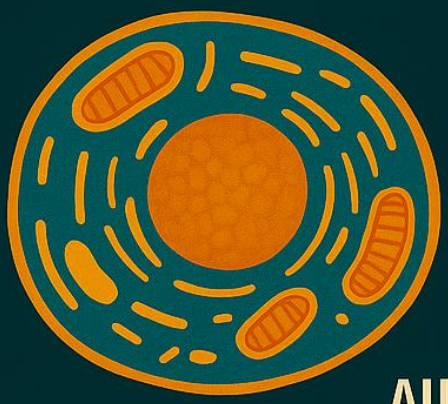
CELL BIOLOGY AND GENETICS



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Learning Objectives

By the end of this course, students will be able to:

1. Explain the structural and functional differences between prokaryotic and eukaryotic cells, and distinguish between plant and animal cells with reference to organelles and cell theory.
2. Illustrate the ultra-structure and composition of plant cells, including detailed analysis of the cell wall, plasma membrane, mitochondria, and plastids, with emphasis on their functions and molecular components.
3. Compare chromosomal features of prokaryotes and eukaryotes, and describe chromosome morphology, types, euchromatin/heterochromatin, and the organization of DNA within chromosomes.
4. Apply Mendel's principles of inheritance and interpret genetic crosses involving Mendelian and non-Mendelian patterns such as incomplete dominance, codominance, gene interactions, and maternal inheritance.
5. Analyze chromosomal behavior in linkage and recombination, including chromosomal mapping using two-point and three-point test cross data.
6. Describe the molecular structure of DNA and RNA, and explain the processes of replication, transcription, translation, and gene regulation in prokaryotes (e.g., Lac Operon).
7. Differentiate between classical and molecular gene concepts, and explain gene functionality using cis–trans tests, allelism, and recombination events.
8. Understand sex determination mechanisms in plants and evaluate genetic and environmental factors influencing sexual development using case studies.
9. Calculate and interpret allele and genotype frequencies in populations using Hardy-Weinberg law, and assess evolutionary forces that disrupt genetic equilibrium.
10. Integrate knowledge of cellular and molecular biology to explain how genetic information is inherited, expressed, and regulated in plants and other organisms.

Unit-1: Cell and Its Organelles (8 Hrs)

1.1 Cell Theory and Types of Cells

The foundation of modern biology lies in the **Cell Theory**, initially proposed in the 19th century. The **historical background** of this theory traces back to Matthias Schleiden and Theodor Schwann, who proposed that all living organisms are composed of cells. Later, Rudolf Virchow added that all cells arise from pre-existing cells, establishing the modern cell theory. This theory now includes key points: cells are the basic units of life, all organisms are made of cells, and all cells come from existing cells.

Modern cell theory builds upon these ideas with molecular insights, emphasizing the role of DNA as hereditary material and the importance of energy flow within cells.

The **differences between prokaryotic and eukaryotic cells** are significant. Prokaryotic cells, found in bacteria and archaea, lack a membrane-bound nucleus and organelles, while eukaryotic cells, found in plants, animals, fungi, and protists, possess a true nucleus and various organelles.

A **comparison between animal and plant cells** reveals key structural differences. Plant cells have a cell wall, large central vacuole, and plastids, including chloroplasts, while animal cells have centrioles and are generally more flexible in shape.

1.2 Ultra-Structure of a Plant Cell

A **plant cell** is surrounded by a rigid cell wall and contains a variety of membrane-bound organelles, each performing specific functions. Important components include the nucleus, mitochondria, plastids, endoplasmic reticulum, Golgi apparatus, vacuole, and ribosomes. These organelles collectively maintain homeostasis and ensure proper physiological function.

1.3 Ultra-Structure of the Cell Wall

The **cell wall** is a non-living, rigid structure composed primarily of **cellulose**, with other polysaccharides like **hemicellulose, pectin,** and structural polymers like **lignin** contributing to strength and flexibility. The wall is organized into three layers: **primary wall** (young, flexible), **secondary wall** (thicker, lignified), and **middle lamella** (rich in pectins, binds adjacent cells).

Plasmodesmata, microscopic channels in the cell wall, facilitate symplastic transport between adjacent cells and maintain tissue continuity, contributing to **cell wall permeability** and intercellular communication.

1.4 Ultra-Structure of Plasma Membrane

The **plasma membrane** is a selectively permeable boundary composed of a lipid bilayer with embedded proteins. Its structural organization has been explained by several models, the most accepted being the **Fluid Mosaic Model**, proposed by Singer and Nicolson, which describes a dynamic and flexible membrane.

Other models include the **Unit Membrane Model** and the **Danielli-Davson Model**, both of which were earlier attempts to describe membrane structure. The **plasma membrane functions** in transport, signal reception, intercellular communication, and maintaining homeostasis.

1.5 Polymorphic Cell Organelles – Plastids

Plastids are semi-autonomous, double-membrane organelles found in plant cells. They are polymorphic and differentiated into three main types:

- **Chloroplasts** (photosynthesis),
- **Chromoplasts** (pigment synthesis), and
- **Leucoplasts** (storage).

Chloroplasts have a complex **ultra-structure** consisting of outer and inner membranes, stroma, thylakoids, and grana. The **Plastid DNA (ptDNA)** is circular and encodes essential proteins, playing a crucial role in plastid replication and gene expression.

1.6 Ultra-Structure of Mitochondria

Mitochondria are known as the powerhouse of the cell, with a double-membrane structure. The **outer membrane** is smooth, while the **inner membrane** is folded into **cristae**, increasing surface

area for energy production. The matrix contains enzymes, mitochondrial DNA (mtDNA), and ribosomes.

Mitochondrial DNA is circular and independent of nuclear DNA, enabling mitochondria to produce some of their own proteins. Mitochondria are the central site for **cellular respiration**, converting biochemical energy from nutrients into ATP.

Unit-2: Chromosomes (8 Hrs)

2.1 Prokaryotic vs Eukaryotic Chromosomes

Prokaryotic chromosomes are usually a single, circular DNA molecule without associated histones, found in the nucleoid region. In contrast, **eukaryotic chromosomes** are linear, associated with histones, and enclosed within a nucleus.

Key differences include **structure**, presence of histones, **genome organization**, and complexity, with eukaryotes having a more compartmentalized and organized genetic system.

2.2 Morphology of Eukaryotic Chromosomes

Eukaryotic chromosomes show distinct **structural components** such as the **centromere** (attachment point for spindle fibers), **arms**, and **telomeres** (protect chromosome ends). Based on centromere position, chromosomes are classified as:

- **Metacentric** (centromere in middle),
- **Submetacentric**,
- **Acrocentric**, and
- **Telocentric** (centromere at end).

2.3 Euchromatin and Heterochromatin

Euchromatin is less condensed, transcriptionally active, and stains lightly, whereas **heterochromatin** is highly condensed, inactive, and dark-staining. These two forms regulate **gene expression**, with euchromatin enabling gene activity and heterochromatin often silencing genes.

2.4 Karyotype and Ideogram

A **karyotype** is a photographic representation of an individual's complete set of chromosomes, arranged by size and shape. It helps in detecting chromosomal abnormalities. An **ideogram** is a schematic diagram of chromosomes, used to show characteristic banding patterns and chromosome number.

Karyotyping techniques include using metaphase chromosome spreads, G-banding, and digital imaging.

2.5 Chromosomal Aberrations

Structural aberrations include:

- **Deletion**: Loss of a chromosome segment
- **Duplication**: Repetition of a segment
- **Inversion**: Reversal of a segment
- **Translocation**: Movement of a segment to a non-homologous chromosome

Numerical aberrations involve changes in chromosome number:

- **Aneuploidy**: Gain or loss of single chromosomes (e.g., trisomy)
- **Polyploidy**: Multiple sets of chromosomes, common in plants

2.6 DNA Organization in Chromosomes

The **nucleosome model** describes the basic unit of chromatin, where DNA wraps around histone proteins forming a "beads on a string" structure. This condenses further into the **solenoid model**, forming a 30 nm fiber.

Higher-order chromatin structures result in further folding and organization, ultimately producing the compact metaphase chromosome seen during cell division.

Unit-3: Mendelian and Non-Mendelian Genetics (10 Hrs)

3.1 Mendel's Laws of Inheritance

The foundation of classical genetics lies in the pioneering work of **Gregor Mendel**, who conducted hybridization experiments on garden pea (*Pisum sativum*) plants. Based on his observations, he proposed three fundamental laws of inheritance that explain how traits are passed from one generation to the next.

The **Law of Dominance** states that when two alleles for a trait are present in an individual, one may mask the expression of the other. The expressed allele is called dominant, and the masked one is recessive. This law explains why certain traits appear in the first filial (F_1) generation.

The **Law of Segregation** asserts that allele pairs separate during gamete formation, and each gamete receives only one allele from each pair. This explains the 3:1 ratio seen in the monohybrid F_2 generation, as alleles segregate independently into gametes.

The **Law of Independent Assortment** proposes that genes for different traits segregate independently during gamete formation. This law is evident in dihybrid crosses, where Mendel observed a 9:3:3:1 phenotypic ratio in the F_2 generation, showing that traits are inherited independently of one another.

3.2 Extensions to Mendelian Genetics

Although Mendel's laws laid the groundwork for genetics, many traits in nature do not follow simple dominant–recessive patterns. These are explained through **extensions to Mendelian genetics**.

Incomplete dominance occurs when the heterozygous phenotype is intermediate between the two homozygous phenotypes. A classic example is the cross between red and white *Mirabilis jalapa* flowers, which produces pink F_1 offspring.

Co-dominance refers to a situation where both alleles in a heterozygous individual are fully expressed. An example is the **AB blood group** in humans, where both A and B antigens are expressed on the red blood cells.

Multiple alleles exist when a gene has more than two alternative forms in a population. The **ABO blood group system** in humans is governed by three alleles (I^A, I^B, and i), where the combination of alleles determines the blood type. Although an individual carries only two alleles, multiple alleles increase the genetic variation within a population.

3.3 Gene Interactions

In many cases, **genes do not act independently** but interact with each other to influence a trait. Such **gene interactions** can modify the expected Mendelian ratios.

Complementary genes require the presence of two dominant alleles at different loci to produce a particular phenotype. For example, in sweet peas, both genes A and B are required for flower color; without both, the flower remains white.

Supplementary genes involve one gene modifying or enhancing the effect of another. In maize, for instance, one gene may control the formation of pigment, while another enhances its intensity.

Duplicate genes occur when two genes perform the same function, and the presence of either one results in the same phenotype. An example from plants is seen in shepherd's purse (*Capsella bursa-pastoris*), where two gene loci control seed shape and either gene can compensate for the other.

3.4 Linkage and Crossing Over

Linkage refers to the tendency of genes located close together on the same chromosome to be inherited together. Mendel's law of independent assortment applies only to genes on different chromosomes or far apart on the same chromosome. The concept of linkage was first observed in *Drosophila melanogaster* by Morgan.

Crossing over is the exchange of genetic material between homologous chromosomes during meiosis, leading to the formation of new allele combinations. It can be of different types—single, double, or multiple crossovers—depending on the number of break-and-exchange events.

Chromosomal mapping is a technique used to determine the relative positions of genes on a chromosome. This is done using **two-point and three-point test crosses**, where the frequency of recombination is used to estimate distances between genes. A 1% recombination frequency corresponds to 1 map unit or centiMorgan (cM).

3.5 Maternal Inheritance

Maternal inheritance, also known as **extranuclear inheritance**, is the transmission of genes located outside the nucleus, particularly in organelles like mitochondria and chloroplasts. These

organelles are typically inherited only from the **mother**, as the cytoplasm of the egg contributes the majority of these structures.

The phenomenon was demonstrated by **Correns' experiment on *Mirabilis jalapa***, where leaf color in offspring was found to be determined by the mother plant's phenotype. Crosses between green, variegated, and white-leaved plants revealed that chloroplast inheritance follows a non-Mendelian pattern, as chloroplasts are inherited maternally.

Other examples include mitochondrial inheritance in yeast and certain human diseases caused by mutations in mitochondrial DNA. These patterns illustrate that **not all hereditary information is stored in the nucleus**, challenging the central dogma and expanding the scope of genetics.

Unit-4: Structure and Function of DNA (10 Hrs)

4.1 Watson and Crick Model of DNA

The discovery of the DNA structure by **James Watson and Francis Crick** in 1953 revolutionized molecular biology. Their proposed **double helix model** revealed that DNA is composed of two long strands coiled around each other, forming a spiral staircase-like structure. Each strand consists of a sugar-phosphate backbone, with nitrogenous bases (adenine, thymine, cytosine, guanine) projecting inward.

Base pairing rules are highly specific: adenine (A) pairs with thymine (T), and cytosine (C) pairs with guanine (G). These pairs are held together by hydrogen bonds—two between A and T, and three between C and G—contributing to the stability of the molecule. This specificity is crucial for accurate DNA replication and transcription.

The **complementary nature of DNA strands** allows each strand to serve as a template during replication. This feature also plays a vital role in ensuring genetic continuity and repair, enabling precise copying of genetic material from one generation to the next.

4.2 DNA Replication

DNA replication is the process by which a cell duplicates its DNA before cell division. The mechanism is **semiconservative**, meaning each daughter DNA molecule consists of one parental and one newly synthesized strand. This model was confirmed by the Meselson-Stahl experiment.

Several **enzymes** are involved in this complex process. **Helicase** unwinds the double helix at the origin of replication, creating a **replication fork**. **DNA polymerase** adds complementary nucleotides to the growing strand, ensuring accuracy and fidelity. **Ligase** joins the Okazaki fragments on the lagging strand, completing the synthesis of a continuous DNA molecule.

The **replication fork** represents the region where the DNA is actively being unwound and copied. It consists of a leading strand (synthesized continuously) and a lagging strand (synthesized in fragments), coordinated by a multi-enzyme complex.

4.3 Transcription and RNA

Transcription is the process by which the genetic code from DNA is transcribed into messenger RNA (mRNA). This occurs in the nucleus of eukaryotic cells and involves the synthesis of a complementary RNA strand from a DNA template. RNA polymerase binds to the promoter region of the gene and catalyzes the addition of ribonucleotides in the 5′ to 3′ direction.

There are three main **types of RNA**, each with specific roles:

- **mRNA (messenger RNA)** carries the genetic information from DNA to the ribosome.
- **tRNA (transfer RNA)** transports specific amino acids to the ribosome during protein synthesis.
- **rRNA (ribosomal RNA)** forms the structural and enzymatic core of the ribosome.

The **functions of RNA** are diverse and essential to gene expression. Beyond acting as intermediaries in protein synthesis, RNA molecules can regulate gene expression and catalyze biochemical reactions, as seen in ribozymes.

4.4 Genetic Code and Translation

The **genetic code** is the set of rules by which the nucleotide sequence of mRNA is translated into a sequence of amino acids in a protein. It is **triplet-based**, meaning each codon (three nucleotides) specifies one amino acid. The code is **universal**, **non-overlapping**, and **degenerate**, meaning that more than one codon can code for the same amino acid.

Translation is the process of protein synthesis and occurs in three stages:

- **Initiation** involves the assembly of the ribosome, mRNA, and initiator tRNA at the start codon.
- **Elongation** is the stage where amino acids are added one by one to the growing polypeptide chain as the ribosome moves along the mRNA.
- **Termination** occurs when a stop codon is reached, releasing the complete polypeptide and disassembling the translation machinery.

Translation occurs in the cytoplasm and is a critical step in the expression of genetic information.

4.5 Regulation of Gene Expression in Prokaryotes

In **prokaryotes**, gene expression is tightly regulated to ensure efficient use of resources. The **operon concept**, introduced by Jacob and Monod, describes a group of genes regulated together and transcribed as a single mRNA. An operon includes a promoter, an operator, and structural genes.

The **lac operon** in *E. coli* is a well-known example of gene regulation. It contains genes responsible for the metabolism of lactose and is controlled by a repressor protein. In the absence of lactose, the repressor binds to the operator and blocks transcription. When lactose is present, it binds to the repressor, inactivating it and allowing gene expression.

Gene regulation can be of two types: **inducible systems**, where transcription is turned on in response to a stimulus (e.g., lac operon), and **repressible systems**, where transcription is turned off when a specific end product is abundant (e.g., trp operon). These systems ensure that genes are expressed only when needed, contributing to cellular economy.

Unit-5: Gene Concept and Sex Determination (9 Hrs)

5.1 Evolution of Gene Concept

The understanding of the gene has evolved significantly over time. In the **classical gene concept**, a gene was considered the smallest indivisible unit of heredity that governs a specific trait. This concept was shaped by Mendelian principles and early genetic studies that observed how traits

were inherited in predictable patterns. However, with the discovery of DNA and molecular biology advances, the **molecular gene concept** emerged. Here, a gene is defined as a specific segment of DNA that encodes a functional product—either a protein or RNA molecule.

A more refined view considers the **gene as a unit of function and recombination**. According to this, a gene is not just a structural segment but a functional unit that expresses a product and can undergo recombination. Seymour Benzer's work on bacteriophage T4 showed that recombination could occur within a gene, leading to the concepts of cistron (functional unit), recon (recombination unit), and muton (mutation unit). This perspective bridged classical genetics with molecular biology and laid the foundation for modern genomic understanding.

5.2 Cis–Trans Test and Functional Allelism

The **cis–trans test**, also known as the **complementation test**, is a fundamental genetic method used to determine whether two mutations associated with a particular phenotype occur in the same gene (allelic) or in different genes (non-allelic). In this test, if two recessive mutations in the heterozygous condition (in trans) restore the normal phenotype, they are considered to complement each other and are thus located in different genes. If the phenotype remains mutant, the mutations are allelic and occur in the same gene.

This test has been instrumental in the **mapping of functional units within genes**, especially in microorganisms like fungi and bacteriophages. It allows geneticists to distinguish between **mutation** (alteration within the same gene) and **recombination** (exchange of segments between different genes), deepening our understanding of gene structure and function. The cis–trans test also laid the groundwork for understanding operon models and gene regulation.

5.3 Sex Determination in Plants

Sex determination in plants is a fascinating area of genetics, as plants exhibit a diverse range of mechanisms. These include **genetic sex determination**, where sex is determined by specific chromosomes or genes, as seen in some dioecious species like *Silene* and *Cannabis*. In contrast, **environmental sex determination** depends on external factors such as temperature, light, or nutrition. For example, in *Cucumis* (cucumber), photoperiod and hormonal balance can influence the expression of male or female flowers.

Another mechanism is **genic balance**, where the ratio of X chromosomes to sets of autosomes determines sex, similar to what is observed in *Drosophila* and also postulated in some plants. **Case studies** in selected plant species highlight the complex genetic and epigenetic controls involved in sex expression. For example, *Papaya* and *Spinacia* (spinach) have been well studied for their sex chromosomes and sex-linked traits. These studies help in crop improvement, hybrid seed production, and understanding the evolutionary biology of sex chromosomes in plants.

5.4 Population Genetics and Hardy-Weinberg Law

Population genetics is the study of genetic variation within populations and how evolutionary forces act on this variation. It focuses on **allele and genotype frequencies** in a population and how they change over time. The **Hardy-Weinberg Law** provides a mathematical model to describe a non-evolving population. According to this principle, allele and genotype frequencies in a population remain constant from generation to generation in the absence of evolutionary influences, provided certain conditions are met.

The **assumptions of Hardy-Weinberg equilibrium** include a large population size, random mating, no mutation, no migration, and no natural selection. If these conditions are met, the frequencies of alleles (p and q) and genotypes (p^2, 2pq, q^2) remain stable, providing a baseline to detect evolutionary changes.

However, in real populations, various factors **disturb Hardy-Weinberg equilibrium**. These include **mutation**, which introduces new alleles; **migration**, which brings alleles from other populations; **natural selection**, which favors certain alleles; and **genetic drift**, which causes random fluctuations in allele frequencies, especially in small populations. Understanding these factors helps researchers analyze population structure, evolution, and the dynamics of genetic diseases.

Assessment

Here are **50 multiple-choice questions (MCQs)** based on the 5 units of *Cell Biology and Genetics*. Each question includes four options and the correct answer marked at the end.

✅ **Unit-1: Cell and Its Organelles (20 MCQs)**

1. **Who proposed the cell theory?**
   a) Watson and Crick
   b) Schleiden and Schwann
   c) Hooke and Leeuwenhoek
   d) Mendel and Darwin
   Ans: b

2. **Which is not a part of modern cell theory?**
   a) Cells arise from pre-existing cells
   b) All living organisms are composed of cells
   c) All cells contain a nucleus
   d) Cells are the functional units of life
   Ans: c

3. **Prokaryotic cells lack:**
   a) DNA
   b) Cell membrane
   c) Nucleus
   d) Cytoplasm
   Ans: c

4. **Which of the following is present only in plant cells?**
   a) Mitochondria
   b) Ribosomes
   c) Chloroplasts
   d) Golgi apparatus
   Ans: c

5. **Plasmodesmata are:**
   a) Cell organelles
   b) Nuclear pores
   c) Cytoplasmic connections between cells

d) Cell wall components
Ans: c

6. **Middle lamella is rich in:**
   a) Lignin
   b) Pectin
   c) Cellulose
   d) Protein
   Ans: b

7. **Which theory describes the cell membrane as a fluid lipid bilayer with proteins embedded?**
   a) Lamellar theory
   b) Unit membrane model
   c) Fluid mosaic model
   d) Sandwich model
   Ans: c

8. **Chloroplast DNA is:**
   a) Linear and nuclear
   b) Circular and nuclear
   c) Circular and extranuclear
   d) Linear and cytoplasmic
   Ans: c

9. **Leucoplasts are involved in:**
   a) Pigment synthesis
   b) Storage of starch and oil
   c) Photosynthesis
   d) Energy release
   Ans: b

10. **Cristae are structures found in:**
    a) Nucleus
    b) Golgi bodies
    c) Mitochondria
    d) Chloroplast
    Ans: c

11. **Plasma membrane is composed of:**
    a) Proteins only
    b) Lipids only
    c) Lipids and proteins
    d) Cellulose and proteins
    Ans: c

12. **Which is not an organelle with double membrane?**
    a) Nucleus
    b) Mitochondria
    c) Chloroplast

d) Ribosome
Ans: d

13. **The thylakoid membranes are present in:**
    a) Mitochondria
    b) Lysosomes
    c) Chloroplasts
    d) Nucleolus
    Ans: c

14. **Cell wall is absent in:**
    a) Bacteria
    b) Algae
    c) Fungi
    d) Animals
    Ans: d

15. **What is the function of the plasma membrane?**
    a) Synthesis of protein
    b) Cell division
    c) Regulates passage of materials
    d) ATP production
    Ans: c

16. **Which organelle is known as the powerhouse of the cell?**
    a) Golgi complex
    b) Mitochondria
    c) Nucleus
    d) Ribosome
    Ans: b

17. **The main structural component of the plant cell wall is:**
    a) Protein
    b) DNA
    c) Cellulose
    d) RNA
    Ans: c

18. **Which is considered a semi-autonomous organelle?**
    a) Ribosome
    b) Mitochondria
    c) Nucleolus
    d) Golgi bodies
    Ans: b

19. **Which model does NOT describe membrane structure?**
    a) Fluid Mosaic Model
    b) Sandwich Model
    c) DNA Double Helix Model

d) Unit Membrane Model
Ans: c

20. **Which structure controls entry and exit of materials in cells?**
a) Nucleus
b) Mitochondria
c) Plasma membrane
d) Cell wall
Ans: c

Unit-2: Chromosomes (20 MCQs)

21. **Prokaryotic chromosomes are usually:**
a) Linear and multiple
b) Circular and single
c) Linear and double
d) Circular and double
Ans: b

22. **A chromosome with centromere at one end is called:**
a) Metacentric
b) Acrocentric
c) Telocentric
d) Submetacentric
Ans: c

23. **Heterochromatin is:**
a) Actively transcribed
b) Lightly stained and loose
c) Condensed and inactive
d) Found only in prokaryotes
Ans: c

24. **Telomeres are found at:**
a) Center of chromosome
b) Ends of chromosome
c) Arms of chromosome
d) None of the above
Ans: b

25. **A karyotype shows:**
a) Nucleotide sequences
b) Number and morphology of chromosomes
c) RNA molecules
d) Mitochondrial genes
Ans: b

26. **Euchromatin is associated with:**
a) Inactive genes

b) Condensed DNA
c) Active transcription
d) RNA synthesis only
Ans: c

27. **Which of the following is a structural chromosomal aberration?**
a) Aneuploidy
b) Duplication
c) Polyploidy
d) Euploidy
Ans: b

28. **The centromere is important for:**
a) Chromosome replication
b) Crossing over
c) Spindle attachment
d) Nucleolus formation
Ans: c

29. **Which of the following techniques is used in karyotyping?**
a) ELISA
b) Western blot
c) Chromosome staining
d) PCR
Ans: c

30. **Polyploidy refers to:**
a) Loss of a chromosome
b) Addition of a chromosome
c) Whole sets of chromosomes multiplied
d) Crossing over
Ans: c

Sample MCQs (1–10)

1. **Aneuploidy is a result of:**
    - a) Non-disjunction
    - b) Crossing over
    - c) Mutation
    - d) Gene amplification
      Ans: a) Non-disjunction

2. **Incomplete dominance results in:**
    - a) Intermediate phenotype
    - b) Dominant phenotype
    - c) Recessive phenotype

- d) No phenotype
  Ans: a) Intermediate phenotype

3. **Which law states that alleles segregate independently during gamete formation?**
   - a) Law of independent assortment
   - b) Law of segregation
   - c) Law of dominance
   - d) Hardy-Weinberg Law
     Ans: a) Law of independent assortment

4. **Euchromatin is characterized by:**
   - a) Active transcription
   - b) Dense packing
   - c) Dark staining
   - d) Lack of genes
     Ans: a) Active transcription

5. **Which of the following is a feature of eukaryotic chromosomes?**
   - a) Linear structure
   - b) Circular DNA
   - c) Lack of histones
   - d) Single origin of replication
     Ans: a) Linear structure

6. **ABO blood group is an example of:**
   - a) Multiple alleles
   - b) Incomplete dominance
   - c) Polygenic inheritance
   - d) Epistasis
     Ans: a) Multiple alleles

7. **The Lac Operon is an example of:**
   - a) Inducible system
   - b) Repressible system
   - c) Translation
   - d) Replication
     Ans: a) Inducible system

8. **What is the main component of the plant cell wall?**

- a) Cellulose
- b) Starch
- c) Protein
- d) Lignin
  Ans: a) Cellulose

9. **Which enzyme joins Okazaki fragments?**
   - a) Ligase
   - b) Polymerase
   - c) Helicase
   - d) Primase
     Ans: a) Ligase

10. **mRNA is synthesized during:**

- a) Transcription
- b) Translation
- c) Replication
- d) Mutation
  Ans: a) Transcription

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