UNIT I – CELL STRUCTURE AND FUNCTIONS

Long Answer Questions

Q1. Describe the ultrastructure of a eukaryotic cell with neat labelled diagram.

A eukaryotic cell is a complex cell that has a true nucleus and many membrane-bound organelles. These cells are found in plants, animals, fungi and protists, and they are usually larger than prokaryotic cells. The cell is surrounded by a plasma membrane which separates the internal cytoplasm from the external environment.

The plasma membrane is a thin, flexible layer made mainly of a phospholipid bilayer with proteins. It is selectively permeable and controls what enters and leaves the cell. Inside the membrane is the cytoplasm, a jelly-like fluid that contains water, ions, enzymes and many dissolved molecules. All organelles are suspended in the cytoplasm and many metabolic reactions occur here.

The nucleus is the control centre of the cell. It is surrounded by a double nuclear membrane with pores that allow exchange of materials between nucleus and cytoplasm. Inside the nucleus there is chromatin (DNA + proteins) and one or more nucleoli. DNA carries genetic information and controls protein synthesis, growth and cell division.

Mitochondria are double-membrane organelles called the "powerhouses of the cell". The inner membrane is folded into cristae and the inner space is the matrix. Enzymes in the matrix and on the cristae help in respiration and in the production of ATP, the energy currency of the cell.

The endoplasmic reticulum (ER) is a network of membrane-bound tubules and sacs. Rough ER has ribosomes and is involved in protein synthesis and transport. Smooth ER does not have ribosomes and is involved in lipid synthesis, detoxification of drugs and storage of calcium ions.

The Golgi apparatus is a stack of flattened sacs. It modifies, sorts and packages proteins and lipids received from the ER. It forms lysosomes, secretory vesicles and is important in

secretion of hormones and enzymes.

Lysosomes are small vesicles containing hydrolytic enzymes. They digest worn-out organelles, food particles and foreign bodies. Because they can digest the cell if they burst, they are sometimes called "suicide bags".

Vacuoles are membrane-bound sacs. In plant cells there is usually a large central vacuole filled with cell sap; it maintains turgor pressure and stores water, ions and waste. In animal cells small vacuoles may be present for storage and transport.

In plant cells, chloroplasts are present. They contain chlorophyll and have thylakoids stacked as grana, surrounded by stroma. They carry out photosynthesis and convert light energy into chemical energy in the form of glucose.

Animal cells contain centrioles, which are cylindrical structures made of microtubules located near the nucleus. They help in the formation of spindle fibres during cell division.

Altogether, the plasma membrane, cytoplasm, nucleus and various organelles work together to keep the cell alive and functioning.
(When you write in the exam, draw an oval animal cell and neatly label: plasma membrane, cytoplasm, nucleus, nucleolus, mitochondria, ER, Golgi apparatus, lysosomes, ribosomes, centrioles and vacuole.)

Q2. Explain the fluid mosaic model of cell membrane and its functions.

The Fluid Mosaic Model, proposed by Singer and Nicolson in 1972, explains the detailed structure of the cell membrane. According to this model, the membrane is a fluid phospholipid bilayer with proteins floating in it like icebergs in a sea.

Each phospholipid molecule has a hydrophilic (water-loving) head and two hydrophobic (water-hating) tails. In the bilayer, the hydrophilic heads face the watery environments inside and outside the cell, while the hydrophobic tails face each other in the interior. This

arrangement forms a stable barrier between the cell and its surroundings.

Membrane proteins are scattered in this bilayer. Integral (intrinsic) proteins span the bilayer and act as channels, carriers or pumps for transport of substances. Some integral proteins function as receptors for hormones and other signals. Peripheral (extrinsic) proteins are loosely attached to the inner or outer surface and help in cell support, enzyme activity and signaling.

Carbohydrate chains may be attached to proteins and lipids to form glycoproteins and glycolipids. These play important roles in cell recognition, cell-to-cell adhesion and immune responses.

In animal cells, cholesterol molecules are present between the phospholipids. Cholesterol helps to maintain proper membrane fluidity. It prevents the membrane from becoming too rigid at low temperatures and too fluid at high temperatures.

The model is called "fluid" because phospholipids and some proteins can move laterally within the layer, giving the membrane a flexible, fluid nature. It is called "mosaic" because of the patchwork arrangement of different proteins embedded in the lipid bilayer.

Functions of the cell membrane include:

It acts as a selectively permeable barrier, controlling entry and exit of ions, nutrients and waste products.

It allows transport by diffusion, osmosis and active transport.

Membrane proteins function as channels, carriers, pumps, enzymes and receptors.

Glycoproteins and glycolipids help in cell recognition, immune response and cell adhesion.

The membrane maintains cell shape and attaches to the cytoskeleton and extracellular matrix.

Thus, the Fluid Mosaic Model gives a clear and accepted picture of how the cell membrane is built and how it works.

Q3. Write an essay on the structure and functions of cell organelles.

A eukaryotic cell contains many membrane-bound and non-membrane-bound organelles, each with a special structure and function. Together they keep the cell alive and allow it to carry out different activities.

The nucleus is the largest organelle and contains the genetic material DNA. It is surrounded by a double membrane with nuclear pores. Inside the nucleus there is chromatin and a nucleolus where rRNA is synthesized. The nucleus controls protein synthesis, cell division, growth and all metabolic activities.

Mitochondria are double-membrane organelles. The inner membrane is folded into cristae which increase the surface area for respiration enzymes. The inner space is the matrix. Mitochondria carry out aerobic respiration and produce ATP, so they are called the powerhouses of the cell.

The endoplasmic reticulum (ER) forms a network of membranes throughout the cytoplasm. Rough ER bears ribosomes and is involved in synthesis and transport of proteins, especially those that are secreted or routed to membranes. Smooth ER does not have ribosomes and is involved in lipid synthesis, detoxification of drugs, metabolism of carbohydrates and storage of calcium.

The Golgi apparatus consists of a stack of flattened membranous sacs called cisternae. It receives proteins and lipids from ER, modifies them (for example by adding sugars), sorts and packages them into vesicles. It forms lysosomes and secretory vesicles and plays a key role in secretion processes.

Lysosomes are membrane-bound vesicles containing digestive (hydrolytic) enzymes. They digest food particles taken in by endocytosis, destroy damaged organelles and help in recycling

of cell components. If they rupture, the cell may be destroyed, so they are called suicide bags.

Vacuoles are membrane-bound sacs used for storage. In plant cells, a large central vacuole stores water, ions, pigments and waste products and maintains turgor pressure. In animal cells vacuoles are smaller and participate in storage and transport.

In plant cells, chloroplasts are present. These are double-membrane organelles with internal thylakoid membranes arranged in grana, surrounded by stroma. They contain chlorophyll and other pigments and carry out photosynthesis, converting light energy into chemical energy.

The cytoskeleton is made of microtubules, microfilaments and intermediate filaments. It gives shape to the cell, helps in movement, supports organelles and is involved in cell division.

Centrioles (in animal cells) are cylindrical structures made of microtubules that help in spindle formation during cell division.

Together, all these organelles work in coordination so that the cell can grow, respond to stimuli, divide, and maintain homeostasis.

Q4. Describe the structure and types of chromosomes. Add a note on polytene and lampbrush chromosomes.

Chromosomes are thread-like structures present in the nucleus of eukaryotic cells. They are made of DNA and proteins (histones and non-histones). Each chromosome has a constricted region called the centromere, where spindle fibres attach during cell division, and two arms extending from the centromere. At the ends, chromosomes have protective structures called telomeres.

On the basis of centromere position, chromosomes are of four main types:

Metacentric – centromere is in the middle; both arms are equal in length; chromosome appears V-shaped in anaphase.

Submetacentric – centromere is slightly off centre; one arm is longer than the other; chromosome appears L-shaped or J-shaped.

Acrocentric – centromere is near one end; one very long arm and one very short arm; appears J-shaped.

Telocentric – centromere at the terminal end; only one arm; appears I-shaped. (Common in some animals, not in humans.)

Polytene chromosomes are giant chromosomes found in the salivary glands of some insect larvae (for example, Drosophila). They are formed by repeated DNA replication without cell division (endoreduplication), so many chromatids remain attached together. Under the microscope, they show dark and light bands. They are useful in cytogenetic studies and in understanding gene activity.

Lampbrush chromosomes are large, bivalent chromosomes seen in oocytes of many vertebrates (for example amphibians) during the diplotene stage of meiosis. They have many lateral loops that look like brush bristles. These loops are regions of active transcription where a large amount of RNA is being synthesized. Lampbrush chromosomes help in studying gene expression and chromosome organization.

Thus, chromosomes vary in shape and size, and special types like polytene and lampbrush chromosomes are very important in genetics and cytology.

Q5. Explain structural and numerical chromosomal aberrations with suitable examples.

Chromosomal aberrations are changes in the structure or number of chromosomes. They can cause genetic disorders, developmental problems or may be used in plant and animal breeding.

Structural aberrations involve changes in the structure of a chromosome. The main types are:

Deletion – a segment of chromosome is lost. Example: deletion in the short arm of

chromosome 5 causes Cri-du-chat syndrome in humans.

Duplication – a segment of chromosome is repeated, leading to extra genetic material. This can cause abnormalities or sometimes have no visible effect.

Inversion – a segment breaks and rejoins in the reverse orientation. In paracentric inversion, the inverted segment does not include the centromere; in pericentric inversion, it includes the centromere. Inversions can disturb gene order and crossing over.

Translocation – a segment from one chromosome is transferred to a non-homologous chromosome. In reciprocal translocation, two chromosomes exchange segments. Some cancers and hereditary diseases are due to translocations (for example, Philadelphia chromosome in chronic myeloid leukemia).

Numerical aberrations involve changes in chromosome number:

Aneuploidy – gain or loss of one or a few chromosomes. Examples:

Trisomy 21 (Down syndrome) – presence of an extra chromosome 21 ($2n + 1$).

Turner syndrome – monosomy of X chromosome in females (XO).

Klinefelter syndrome – extra X chromosome in males (XXY).

Euploidy – change in the whole set of chromosomes. Triploidy ($3n$), tetraploidy ($4n$) and higher polyploidy are common in plants and are used for crop improvement.

These chromosomal aberrations may arise due to errors in meiosis, exposure to radiation, chemicals or viruses. They are important in evolution, breeding and medical genetics.

Short Answer Questions

Q1. Give differences between prokaryotic and eukaryotic cells.

Prokaryotic cells have no true nucleus; their DNA lies in a nucleoid region without a nuclear membrane. Eukaryotic cells have a true nucleus with a nuclear envelope. Prokaryotes lack membrane-bound organelles like mitochondria, ER and Golgi apparatus, while eukaryotes possess all these organelles. Prokaryotic cells are generally smaller (1–10 μm), while eukaryotic cells are larger (10–100 μm). Prokaryotes usually have a single circular chromosome, while eukaryotes have multiple linear chromosomes.

Q2. What are the functions of Golgi apparatus?

The Golgi apparatus modifies proteins and lipids received from the endoplasmic reticulum, for example by glycosylation. It sorts and packages these materials into vesicles for transport to different parts of the cell or for secretion outside the cell. It forms lysosomes and secretory vesicles and plays an important role in the formation of cell wall materials in plant cells. Thus, it is essential for proper processing and delivery of cell products.

Q3. Write a short note on plasmids.

Plasmids are small, circular, double-stranded DNA molecules found mainly in bacteria, separate from the main chromosomal DNA. They can replicate independently. Plasmids often carry genes that give advantages such as antibiotic resistance or toxin production. In biotechnology, plasmids are used as vectors to carry foreign genes into host cells for cloning and expression, so they are very important tools in genetic engineering.

Q4. Name the types of chromosomes based on centromere position.

Based on centromere position, chromosomes are of four types:

Metacentric – centromere in the middle; arms equal.

Submetacentric – centromere slightly off centre; one arm longer.

Acrocentric – centromere very near one end; one very short arm and one long arm.

Telocentric – centromere at the terminal end; effectively one arm.

Q5. Write the structure and function of mitochondria.

Mitochondria are double-membrane organelles. The outer membrane is smooth, and the inner membrane is folded into cristae which increase surface area. The inner space is filled with matrix containing enzymes, DNA and ribosomes. Mitochondria carry out aerobic respiration and produce ATP, the main energy currency of the cell. Therefore, they are called the powerhouses of the cell. Cells that need a lot of energy, like muscle cells, have many mitochondria.

Q6. Mention special features of plant cells.

Plant cells have a rigid cell wall made mainly of cellulose outside the plasma membrane; it provides shape, support and protection. They contain a large central vacuole filled with cell sap which maintains turgor pressure and helps keep the plant upright. Plant cells have chloroplasts with chlorophyll, allowing them to perform photosynthesis and make their own food. They usually lack centrioles and have plasmodesmata, small channels that connect neighbouring cells and allow communication. Because of these features, plant cells are well adapted to a stationary lifestyle and efficient light capture.

UNIT 2 – CELL CYCLE, MITOSIS, MEIOSIS, CELL DEATH

Long Answer Questions

Q1. Describe the eukaryotic cell cycle and its regulation.

The cell cycle is the ordered series of events by which a cell grows, duplicates its DNA and divides into two daughter cells. It ensures that each daughter cell receives a complete set of chromosomes. The eukaryotic cell cycle has four main phases: G_1, S, G_2 and M.

G_1 phase (first gap) – This is the first growth phase after cell division. The cell increases in size, synthesizes proteins, RNA and organelles, and prepares for DNA replication. If conditions are not suitable, the cell may enter a resting phase called G_0.

S phase (synthesis) – DNA replication occurs in this phase. Each chromosome is duplicated to form two identical sister chromatids joined at the centromere. This ensures that each daughter cell will receive a full set of genetic material.

G_2 phase (second gap) – The cell continues to grow, synthesizes proteins needed for mitosis and checks for any DNA damage. If errors are found, they are repaired before the cell enters mitosis.

M phase (mitosis + cytokinesis) – In this phase, the nucleus divides (mitosis), followed by division of the cytoplasm (cytokinesis), resulting in two daughter cells with the same chromosome number as the parent cell.

Regulation of the cell cycle is very important to prevent uncontrolled cell division and cancer. Regulation occurs at specific checkpoints:

G_1 checkpoint – the cell checks its size, nutrients and DNA damage. If conditions are not favourable, the cycle may stop or the cell may enter G_0.

G_2 checkpoint – the cell checks whether DNA replication is complete and whether there is

any DNA damage.

M checkpoint (spindle checkpoint) – ensures that all chromosomes are properly attached to spindle fibres before separation.

Key regulatory molecules are cyclins and CDKs (cyclin-dependent kinases). Cyclins increase and decrease in amount during the cycle and activate CDKs, which then phosphorylate specific proteins to push the cell from one phase to the next. If damage is severe, the cell may be directed to undergo apoptosis (programmed cell death) to protect the organism.

Thus, the cell cycle is a tightly controlled process that balances cell growth, division and death.

Q2. Explain the stages of mitosis with neat diagrams and write its significance.

Mitosis is the division of the nucleus that produces two genetically identical daughter cells from a single parent cell. It occurs in somatic (body) cells and maintains the chromosome number. Mitosis has four main stages: prophase, metaphase, anaphase, telophase, followed by cytokinesis.

Prophase

Chromatin condenses into visible chromosomes, each consisting of two sister chromatids joined at a centromere.

The nuclear membrane and nucleolus gradually disappear.

The centrosomes move to opposite poles and spindle fibres begin to form.

Metaphase

Chromosomes line up at the cell's equatorial plane (metaphase plate).

Spindle fibres attach to the centromeres of each chromosome.

This arrangement ensures that each sister chromatid will move to opposite poles.

Anaphase

Centromeres split and sister chromatids separate.

The chromatids (now individual chromosomes) are pulled to opposite poles by the shortening spindle fibres.

Each pole receives an identical set of chromosomes.

Telophase

Chromosomes reach the poles and begin to decondense back into chromatin.

Nuclear membranes and nucleoli reappear around each set of chromosomes.

The spindle apparatus disassembles.

Cytokinesis

Division of the cytoplasm.

In animal cells, a cleavage furrow forms and deepens until the cell splits into two.

In plant cells, a cell plate appears in the centre and expands outward, forming a new cell wall.

Significance of mitosis:

Helps in growth of multicellular organisms by increasing cell number.

Responsible for repair and regeneration of tissues (e.g., healing of wounds).

In some organisms, it is involved in asexual reproduction.

Maintains the same chromosome number and genetic makeup in daughter cells, preserving genetic stability.

(In the exam, draw a simple sequence of diagrams for prophase, metaphase, anaphase, telophase and cytokinesis.)

Q3. Explain the stages of meiosis and compare it with mitosis.

Meiosis is a special type of cell division that produces four haploid (n) cells from one diploid (2n) cell. It occurs in germ cells and is essential for gamete formation and sexual reproduction. Meiosis consists of two successive divisions: Meiosis I and Meiosis II.

Meiosis I (reductional division)

Prophase I – the longest and most complex stage. Homologous chromosomes pair in a process called synapsis, forming bivalents (tetrads). Crossing over occurs between non-sister chromatids at chiasmata, exchanging DNA segments and creating new genetic combinations.

Metaphase I – homologous chromosome pairs align at the equator. Spindle fibres attach to the centromeres.

Anaphase I – homologous chromosomes (not chromatids) separate and move to opposite poles. Each pole receives a haploid set of chromosomes.

Telophase I and cytokinesis – chromosomes may decondense partially and the cell divides into two haploid daughter cells.

Meiosis II (equational division)

Meiosis II is similar to mitosis and occurs in each haploid cell formed after Meiosis I.

Prophase II – chromosomes condense again; new spindle apparatus forms.

Metaphase II – chromosomes align at the equator.

Anaphase II – centromeres split and sister chromatids separate to opposite poles.

Telophase II and cytokinesis – nuclei reform and cytoplasm divides, resulting in four haploid daughter cells, each genetically different.

Comparison of mitosis and meiosis

Number of divisions: Mitosis has one division; meiosis has two.

Number of daughter cells: Mitosis produces 2 cells; meiosis produces 4 cells.

Chromosome number: Mitosis maintains the same chromosome number ($2n \rightarrow 2n$); meiosis halves it ($2n \rightarrow n$).

Genetic variation: Mitosis produces genetically identical cells; meiosis produces genetically different cells due to crossing over and independent assortment.

Site: Mitosis occurs in somatic cells; meiosis occurs in germ cells (ovaries and testes).

Thus, mitosis is important for growth and repair, whereas meiosis is essential for sexual reproduction and genetic diversity.

Q4. Write an essay on cell death – senescence, necrosis and apoptosis.

Cells do not live forever; they may die in different ways. The main types related to this syllabus are senescence, necrosis and apoptosis.

Senescence (cell ageing)

Cells have a limited capacity to divide, called the Hayflick limit.

After many divisions, cells enter a state where they are still alive but no longer divide and function less efficiently.

Senescent cells accumulate in tissues and contribute to ageing of organs.

Necrosis (accidental cell death)

Caused by external factors like injury, toxins, infection or lack of blood supply.

Cells swell, their membranes rupture, and contents leak into surrounding tissue.

This leakage causes inflammation and may damage nearby cells.

Examples: tissue death in heart attack, severe infections or burns.

Apoptosis (programmed cell death)

A controlled, energy-dependent process where cells activate internal "suicide" pathways.

The cell shrinks, chromatin condenses, DNA is fragmented, and the cell breaks into small apoptotic bodies.

These bodies are quickly removed by phagocytic cells without inflammation.

Apoptosis is important in embryonic development (e.g., separation of fingers and toes), removal of virus-infected or cancerous cells, and maintenance of normal cell numbers.

Together, senescence, necrosis and apoptosis regulate cell populations and help maintain the

health and structure of tissues.

Short Answer Questions – Unit 2

Q1. Write a short note on binary fission.

Binary fission is a simple type of asexual reproduction seen in bacteria and some unicellular organisms like Amoeba. The circular DNA replicates and the two copies move to opposite ends of the cell. Then a new cell wall (septum) forms in the middle, gradually dividing the cytoplasm. Finally, the cell splits into two daughter cells that are genetically identical to the parent. This process is quick and allows rapid increase in population under favourable conditions.

Q2. Give differences between mitosis and meiosis.

Mitosis involves one nuclear division and produces two diploid, genetically identical daughter cells. It occurs in somatic cells for growth, repair and asexual reproduction. There is no crossing over and chromosome number remains the same.
Meiosis involves two nuclear divisions and produces four haploid, genetically different daughter cells. It occurs in germ cells to form gametes. Crossing over and independent assortment occur in Meiosis I, creating variation, and the chromosome number is halved.

Q3. Write a note on Prophase I of meiosis.

Prophase I is the longest and most important phase of meiosis. Homologous chromosomes pair in a process called synapsis, forming bivalents (tetrads). Non-sister chromatids of homologous chromosomes exchange segments at chiasmata; this is called crossing over. Crossing over produces new combinations of alleles and is a major source of genetic recombination. Prophase I is divided into sub-stages: leptotene, zygotene, pachytene, diplotene and diakinesis, each showing specific chromosomal changes.

Q4. What is cytokinesis?

Cytokinesis is the division of the cytoplasm that occurs after nuclear division (mitosis or meiosis). Its function is to physically separate the cell into two daughter cells. In animal cells, a cleavage furrow forms and pinches the cell into two. In plant cells, a cell plate appears in the centre and gradually develops into a new cell wall. Without proper cytokinesis, cells may have multiple nuclei or abnormal size.

Q5. Define apoptosis and state its importance.

Apoptosis is programmed cell death in which a cell actively destroys itself in a controlled manner. The cell shrinks, DNA is cut into fragments, and the cell splits into apoptotic bodies that are removed by phagocytic cells without causing inflammation. Apoptosis is important in shaping organs during development, removing damaged or infected cells, eliminating potentially cancerous cells and maintaining normal cell numbers in tissues. When apoptosis fails or is excessive, it can lead to diseases such as cancer, autoimmune disorders or neurodegenerative conditions.

UNIT 3 – PRINCIPLES AND MECHANISM OF INHERITANCE

Long Answer Questions

Q1. Explain Mendel's laws of inheritance with suitable crosses and ratios.

Gregor Mendel worked on pea plants and studied the inheritance of traits like height, seed shape and seed colour. From his experiments he proposed two important laws: Law of Segregation and Law of Independent Assortment.

1. Law of Segregation (Monohybrid cross)

Each trait is controlled by a pair of factors called alleles. During gamete formation these alleles separate (segregate) so that each gamete receives only one allele of each pair.

Example: Inheritance of plant height in peas.

Tall plant = TT, dwarf plant = tt

P generation: TT (tall) × tt (dwarf)

F_1 generation: All plants Tt (tall)

F_2 generation: Cross Tt × Tt

Genotypes in F_2: TT, Tt, Tt, tt

Genotypic ratio = 1 TT : 2 Tt : 1 tt

Phenotypic ratio = 3 tall : 1 dwarf

This shows that alleles segregate and recombine in the offspring.

2. Law of Independent Assortment (Dihybrid cross)

Alleles of different genes assort independently during gamete formation, if the genes are on different chromosomes.

Example: Seed shape and seed colour.

Round yellow = RRYY, wrinkled green = rryy

P generation: RRYY × rryy

F_1 generation: All RrYy (round yellow)

F_2 generation: Cross RrYy × RrYy

Phenotypic ratio in F_2 =

9 round yellow : 3 round green : 3 wrinkled yellow : 1 wrinkled green (9:3:3:1)

This ratio shows that the two pairs of factors (R/r and Y/y) assort independently.

Thus, Mendel's laws explain the basic patterns of inheritance and form the foundation of classical genetics.

Q2. Describe deviations from Mendel's ratios – incomplete dominance, co-dominance, epistasis, penetrance, expressivity, pleiotropy and phenocopy.

Not all traits follow the simple Mendelian 3:1 or 9:3:3:1 ratios. Some important deviations are:

Incomplete dominance – The heterozygote shows an intermediate phenotype between the two homozygotes.

Example: Mirabilis jalapa (four-o'clock plant).

RR = red, rr = white, Rr = pink.

F_2 ratio = 1 red : 2 pink : 1 white.

Co-dominance – Both alleles in a heterozygote are fully expressed.

Example: ABO blood group. I^AI^B individuals express both A and B antigens (blood group AB).

Epistasis – One gene masks or modifies the expression of another non-allelic gene.

Example: In coat colour of some animals, one gene controls pigment production and another controls pigment type. If pigment is not produced, the colour gene cannot show its effect, giving modified ratios like 9:3:4 or 12:3:1 instead of 9:3:3:1.

Penetrance – The percentage of individuals with a particular genotype who actually express the expected phenotype. If a gene has 70% penetrance, only 70 out of 100 individuals with that genotype show the trait.

Expressivity – The degree or intensity with which a genotype is expressed. Individuals with the same genotype may show mild, moderate or severe forms of the same disease.

Pleiotropy – A single gene affects more than one trait.
Example: Marfan syndrome in humans affects skeleton, eyes and heart with one gene defect.

Phenocopy – An environmental factor produces a phenotype that mimics a genetic disorder, even though there is no mutation in the gene.

These patterns show that inheritance can be more complex than simple Mendelian ratios.

Q3. Explain multiple allelism with examples.

Multiple allelism means that a gene has more than two alleles in the population, even though an individual carries only two alleles (one from each parent).

Example 1 – ABO blood group in humans
The gene for ABO blood group has three alleles: IA, IB and i.

IA and IB are co-dominant to each other.

i is recessive to both IA and IB.

Genotype → Phenotype

IAIA or IAi → Blood group A

IBIB or IBi → Blood group B

IAIB → Blood group AB

ii → Blood group O

Example 2 – Coat colour in rabbits

A series of alleles like C, cch, ch and c controls coat colour. Different combinations of these alleles give different colours and patterns.

Multiple alleles increase the variety of phenotypes seen in a population.

Q4. Describe the mechanisms of sex determination in Drosophila, birds, man and Bonellia.

Different organisms use different systems for sex determination.

1. Humans (man) – XY system

Females are XX and males are XY.

Females produce only X-bearing eggs. Males produce two types of sperms: X-bearing and Y-bearing.

X egg + X sperm → XX (female)

X egg + Y sperm → XY (male)

Thus, the sex of the child is decided by the sperm from the father.

2. Drosophila (fruit fly)

Females are XX and males are XY, but sex is determined by the X:A ratio (number of X chromosomes to sets of autosomes).

XX with 2 sets of autosomes → X:A = 1.0 → female

XY with 2 sets of autosomes → X:A = 0.5 → male

Intermediate ratios may produce intersex or metafemale forms.

3. Birds – ZW system

In birds, males are ZZ and females are ZW. Here the female is heterogametic.

Male (ZZ) produces only Z sperms.

Female (ZW) produces two types of eggs: Z and W.

Z egg + Z sperm → ZZ (male)

W egg + Z sperm → ZW (female)

4. Bonellia (marine worm) – Environmental sex determination

Larvae that settle alone on the sea floor develop into large females.

Larvae that come in contact with the proboscis of an adult female develop into tiny males that live attached to the female.

Here the environment (presence of female) decides whether the larva becomes male or female.

These examples show both chromosomal and environmental mechanisms of sex determination.

Short Answer Questions – Unit 3

Q1. Why were pea plants chosen by Mendel?

Pea plants are easy to grow and need little space. They have a short life cycle, so many generations can be observed in a few years. They show clear contrasting characters like tall/dwarf, round/wrinkled and yellow/green seeds. They are mainly self-pollinated but can also be cross-pollinated by hand. All these features made pea plants ideal for Mendel's experiments.

Q2. Explain incomplete dominance with an example.

In incomplete dominance, the heterozygote shows an intermediate phenotype. Neither allele is completely dominant. A classic example is Mirabilis jalapa (four-o'clock plant). Red flower (RR) crossed with white flower (rr) gives pink flowers (Rr) in F_1. In F_2, the ratio is 1 red : 2 pink : 1 white.

Q3. What is co-dominance?

Co-dominance is a type of inheritance where both alleles in a heterozygote are fully expressed. Example: AB blood group in humans. Genotype I^AI^B produces AB blood group with both A and B antigens on red blood cells.

Q4. Define penetrance and expressivity.

Penetrance is the percentage of individuals with a specific genotype who actually show the expected phenotype. Expressivity is the degree or extent to which a genotype is expressed in an individual. Together they explain why people with the same genotype may show differences in the presence and severity of a trait.

Q5. Write a short note on pleiotropy.

Pleiotropy occurs when one gene influences multiple traits. For example, in Marfan syndrome a mutation in a single gene affects the skeleton, eyes and cardiovascular system. Thus one gene can have many phenotypic effects.

UNIT 4 – LINKAGE, RECOMBINATION, NON-MENDELIAN INHERITANCE & HARDY–WEINBERG LAW

Long Answer Questions

Q1. Explain linkage and crossing over with cytological proof and significance.

Genes located on the same chromosome are said to be linked. Linked genes tend to be inherited together and show parental combinations more frequently than new combinations.

The closer two genes are on a chromosome, the stronger the linkage.

Crossing over is the exchange of DNA segments between non-sister chromatids of homologous chromosomes during Prophase I of meiosis (pachytene stage). At sites called chiasmata, chromatids break and rejoin, producing recombinant chromatids with new combinations of alleles.

Cytological proof:
Under the microscope, homologous chromosomes can be seen joined at chiasmata, which represent physical points of crossing over. Genetic experiments in Drosophila showed that the percentage of recombinants in the offspring is proportional to the distance between genes.

Significance:

Linkage explains why some traits often appear together in families or crosses.

Crossing over breaks linkage and produces recombinant types, increasing genetic variation.

Recombination frequencies are used to draw linkage maps, in which 1% recombination is taken as 1 map unit or 1 centiMorgan (cM).

Thus, linkage and crossing over are key concepts for understanding chromosome behaviour and gene mapping.

Q2. Describe cytoplasmic inheritance with suitable examples.

In cytoplasmic inheritance, genes are located in organelles such as mitochondria and chloroplasts, which are present in the cytoplasm. These genes are usually inherited from the mother, so the pattern is maternal inheritance.

Examples:

Leaf variegation in Mirabilis jalapa – Green, white and variegated leaves are controlled by chloroplasts in the egg cytoplasm. Seeds from a branch with green, white or variegated leaves give similar types of offspring, showing chloroplast inheritance.

Shell coiling in snails – The direction of shell coiling depends on the genotype of the mother, because early development is influenced by substances in the egg cytoplasm.

Cytoplasmic male sterility (CMS) in plants – Mitochondrial genes cause failure to produce functional pollen. It is maternally inherited and is widely used in hybrid seed production.

Mitochondrial diseases in humans – Some neuromuscular diseases are transmitted from affected mothers to all their children, but affected fathers do not pass the disease to their children.

These examples show that not all hereditary information is in the nucleus; organelles also carry genes that follow special patterns of inheritance.

Q3. Write an essay on Hardy–Weinberg equilibrium and factors affecting it.

The Hardy–Weinberg equilibrium describes the behaviour of gene frequencies in a population that is not evolving. It provides a mathematical model for population genetics.

Statement:
In a large, randomly mating population with no mutation, migration or natural selection, the allele and genotype frequencies remain constant from generation to generation. Such a population is in Hardy–Weinberg equilibrium.

For a gene with two alleles A and a:

Let p = frequency of allele A

Let q = frequency of allele a

Then $p + q = 1$

Genotype frequencies in the next generation will be:

$AA = p^2$

$Aa = 2pq$

$aa = q^2$

So $p^2 + 2pq + q^2 = 1$. These frequencies remain constant as long as the basic conditions are satisfied.

Factors that disturb Hardy–Weinberg equilibrium:

Mutation – Creates new alleles or changes existing ones, slowly changing allele frequencies.

Migration (gene flow) – Movement of individuals between populations brings new alleles into a population or removes alleles from it.

Natural selection – Individuals with certain genotypes have better survival or reproduction, so their alleles increase in frequency.

Non-random mating – Inbreeding or assortative mating changes genotype frequencies (more homozygotes or certain combinations), even if allele frequencies remain the same.

Small population size (genetic drift) – In small populations, chance events can cause large random changes in allele frequencies from one generation to the next.

When any of these forces act, the population moves away from Hardy–Weinberg equilibrium and evolution takes place. Thus, the Hardy–Weinberg principle serves as a baseline for detecting evolutionary change.

Short Answer Questions – Unit 4

Q1. What is recombination frequency?

Recombination frequency is the percentage of recombinant offspring produced in a cross involving two genes. Recombinant offspring show new combinations of traits due to crossing over.

Recombination frequency =
(Number of recombinant offspring ÷ Total offspring) × 100

A high recombination frequency means the genes are far apart; a low frequency means they are closely linked. It is used to make linkage maps (1% recombination = 1 cM).

Q2. Write a short note on maternal effect.

Maternal effect occurs when the phenotype of the offspring is mainly determined by the genotype or condition of the mother, rather than the offspring's own genotype, especially in early development. This is because the egg cytoplasm contains mRNAs, proteins and other factors made by the mother. Shell coiling in snails is a classic example, where the direction of coiling depends on the mother's genotype.

Q3. What is cytoplasmic male sterility?

Cytoplasmic male sterility (CMS) is a maternally inherited trait in which plants fail to produce functional pollen due to mitochondrial genes. Female parts are normal and can form seeds when fertilised with pollen from a fertile plant. CMS is very useful in agriculture to produce hybrid seeds without manual removal of anthers.

Q4. Explain mitochondrial inheritance with an example.

Mitochondrial inheritance involves genes present in mitochondrial DNA. Since mitochondria are

usually inherited from the egg, mitochondrial traits are passed from mothers to all their children, but not from fathers. An example is Leber's hereditary optic neuropathy (LHON), where mutations in mitochondrial genes lead to degeneration of the optic nerve and loss of vision.

Q5. State Hardy-Weinberg law.

The Hardy-Weinberg law states that in a large, randomly mating population with no mutation, migration or natural selection, the allele and genotype frequencies remain constant from generation to generation. For two alleles A and a, $p + q = 1$ for allele frequencies and $p^2 + 2pq + q^2 = 1$ for genotype frequencies.