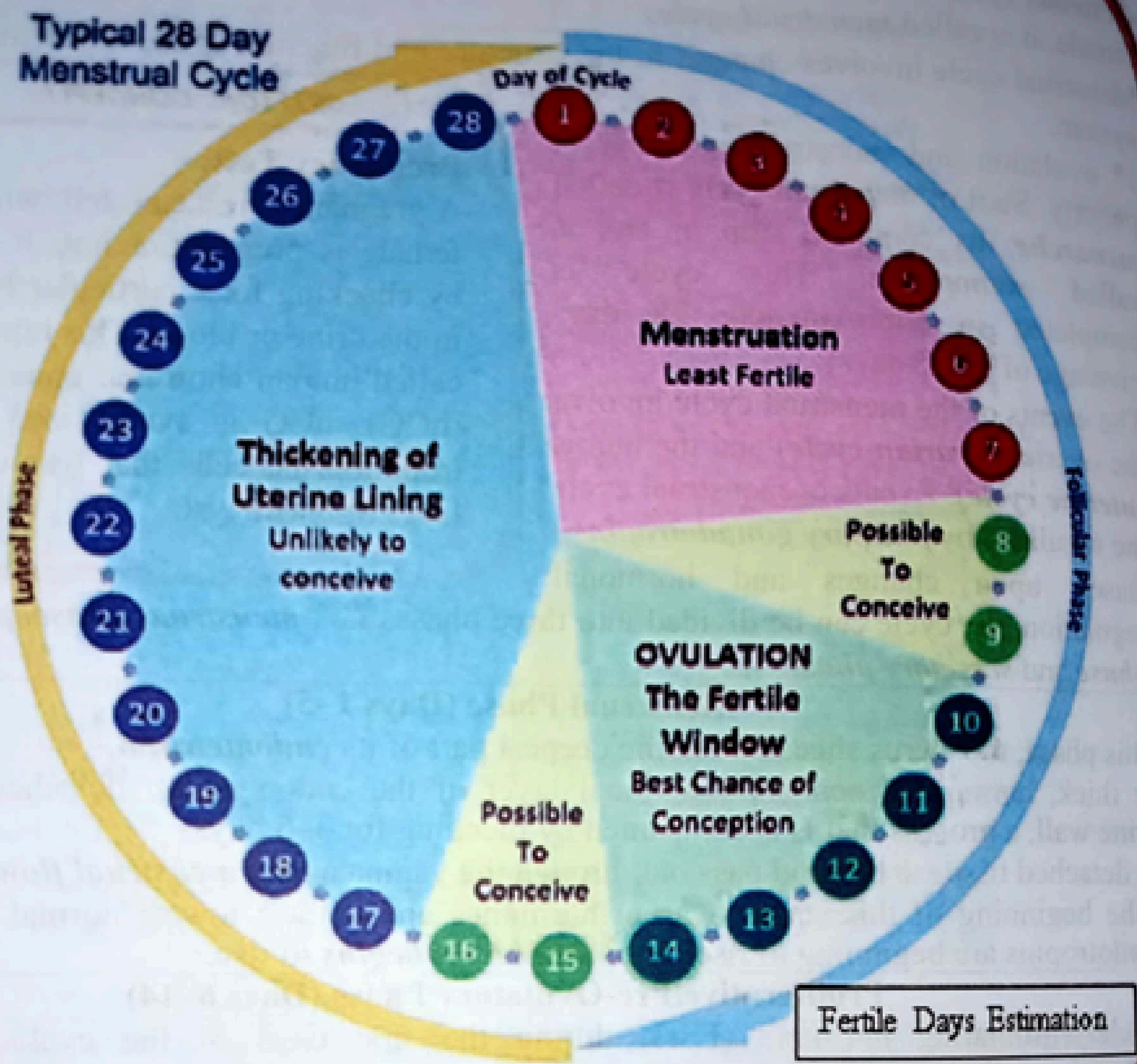
CRITICAL CONCEPT!

Fertile Period:



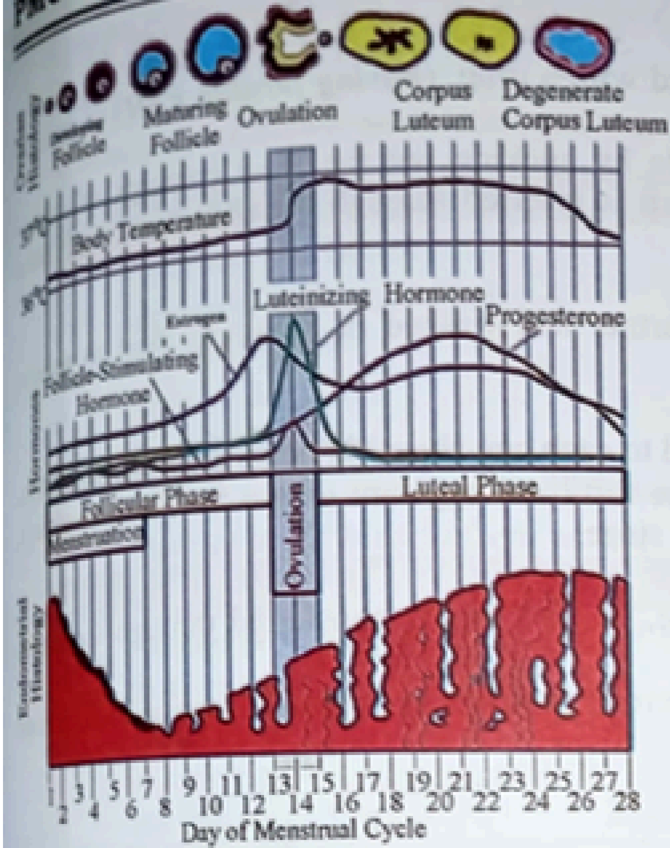
Fertile Days Estimation

CRITICAL THINKING

3. In females, considering menstrual cycle, rapidly rising estrogen levels signify that:
A. Ovulation cannot occur
B. Ovulation has occurred
C. Ovulation is just to occur
D. Ovulation is occurring

4. All of the following hormones are produced by the placenta except:
A. Human chorionic gonadotrphin
B. Human placental lactogen
C. Progesterone
D. Luterotrophic hormone

5. Which of the following cannot be the function of Estrogen?
A. Strengthen bones
B. Anti-aging effects
C. Protection of heart from cholesterol
D. Feeling of Fear creation



CRITICAL CONCEPT!

Estrogen is much diversified hormone in human species. It is also having a lot of functions other than the secondary sexual character development process.

CRITICAL CONCEPT!

Oxytocin is a hormone that acts on organs in the body (including the breast and uterus) and as a chemical messenger in the brain, controlling key aspects of the reproductive system, including childbirth and lactation, and aspects of human behaviour.

Feature	Oestrous Cycle	Menstrual Cycle
Occurrence	All mammals except human	Human female
Release of Estrogen	At low level	At higher level
If fertilization does not occur	Resorption of endometrium	Destruction and discharge of endometrium (Menstrual flow)
Ovulation	Requires physical stimulus of mating	Under hormonal control

CRITICAL THINKING

6. **Inhibin hormone in males released by sertoli cell while in females released by:**
   A. Cumulus cells B. Zona Pellucida
   C. Corona Radiata D. Granulosa cells
7. **Which of the following cannot be the function of Estrogen?**
   A. Strengthen bones B. Anti-aging effects
   C. Protection of heart from cholesterol D. Feeling of Fear creation

IN VITRO FERTILIZATION

- It means fertilization outside of the female body, and is the most effective types of ***assisted reproductive technology.***
- It is often used when a woman's fallopian tubes are blocked or when a man produces few sperms.
- This technique involves fertilizing one or more eggs outside the body and then transferring the ***fertilized eggs/pre-embryos*** back into the uterus.

Procedure

i. **Isolation of Eggs**

- In this procedure, the ovary is stimulated with a drug, (***having fertility FSH***) to produce several eggs.
- Eggs can be collected from the follicle by sucking out the fluid contents of mature follicles with a fine hollow needle which is inserted through the abdominal wall under general anesthetic.

ii. **Collection of Sperms**

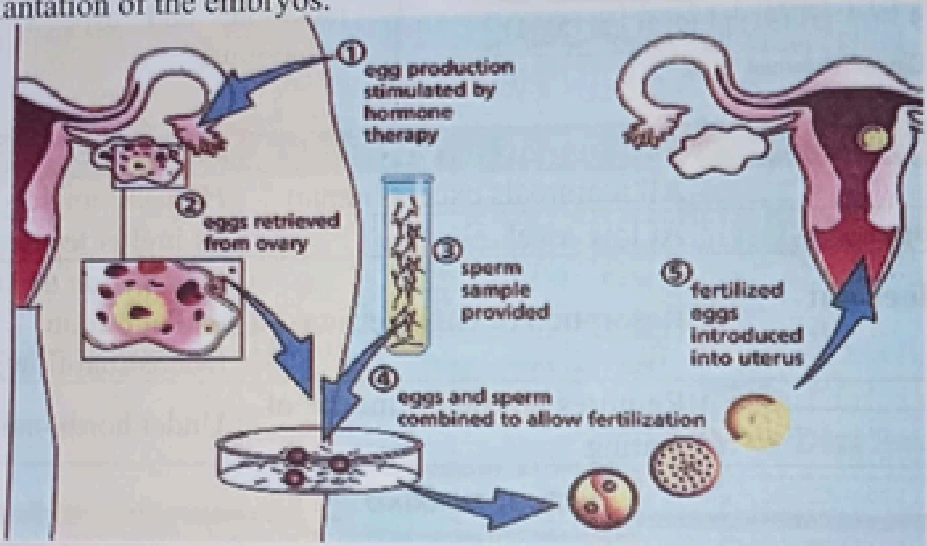
- Sperms are collected from the male partner and washed in a culture fluid to remove seminal fluid.

iii. **Fertilization**

- About ***100,000 healthy sperms*** are added to each egg about six hours after egg collection.
- This is done in a glass dish or tube. The fertilized eggs are grown for about two days, after which they are usually at 2 to 8 cell stage.

iv. **Implantation into the Uterus**

- After examination under the microscope, the embryo is transferred through the cervix into the uterus using a fine plastic tube.
- She is subsequently treated with progesterone to promote favorable uterine environment for implantation of the embryos.



SEXUALLY TRANSMITTED DISEASES

Feature	Gonorrhea	Syphilis	Genital Herpes	AIDS
Causative Agent	Gram positive bacteria	Spirochaete	Virus	Virus
Name of pathogen	*Neisseria gonorrhoeae*	*Treponema pallidum*	Herpes simplex type II	HIV
Main parts Affected	Mucous membrane of urinogenital tract, eye infection to baby.	Damage to reproductive organs, eyes, bones, joints, CNS, heart, skin. Infection proceeds in 3 stages	Infection of genitalia, genital soreness & ulcers, damage to eyes & CNS in infants.	Destruction of immune system
Source of Transmission	Sexual contact	Sexual contact	Sexual contact	Sexual contact
Treatment	Antibiotics	Antibiotics	Anti-viral drugs	Anti-viral drugs

TOPIC-12 SUPPORT & MOVEMENT

COURSE CONTENT

- Cartilage and Bones
- Divisions of Human Skeleton
- Types of Joints
- Arthritis and Gout
- Types of muscles
- Structure and Ultra-Structure of Skeletal Muscles
- Mechanism of Muscle Contraction

CARTILAGE AND BONE

- Human skeletal system consists of cartilage and bones. The skeleton acts as a framework that supports soft tissues.
- It allows free movement through the action of muscles across joints. The study of bones and cartilage is called ***osteology***. The features of both cartilage and joints are mentioned in the following table:

Features	Cartilage	Bone
Definition	Relatively less rigid connective tissue than bones.	Most rigid connective tissue
Collagen	Loosely packed, and type I	Densely packed, and type II
Types	Three types • Hyaline • Elastic • Fibrocartilage	Two Types • Compact • Spongy
Cells types	Only one type • Chondrocytes	Three type of cells • Osteoblasts • Osteoclasts • Osteocytes
Blood vessels/supply	Absent	Present
Minerals	No deposition of minerals	Deposit minerals such as calcium, carbonates, phosphates etc.
External covering	Covered by perichondrium	Covered by periosteum
Reshaping	No	Yes
Healing	No	Yes
Presence	Some places like joints, external ears, trachea etc.	Almost all parts of endoskeleton

PMC Topic-12

CARTILAGE

- It is softer connective tissue than bone.
- It has no blood supply and gets nutrients by diffusion.
- Living cells of cartilage are called chondrocytes.
- Collagen matrix is secreted by chondrocytes.

Types of Cartilage

(i) Hyaline Cartilage

- Most abundant type in human body.
- Found at the movable joints, nose, larynx and trachea.

(ii) Elastic Cartilage

- Matrix containing bundles of collagen fibres.
- Forms external ear/pinnae and the epiglottis.

(iii) Fibrocartilage

- Annulus fibrosus of vertebral disc and epiglottis are examples.

CRITICAL CONCEPT!

Major Functions of Bone:

- Protects vital organs
- Helps in movement
- Blood cells production
- Minerals homeostasis

CRITICAL CONCEPT!

Osteocalcin is an important proteineous hormone release by osteocytes (Connective Tissues) that is important for strong bones. It also acts as a hormone to adjust insulin and glucose levels, increase testosterone, and improve muscle strength and cognitive function.

CRITICAL THINKING

1. **It is not true about cartilage and bones:**
   A. Cartilage and bones are types of connective tissues
   B. Blood vessels penetrate cartilages but not bones
   C. Bones have osteocytes and cartilages have chondrocytes
   D. Bones and cartilages have collagen in them

DIVISIONS OF HUMAN SKELETON

- There are about 350 bones in an infant and 206 in adult human. The human skeleton is primarily divided into two divisions i.e., ***axial skeleton*** (80 bones) and ***appendicular skeleton*** (126 bones).
- Appendicular skeleton is associated with extremities and consists of pectoral girdle with forelimbs and pelvic girdle with hind limbs.

Axial Skeleton

Axial skeleton provides basic framework of body and includes those skeletal parts which are present along the central axis of the body, like skull, vertebral column, rib cage and sternum.

CRITICAL CONCEPT!

Epiphyseal Closure:

The epiphyseal plate or growth plate is a cartilaginous or strong elastic section at the tip of the long bones of the body. Located in the metaphysis, the broader portion on each end of the bone, these sections allow the bones to lengthen as the body develops. Without this plate the body would be unable to grow taller. Epiphyseal closure or the stoppage of bone growth occurs between the ages of eighteen and twenty-five.

- Primary function of skull is protection of brain, while vertebral column provides protection to spinal cord. It has ***four curvatures***.

Major part	Sub-parts		Bones
	Axial Skeleton		
Head (29 bones)	Skull (22 bones)	Cranium/ brain box (8 bones)	• Paired (2): Parietal & Temporal bones • Unpaired (4): Frontal, Occipital, Sphenoid, Ethmoid.
		Face (14 bones)	• Paired (6): Maxilla, Zygomatic, Nasal, Lacrimal, Palatine, Inferior Concha. • Unpaired (2): Mandible, Vomer
	Ear ossicles (6 bones)	———	• 3 pairs, each associated with an ear • Malleus, incus, stapes (smallest bone)
	Hyoid Bone (1)	———	• Small single bone which lies at the base of skull, below the tongue. • Does not articulate with any other bone.
Vertebral Column (33 vertebrae, or 26 bones)		Cervical	• 7 vertebrae found in the neck region • ***Atlas*** is the 1st cervical vertebrae while ***axis*** is the 2nd cervical vertebrae.
		Thoracic	• 12 vertebrae found in the chest region. • These are ribs carrying vertebrae, having large spinous processes.
		Lumbar	• 5 vertebrae and found in the abdominal region.
		Pelvic	• 9 vertebrae, anterior 5 join to form sacrum. • Sacrum articulates with the iliac bones of the hip bone to form the back of the pelvis. • Posterior 4 join to form coccyx (***tail bone***).
Rib cage (24 bones/12 pairs of ribs)	———	———	• 12 pairs articulate posteriorly with thoracic vertebrae. • 10 pairs of ribs connected anteriorly with sternum either directly or through costal cartilage. • 7 pairs (1st to 7th pair) connect anteriorly with sternum directly (***True ribs***). • 3 pairs (8th, 9th and 10th) connect with sternum through costal cartilages (***False ribs***). • 2 pairs (11th and 12th) are of ***floating ribs*** since they don't attach to the sternum. • The rib cage provides support for a semi-vacuum chamber called ***chest cavity***.
Sternum/chest bone (1 bone)			• It is a ***flat bone*** that sits at the front of the chest and is connected to the ribs with cartilage.

PMC Topic-12

Appendicular Skeleton

- Appendicular skeleton includes those skeletal parts which are present in appendages. These are pectoral girdle, pelvic girdle, forelimbs and hind-limbs.

Appendicular Skeleton	
Pectoral Girdle (4)	• To scapula (Shoulder blade) • To clavicle (Collar bone/ Beauty bone) connects scapula with sternum.
Upper limb/Fore limb (30x2)	• 1 ***Humerus*** (Upper arm), it is a long bone, the end of which has a spherical head, which fits into the glenoid cavity. • 1 ***Radius*** and1 ***ulna*** (Forearm). Radius is a long, outer bone (on the thumb side) while ulna is long and slightly bigger bone and located on the inner side of the forearm. • 8 ***carpals*** (Wrist bones), consist of two rows of eight short bones. • 5 ***metacarpals***, making up palm of the hand. • 14 phalanges (Fingers/ Digits), each finger possesses three phalanges except thumb which comprises of two phalanges.
Pelvic Girdle (2)	• Pelvic girdle attaches the hind limb to the vertebral column and consists of ***2 coxal/hip bones***. • Each coxal bone is formed by the ***fusion*** of three bones i.e., ***ilium***, ***ischium*** and ***pubis***. • The two halves of the pelvic girdle are joined at the ***pubic symphysis***. A cavity called ***acetabulum*** is also present.
Lower limb/ Hind limb (30x2)	• 1 ***Femur*** (Upper leg) or the ***thighbone*** is a longest and strongest bone in the human body with a head, which fits into the acetabulum. • 1 ***Patella*** (Knee cap) is embedded in a long tendon which runs over the knee joint. • 1 ***Tibia*** and1= ***fibula*** (Lower leg) • 7 ***Tarsals*** (Heel) which are tightly attached to form the ankle. • 5 Meta-tarsals (Sole) which articulates with the tarsals and phalanges to form the sole of the foot. • 14 ***Phalanges*** (Digits/ Toes) are small bones which make up the toes. • Each toe of the foot possesses three phalanges except big toe, which comprises of two phalanges.

Joints Formed by the Bones of Human Skeleton

Joint	Type	Formation
Shoulder Joint	Ball & Socket Joint	Head of humerus & glenoid cavity of scapula
Elbow Joint	Hinge Joint	Distal end of humerus and proximal ends of radius & ulna
Wrist Joint	Multistage Joint	Distal ends of radius & ulna and carpals
Hip Joint	Ball & Socket Joint	Head of femur & acetabulum of hip bone
Knee Joint	Hinge Joint	Distal end of femur and proximal ends of tibia & fibula
Ankle Joint	Multistage Joint	Distal ends of tibia & fibula & tarsals
Superior radioulnar Joint	Pivot Joint	Proximal ends of radius and ulna.

TYPES OF JOINTS

'A joint or articulation is a place where two or more bones and cartilage come together.' The scientific study of the structure and function of joints is called ***arthrology***.

Joints have two fundamental functions which are:

- They give ***mobility to the skeleton***.
- ***Hold the skeletal parts together***.

Classification of Joints

- The joints mainly are classified as on the basis of structure and function. Structural classification of joints is based on the material binding the bones together and whether or not a joint cavity is present while functional classified is based on the amount of movement allowed by them.
- Structurally, there are three types of joints; fibrous (immovable), cartilaginous (slightly movable), and synovial joints (freely movable).

CRITICAL THINKING

2. Bones forming sutures are connected with each other by tissues having:

A. Titin B. Actin
C. Myosin D. Collagen

Features	Fibrous joints	Cartilaginous joints	Synovial joints
Structure	Adjacent bones are directly connected to each other by fibrous connective tissue consisting of collagen	Adjacent bones are united by fibrocartilage or hyaline cartilage	Ends of bones are covered with hyaline cartilage and held together by a surrounding, tube-like capsule of dense fibrous tissue. The joint capsule is composed of an outer layer of ligaments and inner lining of synovial membrane.
Joint cavity	Absent	Absent	Yes, specifically called ***synovial cavity*** and is filled with ***synovial fluid***
Mobility	Immovable	Slightly moveable	Freely moveable
Location	Bones of skull, Root of tooth and socket of jawbones	Costal cartilages that attach ribs with the sternum, pubic symphysis Between wrist and ankle bones	Hinge joint, Pivot joint, Ball and socket joint
Functions	Support and protection to delicate structures	Gliding of bones	Free movement of skeleton

- Based on the structure and movements allowed, the synovial joints are classified further in different categories.

Features	Hinge Joint	Ball & Socket Joint
Structure	Cylindrical projection of one bone fits into a trough-shaped surface on another	Spherical or hemispherical head of one bone articulates with the cuplike socket of another
Arrangement of Muscles	Pair of muscles are arranged in the same plane as that of joints.	Such joints have at least two pairs of muscles, present perpendicular to each other.
Direction of Movement	Single plane/Two directions (Flexion and extension only)	Multiple planes/several directions
Examples	Elbow and knee joints	Shoulder and hip joints
Function	Free movement (Lift heavy loads)	Free movement

ARTHRITIS AND GOUT

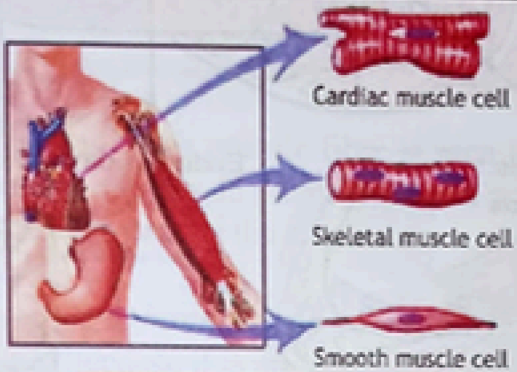
- It is the ***inflammation of joints*** characterized by the degeneration and damage to the joint tissue.
- The typical symptoms of arthritis include pain after walking which may later occur even at rest, creaking sounds in joints, difficulty in getting up from a chair and pain on walking up or down stairs.
- ***Osteoarthritis*** is a progressive disease in which the articular cartilages gradually soften and disintegrate. It affects knee, hip and intervertebral joints.
- ***Rheumatoid arthritis*** is the result of an auto-immune disorder in which synovial membrane becomes inflamed due to faulty immune system.
- ***Gouty arthritis*** results form a metabolic disorder in which an abnormal amount of ***uric acid*** is retained in the blood and sodium urate crystals are deposited in the joints.

TYPES OF MUSCLES

- Muscles are the specialized tissues of ***mesodermal origin*** that can undergo contraction and relaxation and provide movements to body parts or the whole body. The study of the muscles is called ***myology***.
- The most distinguishing functional characteristic of muscles is their ability to ***transform ATP into mechanical energy***. In doing so, they become capable of exerting force.
- Earliest forms of muscles to be evolved are smooth muscles which are present throughout animal kingdom. Cardiac muscles and skeletal muscles are found only in vertebrates.
- Cardiac muscles have ***intercalated disc***.
- They also function to hold body parts in ***postural positions***, ***movement of body fluids*** and ***heat production***.

Features	Smooth	Cardiac	Skeletal
Muscle appearance	Unstriped/Non-striated	Irregular stripes (striated)	Regular stripes/Striated
Cell shape	Spindle	Branched	Spindle or cylindrical
Number of nuclei	One per cell	One per cell	Many per cell
Speed of contraction	Slow	Intermediate	Slow to rapid

Fatigue	Not possible	Not possible	Possible
Contraction caused by	Spontaneous, stretch, nervous system, hormones	Spontaneous	Nervous system
Voluntary control	Usually no control	Usually no control	Have control
Location	Blood vessels, GIT, other hollow organs	Heart only	Associated with bones
Function	Controls movement of substances through hollow organs	Pumps blood	Moves the skeleton and heat production



CRITICAL THINKING

3. A property of cardiac myocytes is:
A. Voluntary control
B. Fatigue resistance
C. Spindle shaped cell
D. Unstripped

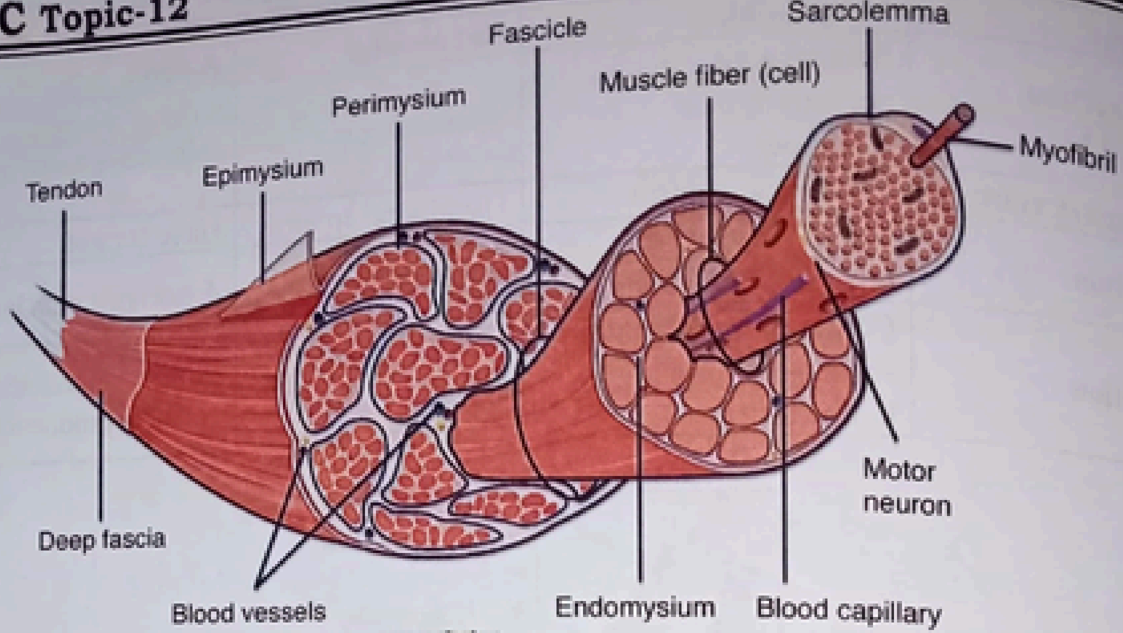
4. Which of the following type of tissue can be called as glandular tissues?
A. Muscle tissue
B. Connective tissue
C. Nervous tissue
D. Epithelial

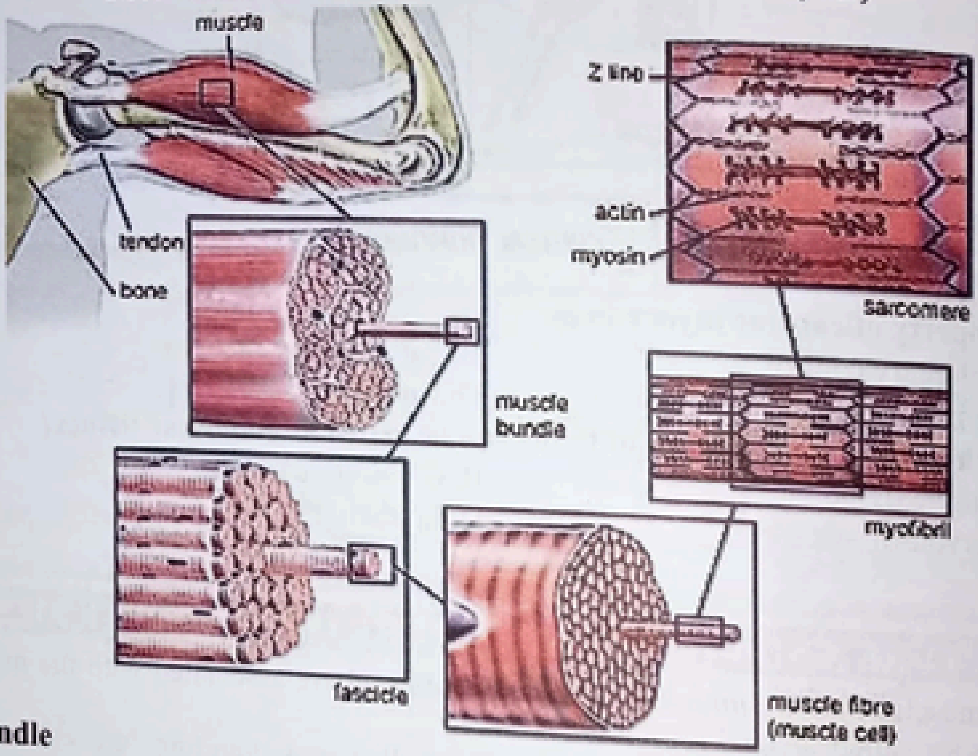
STRUCTURE AND ULTRA-STRUCTURE OF SKELETAL MUSCLE

- The muscles that are ***attached to the skeleton*** and are associated with the movement of bones are called skeletal muscles.
- The skeletal muscles are consciously controlled and therefore, are called ***voluntary muscles***.
- Generally, each end of the entire muscle is attached to bone by a bundle of collagen, non-elastic fibers known as ***tendons***.

Feature	Tendon	Ligament
Nature	Inelastic connective tissue	Elastic connective tissue
Function	Attaches muscle to bone	Holds bones at joints

- Externally, muscle is covered in a connective tissue wrapping called ***epimysium***. Each muscle is divided into discrete bundles of muscle cells called ***fascicles***. The fascicle is surrounded by ***perimysium***. Each muscle fibre within the fascicle is covered by a layer of connective tissue called ***endomysium***.
- Structural scheme of a skeletal muscle is given below:
  Skeletal muscles → Muscle bundles → Muscle fibers → Myofibrils → Sarcomere (smallest contractile unit of muscle fiber) → Myofilament (Actin and Myosin).





Muscle Bundle

- Muscles bundles are also called as ***muscle fasciculi***.
- These are bounded by a connective tissue called ***perimysium***.
- Muscle bundles are further composed of muscle fibers or cells.

Muscle Fibers

- Each muscle fiber is a ***long, cylindrical and huge cell*** with the diameter of about ***10-100 µm*** and contain ***multiple oval nuclei*** which are arranged just beneath its sarcolemma.
- The sarcolemma of muscle fibres penetrates deep into the cell to form a hollow elongated tube, ***the transverse tubule/T-tubule***.
- Sarcoplasm of the muscle fiber is similar to the cytoplasm of other cells, but it contains usually large amount of ***stored glycogen*** and unique oxygen binding protein e.g. ***myoglobin***.

- Sarcoplasmic reticulum is continuous system of sarco-tubules extending throughout the sarcoplasm around each myofibril. It is like endoplasmic reticulum but ***devoid of ribosomes***. These act as ***store-house of Ca^{+2}***.
- Each muscle fiber further contains large number of myofibrils.

CRITICAL THINKING

5. A structure around cell that has channels and gates for movement of solute molecules:

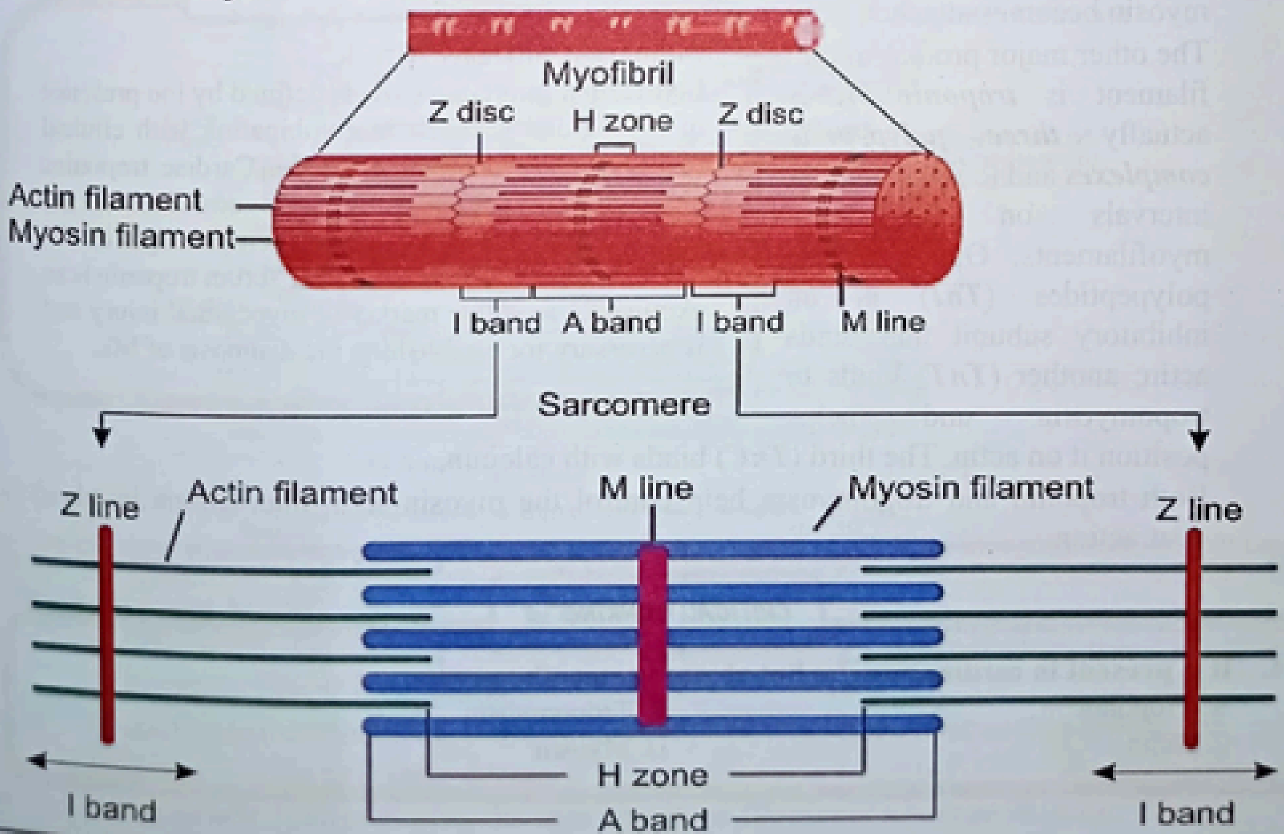
A. Epimysium B. Sarcolemma
C. Sarcoplasmic reticulum D. Endomysium

Myofibrils

- When viewed in high magnification, each muscle fibre is seen to contain a large number of myofibrils, ***1-2 µm in diameter*** that run in parallel fashion and extend entire length of cell. Bundles of these fibrils are enclosed by the sarcolemma.

Banding Pattern

- Myofibril has ***series of dark and light bands***.
- Each dark band is called ***A-band*** because it is anisotropic i.e., it can ***polarize visible light***. The light band is called ***I-band*** because it ***cannot polarize visible light***. It gives cell as whole its ***striped appearance***.
- Each A-band has a lighter stripe in its mid-section called ***H-zone***. The H-zone is bisected by a dark line called ***M-line***. The I-band has mid line called ***Z-line***.
- A ***sarcomere*** is the region of a myofibril between two successive Z-lines and is the ***smallest contractile functional unit*** of muscle fibres.



Ultra-structure of Myofilaments

- Myofilament is made up of thick and thin filament. The ***central thick filaments*** extend the entire length of the A-band while the thin filaments extend across the I-band and partly into A-band.

(i) Thick Filament

- Thick filament is about ***16nm in diameter*** and is ***composed of myosin***.
- Each myosin molecule has a ***tail*** terminating in ***two globular heads***. Myosin tail consists of two long polypeptide chains coiled round each other.
- Each thick filament contains about 300 myosin molecules bundled together with their tails forming the central part of the thick filament and their heads facing outward and in opposite directions at each end.
- The heads are sometimes called ***cross bridges*** because they link the thick and thin myofilaments together during contraction.
- Each myosin filament is surrounded by six actin filaments on each end.

(ii) Thin Filaments

- Thin filaments are ***7-8 nm thick*** and are composed of three proteins e.g., ***actin***, ***tropomyosin*** and ***troponin***.
- The ***actin*** molecules are arranged in two chains which twist around each other like a twisted double strand of pearls.
- The kidney-shaped polypeptide subunits of actin, called globular actin or ***G-actin***, bear the active sites to which the myosin heads attach during contraction. G-actin monomers are polymerized into ***long actin filaments***.
- Twisting around the actin chains are two strands of another protein, ***tropomyosin***. When the muscle is at rest, the tropomyosin is disposed in such a way that it covers the sites on the actin chain where head of myosin becomes attached.
- The other major protein in thin filament is ***troponin***. It is actually ***three polypeptide complexes*** and found at regular intervals on the thin myofilaments. One of these polypeptides (***TnI***) is an inhibitory subunit that binds actin; another (***TnT***) binds to tropomyosin and helps position it on actin. The third (***TnC***) binds with calcium.
- Both troponin and tropomyosin help control the myosin-actin interactions involved in contraction.

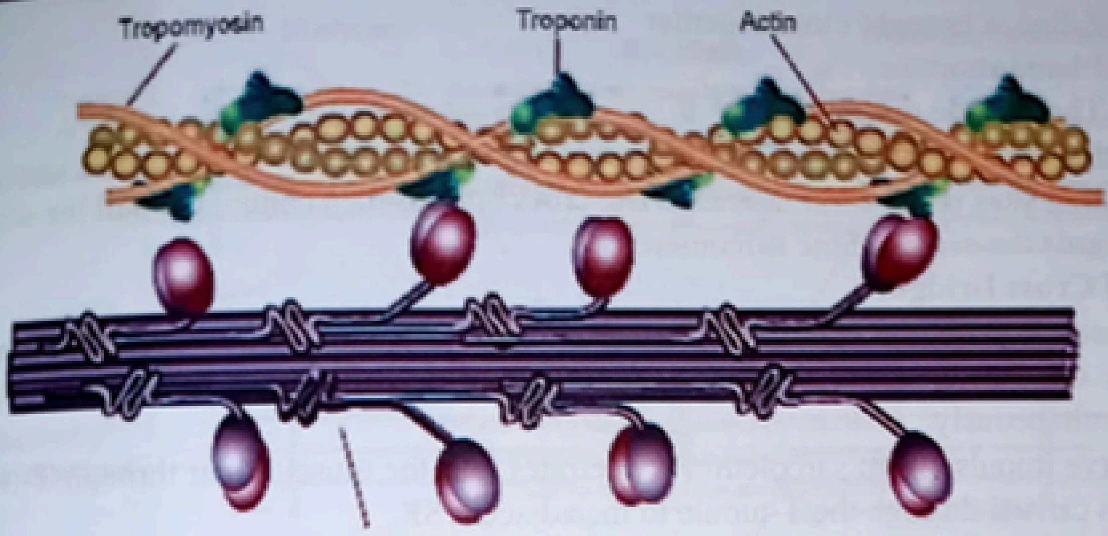
CRITICAL CONCEPT!

Biomarker of Heart Attack:
Myocardial infarction (MI) is defined by the presence of myocardial necrosis in combination with clinical evidence of myocardial ischemia. Cardiac troponins are regulatory proteins within the myocardium that are released into the circulation when damage to the myocyte has occurred. Therefore, serum troponin is an exquisitely sensitive marker of myocardial injury and is necessary for establishing the diagnosis of MI.

CRITICAL THINKING

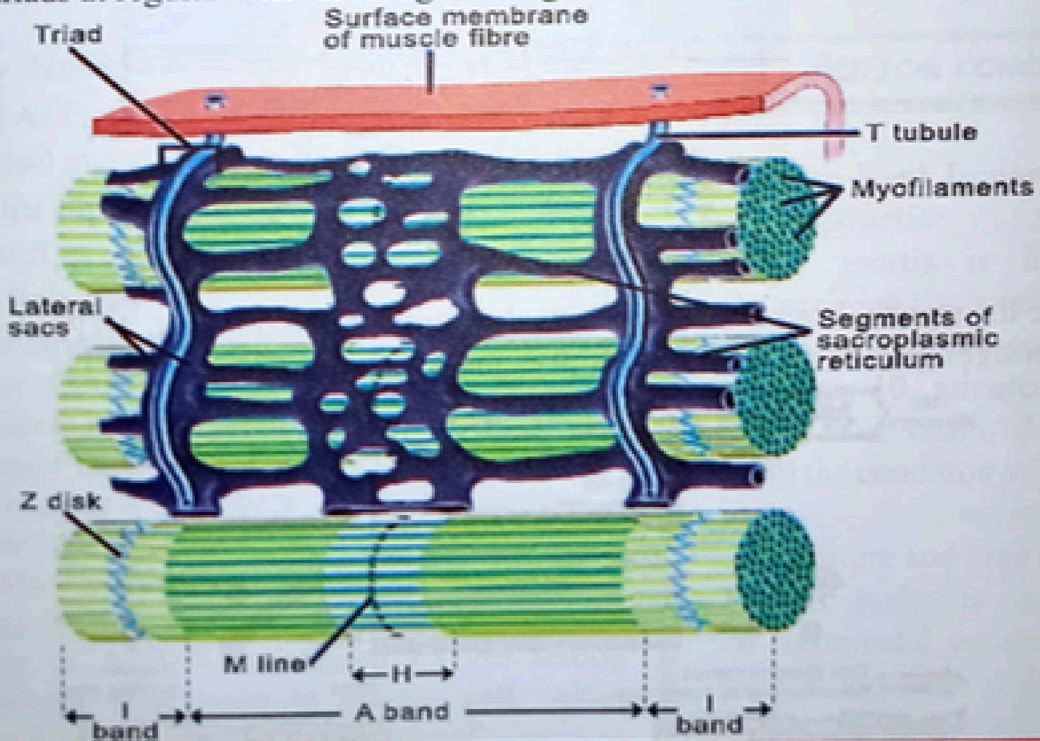
6. It is present in cardiac muscles but absent in smooth muscles:

A. Troponin
B. Tropomyosin
C. Actin
D. Myosin



T-Tubules, T-System & Triad

- The sarcolemma of muscle fiber cell penetrates deep into the cell to form hollow elongated tube, the transverse tubule or T-tubule, the lumen of which is continuous with the extracellular fluid.
- Thousands of T-tubules of each muscle cell are collectively called as ***T-system***. It extends and encircles the myofibril at the level of ***Z-line*** or ***A-I junction***.
- The T-tubule and the terminal portion of the adjacent envelope of sarcoplasmic reticulum form triads at regular interval along the length of the fibril.



MECHANISM OF MUSCLE CONTRACTION

Sliding Filament Model

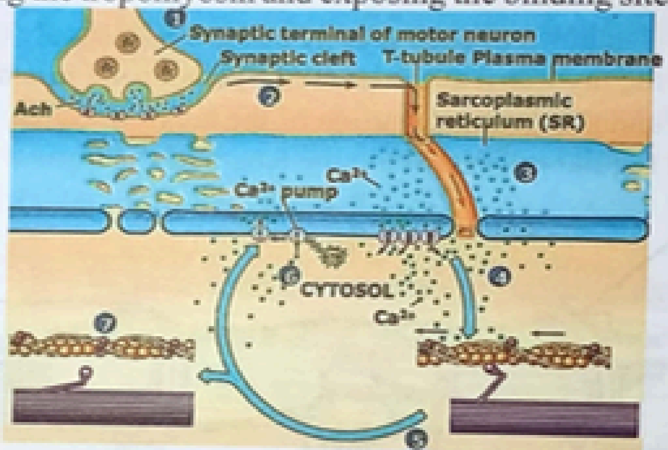
- In 1954, H. Huxley and A. F. Huxley and their colleagues suggested a hypothesis to explain all events in muscle contraction.
- According to this model, the thin filaments slide past the thick ones so that actin and myosin filaments overlap to greater degree.
- When muscle fibre contracts, the ***thin and thick filaments undergo shifting***, thus

1. Z-line is brought close together
2. I-band shortens
3. The H-zone disappear

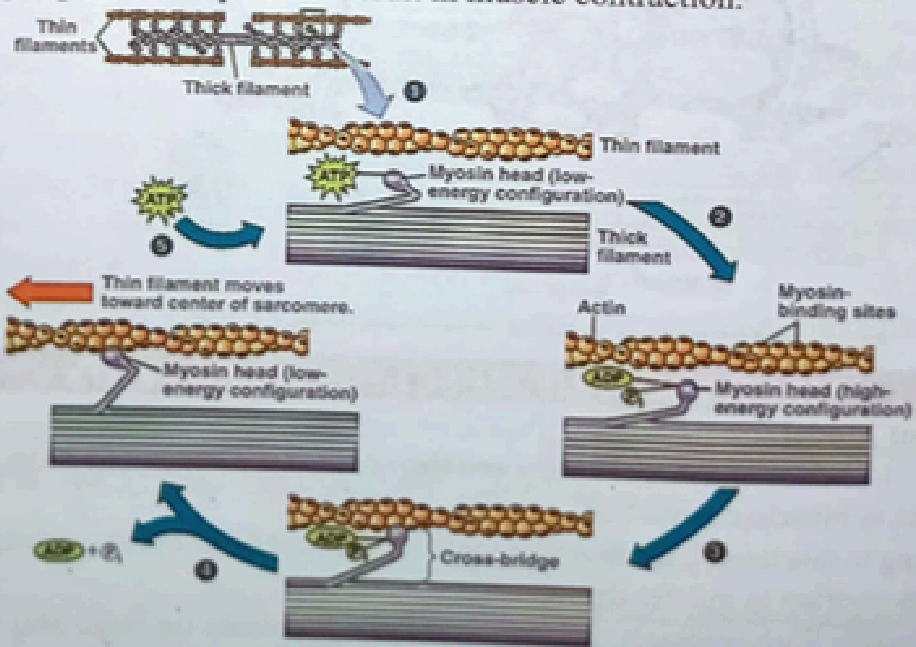
- In this process of contraction, the ***cross bridges*** of thick filament become attached to binding sites in the actin filament. The cross bridges then contract to pull the actin filament towards the center of the sarcomere.

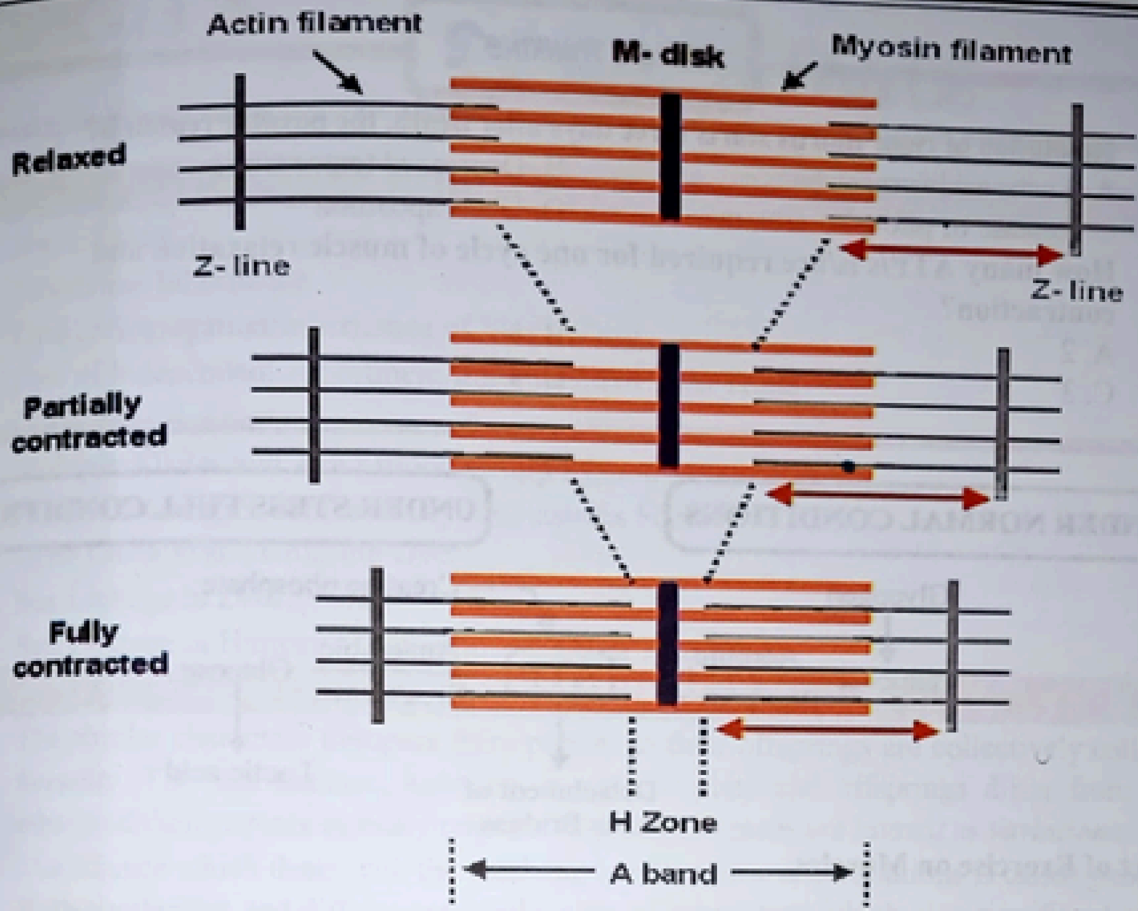
Control of Cross Bridges

- Muscle contraction is initiated by nerve impulse arriving at the ***neuromuscular junction***. All the fibers innervated by a single motor neuron are a ***motor unit*** and contract simultaneously.
- Nerve impulse from sarcolemma penetrates into the muscle fiber through T-tubule. Then it is carried through the T-tubule to the adjacent SR.
- The ***calcium gates*** of sarcoplasmic reticulum open releasing calcium in cytosol.
- When muscle is at rest, the tropomyosin is disposed in such a way that it covers the sites on the actin chain where the heads of myosin become attach.
- When Ca^{2+} binds with the troponin molecules, they cause them to move slightly. This has the effect of displacing the tropomyosin and exposing the binding sites for the myosin head.



- Once the myosin head has become attached to the actin filament, ATP is hydrolyzed and the bridges goes to its cycle and result in muscle contraction.





- *Rigor Mortis* is stiffening of the body after death. Since ATP is required to break the bond between actin and myosin, which get deficient after death, thus the bridges can't be broken, and the body gets stiff.

All or None Response

- The contraction of each muscle fibre is based on 'all or none' principle i.e. *all of its fibrils* participate in contraction.
- However, the degree of contraction depends upon the number of fibers that participate in contraction.

Energy for Muscle Contraction

- Energy for muscle contraction comes from ATP. Supply of ATP is maintained by the aerobic breakdown of glucose in muscle cell, which comes from stored glycogen in the cell.
- When more energy is required due to high metabolism, it is provided by another energy storing substance called ***creatine phosphate***.

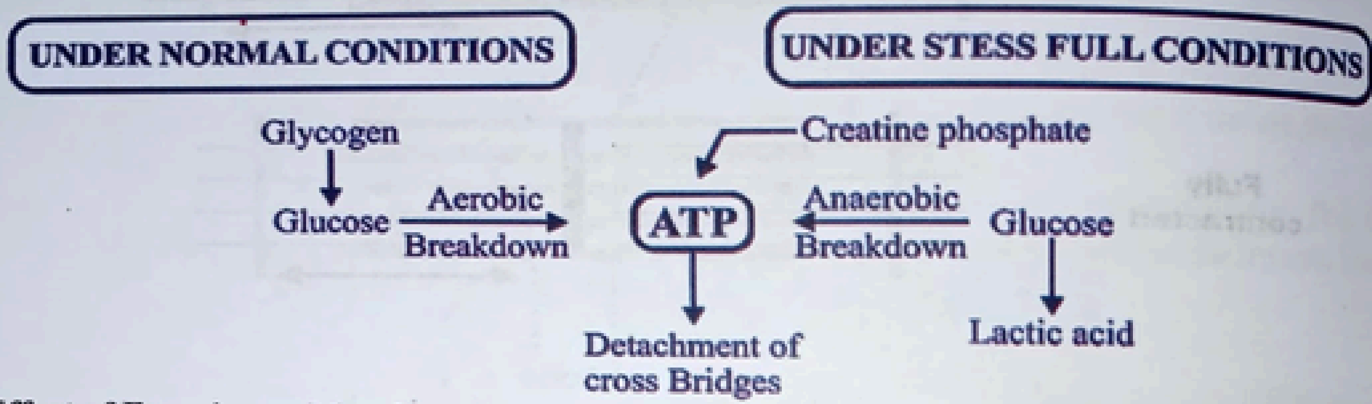
CRITICAL CONCEPT!

Medico-legal Importance of Rigor Mortis:
Rigor mortis is useful in determining the time of death. Onset of stiffness starts between 10 minutes and 3 hours after death, depending upon the condition of the body and environmental temperature and time of death. If the body is active or environmental temperature is high at the time of death, the stiffness sets in quickly.

- Sometimes during oxygen deficiency or very high metabolic activity, such as prolonged or strenuous muscular activity, ATP requirement is met by anaerobic breakdown of glucose into lactic acid. Lactic acid accumulation causes ***muscle fatigue***. At rest, *1/5* of lactic acid is broken aerobically and its energy is used to change the remaining *4/5* lactic acid into glucose.

CRITICAL THINKING

6. **Resolution of rigor mortis starts three days after death, the possible reason is?**
   A. Lactic acid fermentation
   B. Decreased temperature
   C. Release of phospho-creatin
   D. Decomposition
7. **How many ATP/s is/are required for one cycle of muscle relaxation and contraction?**
   A. 2
   B. 1
   C. 3
   D. 4



Effect of Exercise on Muscles

- The amount of work a muscle does is reflected in changes in the muscle itself. For example;
  1. Increase in size of the muscle
  2. Increase in its strength
  3. More efficient and fatigue resistant
  4. Capillaries surrounding muscle fibers and mitochondria in it increases
  5. Synthesize more myoglobin
- Complete immobilization of muscle leads to ***muscle weakness*** and ***severe atrophy***.

CRITICAL THINKING

8. **ATP produced within cell is not used for:**
   A. Movement of calcium ions back to SR
   B. Muscle contraction
   C. Muscle relaxation
   D. Movement of calcium ions into sarcoplasm

TOPIC-13

VARIATION & GENETICS / INHERITANCE

COURSE CONTENT

- Basic Terms
- Mendelian Inheritance
- Law of Segregation/Inheritance of Single Trait
- Law of Independent Assortment/Inheritance of Two Traits
- Dominance Relations
- Multiple Alleles and ABO Blood Group System
- Rh Blood Group System and Erythroblastosis Foetalis
- Gene Linkage and Crossing Over
- Sex Linkage in *Drosophila*
- Sex Linkage in Humans (Hemophilia & Color Blindness)

BASIC TERMS

- The similar characters that pass from parents to their offsprings are collectively called as ***heredity***. The resemblance, however, is not complete and offsprings differ from each other and their parents in many respects. These differences are known as ***variations***.
- The science which deals with the mechanism of heredity and variations is called ***genetics.*** Both similarities and differences are the parts of inheritance which play significant role in the ***formation of new species***.

Gene

- It is the ***basic unit of biological information***. In fact, the DNA stores all sort of biological information coded in the sequence of its bases in a linear order, and genes are actually parts of DNA comprising its base sequences.
- Gene can also be defined as 'the sequence of nucleotides that specifies sequence of amino acids in a polypeptide chain/protein molecule'.
- Hereditary characteristics pass from parents to offspring through genes in their gametes.
- When genes pass in the form of intact parental combination between generations, inherited similarities are conserved; but when these shuffle, mutate or juggle with each other, variations emerge.

Locus

- The position of a gene on the chromosome is called its locus.

Allele

- Genes form pairs on pairs of homologous chromosomes. One member of a gene pair is located on one homologue and the other member on the other homologue.
- Partners of a gene pair are called ***alleles***.
- Each allele of a gene pair occupies the same gene locus on its respective homologue. Both alleles on one locus may be identical or different from each other.

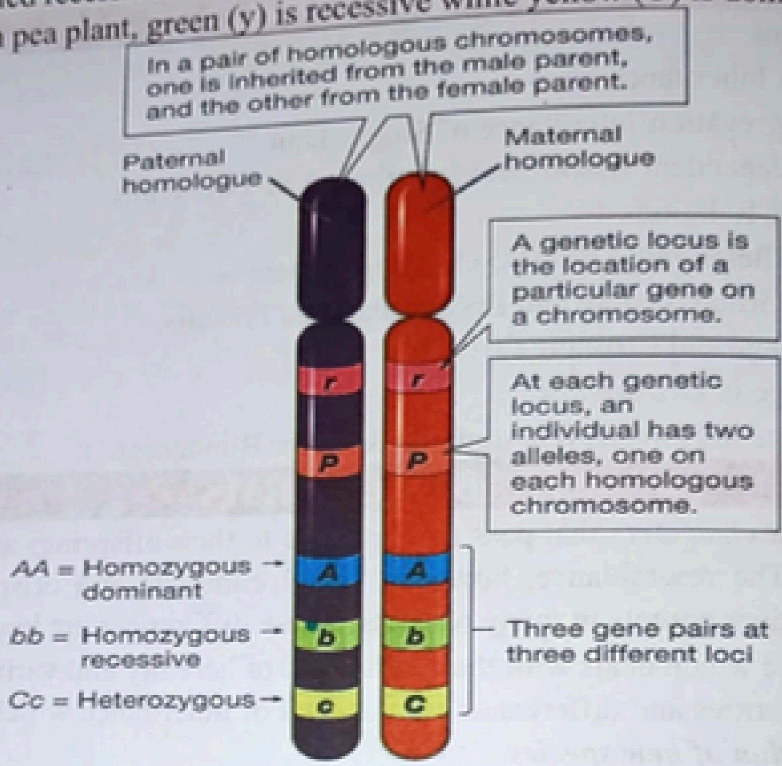
Dominant Allele

- Such an allele that masks the effect of other allele in a pair is called dominant allele and such trait is called dominant trait.

- For example, in pea plant, round (R) is dominant over wrinkled (r).

Recessive Allele

- Such an allele that is masked by another allele in a gene pair is called recessive allele and such trait is called recessive trait.
- For example, in pea plant, green (y) is recessive while yellow (Y) is dominant.



Gene Pool

- All the genes/alleles found in a breeding population at a given time are collectively called the gene pool.
- It consists of all the alleles at all genes loci in all individuals of the population.
- For a diploid species, each locus is represented twice in a genome of the individual who may be either homozygous or heterozygous.

Phenotype

- Physical appearance of a trait is called phenotype.
- For example, round and wrinkled are phenotypes of seed shape as the shape is a trait.

Genotype

- Genotype is the genetic complement i.e. the genes in an individual for a particular trait.
- For example, genotype of AB blood group is I^AI^B.

Homozygous

- When both alleles of a gene pair in an organism are same, the organism is homozygous for that gene pair.
- An individual with homozygous genotype is called homozygote or true breeding.
- For example, RR is genotype of homozygous round seeded pea plant.

Heterozygous

- If both alleles of a gene pair are different from each other, the organism is heterozygous for that gene pair.
- An individual with heterozygous genotype is called heterozygote or hybrid.
- For example, Rr is genotype of heterozygous round seeded pea plant.

MENDELIAN INHERITANCE

- In 1860's, Mendel discovered mechanism of inheritance based on his experimental work with pea plants. The first step of his experimental work was to develop true or pure breed varieties.
- A plant that produces all the offsprings of its own phenotype upon self-fertilization is called ***true/pure breeding plants***. These plants can be developed by repeated self-fertilization through successive generations until pure breed is achieved.
- Mendel studied ***seven pairs of contrasting traits*** for each contrasting phenotype; he developed a pure breeding plant.
- In second step, he performed ***hybridization***, a cross fertilization between two individuals having contrasting phenotypes.

Selection of Pea Plant

- Mendel performed series of breeding experiments on garden pea (*Pisum sativum*) in his monastery garden for eleven years. He selected pea plant for experiments due to following reasons:
- Pea plants were easy to cultivate.
- Its flowers were hermaphrodite. It was normally self-fertilized but could be cross-fertilized.
- It has short generation time.
- It has many sharply distinct traits and each trait had two clear cut alternative forms or varieties.

CRITICAL

Mendelian Traits:

Mendel's seven traits were on total four chromosomes.

Trait	Chromosome Number
Seed Shape	7
Stem Length	4
Seed Color	1
Flower color	1
Pod Color	5
Pod Shape	4
Position of Flower	4

Contrasting Traits Studied by G. Mendel

Character	Dominant Trait	Recessive Trait
Stem length	Tall	Dwarf
Pod shape	Inflated	Constricted
Seed shape	Round	Wrinkled
Seed colour	Yellow	Green
Flower position	Axial	Terminal
Flower colour	Purple	White
Pod colour	Green	Yellow

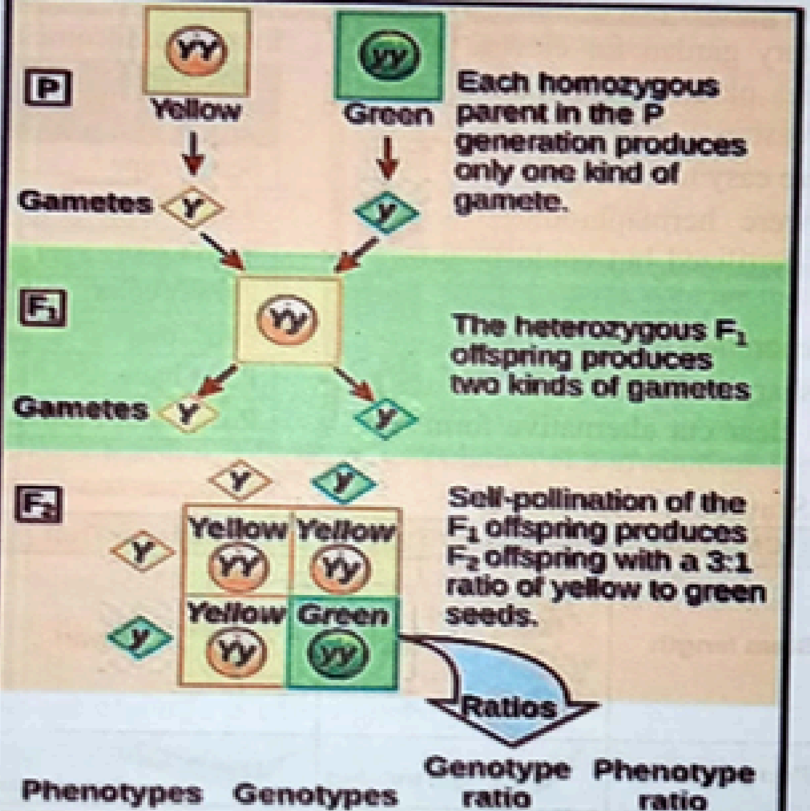
LAW OF SEGREGATION/INHERITANCE OF SINGLE TRAIT

Statement

'The two co-existing alleles for each trait in an individual segregate (separate) from each other at meiosis, so that each gamete receives only one of the two alleles. Alleles unite again at random fertilization of gametes when zygote is formed'.

Monohybrid Cross

- Mendel studied inheritance of single trait in ***monohybrid cross*** in which two plants are crossed that differ on single trait.
- For the study of single trait of inheritance, he crossed a pure breeding yellow seed colored plants with a pure breeding green seed colored plants. He observed that ***F_1 generation*** was comprised entirely of individuals exhibiting only one parental phenotype i.e., yellow seed colored.
- When F_1 generation was ***interbred/self-fertilized***, its offsprings/***F_2 generation*** showed a 3:1 ratio for yellow and green seed colors.



Phenotypes	Genotypes	Genotype ratio	Phenotype ratio
Yellow	YY Yy	1 2	3
Green	yy	1	1

- Mendel got similar results and the same 3:1 ratio in offspring of monohybrid crosses for all the seven contrasting pairs of traits.
- Mendel proceeded a step ahead. He self-fertilized F_2 plants to get the F_3 generation. He observed that 1/3 of F_2 round produced only round (appeared true of pure breeding like P_1 round), while 2/3 of F_2 round produced both round and wrinkled in 3:1 (appeared non-pure breeding like F_1 round); but F_2 wrinkled produced only wrinkled (pure breeding).

Interpretations of Results

- Based upon these observations, Mendel concluded that each contrasting form (phenotype) of a trait, e.g., yellow or green colors of seed was determined by ***particulate hereditary factors***, which he called **"*elementens*"** (now called genes).

- These factors carrying hereditary information were transmitted from parents to offspring through gametes.
- Each pea plant had a pair of these factors (now called ***alleles***, the alternative form of gene on the same locus).
- One derived from the male parent and other from the female parent.
- Yellow is dominant over green.

Phenotypic and Genotypic Expressions

- ***Phenotype*** ratio of F_2 generation is ***3:1***.
- ***Genotype*** ratio of F_2 generation is ***1:2:1***.

Test Cross

It is a mating in which an individual showing a dominant phenotype is crossed with an individual showing its recessive phenotype.

Significance

This cross is used to find out the homozygous or heterozygous nature of the genotype of those individuals showing dominant phenotype.

Details

- A phenotypically yellow colored seed could be homozygous (YY) or heterozygous (Yy).
- If the seed is ***homozygous yellow*** (YY), it will grow into a pea plant that forms all gametes with only 'Y' alleles. Green seed plants are always homozygous recessive, and form all gametes with 'y' alleles. Fertilization will result in 100% yellow colored seed progeny, and showed that the tested phenotypically dominant individual is homozygous.
- If the seed is ***heterozygous yellow*** (Yy), it will grow into a plant that forms half the gametes with 'Y' and half with 'y'. Green seed plants will form only 'y' type of gametes. Fertilization will result into 50% yellow and 50% green seed progeny, and show that tested phenotypically dominant individual is heterozygous.

CRITICAL THINKING ?

1. Suppose growth hormone gene has two alleles. One allele has locus designated as 11Ai reduces growth of bones than its counterpart allele present at locus designated as 11Aii of bones shows more growth. Expression of later allele would be termed as:

A. Complete dominance B. Epistasis
C. Incomplete dominance D. Codominance

2. Mendel's law of independent assortment may not be applicable on which of the following contrasting pair of traits?

A. Seed shape and stem length B. Stem length and pod shape
C. Pod color and pod shape D. Seed color and seed shape

LAW OF INDEPENDENT ASSORTMENT/INHERITANCE OF TWO TRIATS

Statement

'When two contrasting pairs of traits are followed in the same cross, their alleles assort independently into gametes'.

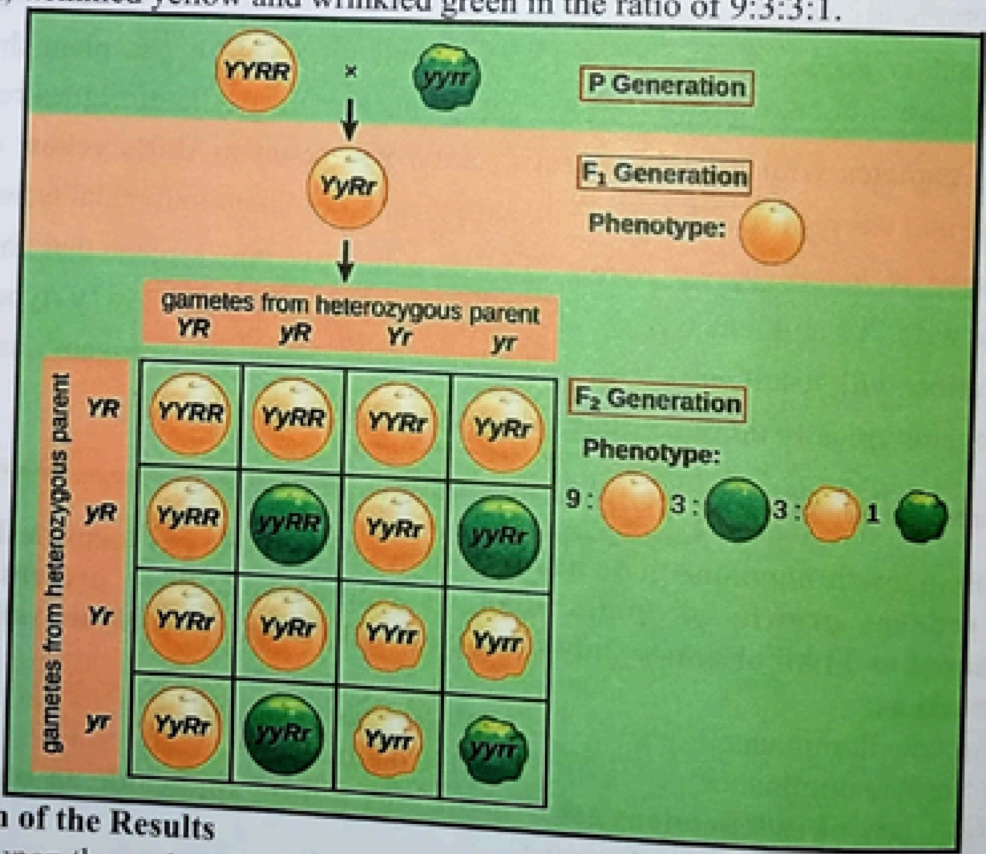
- The distribution of alleles of one trait into gametes has no influence on the distribution of alleles of the other trait.

Dihybrid Cross

- The inheritance of two traits simultaneously can be studied in dihybrid cross i.e., a cross between two individuals, which are different on two traits.
- The two of the seven characters Mendel studied were seed color and shape. Seed shape may be either round (dominant) or wrinkled (recessive) and color of these seeds may be either yellow (dominant) or green (recessive).

Phenotypic & Genotypic expression

- When he crossed a homozygous round yellow (RRYY) plants with homozygous wrinkled green (rryy) plants, all the offsprings were with both dominant phenotypes in F_1 generation.
- In order to analyze the genotypes of F_1 plants, Mendel self-fertilized them and produced F_2 generation. He was expecting that dominant and recessive combinations could be produced in 3:1 in F_2 generation as he had obtained in monohybrid cross, but he observed that offspring were produced in ***four phenotypic combinations*** i.e., round yellow, round green, wrinkled yellow and wrinkled green in the ratio of 9:3:3:1.



Interpretation of the Results

- Based upon these observations, Mendel concluded that the F_1 offspring were dihybrid i.e., heterozygous (RrYy) for both traits.
- An F_1 can produce four classes of gametes, e.g., ***RY, Ry, rY, ry***, in equal quantities. If the sperms of the four classes are crossed with eggs of the four types, there will be 16 equally

probable ways in which the alleles can combine in F_2 generation as shown in the Punnet square in the above figure. These combinations make up four phenotypic categories with a ratio of 9:3:3:1.

Limitations of Law of Independent Assortment

- Genes are located on chromosomes at specific loci. Independent assortment of genes depends upon independent assortment of their chromosomes.
- All the genes present on a homologous pair of chromosomes are linked to each other in the form of a linkage group. These cannot assort independently.
- Those alleles assort independently whose alleles are riding non-homologous chromosomes.

Usefulness of Law of Independent Assortment

i) Mendel's law of independent assortment explains that if two parents have unique set of traits which are desired to express in one individual, so it is possible only because of independent assortment.

ii) Furthermore, if two parents have such traits which they do not want to be expressed in their offspring. This is also possible only because of independent assortment.

Scope of Independent Assortment in Variation

i) Beside mutation and crossing over (which are sources of variation), independent assortment of traits is also a major source of variations in successive generations.

ii) It is only due to the crossing over and independent assortment of the traits that the characteristics may appear in new combination in next generation which often seems necessary for adaptations in varying environment.

Probability and Product Rule

- Probability is the ***chance of an event to occur*** e.g. in F_2 offspring of a monohybrid cross the independent chance for a seed to be round is 3/4 and wrinkled 1/4.
- When two independent events are occurring simultaneously like in dihybrid cross, the ratio of each joint phenotypic combination can be obtained by ***multiplying the probabilities of individual phenotypes***. It is called product rule.

Event No.1 Seed Shape Independent Probability	Event No.2 Seed Colour Independent Probability	Both Events at a Time Seed Shape & Colour Joint Probability
Round = 3/4	Yellow = 3/4	Round Yellow = 3/4 x 3/4 = 9/16
Round = 3/4	Green = 1/4	Round Green = 3/4 x 1/4 = 3/16
Wrinkled = 1/4	Yellow = 3/4	Wrinkled Yellow = 1/4 x 3/4 = 3/16
Wrinkled = 1/4	Green = 1/4	Wrinkled Green = 1/4 x 1/4 = 1/16

DOMINANCE RELATIONS

- ***Dominance*** is a physiological effect of an allele over its partner allele on the same gene locus.
- The relationships between the contrasting alleles at the same locus in heterozygous state are called ***dominance relations***.
- Although Mendel had observed mainly only complete dominance, but later on many geneticists became able to explain several exceptions to the Mendelian inheritance that could not be explained on the basis of complete dominance.
- These exceptions are said to be ***non-Mendelian inheritance patterns*** and include incomplete/partial dominance, co-dominance and over dominance, each indicating a different style of their functional effect upon each other. These relations are summarized in the following table:

Feature	Complete Dominance	Incomplete Dominance	Co-dominance	Over Dominance
Alleles in Heterozygote	One allele completely masks the effect of other	Both alleles are expressed partially	Both alleles are expressed fully	One allele boosts effect of other allele
Phenotype of Heterozygote	Resembles with one homozygote	Intermediate between both homozygotes	Distinct from both homozygotes	Exceeds in quantity from homozygote
Expression of Alleles	Capital letter for dominant and small letter for recessive	Different expression e.g. R_1 and R_2	Different expression e.g. M and N blood group antigens	Different expression for dominant and recessive e.g. w- and w^+
Phenotype & Genotype Ratios	Different	Same	Same	Same
Need of Test Cross	✓	×	×	×
Examples	All seven traits studied by Mendel	Flower color in 4 O'clock plant	AB and MN blood groups	Fluorescent pigments in eyes of *Drosophila*

MULTIPLE ALLELES AND ABO BLOOD GROUP SYSTEM

Multiple Alleles

- All such altered alternative forms of a gene, whose ***number is more than two*** are called multiple alleles.
- ***Gene mutations*** may produce many different alleles of a gene. Some genes may have as many as ***300 alleles***.
- Any two of these multiple alleles can be present in the genome of a diploid organism, but a haploid organism or a gamete has just one of them in its genome.

ABO Blood Group System

- A well-known example of multiple alleles is the ABO blood group system in humans, which was discovered by ***K. Landsteiner in 1901***.
- This system has four different phenotypes which are distinct from each other on the basis of specific antigens on the surface of RBCs.
- ***Bernstein*** explained the genetic basis of ABO blood group system in 1925. This blood group system is encoded by a ***single polymorphic gene 'I'*** (which stands for isohaemagglutinogen) which is located on ***chromosome 9***. It has three multiple alleles 'I^A', 'I^B' and 'i'.
- Allele 'I^A' specifies the production of antigen 'A', allele 'I^B' specifies the production of antigen 'B', and allele 'i' does not specify any antigen.
- Their dominance relations are interesting too. Alleles 'I^A' and 'I^B' is co-dominant to each other because each expresses equally in I^AI^B heterozygote to produce 'AB' phenotype. But allele 'i' is recessive to both 'I^A' and 'I^B'.

Phenotypes & Genotypes

Phenotype/Blood Group	Genotype	Antigen on the Surface of RBCs	Antibodies in Blood Plasma
A	I^AI^A, I^Ai	A	Anti-B antibody
B	I^BI^B, I^Bi	B	Anti-A antibody
AB	I^AI^B	Both the antigen 'A' and 'B'	Neither anti-A nor anti-B antibodies
O	ii	Neither antigen A nor antigen B	Both Anti-A and anti-B antibodies

- The blood group alleles start their expression at ***early embryonic stage*** and keep on expressing themselves till death. Therefore, the blood group phenotype of a person never changes throughout life.
- On the other hand, anti-A and anti-B antibodies appear in blood plasma during the ***first few months after birth***. They are naturally occurring in the absence of corresponding antigens.

Transfusion Principle

- When transfusions are carried out between two incompatible (different) blood groups, antigens of donor react with the antibodies (also called ***agglutinins***) of the recipient, then the red blood cells clump with one another.
- The clumping of red blood cells is known as ***agglutination***. Therefore, the transfusions are carried out on the basis of donor's antigens and recipient's antibodies.

CRITICAL CONCEPT!

Blood Transfusion in Patients with Bombay Phenotype:
When individuals with the Bombay phenotype need blood transfusion, they can receive only autologous blood or blood from another Bombay blood group. Transfusing blood group 'O' red cells to them can cause a fatal hemolytic transfusion reaction.

- Agglutination leads to serious results because ***clumped cells cannot pass through the fine capillaries***. The blood samples of donor and recipient are ***cross-matched*** for compatibility before giving transfusion.

Blood Transfusion

Blood Group	Donated To	Receives From
A	A, AB	A, O
B	B, AB	B, O
AB (Universal recipient)	AB	A, B, AB, O
O (Universal donor)	A, B, AB, O	O

CRITICAL THINKING

3. **What is incorrect about ABO blood groups system?**

	Blood Group	Antigen	Antibody	Genotype	Donor for	Recipient of
A.	A	A	Anti B	I^AI^A	A, AB	A, O
B.	B	B	Anti A	I^BI^B	B, AB	B, O
C.	AB	AB	No	I^AI^B	A, AB, B	AB
D.	O	No	Anti A and Anti B	ii	A, AB, B, O	O

4. **If father is homozygous for blood group 'A' and mother is 'O', and both are carrier for H–gene, then probability of phenotypically 'O' child in their progeny will be:**

A. 0
B. 25%
C. 50%
D. 100%

Rh BLOOD GROUP SYSTEM AND ERYTHROBLASTOSIS FOETALIS

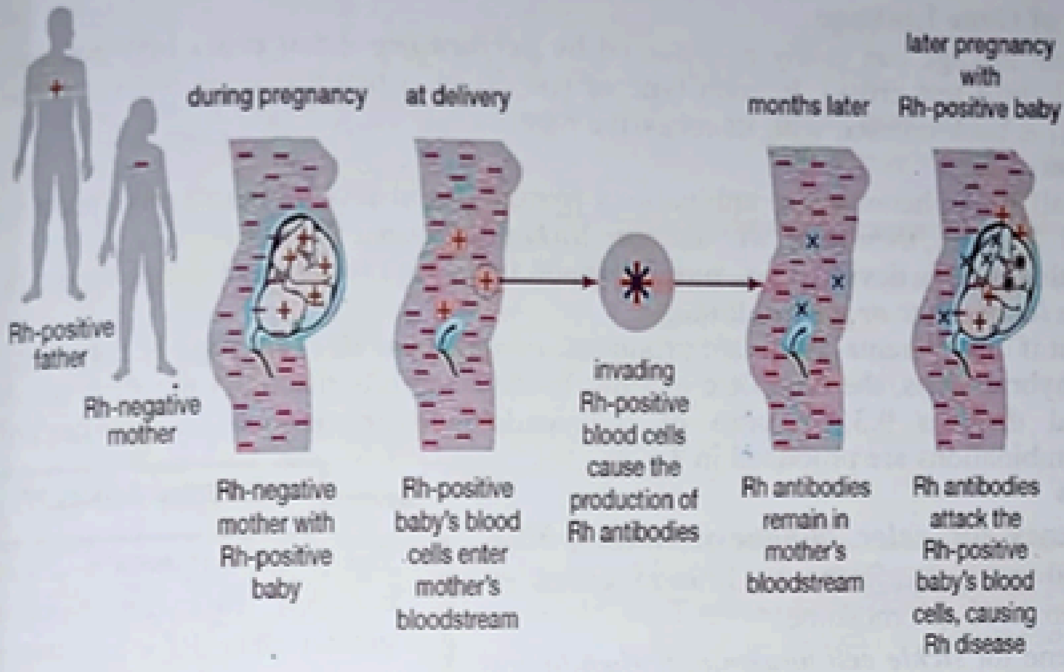
Rh Blood Group System

- ABO blood type is further differentiated by a ***positive or negative sign***. This positive or negative sign refers to the presence or absence of another blood group system antigen called ***Rh factor***, which is present on the ***surface of RBCs***.
- The Rh blood group system is clinically the most important blood group system after ABO. The name of this system is derived from ***Rhesus monkey***, because its antigen was first discovered in it by ***Landsteiner in 1930s***.
- Rh blood group system is encoded by ***three genes e.g., C, D, E***, which occupy ***two tightly linked loci***.
- Alleles for 'gene D' occupy one locus called 'locus D' while 'gene C' and 'gene E' alternatively occupy the other locus.
- The 'locus D' is of prime importance because it determines the formation of '***D antigen/Rh factor***', while its alternative 'allele d' inhibits the formation of Rh factor.
- 'Allele D' is ***completely dominant*** over 'allele d', therefore, persons having genotypes 'DD' or 'Dd' have D antigen on their RBCs and are Rh positive. Persons with genotype 'dd' do not have Rh factor and are Rh negative.

Phenotype/Blood Group	Rh-Factor/ Antigen D	Genotype	Anti Rh Antibodies	Can Donate To	Can Receive From
Rh^{+ve}	Present	DD, Dd	Not produced	Rh^{+ve}	Rh^{+ve}, Rh^{-ve}
Rh^{-ve}	Absent	dd	Produced (If stimulated)	Rh^{+ve}, Rh^{-ve}	Rh^{-ve}

Erythroblastosis Foetalis

- Erythroblastosis foetalis/materanal-foetal Rh incompatibility results when as Rh^{-ve} woman, married to Rh^{+ve} man conceives a child who is Rh^{+ve}.
- If the RBCs of Rh^{+ve} foetus cross the placental barrier and enter into Rh^{-ve} mother's blood stream, then the mother's immune system reacts to the foetal Rh-antigen stimulus by producing large number of anti-Rh antibodies.
- The first Rh incompatible pregnancy may not face much problems. But when placenta detaches at birth, a large number of foetal cells enter mother's blood stream and stimulate production of large amount of anti-Rh antibodies by the mother. These anti-Rh antibodies persist in mother's blood for a long time and are persistent risk for the next Rh^{+} foetus.
- When mother's anti-Rh antibodies seep through placenta into the circulation of foetus, they start ***hemolysis*** of RBCs of the foetus, which results in ***anemia***. This anemia may lead to ***abortion*** or ***still birth***.



- Even if the pregnancy continues, the ***liver and spleen of the foetus swell*** as they rapidly produce RBCs. The breakdown product of RBC called ***bilirubin*** also accumulates in the foetus.
- Bilirubin damages his brain cells and turns skin and whites of the eye yellow of the foetus. This condition is ***jaundice***.

Control of Rh Incompatibility

- Rh sensitization of Rh^- mother is avoided by a simple therapy. She is given an injection of ***Rh-antiserum during early pregnancy and immediately after birth***.
- The Rh–antibodies in the Rh-antiserum will destroy Rh+ RBC of the foetus before they stimulate production of maternal anti–Rh antibodies. The injected antiserum disappears before the next pregnancy.

GENE LINKAGE AND CROSSING OVER

Gene Linkage

- Phenomenon of staying together of all the genes of a chromosome is called ***gene linkage***.
- Gene linkage is a physical relationship between genes.
- The number of genes in a cell is far greater than the number of chromosomes. In fact each chromosome has hundreds and thousands of genes. So, a chromosome carries its linked genes en block in form of ***linkage group***.
- The number of linkage groups corresponds to the number of homologous pairs of chromosomes. For example, ***man has 23 linkage groups***.
- The linked genes tend to be inherited together in offspring, so usually they do not show recombination and do not assort independently. So the idea Mendelian ratio of independent assortment is deviated.

Types of Gene Linkage

i. **Autosomal linkage**
If genes are linked on autosomes, their linkage is called ***autosomal linkage***. Similarly,

ii. **Sex Linkage**
If genes are linked on sex chromosome, their linkage is called ***sex linkage***.

Detection of Gene Linkage

- Gene linkage can easily be detected by ***performing a test cross*** between two gene pairs (dihybrid test cross). In such type of test cross, a heterozygous individual for two traits (F_1) is back crossed with its recessive parent (P_1).

Conclusion

i. If all four phenotypic combinations (parental and recombinants) are produced in equal 1:1:1:1 ratio, then there would be ***no linkage*** between the genes.

ii. If this ratio is deviated i.e., more parental types and less recombinant types, this indicates the ***incomplete or partial linkage.***

iii. But if only parental types are produced, ***complete or tight linkage*** is believed. In a typical dihybrid cross, the complete or tight linkage inhibits the outcome of recombinant types and disturbs 9:3:3:1 ratio of independent assortment, as a result, only parental combinations are produced in 3:1.

Examples

- Genes for ***color blindness, haemophilia,*** and ***gout*** etc. form one linkage group on human X-chromosome.
- Gene for ***sickle cell anaemia, leukemia*** and ***albinism*** etc. form linkage group on human chromosome 11.

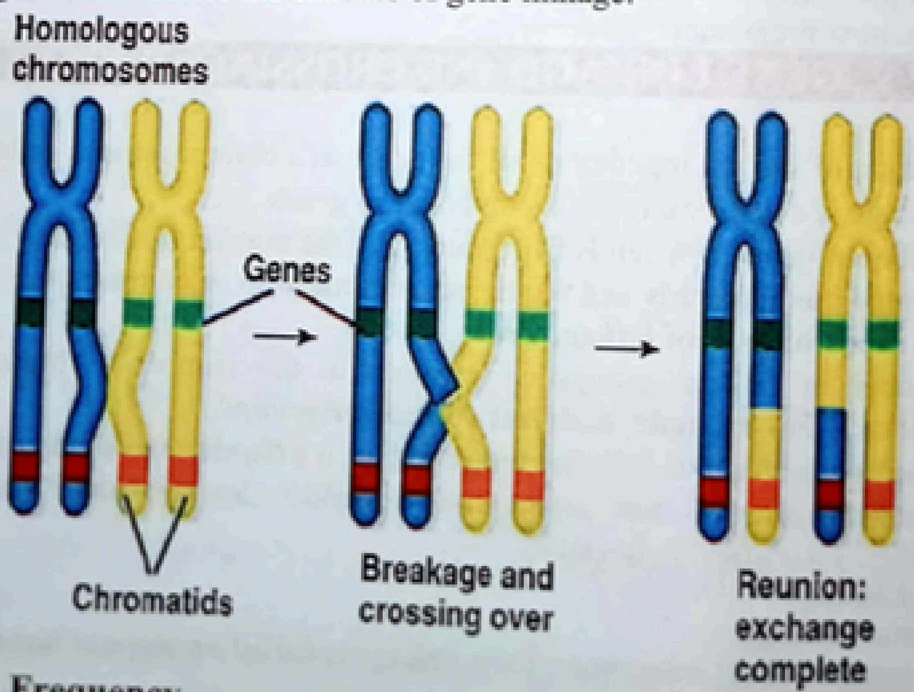
CRITICAL CONCEPT!

The recombination frequency between two genes cannot be greater than 50% because random assortment of genes generates 50% recombination (non-linked genes produce 1:1 parental to non-parental). Thus, the recombination frequency would be non-parental/total --> 1/(1+1) = 50%).

Crossing Over

Crossing over is an exchange of segments between ***non-sister chromatids of homologous chromosomes*** during meiosis.

- Linked genes can be separated by ***crossing over***. Closer the two gene loci, more strongly their genes linked. The farther apart two genes lie; greater are chances of their separation through crossing over.
- Crossing over minimizes the chances of gene linkage.



Recombination Frequency

- Cross over or recombination frequency is the proportion of recombinant types between two gene pairs as compared to the sum of all combinations.

- The recombination frequencies between two linked genes can be calculated by backcrossing the heterozygote to a homozygote double recessive.
- Its value is directly proportional to distance between the linked gene loci.
- Genes can be mapped on a chromosome on the basis of their recombination frequencies.

CRITICAL THINKING

5. **Suppose if we have more than 50% recombinant frequency in any case, then what would be the best interpretation of that case?**
A. Gene are present on same chromosomes
B. Genes are linked
C. Genes are having possibility of crossing over
D. Genes are present on different homologous pair

SEX LINKAGE IN *DROSOPHILA*

- T. H. Morgan (1910) provided experimental evidence in support of chromosomal theory of heredity through discovery of sex linkage in *Drosophila*.

Reasons for Selection of *Drosophila*

Drosophila is a very useful organism for genetic studies for many reasons. For example;

(i) Easy collection & culturing
(i) Sexual dimorphism
(ii) Short generation time
(iii) Excellent for genetic studies
(iv) Fairly large number of distinct contrasting traits e.g., 85 traits identified by Morgan and his colleagues.
(v) Part of human genome project

Morgan's Experiments and Crosses

- Morgan raised cultures of *Drosophila* flies to study different traits, such as colour of the eye.
- Normal fruit flies, the ***wild type***, have bright red eyes. One of his coworkers Calvin Bridges, observed an unusual white eye mutant male fly.

Step 1: Normal Cross

Morgan mated white eyed male with a wild type red eyed female. All 1237 offspringS of this cross had red eyes. Morgan concluded that red eye is dominant trait.

Step 2: Normal Cross

Morgan allowed males and females of F_1 generation to mate and produce F_2 generation. He counted 2459 red eyed females, 1011 red eyed males and 782 white eye males among F_2.

Observations

Different observations got by this cross were;

- Offspring produced due to this cross were red-eyed females, red-eyed males and white-eyed males.
- The proportion of 3470 red eyed to 782 white eyed flies did not perfectly fit into Mendelian 3:1 ratio.
- The number of recessive phenotype individuals were too small.
- All the white-eye flies were only males. There was no white eye female in F_2.

Conclusion

The inheritance of eye color somehow seemed to be related to the sex of offspring. Morgan proposed that;

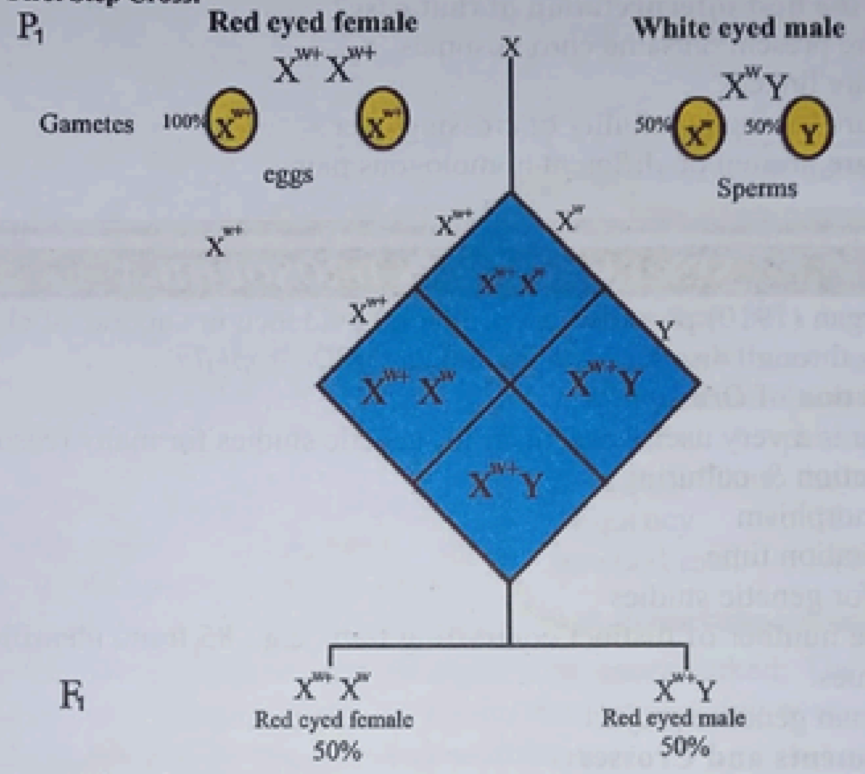
(i) The gene for eye color is located on X-chromosome.

(ii) The alleles for eye color are present only on X-chromosome. There is no corresponding allele for this trait on Y-chromosome.

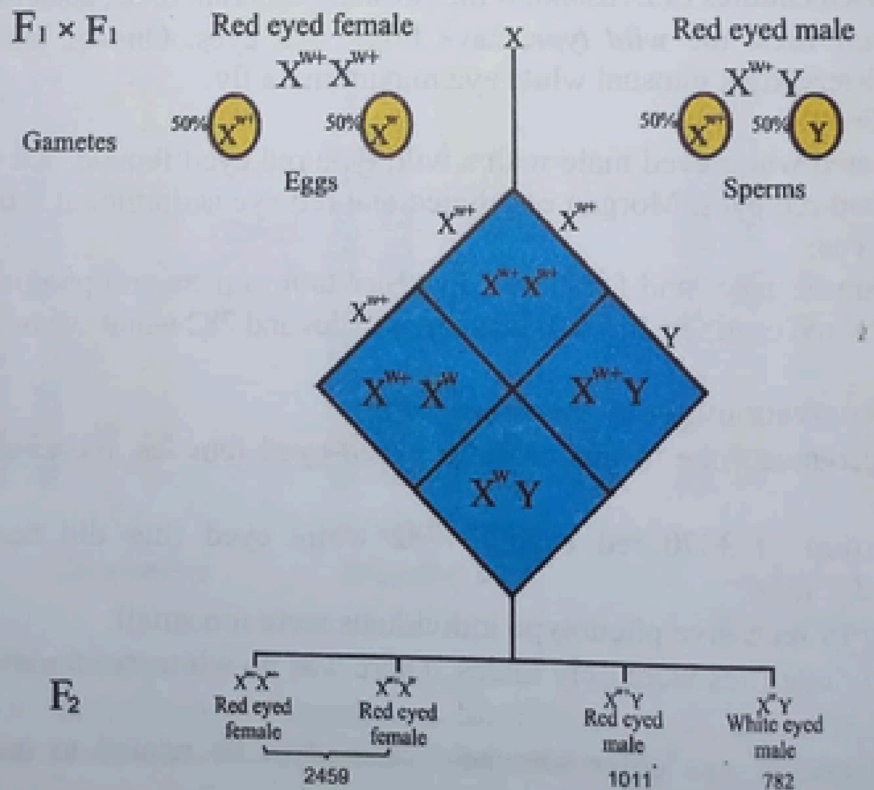
(iii) Single recessive allele on X-chromosome can express itself in males because Y-chromosome is empty for that gene.

- Now we can relate these crosses with genotype. The genotype of the parents of P_1 cross were $X^{W+}X^{W+}$ for red eye female and $X^{W}Y$ for white eye male.

First Step Cross:

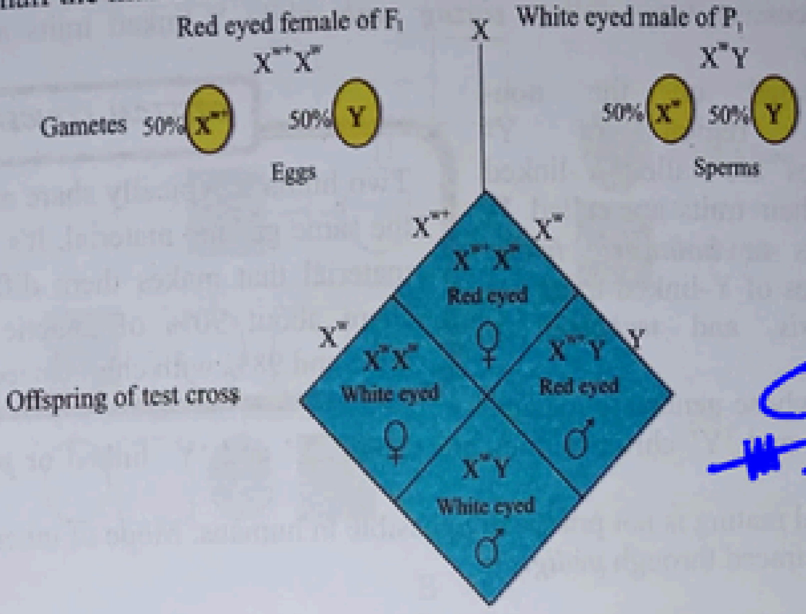


Second Step Cross:



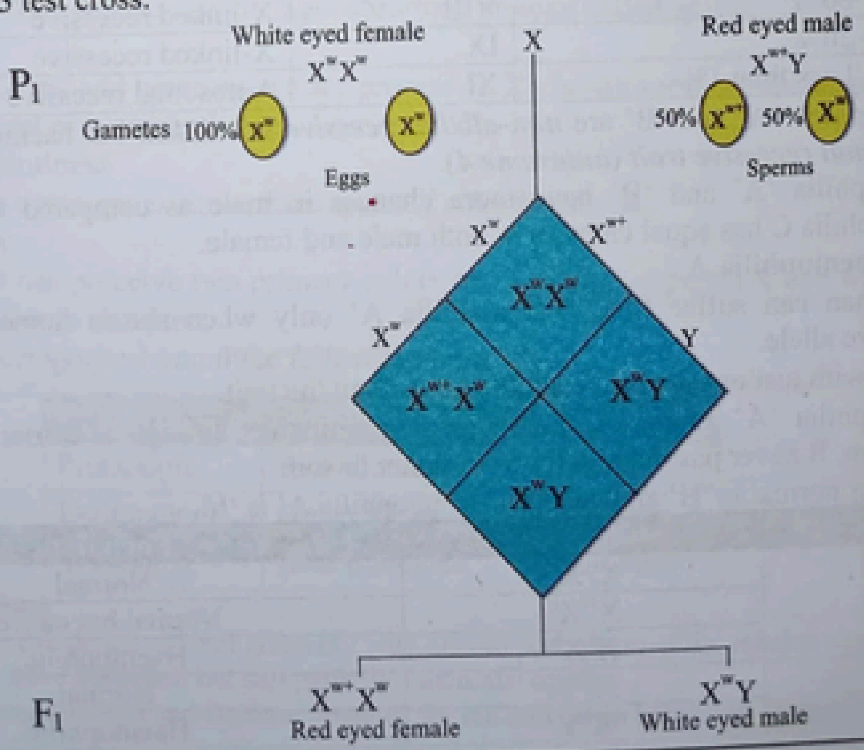
Step 3: Test Cross

- Morgan wanted to test his hypothesis. He crossed the P_1 white eyed male (X^wY) with one of its own daughters (the red-eyed heterozygous female from F_1 generation).
- Out of total offspring of this cross, half female offspring had red eyes and half had white. Similarly, half the males had red eyes and half had white.



Step 4: Reciprocal Cross/ Confirmatory Test

- Appearance of white-eyed female provided an opportunity for a further confirmatory test.
- Morgan mated a white-eyed female with a red-eyed male. All female offspring had red eyes and all male offspring had white eyes.
- When F_1 red-eyed females and white-eyed males were mated to produce F_2, then half of the F_2 females had red eyes and half white eyes.
- Similarly, half of the F_2 males had red eyes and half white. This F_1 x F_1 cross was exactly like step 3 test cross.



SEX LINKAGE IN HUMANS

- A trait whose gene is present on X chromosome is called ***X-linked trait***. X-linked traits are commonly referred as sex-linked traits.
- ***X-linked recessive traits*** are common in male while ***X-linked dominant traits*** are common in female.
- X-linked recessive traits follow ***zigzag path*** while Y-linked traits are transmitted in ***straight way***.
- Genes located on the non-homologous region of Y-chromosomes are called Y-linked genes and their traits are called ***Y-linked traits*** or ***holandric traits.*** The examples of Y-linked traits are ***hypertrichosis***, and ***webbing of toes***.

CRITICAL CONCEPT!

Two humans typically share around 99.9% of the same genetic material. It's the 0.1% of the material that makes them different. Humans share about 90% of genetic material with mice and 98% with chimpanzees.

- Such traits whose genes are located on both 'X' and 'Y' chromosomes are called 'X' and 'Y' linked or ***pseudoautosomal traits.***
- Experimental mating is not practically possible in humans. Mode of inheritance of human traits can be traced through ***pedigree***.

Haemophilia

- It is a rare X-linked recessive trait.
- Hemophiliac's blood fails to clot properly after an injury, because it has either reduction or malfunction or complete absence of blood clotting factors.
- It is a serious heredity disease because a haemophiliac may bleed to death even from minor cuts.

Types of Haemophilia

Type	Occurrence	Factor	Genetics
A	80%	VIII	X-linked recessive
B	20%	IX	X-linked recessive
C	Less than 1%	XI	Autosomal recessive

- Haemophilia 'A' and 'B' are ***non-allelic recessive sex-linked*** but haemophilia 'C' is an ***autosomal recessive trait*** (***autosome 4***).
- Haemophilia 'A' and 'B' have more chances in male as compared to female while haemophilia C has equal chances in both male and female.

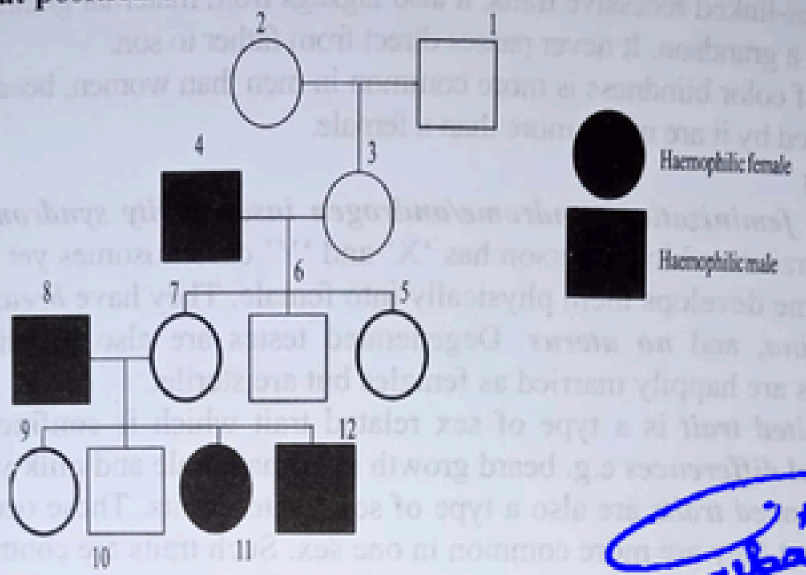
Genetics of Haemophilia A

- A woman can suffer from 'haemophilia A' only when she is homozygous for the recessive allele.
- A man with just one recessive allele will display the trait.
- Haemophilia 'A' zigzags from maternal grandfather through a carrier daughter to a grandson. It never passes directly from father to son.
- Gene for normal is 'H' and gene for 'haemophilia A' is 'h'.

Gender	Genotype	Phenotype
Female	X^HX^H	Normal
	X^HX^h	Normal but carrier
	X^hX^h	Haemophilic
Male	X^HY	Normal
	X^hY	Haemophilic

CRITICAL THINKING

6. **A pedigree of a family is given below. Find out the genotype of individual for hemophilia at position 5:**



Ubaid

A. X^HX^H B. X^HX^h
C. X^hY D. X^HY

Color Blindness

- It is a hereditary disease in which a person cannot differentiate between different colors.
- Normal trichromatic color vision is based on three different kinds of cone cells in the retina, each sensitive to one of the three primary colors, red, green, and blue.
- Each type of cone cell has specific light absorbing proteins called ***opsins***.

Genetics

- The genes for red and green opsins are present on X-chromosome while the gene for blue opsin is present on ***autosome*** *7*.

Types of Colour Blindness

- Mutations in opsin genes cause three types of color blindness:

(i) **Dichromacy**

- A dichromat can perceive two primary colors but is unable to perceive one whose opsins are missing due to mutation.
- It is further categorized into three following types:

Type	Blindness	Perception
Protanopia	Red blindness	Green, Blue
Deuteranopia	Green blindness	Red, Blue
Tritanopia	Blue blindness	Red, Green

(ii) **Protanomalous**

- Some people can detect red and green but with altered perception of the relative shades of these colors. They have abnormal but still partially functional opsins.
- They are protanomalous and deuteranomalous for red and green blindness, respectively.

(iii) **Monochromacy**

- A monochromat can perceive only one color. Monochromacy is true color-blindness.
- ***Blue cone monochromacy*** is an X-linked recessive trait in which red and green cone cells are absent. That is why it is also called ***red-green color blindness***.
- Like any sex-linked recessive traits, it also zigzags from maternal grandfather through a carrier daughter to a grandson. It never passes direct from father to son.
- This type of color blindness is more common in men than women, because chances for a male to be affected by it are much more than a female.

Others Disorders

- ***Testicular feminization syndrome/androgen insensitivity syndrome*** is a rare X-linked recessive trait in which a person has 'X' and 'Y' chromosomes yet tfm genes on their X-chromosome develops them physically into female. They have ***breast, female genitalia, a blind vagina***, and ***no uterus***. Degenerated testes are also present in abdomen. Such individuals are happily married as females but are sterile.
- A ***sex-limited trait*** is a type of sex related trait which is confined to only sex due to ***anatomical differences*** e.g. beard growth in human male and milk yield in cows.
- ***Sex influenced traits*** are also a type of sex related traits. These occur in both males and females, but they are more common in one sex. Such traits are controlled by an allele that is expressed as dominant in one but recessive in the other. This difference is expression is due to ***hormonal difference*** between the sexes. e.g. pattern baldness which is inherited as an autosomal dominant trait in males but as an autosomal recessive trait in females. A heterozygous male can be bald but a heterozygous female is not. A woman can be bald only when she is homozygous recessive.

Traits and Examples

Trait	Example
X-linked recessive	Hemophilia, color blindness, testicular feminization syndrome
X-linked dominant	Hypophosphatemic or vitamin 'D' resistant rickets
Y- linked trait	Maleness
Pseudoautosomal trait	Bobbing in insects
Sex limited trait	Milk yield in cow, beard in man
Sex influenced trait	Baldness

CRITICAL THINKING

5. **An X linked recessive trait which is characterized by difficulty of patient to rise to standing position:**
A. Testicular feminization syndrome
B. Color blindness
C. Duchenne muscular dystrophy
D. Hypophosphatemic rickets

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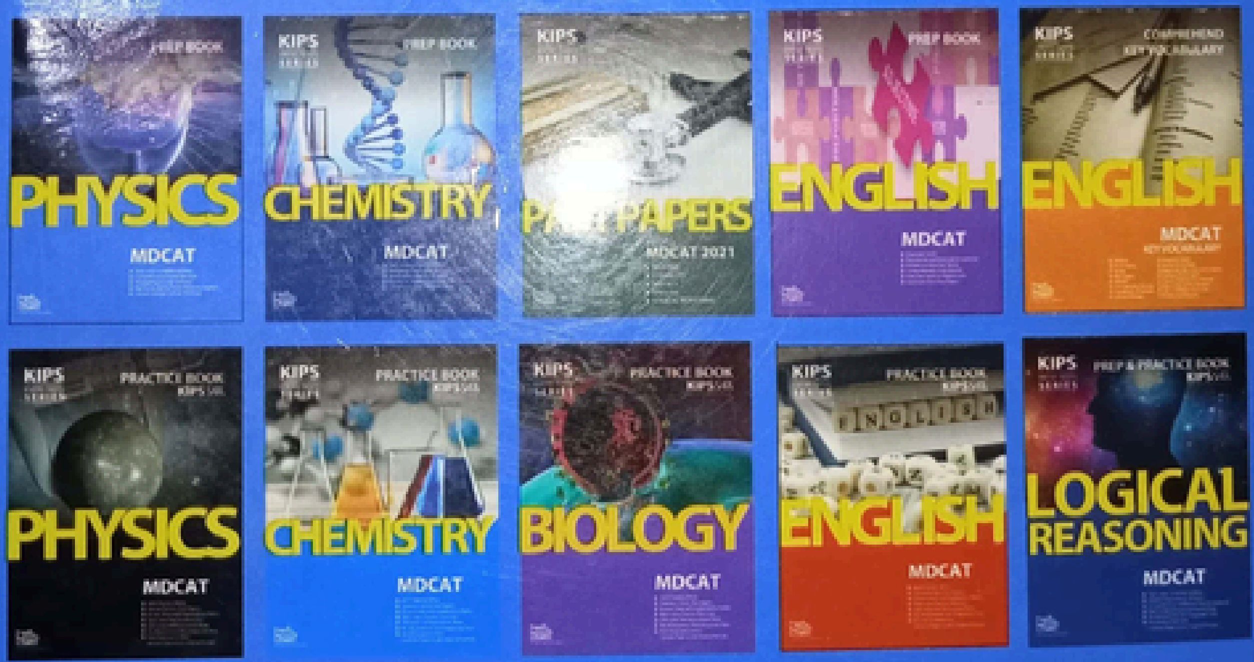

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